4 Plate Tectonics

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4.1 INTRODUCTION

In chapter one, we reviewed the scientific method and the exact meaning of a theory, which is a well-supported explanation for a natural phenomenon that still cannot be completely proven. A **Grand Unifying Theory** is a set of ideas that is central and essential to a field of study such as the theory of gravity in physics or the theory of evolution in biology. The Grand Unifying Theory of geology is the **theory of Plate Tectonics**, which defines the outer portion of the earth as a brittle outer layer that is broken into moving pieces called **tectonic plates**. This theory is supported by many lines of evidence including the shape of the continents, the distribution of fossils and rocks, the distribution of environmental indicators, as well as the location of mountains, volcanoes, trenches, and earthquakes. The movement of plates can be observed on human timescales and easily measured using GPS satellites.

Plate tectonics is integral to the study of geology because it aids in reconstructing earth's history. This theory helps to explain how the first continents were built, how oceans formed, and even helps inform hypotheses for the origin of life. The theory also helps explain the geographic distribution of geologic features such as mountains, volcanoes, rift valleys, and trenches. Finally, it helps us assess the potential risks of geologic catastrophes such as earthquakes and volcanoes across the earth. The power of this theory lies in its ability to create testable hypotheses regarding Earth's history as well as predictions regarding its future.

4.1.1 Learning Outcomes

After completing this chapter, you should be able to:

- Explain several lines of evidence supporting the movement of tectonic plates
- Accurately describe the movement of tectonic plates through time
- Describe the progression of a Hawaiian Island and how it relates to the Theory of Plate Tectonics

- Describe the properties of tectonics plates and how that relates to the proposed mechanisms driving plate tectonics
- Be able to describe and identify the features that occur at different plate boundaries

4.1.2 Key Terms

- ɔntinental Crust
- ɔnvergent Boundary
- ivergent Boundary
- rand Unifying Theory
- ot Spot
- ceanic Crust
- idge Push
- Slab Pull
- Slab Suction
- Subduction
- Tectonic plates
- Theory of Plate Tectonics
- Transform Boundary
- Wadati-Benioff Zone

4.2 EVIDENCE OF THE MOVEMENT OF CONTINENTS

The idea that the continents appear to have been joined based on their shapes is not new, in fact this idea first appeared in the writings of Sir Francis Bacon in 1620. The resulting hypothesis from this observation is rather straightforward: the shapes of the continents fit together because they were once connected and have since broken apart and moved. This hypothesis is discussing a historical event in the past and cannot be directly tested without a time machine. Therefore, geoscientists reframed the hypothesis by assuming the continents used to be connected and asking what other patterns we would expect to find. This is exactly how turn of the century earth scientists (such as Alfred Wegener) addressed this important scientific question.

Wegener compiled rock types, fossil occurrences, and environmental indicators within the rock record on different continents (focusing on Africa and South America) that appear to have been joined in the past and found remarkable similarities. Other scientists followed suit and the scientific community was able to compile an extensive dataset that indicated that the continents were linked in the past in a supercontinent called Pangaea (coined by Alfred Wegener) and have shifted to their current position over time. Dating these rocks using the methods discussed in chapter one allowed the scientists to better understand the rate of motion, which has assisted in trying to determine the mechanisms that drive plate tectonics.

4.3 LAB EXERCISE

This lab will use two different ways to input your answers. Most of the questions will be multiple choice and submitted online as you have in previous labs. Other questions will give you a blank box to input your answer as text. Your professor will manually grade this text, such that the format is not as important as your answer. This format allows you the opportunity to show your work using simple symbols and allows the instructor to better see your thought process. Also note, that for many of these questions there is not a single correct answer and seeing your thought process and understanding the material is more important than your answer. Therefore, it is important to show your work.

In addition, several of the exercises that follow use Google Earth. For each question (or set of questions) paste the location that is given into the "search" box. Examine each location at multiple eye altitudes and differing amounts of tilt. For any measurements use the ruler tool, this can be accessed by clicking on the ruler icon above the image.

Part A – Plate Motion and Evidence

As was mentioned above one of the most striking things about the geography of the continents today is how they appear to fit together like puzzle pieces. The reason for this is clear: they once were connected in the past and have since separated shifting into their current positions. Open Google Earth and zoom out to an eye altitude of ~8000 miles. Examine the coastlines of eastern South America and Western Africa and notice how well they match in shape.

There are scientifically important rock deposits in southern Brazil, South America and Angola, Africa that show the northernmost glacial deposits on the ancient continent of Pangaea, which indicates these two areas were once connected. Based on the shape of the two coastlines, give the present day latitude and longitude of two sites along the coast of these countries that used to be connected when the two continents were joined as a part of Pangaea (note: there are multiple correct answers):

1. Brazil (Latitude and Longitude)

2. Angola (Latitude and Longitude)

3. Measure in centimeters the distance (Map Length) between the two points you recorded in the previous question. Given that this portion of Pangaea broke apart 200,000,000 years ago, calculate how fast South America and Africa are separating in cm/year? (Hint: Speed= Distance/Time)

4. When will the next supercontinent form? Examine the Western Coast of South America, the Eastern Coast of Asia, and the Pacific Ocean. If South America and Africa are separating and the Atlantic Ocean is growing, then the opposite must be occurring on the other side of the earth (the Americas are getting closer to Asia and the Pacific Ocean is shrinking). How far apart are North America and Mainland Asia in cm? (measure the distance across the Pacific at 40 degrees north latitude- basically measure between Northern California and North Korea)? Take that distance and divide it by the speed you calculated in question 3 to estimate when the next supercontinent will form. Show your work!

Use the Figures 4.1 and 4.2 to answer questions 5-7.

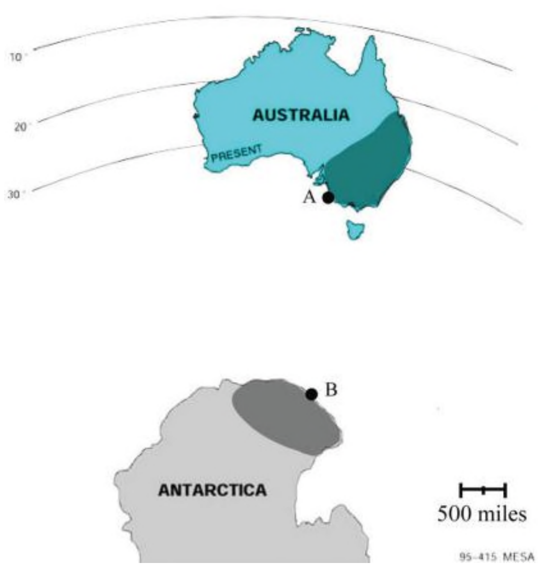

Figure 4.1

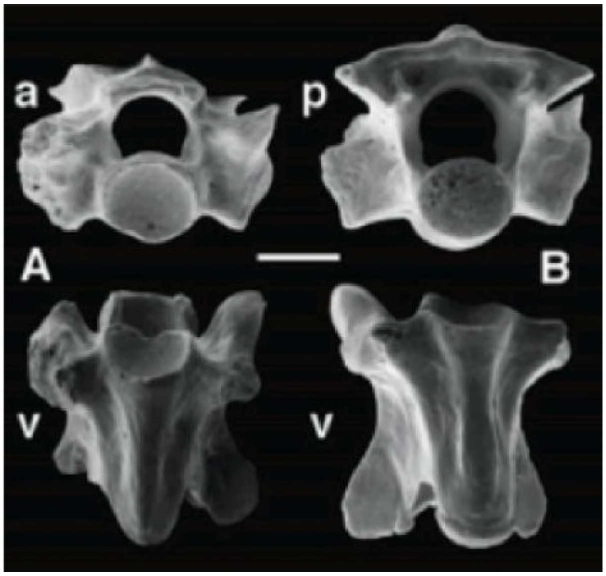

Figure 4.2

Figures 4.1 and 4.2 | The distribution across Australia and Antartica (Figure 4.1) of the fossil snake *Patagoniophis* (Figure 4.2). Obviously, this small snake was unable to swim the immense distance between the contients and, therefore, lived while Australia and Antarctica were still joined together. Figure modified from the Australia Department of Natural Resources and Scanlon (2005), Memoirs of the Queensland Museum.

5. How far have the snake fossils moved apart since they were originally deposited?

a. 1250 miles b. 1700 miles c. 2150 miles d. 2700 miles

6. Given that this portion of the Australian plate moves at a speed of 2.2 inches per year, how old are the snake fossils?

a. 310 million years old
b. 217 million years old
c. 98 million years old
d. 62 million years old
e. 34 million years old

7. There are fossils such as *Glossopteris* and *Lystrosaurus* that are found in rocks in South America and Africa that indicate they were part of Pangaea approximately 200 million years ago. These same fossils can be found in Australia, which indicates it, along with Antarctica, was also part of Pangaea at that time. Based on your answer to question 6 which of the following statements about the break-up of Pangaea is TRUE?

a. Australia and Antarctica separated before the break-up of Pangaea.
b. Australia and Antarctica separated during the break-up of Pangaea.
c. Australia and Antarctica separated after the break-up of Pangaea.

4.4 HOT SPOTS

Another line of evidence that can be used to track plate motion is the location of **hot spots**. Hot spots are volcanically active areas on the Earth's surface that are caused by anomalously hot mantle rocks underneath. This heat is the result of a mantle plume that rises from deep in the mantle toward the surface resulting in melted rocks and volcanoes. These mantle plumes occur deep in the Earth such that they are unaffected by the movement of the continents or the crust under the ocean. Mantle plumes appear to be stationary through time, but as the tectonic plate moves over the hot spot a series of volcanoes are produced. This gives geologists a wonderful view of the movement of a plate through time with the distribution of volcanoes indicating the direction of motion and their ages revealing the rate at which the plate was moving.

One of the most striking examples of a hot spot is underneath Hawaii. The mantle plume generates heat that results in an active volcano on the surface of the crust. Each eruption causes the volcano to grow until it eventually breaks the surface of the ocean and forms an island. As the crust shifts the volcano off the hot spot the volcano loses its heat and become inactive. The volcano then cools down, contracts, erodes, sinks slowly beneath the ocean surface, and is carried by the tectonic plate as it moves through time. As each island moves away from the mantle plume a new island will then be formed at the hot spot in a continual conveyor belt of islands. Therefore, the scars of ancient islands near Hawaii give a wonderful view of the movement of the tectonic plate beneath the Pacific Ocean.

4.5 LAB EXERCISE

Materials

Type "Hawaii" into the search bar of Google Earth and examine the chain of Hawaiian Islands. On a separate sheet of paper please draw yourself a map of the islands and label the following on your map (making sure to include the names), which will be used to answer the following questions.

Islands to include:

Big Island, Maui, Kauai, Nihoa (23 03 32.79N 161 55 11.94W)

a. Put a North arrow on your map.

b. Label the ages of each of the islands determined by radiometric dating of the lava.

Big Island- 0 (active), Maui – 1.1 million, Kauai- 4.7 million, Nihoa- 7.2 million years

a. Place a dot at the center of each island and measure on Google earth the distance between the center of an island and its adjacent island in centimeters (for example measure the distance between the center of the Big Island and Maui).

b. Look closely at each island in Google Earth and record their maximum elevation in centimeters. Remember elevation can be found by placing your cursor over a point and reading the elevation on the lower right of the image by the latitude and longitude. The elevation will be given in meters, but can be converted to centimeters by multiplying by 100. (Hint: tilting the image of the island will help to find the highest point.)

Part B - Hawaii

8. Consider the ages and positions of the islands listed above along with what you know about plate tectonics and hotspots. In what general direction is the Pacific Plate moving?

a. Northwest b. Southeast c. Northeast d. Southwest

9. How fast was the Pacific plate moving during the last 1.1 million years between the formation of the Big Island and Maui in cm/year? To calculate this divide the distance (in centimeters) between the two islands by the difference in their ages.

10. How fast was the Pacific plate moving from 7.2 million years ago to 4.7 million years ago between the formation of Kauai and Nihoa in cm/year? To calculate this divide the distance (in centimeters) between the two islands by the difference in their ages.

11. Examine the headings of the measurements that you took for the previous two questions. The headings indicate the direction the Pacific Plate is moving over the hot spot. How does the direction of motion of the Pacific Plate during the last 1.1 million years differ from direction of movement between 4.7 and 7.2 million years ago? The direction of plate movement in the last 1.1 million years ____________ .

a. shows no change b. has become more southerly c. has become more northerly

12. Zoom out and examine the dozens of sunken volcanoes out past Nihoa, named the Emperor Seamounts. As one of these volcanic islands on the Pacific Plate moves off the hotspot it becomes inactive, or extinct, and the island begins to sink as it and the surrounding tectonic plate cool down. The speed the islands are sinking can be estimated by measuring the difference in elevation between two islands and dividing by the difference in their ages (this method assumes the islands were a similar size when they were active). Calculate how fast the Hawaiian Islands are sinking, by using the ages and elevations of Maui and Nihoa.

13. Using the speed you calculated in the previous question (and ignoring possible changes in sea level), when will the Big Island of Hawaii sink below the surface of the ocean? Divide the current maximum elevation of the Big Island by the rate you calculated in the previous question.

14. Now zoom out to ~4000 miles eye altitude and look at the chain of Hawaiian Islands again. Notice the chain continues for thousands of miles up to Aleutian Islands (between Alaska and Siberia). Examine the northernmost sunken volcano (50 49 16.99N 167 16 36.12E) in this chain. Where was that volcano located when it was still active, erupting, and above the surface of the ocean?

a. 50 49 16.99N 167 16 36.12E   b 52 31 48.72N 166 25 43.14W

c. 27 45 49.27N 177 10 08.75W   d. 19 28 15.23N 155 19 14.43W

4.6 PLATE MATERIALS

By now you can see many different lines of evidence that the tectonic plates are moving (there are many additional lines of evidence as well). To build a theory we need an explanation or a mechanism that explains the patterns that we see. The **theory of plate tectonics** states that the outer rigid layer of the earth (the lithosphere) is broken into pieces called tectonic plates (Figure 4.3) and that these plates move independently above the flowing plastic-like portion of the mantle (Asthenosphere).

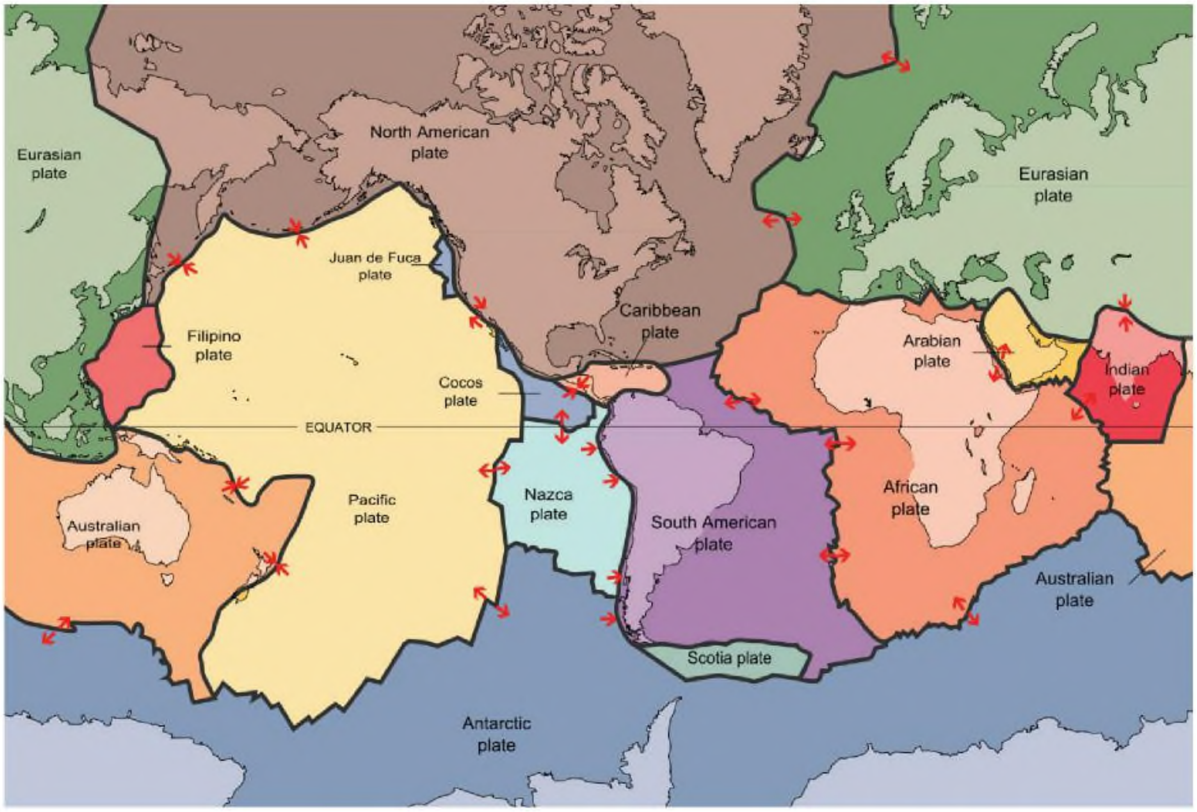

Figure 4.3 | Tectonic plates on Earth.
Author: USGS
Source: USGS
License: Public Domain

Tectonic plates are composed of the crust and the upper most mantle that functions as a brittle solid. These plates can be composed of oceanic crust, continental crust or a mixture of both. The **Oceanic Crust** is thinner and normally underlies the world's oceans, while the **Continental Crust** is thicker and like its name consists of the continents. The interaction of these tectonic plates is at the root of many geologic events and features, such that we need to understand the structure of the plates to better understand how they interact. The interaction of these plates is controlled by the relative motion of two plates (moving together, apart, or sliding past) as well as the composition of the crustal portion of the plate (continental or ocean crust). Continental crust has an overall composition similar to the igneous rock granite, which is a solid, silica-rich crystalline rock typically consisting of a mixture of pink (feldspar), milky white (feldspar), clear (quartz), and black (biotite) minerals. Oceanic crust is primarily composed of the igneous rock gabbro, which is a solid, iron and magnesium-rich crystalline rock consisting of a mixture of black and dark gray minerals (pyroxene and feldspar). The difference in rock composition results in distinctive physical properties that you will determine in the next set of questions.

4.7 LAB EXERCISE

Part C – Plate Densities

An important property of geological plates is their density (mass/volume). Remember the asthenosphere has fluid-like properties, such that tectonic plates ‘float’ relative to their density. This property is called isostasy and is similar to buoyancy in water. For example, if a cargo ship has a full load of goods it will appear lower than if it were empty because the density of the ship is on average higher. Therefore, the relative density of two plates can control how they interact at a boundary and the types of geological features found along the border between the two plates. Measuring the density of rocks is fairly easy and can be done by first weighing the rocks and then calculating their volume. The latter is best done by a method called fluid displacement using a graduated cylinder. Water is added to the cylinder and the level is recorded, a rock is then added to the cylinder and the difference in water levels equals the volume of the rock. Density is then calculated as the mass divided by the volume (Figure 4.4).

The information needed to calculate density was collected for four rocks and can be used to answer the following questions including the weight (in grams) as well as

Figure 4.4 | Method to find the density of a rock. First the weight is measured on a digital scale and then the fluid displacement method is used to determine the volume.
Author: Bradley Deline
Source: Original Work

the volume of water recorded by a graduated cylinder (in milliliters) before and after the rock was added. Note: each line on the graduated cylinder represents 10 ml. When measuring the volume please round to the nearest 10 milliliter line on the graduated cylinder. **Hint**: Surface tension will often cause the water level to curve up near the edges of the graduated cylinder creating a feature called a meniscus. To accurately measure the volume, use the lowest point the water looks to occupy.

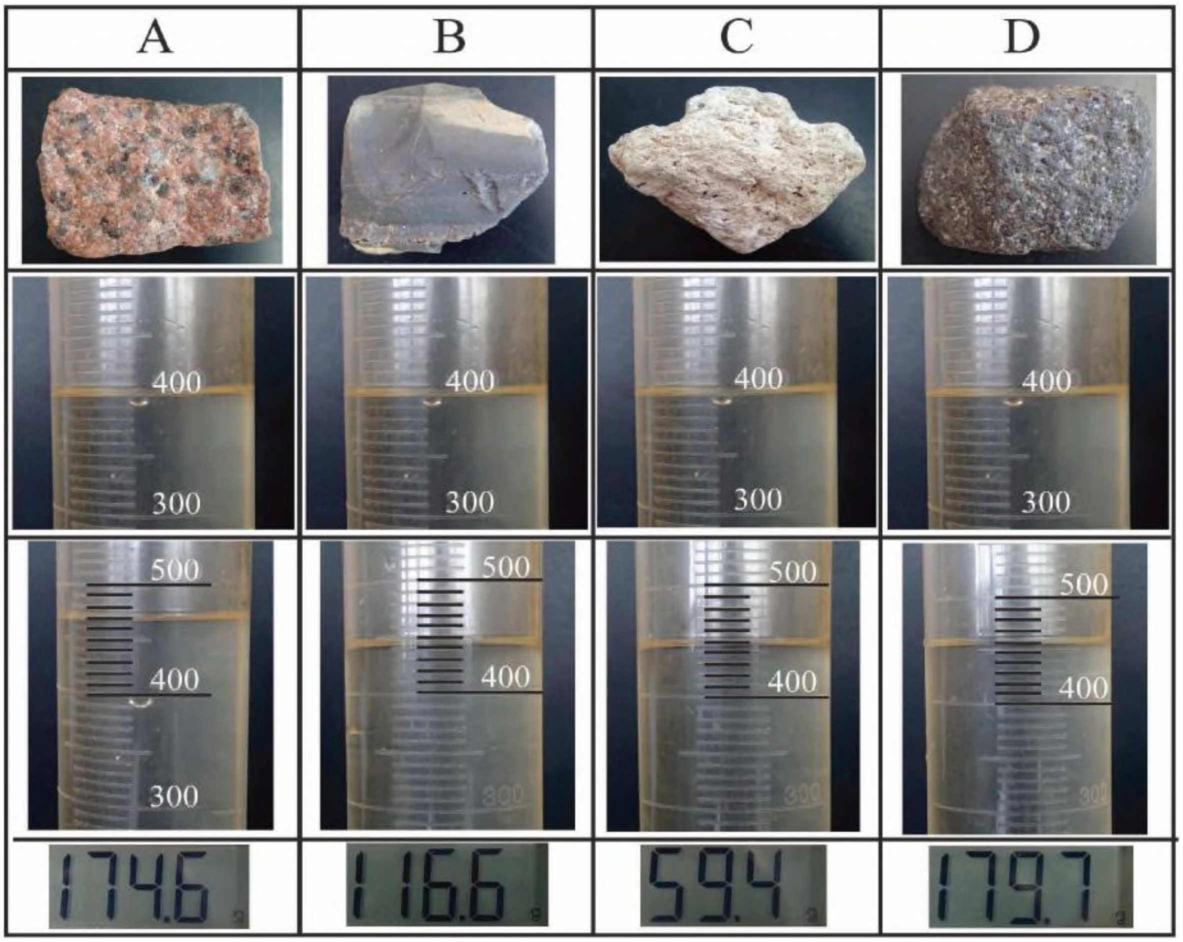

Figure 4.5 | Figure to use to answer questions 15-19.The first row shows images of the four rocks. The second and third rows show the volume (in milliliters) of material in the graduated cylinder before and after the rock was added. The last row shows the mass (in grams) of the four rocks.
Author: Bradley Deline
Source: Original Work
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15. The rock that most closely resembles the composition of continental crust based on the description in the previous section is:

a. A b. B c. C d. D

16. Based on the choice you made for question 15, what is the density of the rocks that make up continental crust? Please give your answer in grams/milliliter.

17. The rock that most closely resembles the composition of oceanic crust based on the description in the previous section is:

a. A b. B c. C d. D

18. Based on the choice you made for question 17, what is the density of the rocks that make up oceanic crust? Please give your answer in grams/milliliter.

19. Remember, because of isostasy the denser plate will be lower than the less dense plate. If oceanic and continental crust collided, based on their densities the ______________ crust would sink below the _________ crust.

a. continental; oceanic b. oceanic; continental

4.8 PLATE BOUNDARIES

Tectonic plates can interact in three different ways they can come together, they can pull apart, or they can slide by each other (Figure 4.6). The other factor that can be important is the composition of the plates (oceanic or continental crust) that are interacting as was explored in the previous section. These three types of motions along with the type of plates on each side of the boundary can produce vastly different structures and geologic events (Table 4.1).

Two plates that are moving apart from each other are called Divergent. **Divergent boundaries** are important because they are the way that continents split apart and break into separate plates as well as where new ocean crust is formed. If a divergent boundary forms within a continent that area stretches apart. This results in the area becoming thinner creating a topographic low or a valley. This extension is not a smooth process so the area is prone to earthquakes as well as volcanic activity. Eventually, the crust gets so thin it will rupture forming a gap between the plates, which will be filled with molten rock forming new oceanic crust. A thin and dense plate will be topographically low and will be covered in water forming a long and narrow sea. As the plates persist in pulling apart new crust is continually being formed at the plate boundary along an elevated crest known as a mid-oceanic ridge.

Two plates that are moving together are called Convergent. **Convergent boundaries** are important because they are the way distinctive plates can join (suture) together to form larger plates as well as where ocean crust is destroyed. The resulting structures we see at convergent boundaries depend on the types of tectonic plates. If two thick and lower density continental plates converge we get a large collision which results in mountains. This is a violent process resulting in many earthquakes, deformation (folds and faults) of rock, and the uplift of mountains. The rocks are also under immense pressure and heat and will eventually become stuck together as a single plate. If a continental plate and an ocean plate converge (continent-ocean convergent plate boundary) there will be **subduction**, where the oceanic plate sinks downward underneath the continental plate. This will result in several features including a deep trench near the subducting plate, abundant earthquakes, and the formation of magma which results in a line of volcanoes along the coast. Associated with this type of plate boundary is the **Wa-dati-Benioff zone**, a zone where earthquakes are produced; this zone ranges in depth from shallow (at the trench) to deep (~600km), indicating that the oceanic plate is sinking into the mantle. If two oceanic plates converge it will also result in subduction with similar features as were just discussed. The only exception will be that the volcanoes will appear on an oceanic plate and will eventually form islands along the tectonic boundary.

When the two plates slide past each other it is called a **Transform boundary**. This type of boundary differs from the previous two in that no new crust is being formed and no old crust is being destroyed. Therefore, there won't be as many striking geologic features. Transform boundaries are often marked by abundant earthquakes that can be close to the surface as well as distinctive patterns of rivers that become offset as the land is moving underneath them. Transform boundaries are also often associated with mid-oceanic ridges. If a the ridge has a jagged or stair-stepped edge the pulling apart of the two tectonic plates will also result in transform motion as you can see in Figure 4.6.

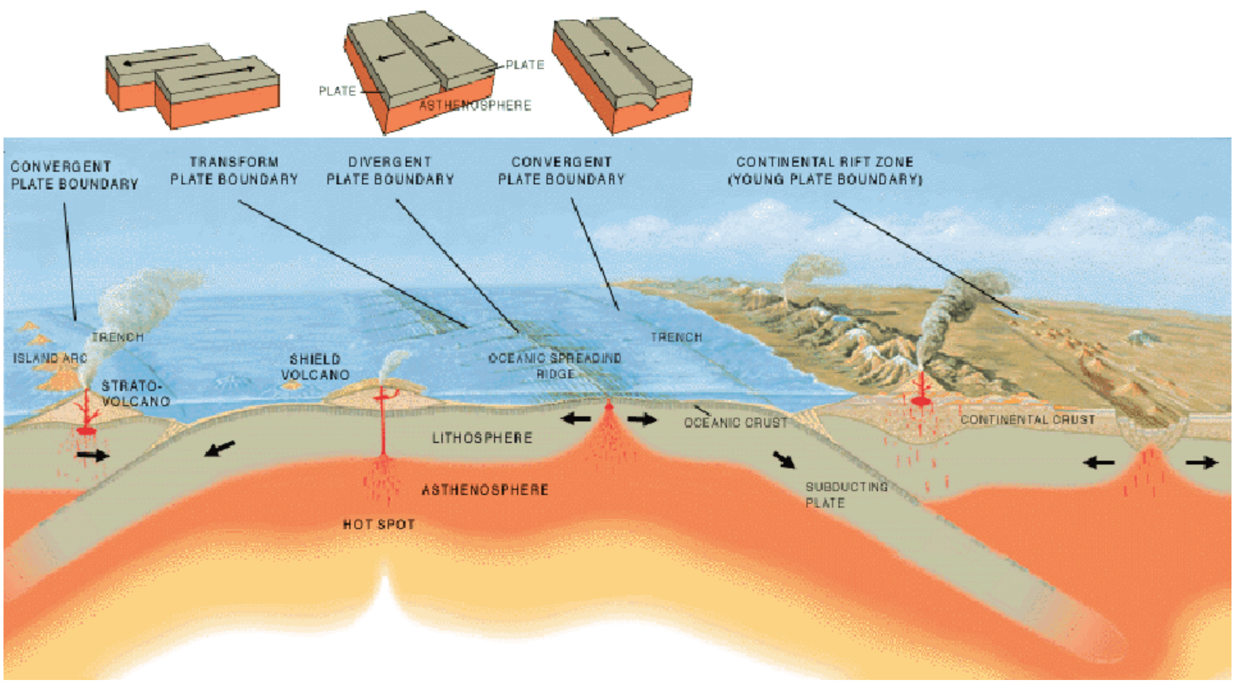

Figure 4.6 | Figure showing multiple plate boundaries and the features associated with them.
Author: José F. Vigil
Source: USGS
License: Public

ıble 4.1. Characteristics of the different Plate Boundaries

›undary ·pe	Plate Compositions	Earthquake Depth	Change in Crust	entifying Features
vergent				
	›ntinent-›ntinent	allow	› change	ft Valley and Volcanoes
	:ean-Ocean	allow	rmation of New Crust	:ean Ridges
›nvergent				
	›ntinent-›ntinent	allow to Intermediate	›tamorphism of Crust	›untains
	›ntinent-:ean	allow to Deep	›lting of Crust	ench and Coastal Volcanoes
	:ean-Ocean	allow To Deep	›lting of Crust	ench and Volcanic Islands
ansform				
	›ntinent-›ntinent	allow	› change	fset rivers
	:ean-Ocean	allow	› change	ten associated with Ocean ridges.

4.9 LAB EXERCISE

Part D – Origin of Magma

Magma is formed from the melting of rock at both convergent and divergent boundaries. However, the processes that occur to melt the rock are quite different. Three different processes are involved in the melting of rocks as we will explore in the following exercise. In Figure 4.7 you can see a graph depicting a variety of temperature and pressure conditions. The increasing temperature with pressure on rocks as you go deeper within the earth through the crust and mantle lithosphere is called the geothermal gradient (shown in black). This gradient shows the actual temperature conditions that exist in the lithosphere. Obviously, the addition or subtraction of heat or pressure can move rocks off that gradient and cause potential change. The orange line represents the temperature and pressure required for a dry mantle rock to start to melt and any point to the right of this line is where melting of lithospheric rock can occur. The blue line represents the temperature and pressure required for a lithospheric rock to melt if water is present.

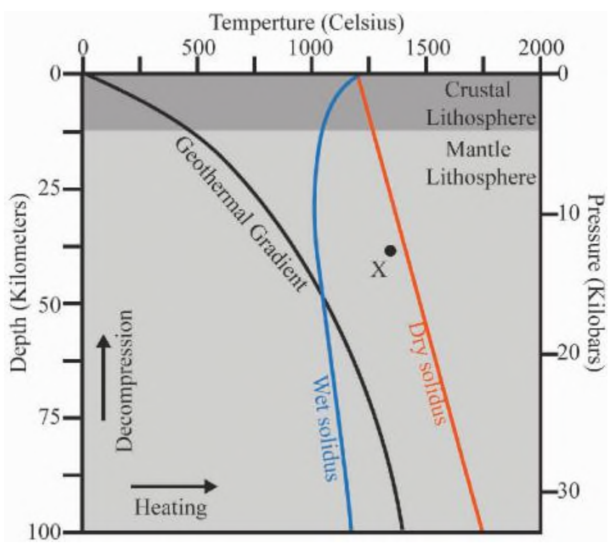

Figure 4.7 | Melting diagram for mantle rock.
Author: Bradley Deline
Source: Original Work
License: CC BY-SA 3.0

20. According to the geothermal gradient, rocks buried 75 km beneath the surface would normally be at what temperature?

At 75 km depth, rocks will be heated to about ___________ degrees Celsius.

a. 1500 b. 1250 c. 1000 d. 750

21. According to the geothermal gradient, rocks at 500 degrees Celsius will be buried how deep?

At 500 degrees Celsius, rocks will be buried to about ___________ km depth.

a. 8 b. 12.5 c. 20 d. 27

22. What is the physical state of a dry mantle rock at point X?

a. Completely melted b. Starting to melt c. Completely solid

23. What happens when the lithosphere at point X is heated to 1500 °C?

a. No change b. Starts to crystallize c. Starts to melt

24. At what depth will the dry mantle rock at point X begin to melt if it is uplifted closer to Earth's surface and its temperature remains the same?

a. 35 km b. 25 km c. 18 km d. 12 km

25. What would happen to the mantle rock at point X if water is added to it?

a. No change b. Starts to crystallize c. Starts to melt

Part E – Boundaries

Earthquakes are great indicators of plate boundaries and are associated with all three boundary types. One type of boundary is unique in having a Wadati-Be-nioff zone. Answer the following questions using Figure 4.8.

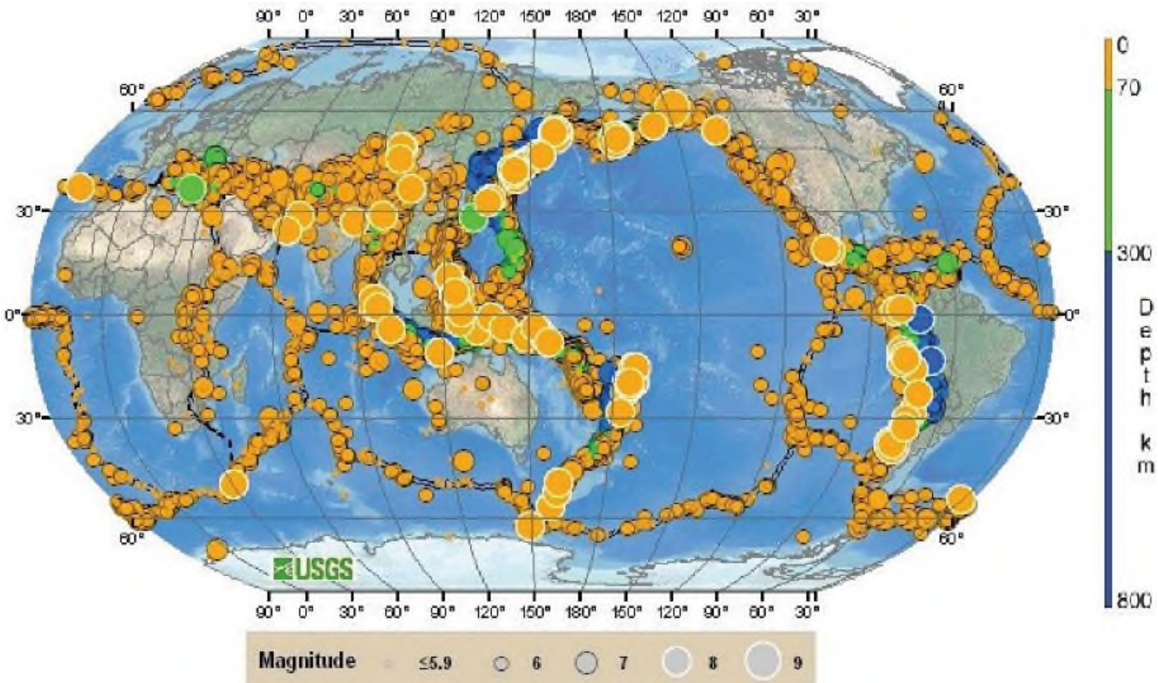

Figure 4.8 | Distribution and depth of Earthquakes.
Author: USGS
Source: USGS
License: Public Domain

26. Which of the following places represent a Wadati-Benioff zone?

a. 10°S, 110°W b. 0°, 0° c. 15°S, 180° d. 30°N, 75°E

27. The Wadati-Benioff zone is associated with which type of plate boundary?

a. Divergent b. Convergent (Continent-Continent) c. Convergent (Continent-Ocean or Ocean-Ocean) d. Transform

Type 34 46 16.16 N 118 44 58.19 W into the search bar in Google Earth and zoom out to an eye altitude of 10 miles. Quail Lake is a dammed river that is sitting directly over top of the San Andres Fault, which is a well-known transform boundary with the North American Plate on the northern side and the Pacific Plate on the southern side. This boundary is running East-West in this area and you may be able to see the boundary better by zooming out.

28. Examine the path of the river that feeds into and flows out of Quail Lake. What direction is the North American plate moving in comparison to the Pacific Plate at this location?

a. East b. West

29. Given that San Francisco is located on the North American Plate and Los Angles is located on the Pacific Plate, are these two cities getting closer together or farther apart over time?

a. Closer b. Farther

Google Earth: Identifying Plate Boundaries

Re-read the section on Plate Boundaries before answering the following questions.

30. Type “15 19 48.78 S 75 12 03.41 W” into the Google Earth Search bar. What type of tectonic plates are present?

a. Ocean- Ocean b. Ocean- Continent c. Continent- Continent

31. What type of plate tectonic boundary is present?

a. Transform b. Convergent c. Divergent

32. Type “6 21 49.68 S 29 35 37.87 E” into the Google Earth Search bar. What type of process is going on at this location?

a. Seafloor spreading b. Continental rifting c. Subduction

33. What features would you expect to occur at this type of boundary?

a. Earthquakes and a trench b. Volcanoes and a valley

c. Mountains and landslides d. Earthquakes and offset rivers

34. Type “28 04 27.04N 86 55 26.84E” into the Google Earth Search bar. What type of tectonic plates are present?

a. Ocean- Ocean b. Ocean- Continent c. Continent- Continent

35. What type of plate tectonic boundary is present?

a. Transform b. Convergent c. Divergent

36. Type “46 55 25.66 N 152 01 25.17 E” into the Google Earth Search bar. What type of tectonic plates are present? Make sure to zoom out to get a good view of the relevant features.

a. Ocean- Ocean b. Ocean- Continent c. Continent- Continent

37. What features would you expect to occur at this type of boundary?

a. Volcanos, earthquakes and a trench b. Volcanoes and a linear valley

c. Mountains and landslides d. Earthquakes and offset rivers

38. Type "43 41 07.81 N 128 16 56.29 W" into the Google Earth Search bar. What type of tectonic plates are present? Hint- make sure to re-read the section on plate boundaries before answering!

a. Ocean- Ocean b. Ocean- Continent c. Continent- Continent

39. What type of plate tectonic boundary is at this exact location?

a. Transform b. Convergent c. Divergent

40. This plate boundary isn't as simple as the previous examples, meaning another nearby plate boundary directly influences it. Zoom out and examine the area, what other type of boundary is nearby?

a. Transform b. Convergent c. Divergent

4.10 PLATE TECTONIC MECHANISMS

The question still remains, why do tectonic plates move? The answer comes down to gravity and mantle convection. You have already studied in chapter two how the mantle flows through time creating convection currents. These convection currents flow underneath the plates and through friction pull them along at the surface as well as when they are subducted which is a force called **slab suction**. Related to this force is **slab pull,** which is a gravitational force pulling the cold subducting plate down into the mantle at a subduction zone. In addition, there is a force from potential energy at ocean ridges called **ridge push**. This is a gravitational force pushing down on the elevated ridge and because of the plates curvature it results in a horizontal force pushing the plate along the earth's surface. These forces all occur deep inside the Earth and operate on very large geographic scales making them difficult to measure. There are several competing models for the mechanisms behind plate motion, such that there are still some areas of debate surrounding the mechanics of plate tectonics which is why Plate Tectonics is a scientific theory. Documenting an event is much easier and more straightforward than explaining why it occurred.

4.11 LAB EXERCISE

Part F – Mechanisms

41. Go back to the location in Google Earth that you examined for question 36 (46 55 25.66 N 152 01 25.17 E). Which of the three proposed plate tectonic mechanisms would NOT occur at this location?

a. Slab pull b. Ridge push c. Slab suction

Reference

Scalon, J. D. 2005. Australia's oldest known snakes: *Patagoniophis*, *Alamitophis* and *c.f. Madtsoia* (Squamata: Madtsoiidae) from the Eocene of Queensland. Memoirs of the Queensland Museum 51: 215-235.

4.11 STUDENT RESPONSES

The following is a summary of the questions in this lab for ease in submitting answers online.

1. Brazil (Latitude and Longitude)

2. Angola (Latitude and Longitude)

3. Measure in centimeters the distance (Map Length) between the two points you recorded in the previous question. Given that this portion of Pangaea broke apart 200,000,000 years ago, calculate how fast South America and Africa are separating in cm/year? (Hint: Speed= Distance/Time)

4. When will the next supercontinent form? Examine the Western Coast of South America, the Eastern Coast of Asia, and the Pacific Ocean. If South America and Africa are separating and the Atlantic Ocean is growing, then the opposite must be occurring on the other side of the earth (the Americas are getting closer to Asia and the Pacific Ocean is shrinking). How far apart are North America and Mainland Asia in cm? (measure the distance across the Pacific at 40 degrees north latitude- basically measure between Northern California and North Korea)? Take that distance and divide it by the speed you calculated in question 3 to estimate when the next supercontinent will form. Show your work!

5. How far have the snake fossils moved apart since they were originally deposited?

a. 1250 miles b. 1700 miles c. 2150 miles d. 2700 miles

6. Given that this portion of the Australian plate moves at a speed of 2.2 inches per year, how old are the snake fossils?

a. 310 million years old
b. 217 million years old
c. 98 million years old
d. 62 million years old
e. 34 million years old

7. There are fossils such as *Glossopteris* and *Lystrosaurus* that are found in rocks in South America and Africa that indicate they were part of Pangaea approximately 200 million years ago. These same fossils can be found in Australia, which indicates it, along with Antarctica, was also part of Pangaea at that time. Based on your answer to question 6 which of the following statements about the break-up of Pangaea is TRUE?

a. Australia and Antarctica separated before the break-up of Pangaea.
b. Australia and Antarctica separated during the break-up of Pangaea.
c. Australia and Antarctica separated after the break-up of Pangaea.

8. Consider the ages and positions of the islands listed above along with what you know about plate tectonics and hotspots. In what general direction is the Pacific Plate moving?

a. Northwest
b. Southeast
c. Northeast
d. Southwest

9. How fast was the Pacific plate moving during the last 1.1 million years between the formation of the Big Island and Maui in cm/year? To calculate this divide the distance (in centimeters) between the two islands by the difference in their ages.

10. How fast was the Pacific plate moving from 7.2 million years ago to 4.7 million years ago between the formation of Kauai and Nihoa in cm/year? To calculate this divide the distance (in centimeters) between the two islands by the difference in their ages.

11. Examine the headings of the measurements that you took for the previous two questions. The headings indicate the direction the Pacific Plate is moving over the hot spot. How does the direction of motion of the Pacific Plate during the last 1.1 million years differ from direction of movement between 4.7 and 7.2 million years ago? The direction of plate movement in the last 1.1 million years ____________ .

a. shows no change b. has become more southerly c. has become more northerly

12. Zoom out and examine the dozens of sunken volcanoes out past Nihoa, named the Emperor Seamounts. As one of these volcanic islands on the Pacific Plate moves off the hotspot it becomes inactive, or extinct, and the island begins to sink as it and the surrounding tectonic plate cool down. The speed the islands are sinking can be estimated by measuring the difference in elevation between two islands and dividing by the difference in their ages (this method assumes the islands were a similar size when they were active). Calculate how fast the Hawaiian Islands are sinking, by using the ages and elevations of Maui and Nihoa.

13. Using the speed you calculated in the previous question (and ignoring possible changes in sea level), when will the Big Island of Hawaii sink below the surface of the ocean? Divide the current maximum elevation of the Big Island by the rate you calculated in the previous question.

14. Now zoom out to ~4000 miles eye altitude and look at the chain of Hawaiian Islands again. Notice the chain continues for thousands of miles up to Aleutian Islands (between Alaska and Siberia). Examine the northernmost sunken volcano (50 49 16.99N 167 16 36.12E) in this chain. Where was that volcano located when it was still active, erupting, and above the surface of the ocean?

a. 50 49 16.99N 167 16 36.12E b 52 31 48.72N 166 25 43.14W

c. 27 45 49.27N 177 10 08.75W d. 19 28 15.23N 155 19 14.43W

15. The rock that most closely resembles the composition of continental crust based on the description in the previous section is:

a. A b. B c. C d. D

16. Based on the choice you made for question 15, what is the density of the rocks that make up continental crust? Please give your answer in grams/milliliter.

17. The rock that most closely resembles the composition of oceanic crust based on the description in the previous section is:

a. A b. B c. C d. D

18. Based on the choice you made for question 17, what is the density of the rocks that make up oceanic crust? Please give your answer in grams/milliliter.

19. Remember, because of isostasy the denser plate will be lower than the less dense plate. If oceanic and continental crust collided, based on their densities the _______________ crust would sink below the _________ crust.

a. continental; oceanic b. oceanic; continental

20. According to the geothermal gradient, rocks buried 75 km beneath the surface would normally be at what temperature?

At 75 km depth, rocks will be heated to about ___________ degrees Celsius.

a. 1500 b. 1250 c. 1000 d. 750

21. According to the geothermal gradient, rocks at 500 degrees Celsius will be buried how deep?

At 500 degrees Celsius, rocks will be buried to about ____________ km depth.

a. 8 b. 12.5 c. 20 d. 27

22. What is the physical state of a dry mantle rock at point X?

a. Completely melted b. Starting to melt c. Completely solid

23. What happens when the lithosphere at point X is heated to 1500 °C?

a. No change b. Starts to crystallize c. Starts to melt

24. At what depth will the dry mantle rock at point X begin to melt if it is uplifted closer to Earth's surface and its temperature remains the same?

a. 35 km b. 25 km c. 18 km d. 12 km

25. What would happen to the mantle rock at point X if water is added to it?

a. No change b. Starts to crystallize c. Starts to melt

26. Which of the following places represent a Wadati-Benioff zone?

a. 10°S, 110°W b. 0°, 0° c. 15°S, 180° d. 30°N, 75°E

27. The Wadati-Benioff zone is associated with which type of plate boundary?

a. Divergent b. Convergent (Continent-Continent)

c. Convergent (Continent-Ocean or Ocean-Ocean) d. Transform

28. Examine the path of the river that feeds into and flows out of Quail Lake. What direction is the North American plate moving in comparison to the Pacific Plate at this location?

a. East b. West

29. Given that San Francisco is located on the North American Plate and Los Angles is located on the Pacific Plate, are these two cities getting closer together or farther apart over time?

a. Closer b. Farther

30. Type "15 19 48.78 S 75 12 03.41 W" into the Google Earth Search bar. What type of tectonic plates are present?

a. Ocean- Ocean b. Ocean- Continent c. Continent- Continent

31. What type of plate tectonic boundary is present?

a. Transform b. Convergent c. Divergent

32. Type "6 21 49.68 S 29 35 37.87 E" into the Google Earth Search bar. What type of process is going on at this location?

a. Seafloor spreading b. Continental rifting c. Subduction

33. What features would you expect to occur at this type of boundary?

a. Earthquakes and a trench

b. Volcanoes and a valley

c. Mountains and landslides

d. Earthquakes and offset rivers

34. Type “28 04 27.04N 86 55 26.84E” into the Google Earth Search bar. What type of tectonic plates are present?

a. Ocean- Ocean

b. Ocean- Continent

c. Continent- Continent

35. What type of plate tectonic boundary is present?

a. Transform

b. Convergent

c. Divergent

36. Type “46 55 25.66 N 152 01 25.17 E” into the Google Earth Search bar. What type of tectonic plates are present? Make sure to zoom out to get a good view of the relevant features.

a. Ocean- Ocean

b. Ocean- Continent

c. Continent- Continent

37. What features would you expect to occur at this type of boundary?

a. Volcanos, earthquakes and a trench

b. Volcanoes and a linear valley

c. Mountains and landslides

d. Earthquakes and offset rivers

38. Type “43 41 07.81 N 128 16 56.29 W” into the Google Earth Search bar. What type of tectonic plates are present? Hint- make sure to re-read the section on plate boundaries before answering!

a. Ocean- Ocean

b. Ocean- Continent

c. Continent- Continent

39. What type of plate tectonic boundary is at this exact location?

a. Transform

b. Convergent

c. Divergent

40. This plate boundary isn’t as simple as the previous examples, meaning another nearby plate boundary directly influences it. Zoom out and examine the area, what other type of boundary is nearby?

a. Transform

b. Convergent

c. Divergent

41. Go back to the location in Google Earth that you examined for question 36 (46 55 25.66 N 152 01 25.17 E). Which of the three proposed plate tectonic mechanisms would NOT occur at this location?

a. Slab pull b. Ridge push c. Slab suction