LAB 1: PLATE TECTONICS

Lab Structure

Recommended additional work	Yes – complete Google Earth Tutorial before Lab 1
Required materials	Pencil, pencil crayons, ruler, printed Plate Boundaries Map

Learning Objectives

After carefully reading this section, completing the exercises within it, and answering the questions at the end, you should be able to:

- Explain the difference between oceanic and continental crust.
- Describe the motion of plates at divergent, convergent, and transform boundaries.
- Characterize divergent, convergent, and transform plate boundaries by their associated geological features and processes.
- Describe how mantle plumes and resulting hot spot volcanoes can be used to determine the direction of plate motion.
- Understand the historical contributions of geoscientists who proposed the theory of plate tectonics.

Key Terms

- Lithosphere
- Continental crust
- Oceanic crust
- Mantle
- Asthenosphere
- Tectonic plate
- Divergent
- Convergent
- Transform
- Seismology
- Volcanology
- Bathymetry
- Topography
- Geochronology
- Mantle plume
- Hot spot

1.1 Discovering Plate Tectonics

As we discovered in the introduction to this lab manual, plate tectonics is the model or theory that we use to understand how our planet works. More specifically it is a model that explains the origins of continents and oceans, folded rocks and mountain ranges, igneous and metamorphic rocks, earthquakes, volcanoes, and continental drift. Plate tectonics was first proposed just over 100 years ago, but did not become an accepted part of geology until about 50 years ago. It took 50 years for this theory to be accepted for a few reasons. First, it was a true revolution in thinking about Earth, and that was difficult for many established geologists to accept. Second, there was a political gulf between the main proponent of the theory Alfred Wegener (from Germany) and the geological establishment of the day, which was mostly centred in Britain and the United States. Third, the evidence and understanding of Earth that would have supported plate tectonic theory simply didn't exist until the middle of the 20th century. Before we delve into the details of plate tectonics, we need to examine some historical context to understand how this theory developed over the course of the 20th century.

Most of the key evidence for plate tectonics came from studying the ocean floor. Before 1900, we knew virtually nothing about the bathymetry and geology of the oceans. By the end of the 1960s, we had detailed maps of the topography of the ocean floors, a clear picture of the geology of ocean floor sediments and the solid rocks underneath them, and almost as much information about the geophysical nature of ocean rocks as of continental rocks. Some of the most influential discoveries by geoscientists in the 20th century that have shaped modern plate tectonic theory are briefly summarized below.

The 1920s to 1950s

Development of acoustic depth sounders to map the ocean floor (Figure 1.1.1) leads to discovery of major mountain chains in all of the world's oceans. During and after World War II, there was a well-organized campaign to study the oceans, and by 1959, sufficient bathymetric data had been collected to produce detailed maps of all the oceans (Figure 1.1.2).

The important physical features of the ocean floor are:

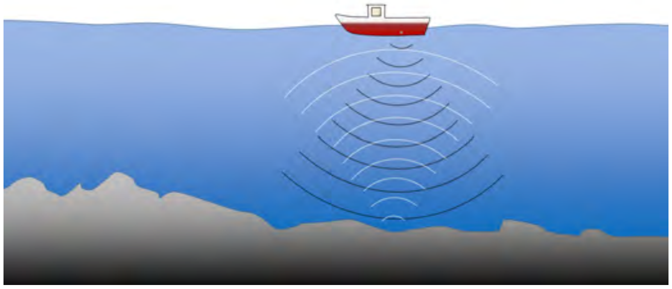


Figure 1.1.1: Depiction of a ship-borne acoustic depth sounder. The instrument emits a sound (black arcs) that bounces off the seafloor and returns to the surface (white arcs). The travel time is proportional to the water depth.

- Extensive linear ridges (commonly in the central parts of the oceans) with water depths in the order of 2,000 to 3,000 m (Figure 1.1.2, inset a)
- Fracture zones perpendicular to the ridges (inset a)
- Deep-ocean plains at depths of 5,000 to 6,000 m (insets a and d)
- Relatively flat and shallow continental shelves with depths under 500 m (inset b)
- Deep trenches (up to 11,000 m deep), most near the continents (inset c)
- Seamounts and chains of seamounts (inset d)

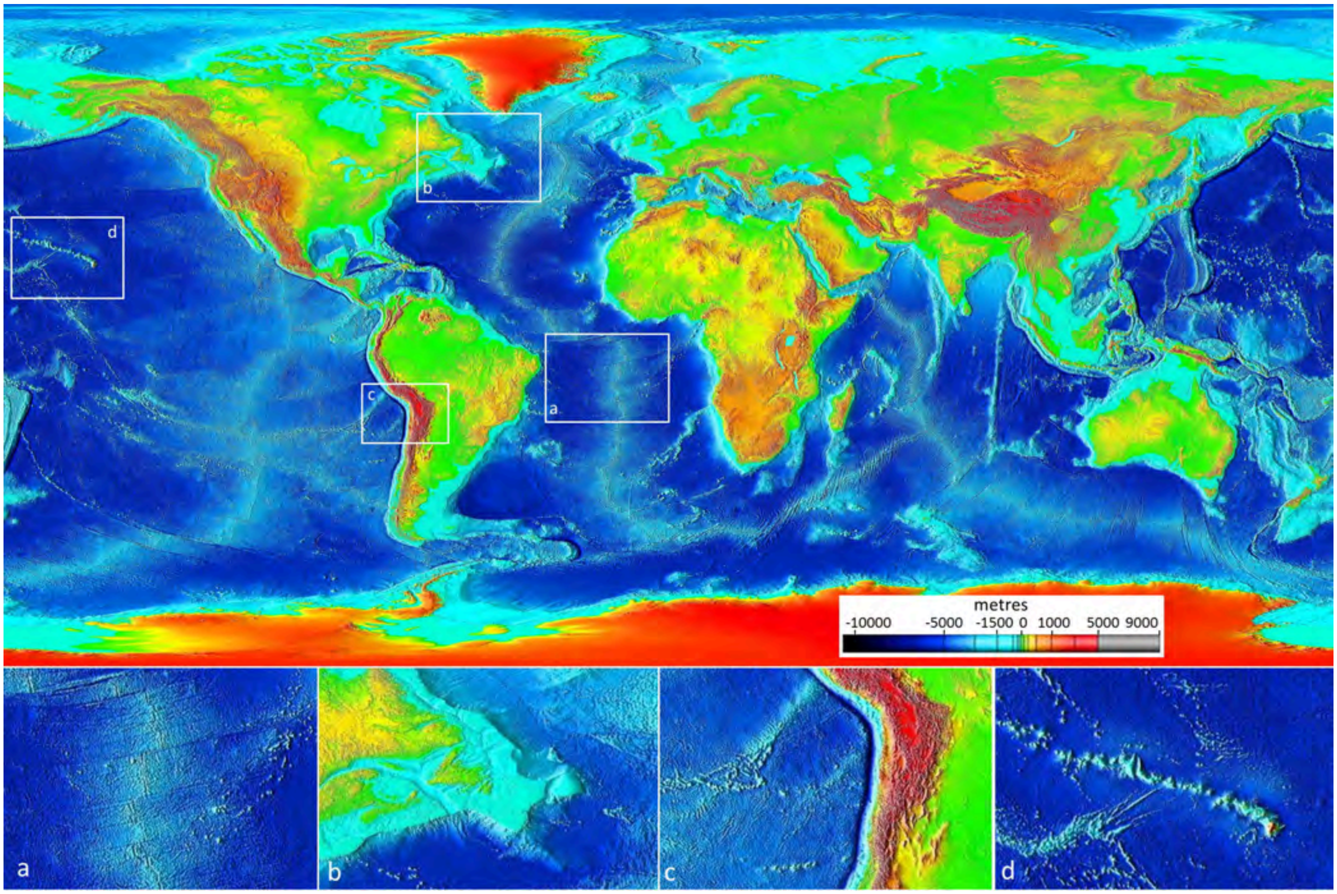


Figure 1.1.2: Ocean floor bathymetry (and continental topography). Inset (a): the mid-Atlantic ridge, (b): the Newfoundland continental shelf, (c): the Nazca trench adjacent to South America, and (d): the Hawaiian Island chain.

With developments of networks of **seismograph stations** in the 1950s, it became possible to plot the locations *and* depths of both major and minor earthquakes with great accuracy. It was found that there is a remarkable correspondence between earthquakes and both the mid-ocean ridges and the deep ocean trenches. In 1954 Gutenberg and Richter showed that the ocean-ridge earthquakes were all relatively shallow, and confirmed what had first been shown by Benioff in the 1930s — that earthquakes in the vicinity of ocean trenches were both shallow and deep, but that the deeper ones were situated progressively farther inland from the trenches (Figure 1.1.3).

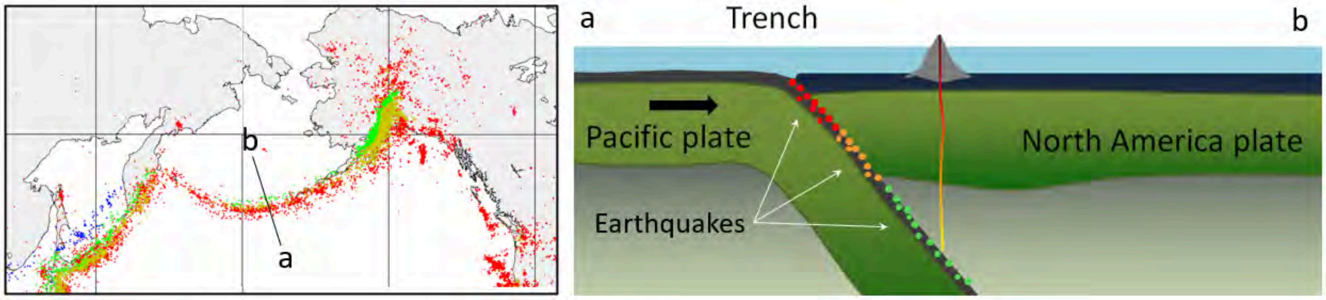


Figure 1.1.3: Cross-section through the Aleutian subduction zone with a depiction of the increasing depth of earthquakes "inshore" from the trench. [Image Description]

Another key component in the case for plate tectonics came from studies of **remnant magnetism** in the rocks that make up the ocean crust. Usually, remnant magnetism is caused by the presence of ferrous (unoxidized) iron on the seafloor, often from a volcanic rock containing grains of magnetite (Fe_3O_4), a highly magnetic mineral. As the mineral magnetite crystallizes from magma, it becomes magnetized with an orientation parallel to that of Earth's magnetic field at that time. Rocks like basalt, which cool from a high temperature and commonly have relatively high levels of magnetite (up to 1 or 2%), are particularly susceptible to being magnetized in this way, but even sediments and sedimentary rocks, as long as they have small amounts of magnetite, will take on remnant magnetism because the magnetite grains gradually become reoriented following deposition.

In the 1950s, scientists from the Scripps Oceanographic Institute in California persuaded the U.S. Coast Guard to include **magnetometer** readings on one of their expeditions to study ocean floor topography. The first comprehensive seafloor **paleomagnetic** data set was compiled in 1958 for an area off the coast of B.C. and Washington State. This survey revealed a bewildering pattern of low and high magnetic intensity in seafloor rocks (Figure 1.1.4). When the data were first plotted on a map in 1961, nobody understood them — not even the scientists who collected them. But these paleomagnetic data became a key piece of evidence for **seafloor spreading**.

Figure 1.1.4: Pattern of seafloor magnetism off of the west coast of British Columbia and Washington.

The 1960s

In 1960, Harold Hess, a widely respected geologist from Princeton University, advanced a theory with many of the elements that we now accept as **plate tectonics**. Hess proposed that:

- new sea floor was generated from mantle material at the ocean ridges,
- old sea floor was dragged down at the ocean trenches and re-incorporated into the mantle,
- plate tectonics are driven by mantle convection currents, rising at the ridges and descending at the trenches (Figure 1.1.5),
- the less-dense continental crust did not descend with oceanic crust into trenches, but that colliding land masses were thrust up to form mountains.

Hess's theory formed the basis for our ideas on **seafloor spreading** and **continental drift,** but it did not deal with the concept that the crust is made up of specific **plates**. Although the Hess model was not roundly criticized, it was not widely accepted (especially in the U.S.), partly because it was not well supported by hard evidence.

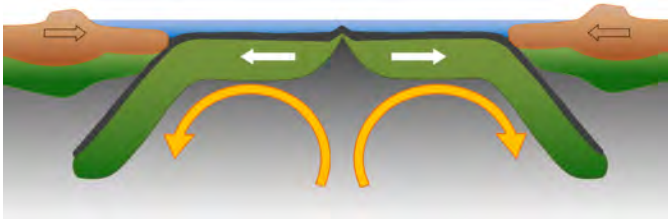


Figure 1.1.5: A representation of Harold Hess's model for seafloor spreading and subduction.

In 1963, J. Tuzo Wilson of the University of Toronto proposed the idea of a **mantle plume** or **hot spot**—a place where hot mantle material rises in a stationary and semi-permanent plume, and affects the overlying crust. He based this hypothesis partly on the distribution of the Hawaiian and Emperor Seamount island chains in the Pacific Ocean (Figure 1.1.6). The volcanic rock making up these islands gets progressively younger toward the southeast, culminating with the island of Hawaii itself, which consists of rock that is almost all younger than 1 Ma. Wilson suggested that a stationary plume of hot upwelling mantle material is the source of the Hawaiian volcanism, and that the ocean crust of the Pacific Plate is moving toward the northwest over this hot spot. Near the Midway Islands, the chain takes a pronounced change in direction, from northwest-southeast for the Hawaiian Islands and to nearly north-south for the Emperor Seamounts. This change is widely ascribed to a change in direction of the Pacific Plate moving over the stationary mantle plume, but a more plausible explanation is that the Hawaiian mantle plume has not actually been stationary throughout its history, and in fact moved at least 2,000 km south over the period between 81 and 45 Ma.[1]

In addition to his contributions on mantle plumes and plate motion, Wilson also introduced the idea that the crust can be divided into a series of rigid plates in a 1965 paper, and thus he is responsible for the term **plate tectonics**.

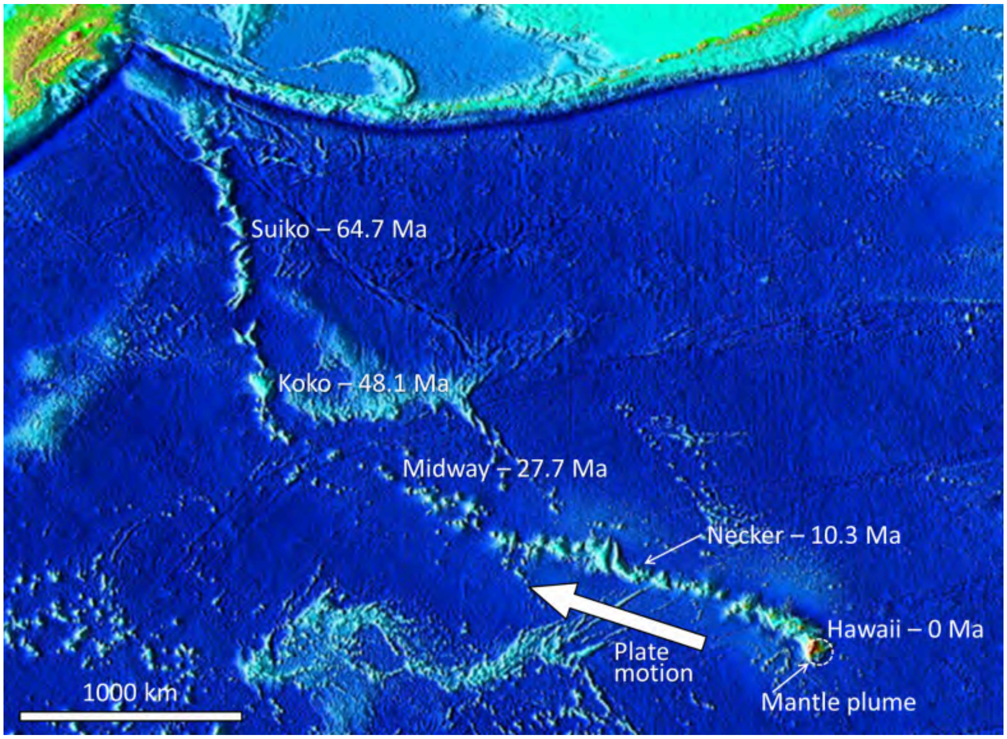


Figure 1.1.6: The ages of the Hawaiian Islands and the Emperor Seamounts in relation to the location of the Hawaiian mantle plume.

Practice Exercise 1.1 Volcanoes and the Rate of Plate Motion

The Hawaiian and Emperor volcanoes shown in Figure 1.1.6 are listed in the table below along with their ages and their distances from the centre of the mantle plume under Hawaii (the Big Island).

Ages of Hawaiian and Emperor volcanoes and their distances from the centre of the mantle plume. Calculate their rate of movement in centimetres per year.

Island	Age	Distance	Rate
Hawaii	0 Ma	0 km	–
Necker	10.3 Ma	1,058 km	10.2 cm/y
Midway	27.7 Ma	2,432 km	
Koko	48.1 Ma	3,758 km	
Suiko	64.7 Ma	4,860 km	

Plot the data on Figure 1.1.7, and use the numbers in the table to estimate the rates of plate motion for the Pacific Plate in cm/year. (The first two are plotted for you.)

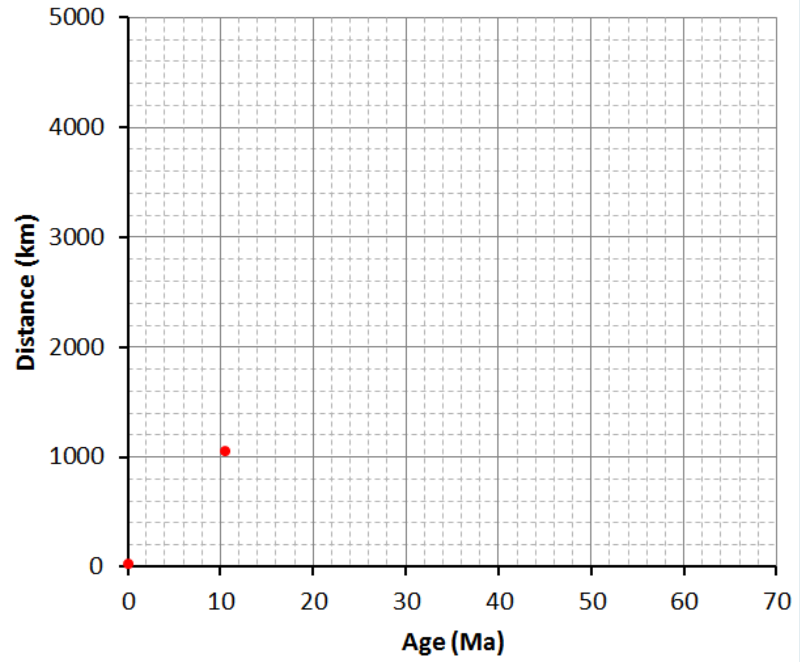


Figure 1.1.7: Graph of hot spot volcano age (millions of years, Ma) against distance (km).

See Appendix 2 for Practice Exercise 1.1 answers.

There is evidence of many such mantle plumes around the world (Figure 1.1.8). Most are within the ocean basins—including places like Hawaii, Iceland, and the Galapagos Islands—but some are under continents. One example is the Yellowstone hot spot in the west-central United States, and another is the one responsible for the Anahim Volcanic Belt in central British Columbia. It is evident that mantle plumes are very long-lived phenomena, lasting for at least tens of millions of years, possibly for hundreds of millions of years in some cases.

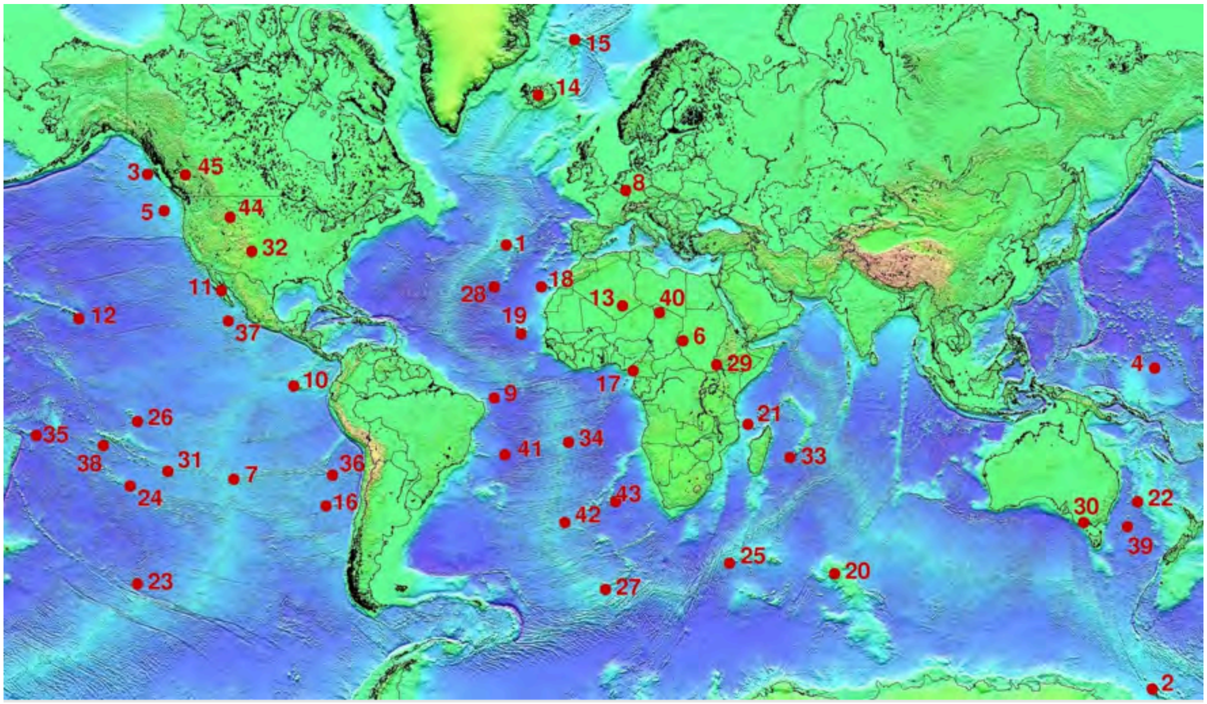


Figure 1.1.8: Mantle plume locations. Selected Mantle plumes: 1: Azores, 3: Bowie, 5: Cobb, 8: Eifel, 10: Galapagos, 12: Hawaii, 14: Iceland, 17: Cameroon, 18: Canary, 19: Cape Verde, 35: Samoa, 38: Tahiti, 42: Tristan, 44: Yellowstone, 45: Anahim

Image Descriptions

Figure 1.1.3 image description: A cross section of the trench formed at the Aleutian subduction zone as the Pacific plate subducts under the North American plate in the middle of the Pacific Ocean. The farther away an earthquake is from this trench (on the North America plate side), the deeper it is. [Return to Figure 1.1.3]

Media Attributions

- Figures 1.1.1, 1.1.3, 1.1.5, 1.1.7: © Steven Earle. CC BY.
- Figure 1.1.2: "Elevation" by NOAA. Adapted by Steven Earle. Public domain.
- Figure 1.1.4: "Juan de Fuca Ridge" by USGS. Adapted by Steven Earle. Public domain. Based on Raff, A. and Mason, R., 1961, Magnetic survey off the west coast of North America, 40° N to 52° N latitude, Geol. Soc. America Bulletin, V. 72, p. 267-270.
- Figure 1.1.6: "Hawaii Hotspot" by National Geophysical Data Center. Adapted by Steven Earle. Public domain.
- Figure 1.1.8: "Hotspots" by Ingo Wölbern. Public domain.

Notes

1. J. A. Tarduno et al., 2003, The Emperor Seamounts: Southward Motion of the Hawaiian Hotspot Plume in Earth's Man-

tle, Science 301 (5636): 1064–1069.

1.2 Plates, Plate Motions, and Plate Boundaries

By the end of 1967 the Earth's surface had been mapped into a series of plates. The major plates are Eurasia, Pacific, India, Australia, North America, South America, Africa, and Antarctic. There are also numerous small plates (e.g., Juan de Fuca, Cocos, Nazca, Scotia, Philippine, Caribbean), and many very small plates or sub-plates. For example the Juan de Fuca Plate is actually three separate plates (Gorda, Juan de Fuca, and Explorer) that all move in the same general direction but at slightly different rates.

Rates of motions of the major plates range from less than 1 cm/y to over 10 cm/y. The Pacific Plate is the fastest, followed by the Australian and Nazca Plates. The North American Plate is one of the slowest, averaging around 1 cm/y in the south up to almost 4 cm/y in the north. Plates move as rigid bodies, so it may seem surprising that the North American Plate can be moving at different rates in different places. The explanation is that plates move in a rotational manner. The North American Plate, for example, rotates counter-clockwise; the Eurasian Plate rotates clockwise.

Boundaries between the plates are of three types:

- **divergent** (i.e., moving apart),
- **convergent** (i.e., moving together), and
- **transform** (moving side by side).

Before we talk about processes at plate boundaries, it's important to point out that there are never gaps between plates. The plates are made up of the **lithosphere.** The lithosphere consists of the **crust**, which can be thin, relatively dense **oceanic crust** or thick, relatively buoyant **continental crust**, and the rigid uppermost part of the **mantle** (Figure 1.2.1). Even though tectonic plates are moving all the time, and in different directions, there is never a significant amount of space between them. Plates are thought to move along the lithosphere-asthenosphere boundary, as the **asthenosphere** is the zone of partial melting. It is assumed that the relative lack of strength of the partial melting zone facilitates the sliding of the lithospheric plates. The fact that the plates include both crustal material and lithospheric mantle material makes it possible for a single plate to be made up of both oceanic and continental crust. For example, the North American Plate includes most of North America (continental crust), plus half of the northern Atlantic Ocean (oceanic crust). The Pacific Plate is almost entirely oceanic, but it does include the part of California west of the San Andreas Fault.

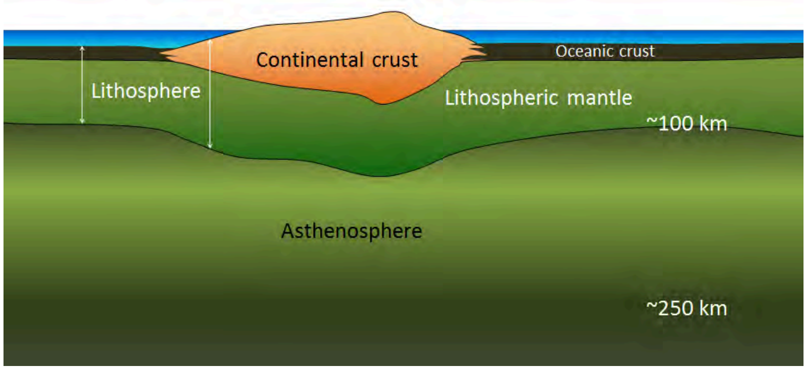


Figure 1.2.1: The crust and upper mantle. Tectonic plates consist of lithosphere, which includes the crust and the uppermost (rigid) part of the mantle.

Divergent Boundaries

Divergent boundaries are spreading boundaries, where new oceanic crust is created from magma derived from **partial melting** of the mantle caused by **decompression** as hot mantle rock from depth is moved toward the surface (Figure 1.2.2). The triangular zone of partial melting near the ridge crest produces oceanic crust that is about 6 km thick. Most divergent boundaries are located at the oceanic ridges, although some are on land.

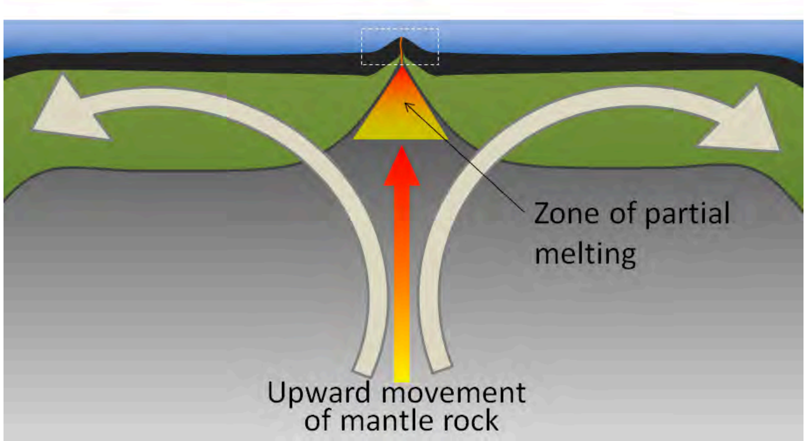


Figure 1.2.2: The general processes that take place at a divergent boundary.

Convergent Boundaries

Convergent boundaries, where two plates are moving toward each other, are of three types, depending on whether oceanic or continental crust is present on either side of the boundary. The types are: ocean-ocean, ocean-continent, and continent-continent.

At an ocean-ocean convergent boundary, one of the plates (oceanic crust and lithospheric mantle) is pushed, or **subducted,** under the other. Often it is the older and colder plate that is denser and subducts beneath the younger and hotter plate. There is commonly an ocean trench along the boundary. The significant volume of water within the subducting material is released as the subducting crust is heated. The water that is released rises and mixes with the overlying mantle. The addition of water to the hot mantle lowers the rocks's melting point and leads to the formation of magma (**flux melting**) (Figure 1.2.3). The magma, which is lighter than the surrounding mantle material, rises through the mantle and the overlying oceanic crust to the ocean floor where it creates a chain of volcanic islands known as an **island arc**.

As described above in the context of Benioff zones (Figure 1.1.3), earthquakes take place close to the boundary between the subducting crust and the overriding crust. The largest earthquakes occur near the surface where the subducting plate is still cold and strong.

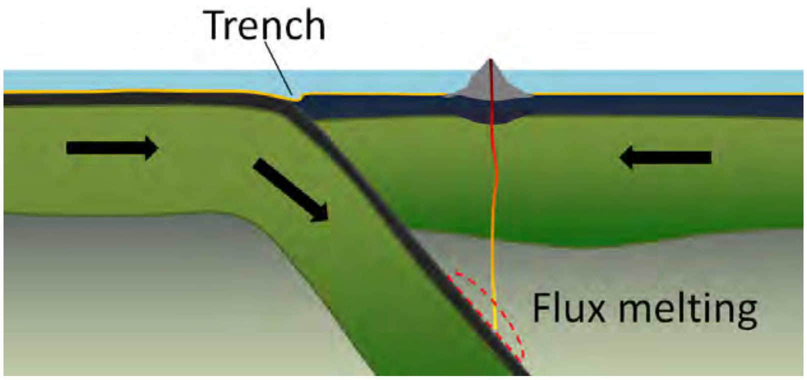


Figure 1.2.3: Configuration and processes of an ocean-ocean convergent boundary.

At an ocean-continent convergent boundary, the oceanic plate is pushed under the continental plate in the same manner as at an ocean-ocean boundary. Sediment that has accumulated on the **continental slope** is thrust up into an accretionary wedge, and compression leads to **deformation** within the continental plate (thrust faults shown in Figure 1.2.4). The mafic magma produced adjacent to the subduction zone rises to the base of the continental crust and leads to partial melting of the crustal rock. The resulting magma ascends through the crust, producing a chain of volcanoes that form a **continental arc.**

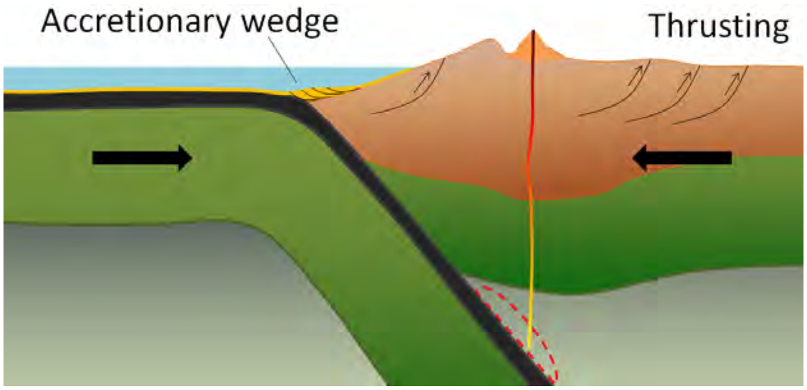


Figure 1.2.4: Configuration and processes of an ocean-continent convergent boundary.

A continent-continent collision occurs when a continent or large island that has been moved along with subducting oceanic crust collides with another continent (Figure 1.2.5). The colliding continental material will not be subducted because it is too light and buoyant, but the root of the oceanic plate will eventually break off and sink into the mantle. There is tremendous deformation of the pre-existing continental rocks, and creation of mountains from that rock, from any sediments that had accumulated along the shores of both continental masses, and commonly also from some ocean crust and upper mantle material.

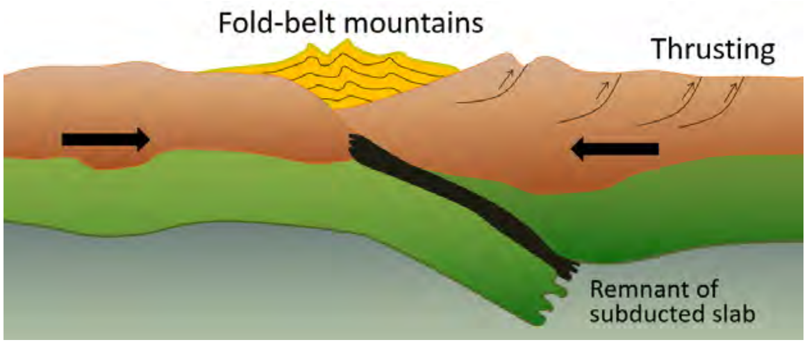


Figure 1.2.5: Configuration and processes of a continent-continent convergent boundary.

Transform Boundaries

Transform boundaries exist where one plate slides past another without production or destruction of crustal material. Although oceanic spreading ridges appear to be curved features on Earth's surface, in fact the ridges are composed of a series of straight-line segments, offset at intervals by faults perpendicular to the ridge (Figure 1.2.6). In a paper published in 1965, Tuzo Wilson termed these features **transform faults**.

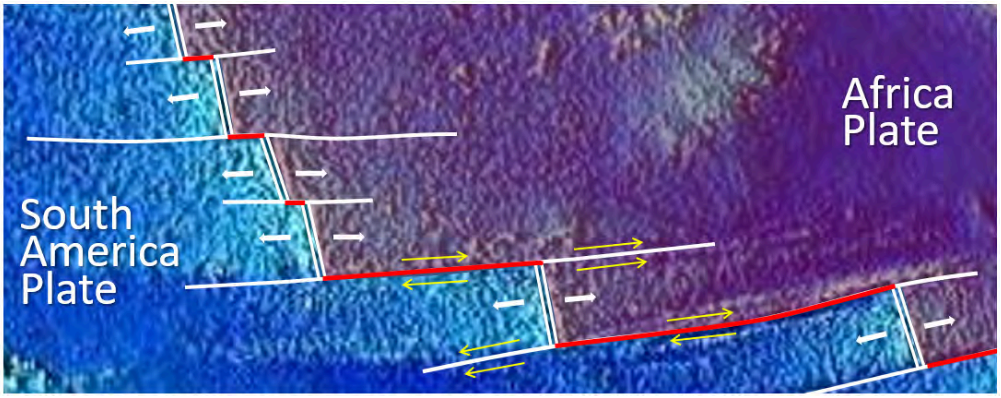


Figure 1.2.6: A part of the mid-Atlantic ridge near the equator. The double white lines are spreading ridges. The solid white lines are fracture zones. As shown by the yellow arrows, the relative motion of the plates on either side of the fracture zones can be similar (arrows pointing the same direction) or opposite (arrows pointing opposite directions). Transform faults (red lines) are in between the ridge segments, where the yellow arrows point in opposite directions.

While most transform faults connect segments of mid-ocean ridges and are thus ocean-ocean plate boundaries, some transform faults connect continental parts of plates. An example is the San Andreas Fault, which extends from the southern end of the Juan de Fuca Ridge to the northern end of the East Pacific Rise (ridge) in the Gulf of California (Figure 1.2.7). The part of California west of the San Andreas Fault and all of Baja California are on the Pacific Plate. Transform faults do not just connect divergent boundaries. For example, the Queen Charlotte Fault connects the north end of the Juan de Fuca Ridge, starting at the north end of Vancouver Island, to the Aleutian subduction zone.

Figure 1.2.7: The San Andreas Fault extends from the north end of the East Pacific Rise in the Gulf of California to the southern end of the Juan de Fuca Ridge. All of the red lines on this map are transform faults.

Media Attributions

- Figures 1.2.1, 1.2.2, 1.2.3, 1.2.4, 1.2.5, 1.2.6, 1.2.7: © Steven Earle. CC BY.

Lab 1 Exercises

Activity I: Plate Boundary Characteristics

In this activity you will learn to identify types of plate boundaries based on the characteristics they exhibit. This activity is based on the "Discovering Plate Boundaries" activity by Dale S. Sawyer at Rice University and modified based on teaching experiences at the SEOS department of the University of Victoria, Canada.

In groups, we will examine five types of plate boundaries today:

- Ocean-Ocean **Divergent** (the boundary between two plates where oceanic crust is being pullled apart)
- Ocean-Ocean **Convergent** (where two plates of oceanic crust are moving toward one another leading to the subduction of one plate)
- Ocean-Continent Convergent (where oceanic and continental crust are moving toward one another leading to the subduction of the oceanic crust)
- Continent-Continent Convergent (where two plates of continental crust are moving toward one another)
- Ocean-Ocean **Transform** (where oceanic crust is moving horizontally in opposite directions across a transform fault)

To start, download or view the plate boundaries map. Seven plate boundaries are highlighted and numbered on your map. You will also be assigned a map displaying one of four data sets: volcanoes, earthquakes, topography/bathymetry, and seafloor age.

You will each, individually, study your data set and attempt to draw conclusions about what geological features and processes characterize each of the numbered plate boundaries.

Later in lab today, you will be joining a live video conference in small groups to share your observations with your group mates. You will be asked to summarize your observations so write down your conclusions and be prepared to teach your peers!

Step 1

Examine your assigned map. Start by locating all the numbered plate boundaries on your assigned map. Are they easy or difficult to find? Looking closely at your data type, start making notes about the ***spatial distribution*** of the data points. Exactly what you look for will vary with data type. For the point data (volcanoes and earthquakes) you are looking for ***distribution patterns***. For surface data (topography and seafloor age) you are looking for where the surface is high and where it is low, where it is old and where it is young. In this activity you are focusing on ***observations, not interpretations,*** meaning that you do not need to worry about why there is or is not a pattern, you just need to observe and record what you see. You are analyzing the data, not interpreting them!

Step 2

Now focus your attention on the numbered plate boundaries on the plate boundaries map. Identify the nature of your data near each of the numbered plate boundaries. Is it high or low, symmetric or asymmetric, missing or not missing, varying along the boundary or constant along the boundary, etc. Complete Table 1.1 below to classify the plate boundaries based on your observations of your assigned data, using the tips below for guidance. Right now, you will only fill in the column for your assigned data set. Remember: do not try to explain the data; just observe!

Below are some suggestions for the kinds of observations that are useful for each data set. Compare your boundary to the types of boundaries on the map as you do this. Remember, the goal is to find unique characteristics for each boundary type.

Volcanoes: Observe and make notes on the distribution patterns. Are the volcanoes near a given boundary randomly distributed, tightly clustered, or do they define a linear trend?

Earthquakes: Observe and make notes on the distribution patterns and depth of the earthquakes. Note both the range of depths (extremes) and the more typical or average. For example, a given boundary might have all shallow earthquakes (0- 33 km) with rare deeper earthquakes between 33 -70 km depth. Earthquakes might be randomly distributed, tightly clustered, or may define a linear trend.

Topography/bathymetry: Look for any topographic features that seem to be related to the boundary, such as nearby mountain chains, deep sea trenches, broad gradual highs or lows, offset (broken and shifted) features, etc. Briefly describe how extreme they are (e.g., a very high or wide mountain chain). Make sure that you understand how the colour scale on the map represents elevations above sea level. For example, your should recognize that bright fuchsia colours correspond to large negative values and represent the deepest parts of ocean where the seafloor is far beneath sea level.

Seafloor age: This data set can be tricky; be careful not to see patterns where there are none! For example, you might observe that in some places, the seafloor age changes from place to place along the boundary. In this case there is no clear pattern and this indicates no relationship between seafloor age and the boundary, but this is still a good observation! Alternately, the seafloor age may be the same everywhere along the boundary, or it may change in a consistent pattern. Do your best to describe what you see, and whether or not your observations fit a clear, consistent pattern.

PLATE BOUNDARY MAP

This map is from Dietmar Mueller, Univ. of Sydney

This map is part of "Discovering Plate Boundaries," a classroom exercise developed by Dale S. Sawyer at Rice University (dale@rice.edu). Additional information about this exercise can be found at http://terra.rice.edu/plateboundary .

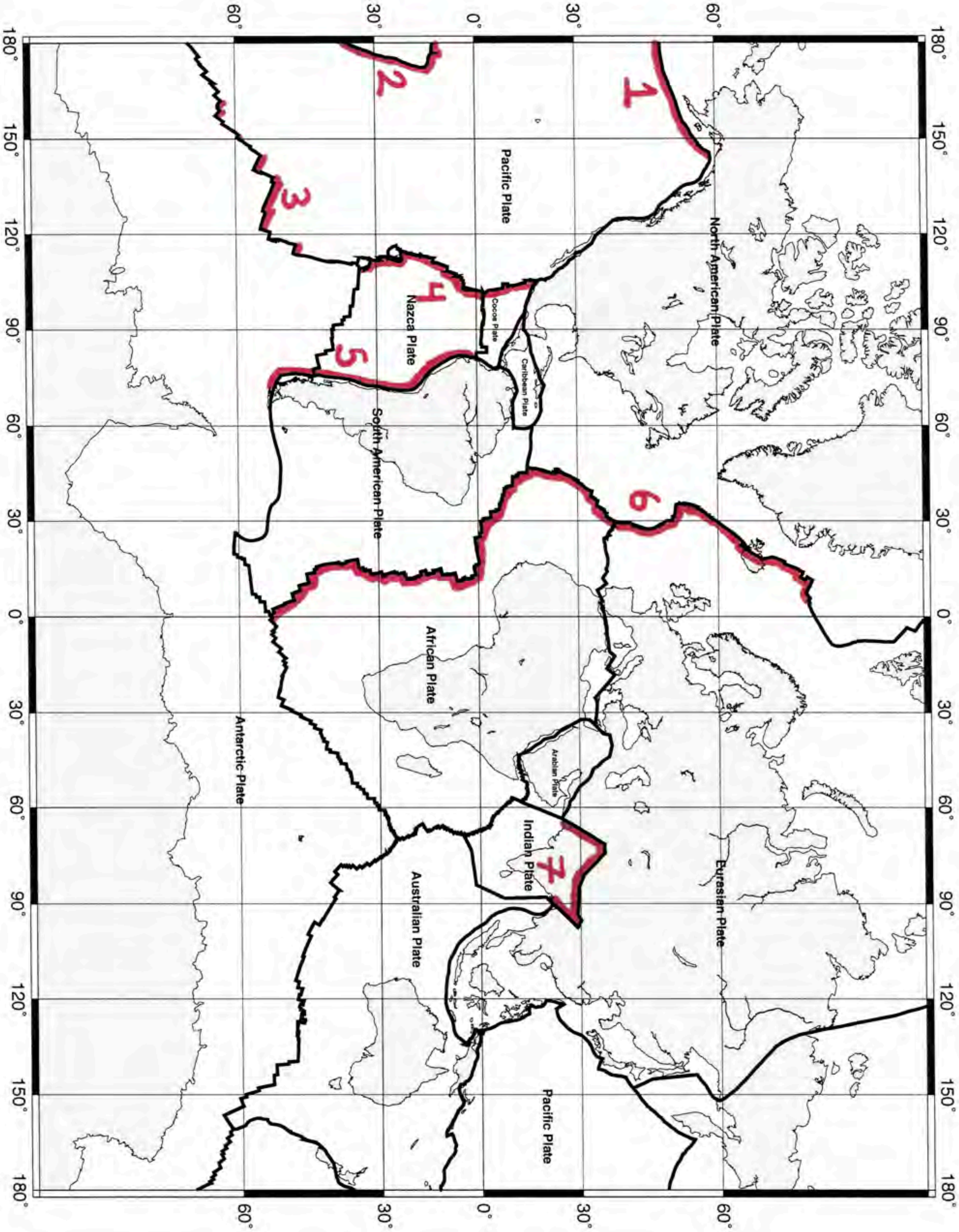


Table 1.1: Summarize the key features from each data set that characterize each type of plate boundary in this table.

Boundary Type	**Volcanism**	**Earthquake Activity**	**Bathymetry/Topography**	**Seafloor Age**
Ocean-Ocean Convergent **(#1 and #2)**				
Ocean-Ocean Transform **(#3)**				
Ocean-Ocean Divergent **(#4 and #6)**				
Ocean-Continent Convergent **(#5)**				
Continent-Continent Convergent **(#7)**				

Step 3

Everyone has been randomly assigned to a group and provided with a link to a video meeting to discuss your observations in real time in groups of four. Each group has at least one representative of each data set. Consider yourselves a group of experts gathering to compare observations. In your group, introduce yourself and what type of data you have been analyzing. Taking turns, each group member will share their observations about their assigned data set from Step 2. It is helpful to share your screen while you teach, so that your group members can see your data. If you are not sure how to share your screen, ask your instructor. Your instructor will periodically join each group video meeting group to check in while you complete this part of the activity.

Work together in your group to complete Table 1.1 by summarizing your observations on the characteristics of each type of plate boundary. By the end of this activity, each member of your group should have a completed Table 1.1. Each group member should be able to describe the characteristics of each type of plate boundary using all four data types.

Activity II: Hot Spot Volcanoes and Plate Motion

In this activity you will use data from chains of hot spot volcanoes in Google Earth Pro to make a rough estimate of the rate of motion of the Pacific Plate, and to determine the direction of plate motion for several different tectonic plates. This activity and the Google Earth data provided are based on the "Determining Plate Rates From Hot Spot Tracks Using Google Earth" activity developed by Susan Schwartz and Erin Todd at the University of California-Santa Cruz.

Step 1

Download the Hawaii-Emperor.kmz file provided by your instructor to examine hot spot volcanoes in Google Earth Pro. Load the file into Google Earth Pro by double-clicking on the file, or in Google Earth Pro by clicking on ***File, Open*** and navigating to where you saved the .kmz file.

Step 2

Once the Hawaii-Emperor.kmz is loaded, click and drag to move it from "Temporary Places" to "My Places." Then save "My Places" by clicking ***File, Save, Save My Places***. This .kmz file will now be available every time you open Google Earth Pro on this computer. ****NOTE:** When you close the program, Google Earth Pro should save everything in "My Places", but to be safe you should manually save "My Places" to your computer whenever you make significant changes to it.

Step 3

Examine the data in the Hawaii-Emperor.kmz file to answer the questions below. Each place marker indicates a location where a volcanic rock was sampled and dated. This type of dating uses radioactive elements in the rock to give geologists a precise age of when the lava cooled and solidified to form a volcanic rock. The number next to each place marker is the age of the rock in millions of years (Ma). The current location of the hot spot at Kilauea Volcano in southeast Hawai'i is shown by the marker labeled 0 Ma.

Hot Spot Volcanoes and Plate Motion Exercise Questions

1. Using what you learned in the Google Earth Tutorial, list the lat/long coordinates of Kilauea Volcano, Diakakuji Seamount (located at the bend in the Hawaii-Emperor chain), and Midway Island.

2. Using what you learned in the Google Earth Tutorial, list the UTM coordinates of Mauna Kea (located near the centre of the island of Hawai'i), the 75.82 Ma volcano near Detroit Seamount (located near the northern end of the Hawaii-Emperor chain), and the 5.77 Ma volcano on Kaua'i. Remember to include the zone at the beginning of the coordinate!

3. Using the ruler tool in Google Earth Pro, found in the top toolbar, measure the distance between the present location of the hot spot at Kilauea Volcano and Midway Island in kilometers (km). Measure the distance as a line from the point of each pin and round to the nearest whole km.

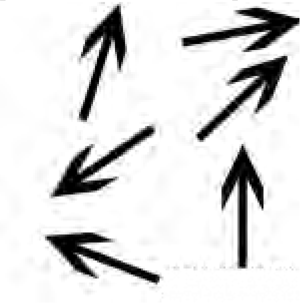
4. Make a rough estimate of the average rate of motion for the Pacific Plate in kilometres per million years. To do this, divide the distance between two volcanoes along the chain by their difference in ages (shown in millions of years, Ma). The rate is calculated as the distance over time. Round to the nearest tenth.

5. Most plate rates reported in scientific literature are measured in cm/yr. Convert your estimated rate to cm/yr. Again, round your result to the nearest tenth. Remember this calculation is a rough estimate!

6. Examine the entire length of the Hawaii-Emperor chain. What do you think might have caused this chain to form such a distinctive "elbow-like" shape?

Download the HotspotVolcanism.kmz file provided by your instructor and load it into Google Earth Pro. Remember to save it in "My Places" once it is loaded into Google Earth Pro! Notice that this file includes the locations of boundaries between tectonic plates as well as place markers and ages for volcanoes along several hot spot chains (or tracks) around the world.

7. Based on the hot spot tracks shown in the HotspotVolcanism.kmz file and the ages of the volcanoes, determine the direction of plate motion for the African, Australian, Nazca, North American, and Pacific plates. Match the plate name to the arrow that most closely illustrates the vector (direction) of motion.



8. Predict whether the plate boundary between the following pairs of plates is *convergent* or *divergent* based on the plate motion determined from the hot spot tracks:

a) Pacific & Nazca Plates

b) South American & African Plates

See Appendix 3 for answers to lab exercises.

Media Attributions

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Summary

The topics covered in this chapter can be summarized as follows:

Section	Summary
1.1 Discovering Plate Tectonics	Giant strides were made in understanding Earth during the middle decades of the 20th century, including discovering magnetic evidence of continental drift, mapping the topography of the ocean floor, describing the depth relationships of earthquakes along ocean trenches, measuring heat flow differences in various parts of the ocean floor, and mapping magnetic reversals on the sea floor. By the mid-1960s, the fundamentals of the theory of plate tectonics were in place.
1.2 Plates, Plate Motions, and Plate Boundaries	Earth's lithosphere is made up of over 20 plates that are moving in different directions at rates of between 1 cm/y and 10 cm/y. The three types of plate boundaries are divergent (plates moving apart and new crust forming), convergent (plates moving together and one being subducted), and transform (plates moving side by side). Divergent boundaries form where existing plates are rifted apart, and it is hypothesized that this is caused by a series of mantle plumes. Subduction zones are assumed to form where accumulation of sediment at a passive margin leads to separation of oceanic and continental lithosphere. Supercontinents form and break up through these processes.
Lab 1 Exercises	Characteristic features of divergent, convergent, and transform plate boundaries can be explored by examining global datasets of volcanology, seismology (earthquakes), topography/bathymetry, and seafloor age displayed on a world map. Since tectonic plates move over a mantle plume that we assume to be stationary, we can use chains or tracks of hot spot volcanoes to interpret the direction of plate motion. By using the age of these hot spot volcanoes, and the distance between volcanoes in the same chain, we can estimate the rate of plate motion.