Name ________________________ Lab section __________

EAS1600 Lab 11

“Plate Tectonics”

Objectives

In this assignment we will review the basic principles of plate tectonics. We will look at the current and past tectonic plate configuration and movements to understand the dynamic nature of the Earth’s interior and geological features of the crust. We will also perform a case study of an earthquake and a fault movement. At the end of this lab, you should be able to:

- determine the location and magnitude of an earthquake based on a seismogram.
- identify tectonic plates and plate boundaries on the physical map of the Earth;
- identify the different types of plate boundaries and the geological features associated with them;
- understand how the movement of plates leads to the occurrence of natural disasters such as earthquakes and volcanism;
- list the most important pieces of evidence that support Wegener’s continental drift theory.

Theoretical background

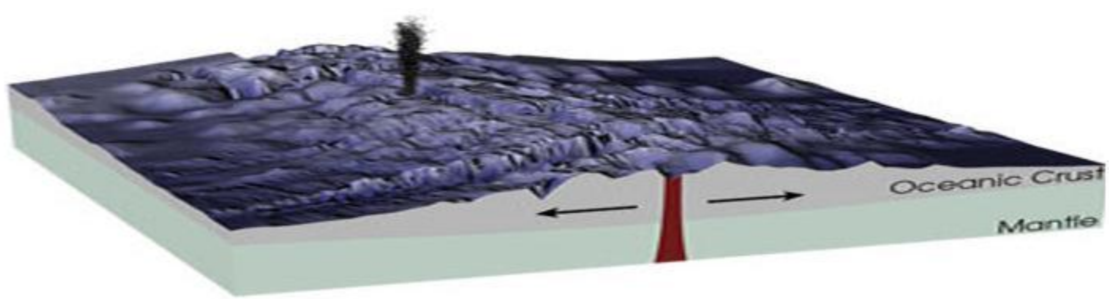
(Partially adopted from AGI/NAGT/Busch/Tasa, “Laboratory Manual in Physical Geology”)

Ever since the first reasonably accurate world maps were constructed in the 1600s, people have proposed models to explain the origin of Earth’s mountain belts, continents, ocean basins, rifts, and trenches. For example, some people proposed that surficial processes, such as catastrophic global floods, had carved our ocean basins and deposited mountains of gravel. Others proposed that global relief was the result of what is now called **tectonism**: large-scale movements and deformation of Earth’s crust. What kinds of tectonic movements occur on Earth, and what process(es) could cause them?

German scientist, Alfred Wegener noticed that the shapes of the continents matched up like pieces of a global jig-saw puzzle. In 1915, he hypothesized that all continents were once part of a single supercontinent, Pangaea, parts of which drifted apart to form the smaller modern continents. However, most scientists were immediately skeptical of Wegener’s **Continental Drift Hypothesis**, because he could not think of a natural process that could force the continents to drift apart. These “anti-drift” scientists viewed continents as stationary landforms that could rise and fall but not drift sideways.

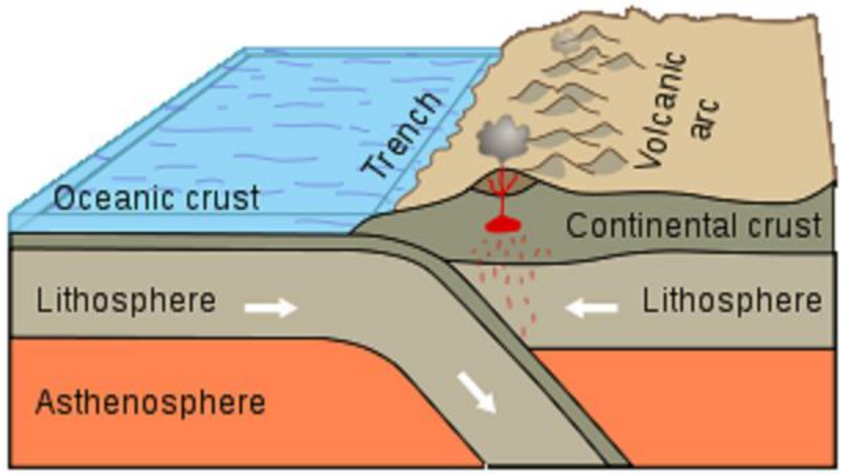
The anti-drift scientists argued that it was impossible for continents to drift or plow through solid oceanic rocks. They also reasoned that Earth was cooling from an older semi-molten state, so it must be shrinking. Their **Shrinking Earth Hypothesis** suggested that the continents were moving together rather than drifting apart. As Earth’s crust shrank into less space, flat rock layers in ocean basins would have been squeezed and folded between the continents (as observed in the Alps). Two other German scientists, Bernard Lindemann (in 1927) and Otto Hilgenberg (in 1933), independently evaluated the Continental Drift and Shrinking Earth Hypotheses. Both men agreed with Wegener's notion that the continents seemed to fit together like a jigsaw puzzle, but they also felt that the ocean basins were best explained by a new **Expanding Earth Hypothesis** (that they developed and published separately). According to this hypothesis, Earth was once much smaller (about 60% of its modem size) and covered entirely by granitic crust. As Earth expanded, the granitic crust split apart into the shapes of the modern continents and basaltic ocean crust was exposed between them (and covered by ocean).

During the 1960s more data emerged in favor of the **Continental Drift Hypothesis**. For example, geologists found that it was not only the shapes (outlines) of the continents that matched up like pieces of a Pangaea jig-saw puzzle. Similar bodies of rock and the patterns they make at Earth's surface also matched up like a picture on the puzzle pieces. Abundant studies also revealed that ocean basins were generally younger than the continents. An American Geologist, Harry Hess, even developed a Seafloor-Spreading Hypothesis to explain this. According to Hess' hypothesis, seafloor crust is created along mid-ocean ridges above regions of upwelling magma from Earth's mantle. As new magma rises, it forces the old seafloor crust to spread apart on both sides of the ridge and cools to form new crust. The seafloor spreads apart in this way until it encounters a trench, whereupon it descends back into the mantle. Hess' hypothesis was supported by studies showing that Earth has a thin, rigid *lithosphere* underlain by a plastic *asthenosphere*. Earthquakes occur below Earth's surface wherever ocean crust is created and wherever it descends back into the mantle. Zones of abundant earthquake and volcanic activity are also concentrated along cracks in the lithosphere that are boundaries (plate boundaries) between rigid stable sheets of lithosphere, called *lithospheric plates*. Thus, by the end of the 1960s a new hypothesis of global tectonics had emerged called the **Plate Tectonics Hypothesis**. It is now the prevailing model of Earth's global tectonism.



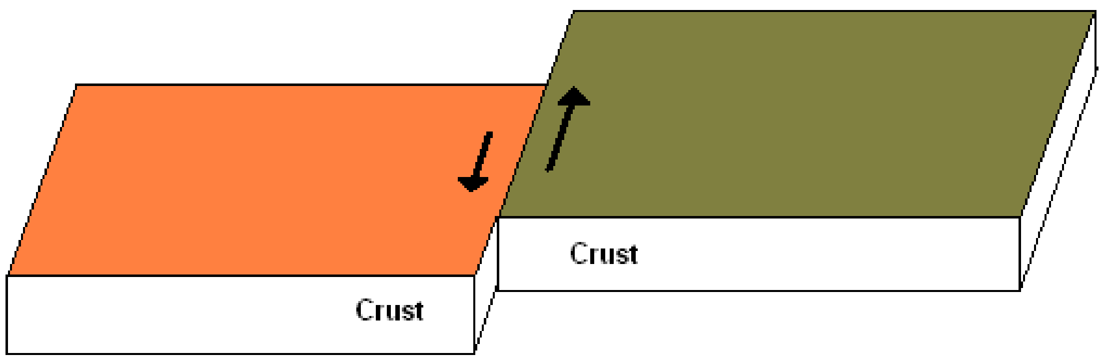
http://earthobservatory.nasa.gov/Study/Tectonics/tectonics_3.htm

Figure 1a. Sea floor spreading occurs at divergent plate margins which generates new oceanic crust.



http://en.wikipedia.org/wiki/File:Active_Margin.svg

Figure 1b. Mountain building occurs at convergent plate margins.



Cartoon by David Gray

Figure 1c. Plates slide laterally past each other at transform plate boundaries.

According to the developing Plate Tectonics Model, the continents are parts of rigid lithospheric plates that move about relative to one another. Plates form and spread apart along divergent boundaries such as mid-ocean ridges (Figure 1a), where magma rises up between two plates, forces them to spread apart, and cools to form new rock on the edges of both plates. Plates are destroyed along convergent boundaries, where the edge of one plate may subduct (descend beneath the edge of another plate) back into the mantle (Figure 1b) or both plates may crumple and merge to form a mountain belt. Plates slide past one another along transform fault boundaries, where plates are neither formed nor destroyed (Figure 1c). The Plate Tectonics

Model does not require the Earth to shrink or expand in size. Earth's size can remain constant, because there are processes that simultaneously form and destroy crust (lithospheric plates).

Most evidence for plate tectonics has come from the detailed observations, maps, and measurements made by field geologists studying Earth's surface directly. However, some of the best modern evidence of lithospheric plate motions is now obtained remotely with satellites orbiting thousands of kilometers above Earth's surface. Several different kinds of satellite technologies and measurement techniques are used, but the most common is the Global Positioning System (GPS).

Now let's have a closer look at the geologic features found at plate boundaries.

Divergent boundaries.

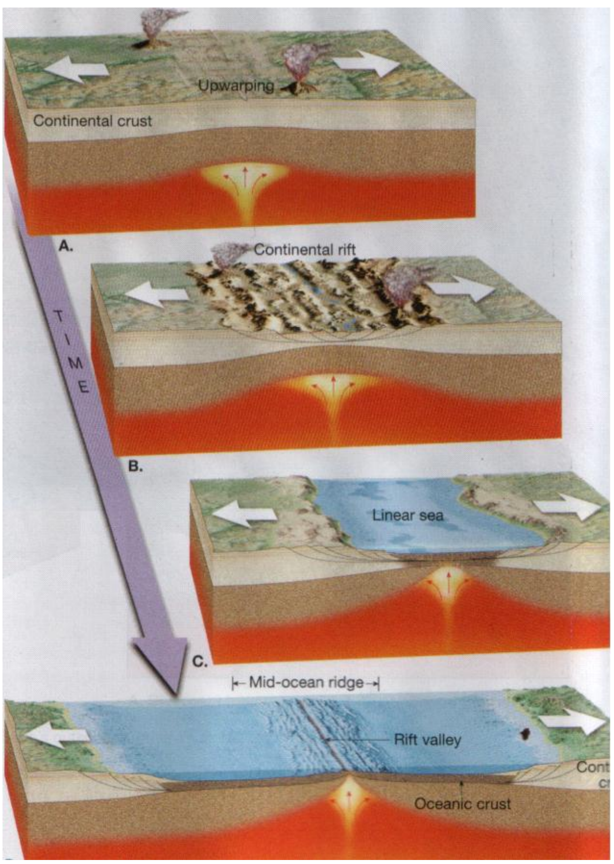


Figure 2. Formation of the Mid-ocean ridge at divergent plate boundary.

A. Continental rifting is thought to occur where tensional forces stretch and thin the crust. As a result, molten rock ascends from the asthenosphere and initiates volcanic activity at the surface.

B. As the crust is pulled apart, large slabs of rock sink, generating a rift valley.

C. Further spreading generates a narrow sea. D. Eventually, an expansive ocean basin and ridge system are created.

(Figure and text caption adopted from "Earth Science" by Tarbuck et al.)

Convergent boundaries.

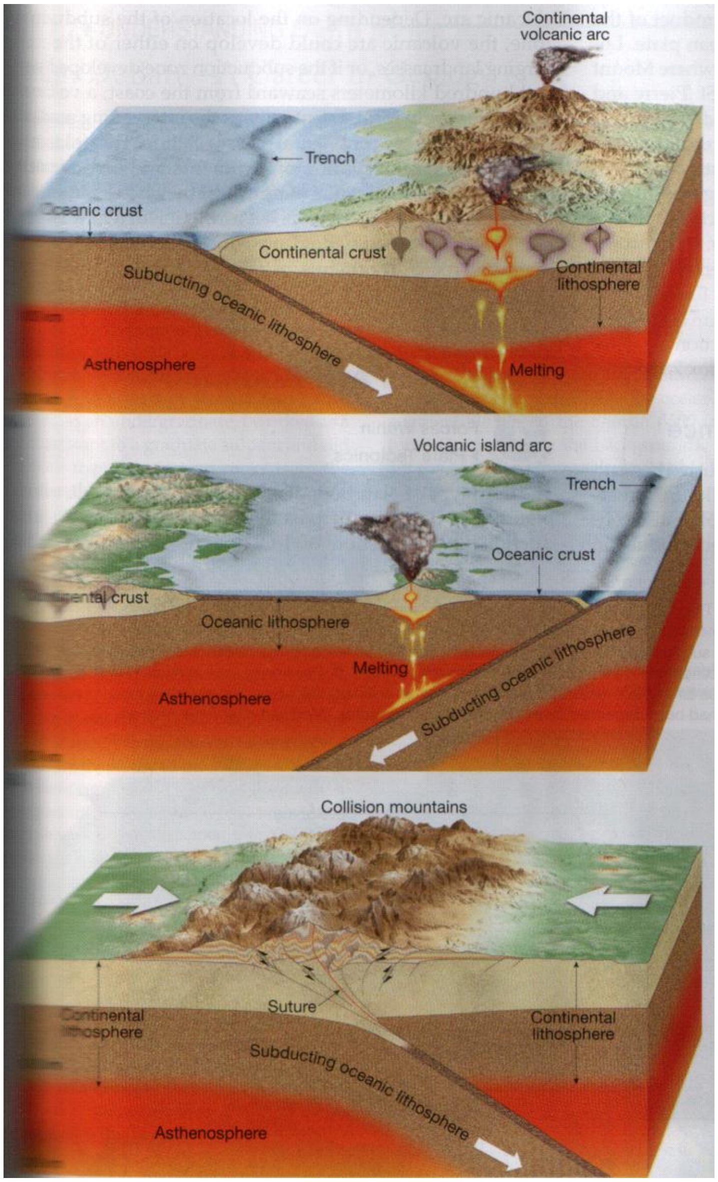


Figure 3. Convergent plate boundaries: at these boundaries two plates collide, so one plate is subducted under another one. There exist three types of convergent boundaries:

A. Oceanic-continental. Note the presence of volcanoes and mountains on the overriding plate, which are called *continental volcanic arc*. Trench forms close to the continental margin. Higher density of the oceanic crust leads to subduction of the oceanic plate under the continental plate.

B. Oceanic-oceanic. Presence of *trench* (which marks the boundary) and a *volcanic island arc* are the most prominent features of this kind of boundary. Aleutian Islands are a typical example of an oceanic-oceanic plate boundary.

C. Continental-continental. Most of the non-volcanic continental mountains are created by collision of two continental plates. The best known example is Himalayan Mountains, created by collision of Indian and Asian plates. Densities of the plates are usually similar, therefore only limited subduction occurs.

((Figure and caption adopted from Tarbuck et al.))

Transform boundaries.

These are the boundaries that are not associated with production or destruction of the crust. Also called transform fault boundary, or strike-slip boundary, this type of margin separates plates that are moving mostly laterally, with very little vertical displacement. Most of the transform boundaries are short in length compared to convergent or divergent boundaries. Most often transform boundaries are found between sections of the ocean divergent boundaries that are moving at slightly different velocities, as shown in Figure 1. Out of the few long transform boundaries, the San Andreas Transform is the most famous; it separates the Pacific and North American plates that are sliding side-by side.

Figure 4 depicts the world's existing tectonic plates, direction of their movements, and the most current data on their relative velocities. Note that earthquakes are concentrated along the plate boundaries, since most earthquakes are caused by slipping tectonic plates.

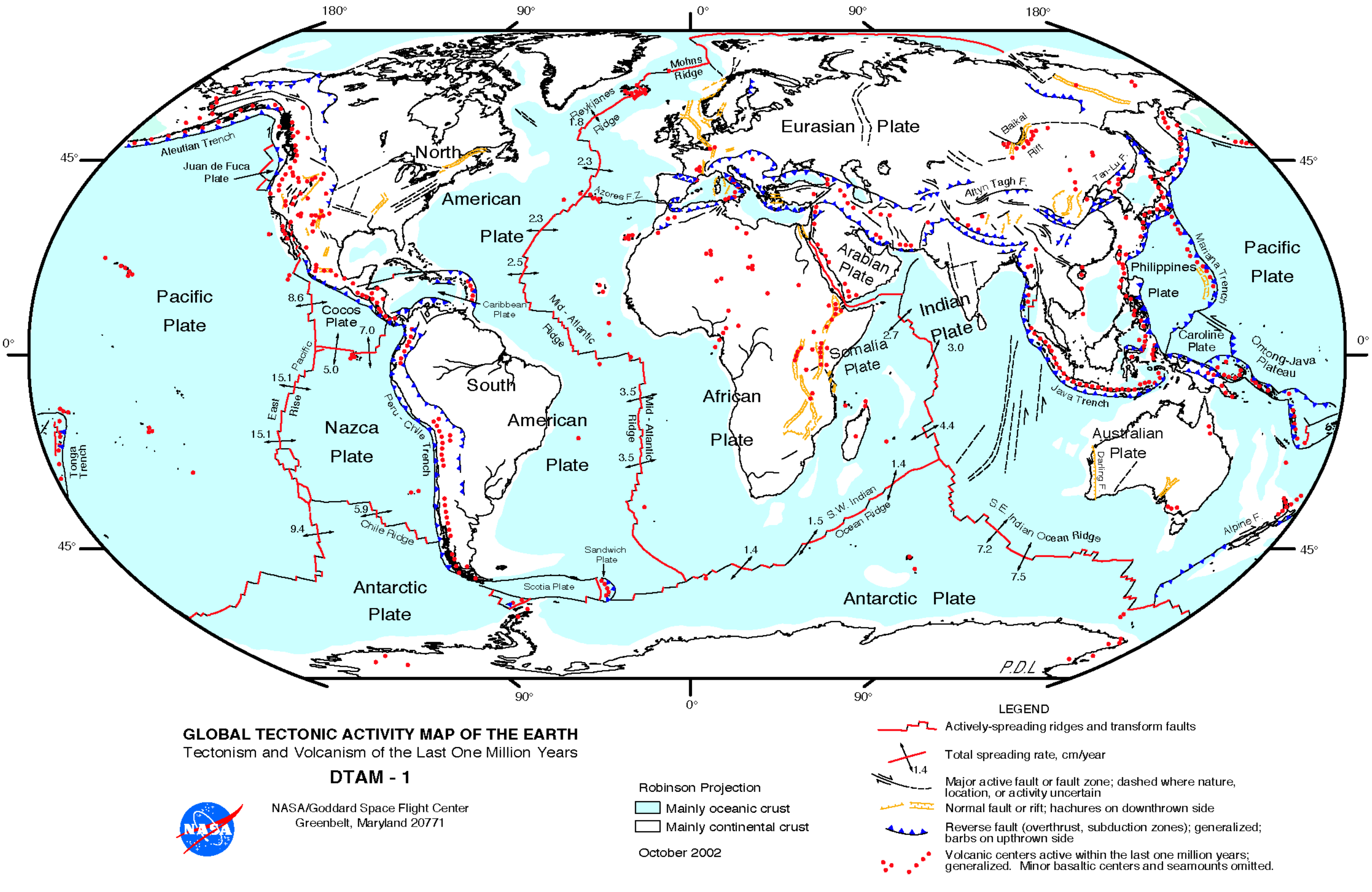


Figure 4. Main plates and plate boundaries.
(figure by NASA: http://denali.gsfc.nasa.gov/dtam/data/ftp/gtam.gif)

Earthquakes. Earthquake is a natural phenomenon that is generated by sudden release of accumulated energy produced by the movement of the tectonic plates. Earthquakes with magnitude larger than 3 units on the Richter scale are easily perceived by people through shaking and movements of the ground. These movements are propagating seismic waves that carry the energy generated by the earthquake to long distances. There are three main types of seismic waves: S- waves, P-waves and surface waves. Figure 5 shows a typical seismogram - recording of the surface movements.

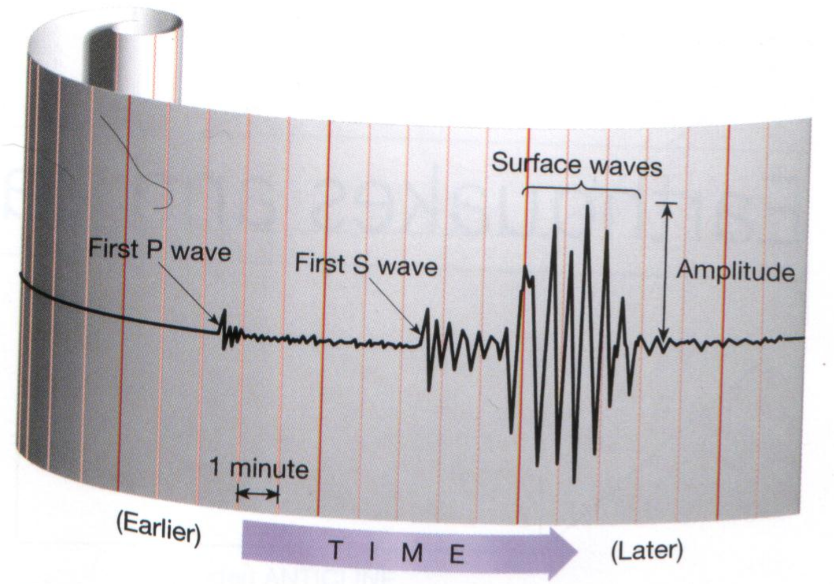


Figure 5. Typical record of seismic waves registered by seismograph.
(figure adopted from "Applications and Investigations in Earth Science", by Tarbuck et al)

Seismic waves travel through the Earth at different velocities: surface waves are the slowest, S-wave (secondary, or shear wave) is slightly faster, and P-wave (primary wave) is the fastest. Seismic wave velocities depend on the density and properties of the propagation media. The typical value of these velocities is several kilometers per second.

Online exercises/activities

http://whs.moodledo.co.uk/mod/resource/view.php?inpopup=true&id=972 **-** is a website with simple animations of plate tectonics, volcanism and earthquakes.

http://www.wwnorton.com/college/geo/earth3/animations.asp **-** a collection of animations on plate tectonics, volcanoes, geology, etc.

Assignment

Part 1

A. Go to the website at the following address:

http://www.sciencecourseware.com/virtualearthquake/

Scroll down to the bottom of the page and click "Execute VirtualEarthquake". Read the description of the exercise. Complete the online exercise for the San Francisco Area Earthquake, **print out the page with the certificate and final Data summary and attach them to this lab** to turn in. (**10 Points**)

B. Complete the following exercise, and answer the questions 1-10.

You have three seismograph recordings from the southern part of Japan and South Korea (figures 6-9 below). The x- axis is time in seconds, y-axis is amplitude in mm.

1. Using these seismograms, determine the amplitude of the earthquake and difference between S and P-waves arrival (S-P interval) for three locations: Pusan, Akita and Tokyo.
2. Then, using the graph of S-P interval dependence on distance, shown in Figure 9, determine the distance from the epicenter to each of the above locations.
3. Find and indicate the location of the earthquake epicenter on the following map (Figure 10). Show all your work (drawings) on the map. (**5 points**)
4. Using the Magnitude determination chart (Figure 11) determine the magnitude of the earthquake. Show all your work (drawings) on the graph. (**5 points**)

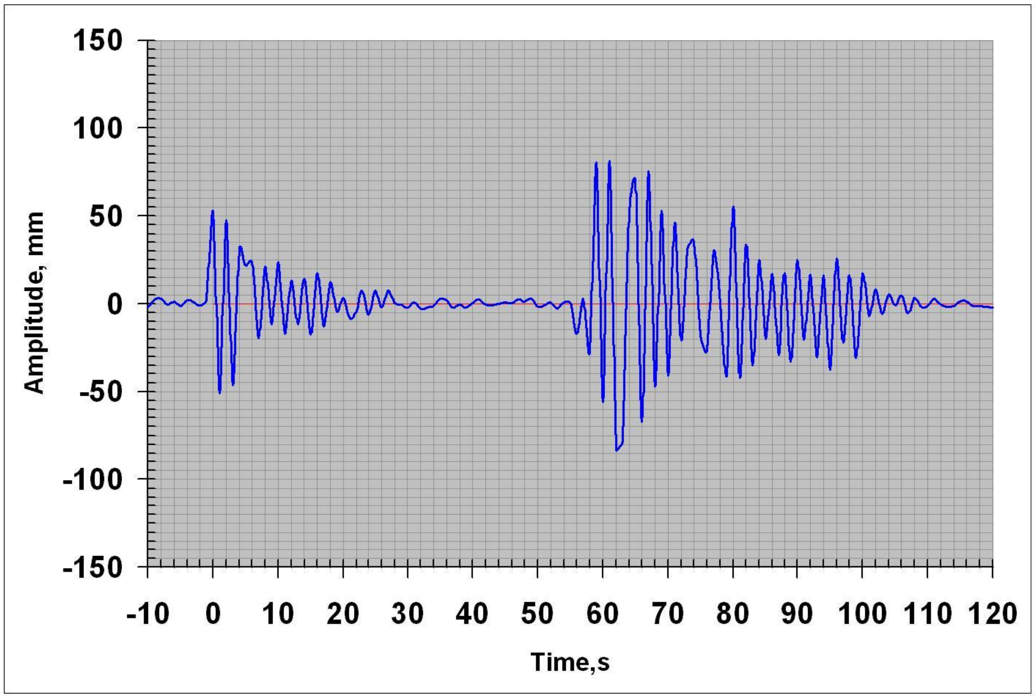


Figure 6. Seismograph recording at location 1 - Pusan

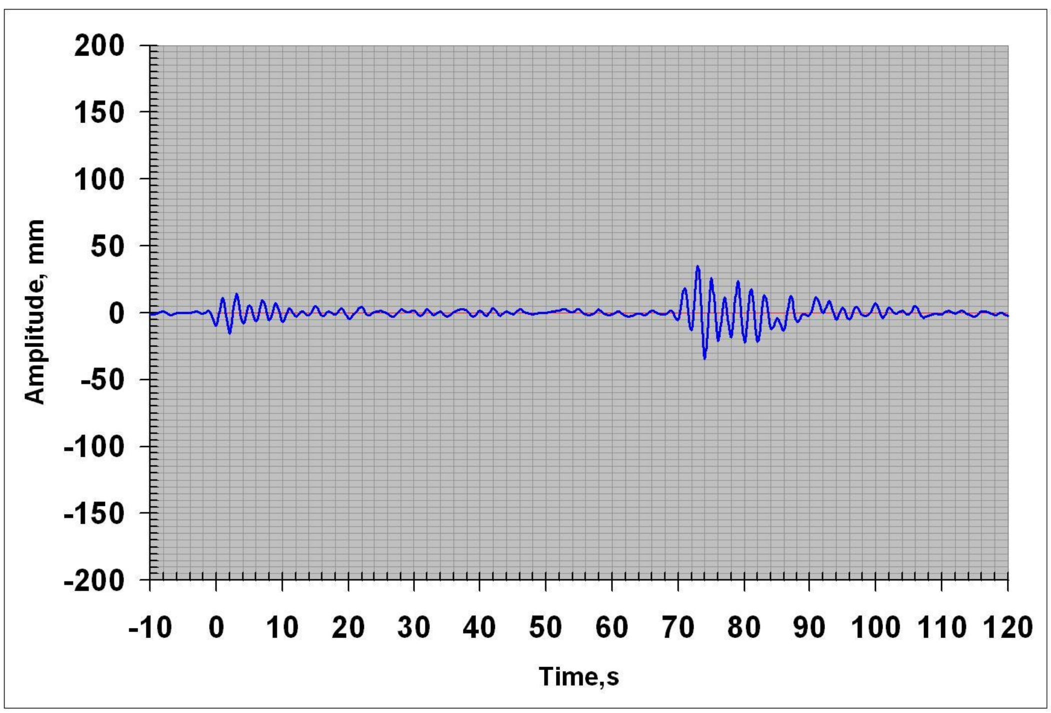


Figure 7. Seismograph recording at location 2 - Akita

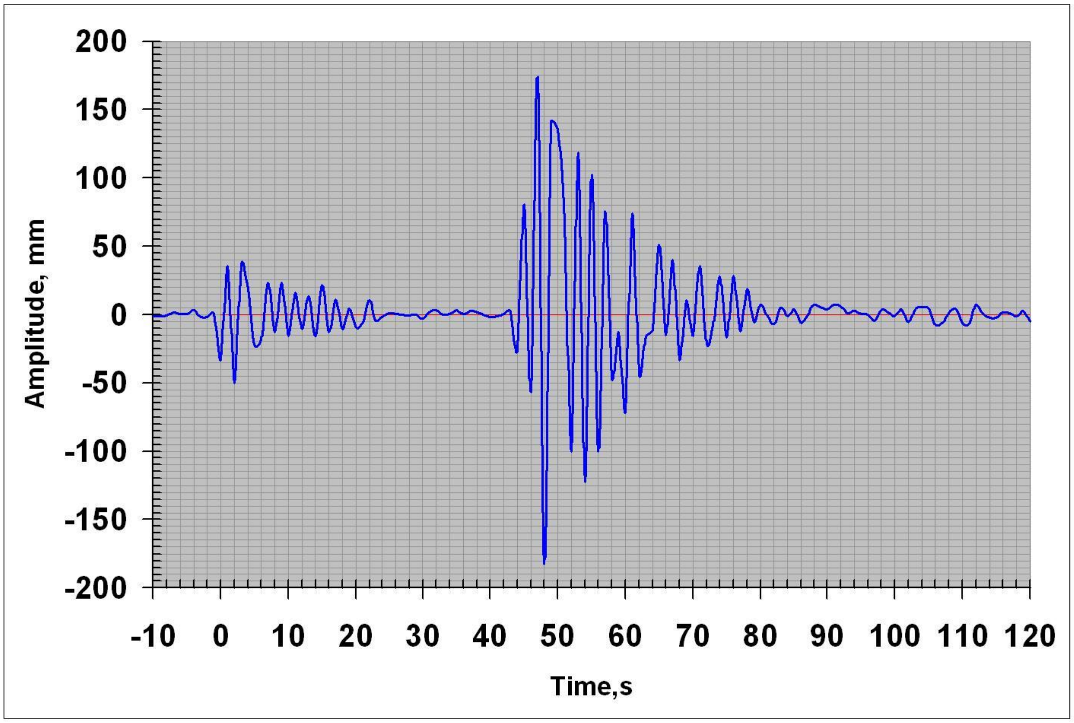


Figure 8. Seismograph recording at location 3 - Tokyo

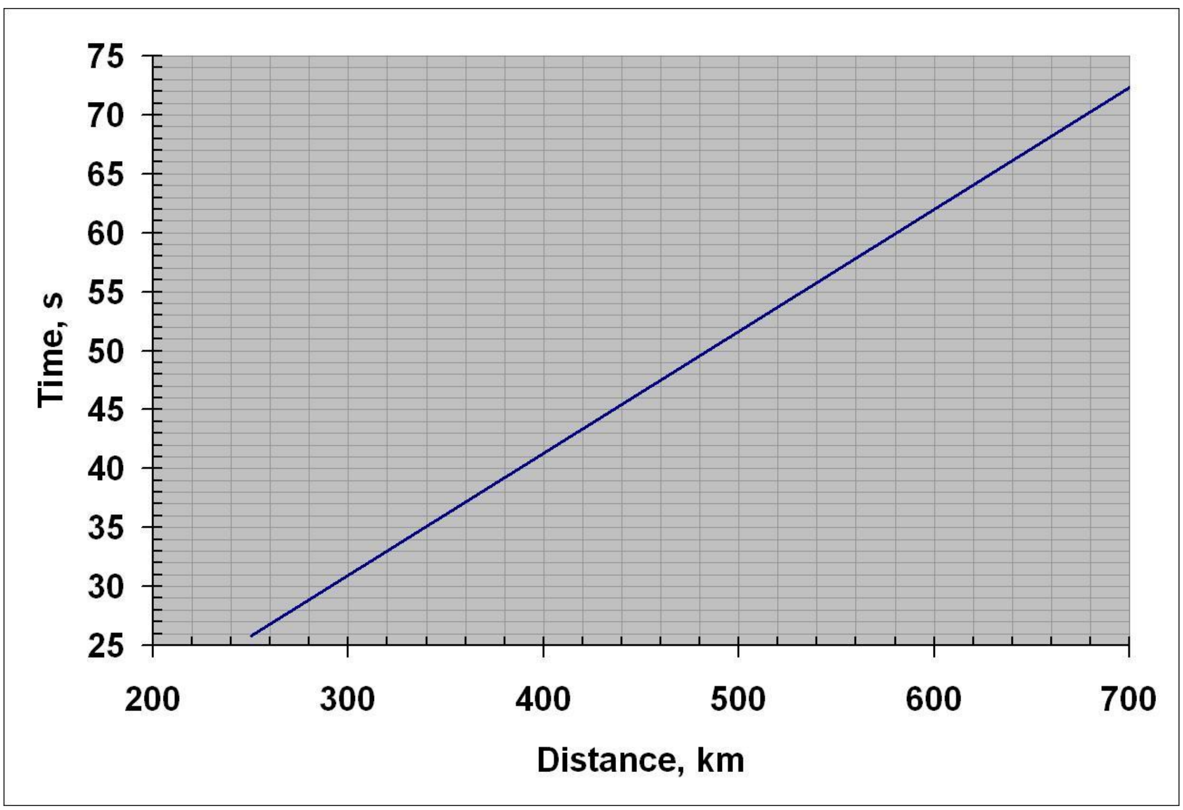


Figure 9. Dependence of the S-P delay time on distance.

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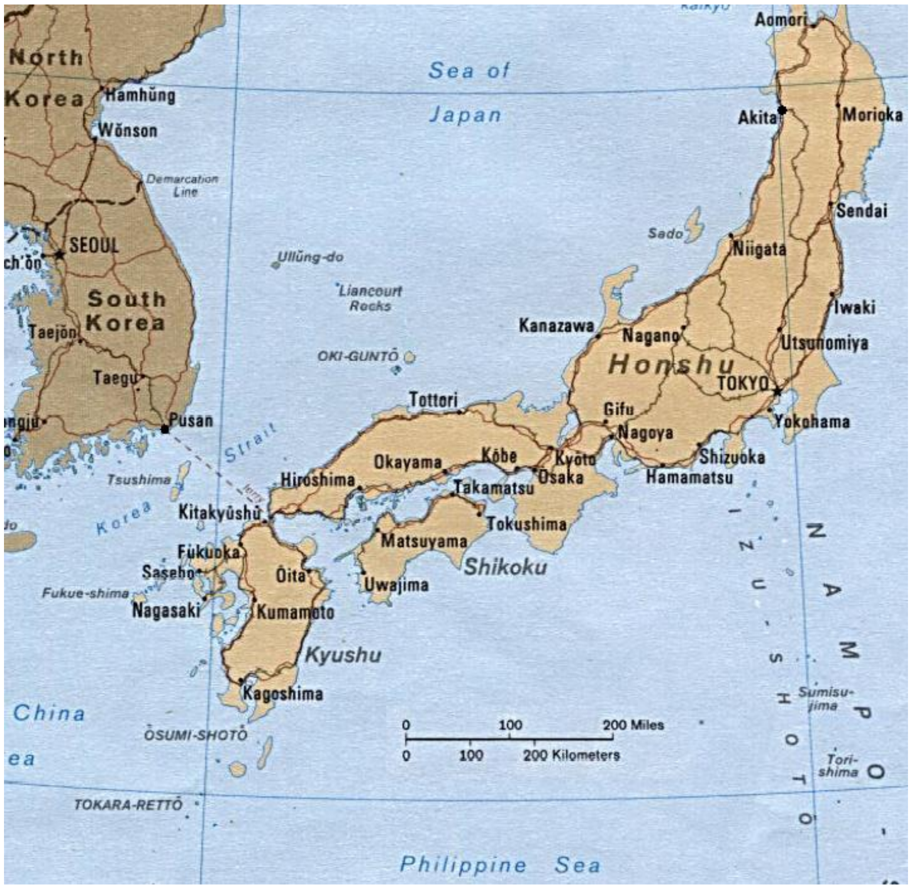

Figure 10. Indicate the earthquake location on this map.
(Image from http://www.lib.utexas.edu/maps/middle_east_and_asia/japan.jpg)

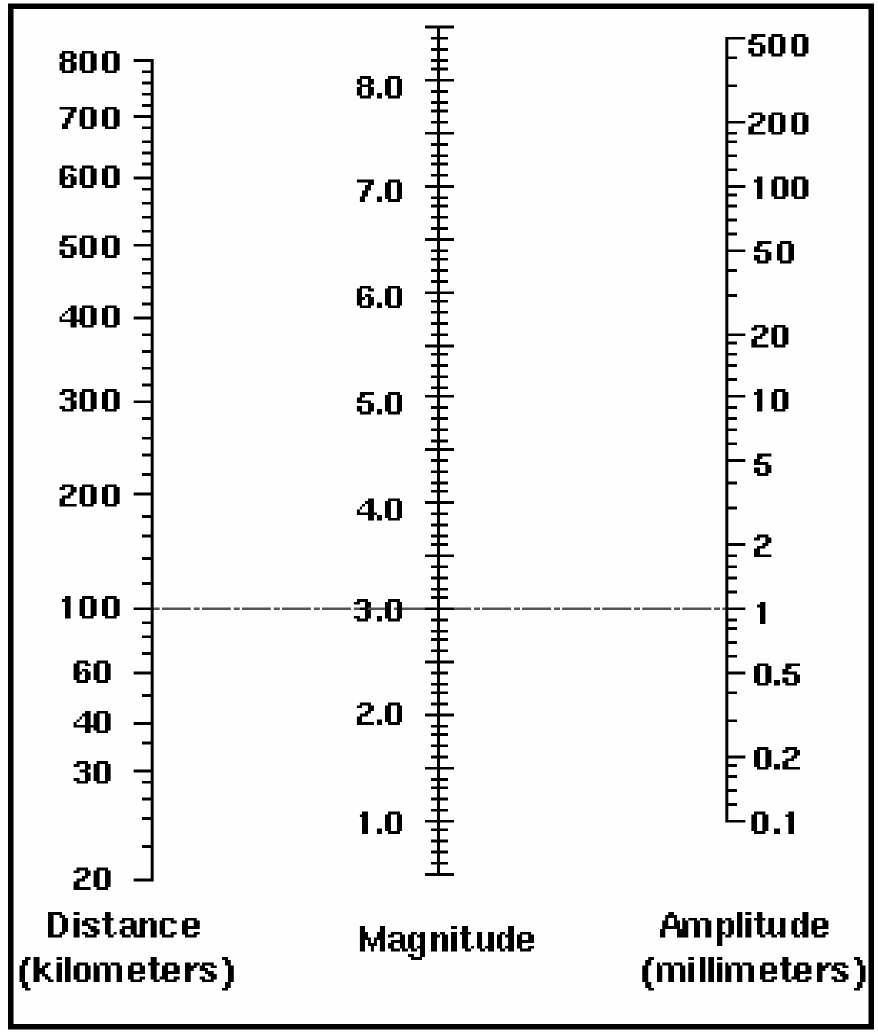

Figure 11. Earthquake magnitude determination chart.

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Question 1. What was the amplitude of the earthquake (in mm) at Pusan ? (2 pts.)

Question 2. What was the amplitude of the earthquake (in mm) at Akita ? (2 pts.)

Question 3. What was the amplitude of the earthquake (in mm) at Tokyo ? (2 pts.)

Question 4. What was the difference between S and P waves arrival (in seconds) at Pusan ? (2 pts.)

Question 5. What was the difference between S and P waves arrival (in seconds) at Akita ? (2 pts.)

Question 6. What was the difference between S and P waves arrival (in seconds) at Tokyo ? (2 pts.)

Question 7. What was the distance from the earthquake epicenter to Pusan (in km)? (3 pts.)

Question 8. What was the distance from the earthquake epicenter to Akita (in km)? (3 pts.)

Question 9. What was the distance from the earthquake epicenter to Tokyo (in km)? (3 pts.)

Question 10. What was the magnitude of the earthquake? (2 pts.)

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Part II: Continental Drift

Procedure:

1. Go to the website at the following address:
http://www.ucmp.berkeley.edu/geology/anim1.html

2. Run the simulation program. Note how the arrangement of the landmass and oceans changes through time. To stop the program, click on the "stop" button on your browser. To restart the simulation, reload the website.

3. Click on each of the boxes to the right of the simulation to learn more about the animal life and general features on Earth during each epoch.

4. Open another window in your browser and go to the following websites:
http://www.scotese.com/paleocli.htm and
http://www.handprint.com/PS/GEO/geoevo.html#Camb

5. Run the simulation programs and note the time interval maps noting the time period and any significant features and occurrences.

Questions:

A. Outline the sequence of geological and tectonic events that occurred on the Earth's surface from 730 million years ago to the present. Highlight all significant events. Use the space provided below for your answer. You may choose to prepare a timeline or list the events in bullet format. (5 Pts.)

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B. When did landmasses start to look like present day continents (not necessarily in the present-day orientation)? (2 Pts.)

C. When does Florida first appear? How did it form? (2 Pts.)

Part III: Plate Boundaries

For questions 11- 16, you will need to identify the type of boundary at the locations labeled **A – F** in the Figure 12 (page 16). If you need to look at the map in detail, use the copy of the map posted on the T-Square in this lab's folder.

Question 11. Location **A** on Figure 12 corresponds to the following type of boundary (choose one from the following): (2 pts.)

(1) Continent-Continent Convergent Plate Boundary
(2) Continent-Ocean Convergent Plate Boundary
(3) Ocean-Ocean Convergent Plate Boundary
(4) Ocean-Ocean Divergent Plate Boundary
(5) Continent-Continent Divergent Plate Boundary
(6) Transform Boundary
(7) No Plate Boundary

Question 12. Location **B** on Figure 12 corresponds to the following type of boundary (choose one from the following): (2 pts.)

(1) Continent-Continent Convergent Plate Boundary
(2) Continent-Ocean Convergent Plate Boundary
(3) Ocean-Ocean Convergent Plate Boundary
(4) Ocean-Ocean Divergent Plate Boundary
(5) Continent-Continent Divergent Plate Boundary
(6) Transform Boundary
(7) No Plate Boundary

Question 13. Location **C** on Figure 12 corresponds to the following type of boundary (choose one from the following): (2 pts.)

(1) Continent-Continent Convergent Plate Boundary
(2) Continent-Ocean Convergent Plate Boundary
(3) Ocean-Ocean Convergent Plate Boundary
(4) Ocean-Ocean Divergent Plate Boundary
(5) Continent-Continent Divergent Plate Boundary
(6) Transform Boundary
(7) No Plate Boundary

<u>Question 14.</u> Location **D** on Figure 12 corresponds to the following type of boundary (choose one from the following): (2 pts.)

(1) Continent-Continent Convergent Plate Boundary
(2) Continent-Ocean Convergent Plate Boundary
(3) Ocean-Ocean Convergent Plate Boundary
(4) Ocean-Ocean Divergent Plate Boundary
(5) Continent-Continent Divergent Plate Boundary
(6) Transform Boundary
(7) No Plate Boundary

<u>Question 15.</u> Location **E** on Figure 12 corresponds to the following type of boundary (choose one from the following): (2 pts.)

(1) Continent-Continent Convergent Plate Boundary
(2) Continent-Ocean Convergent Plate Boundary
(3) Ocean-Ocean Convergent Plate Boundary
(4) Ocean-Ocean Divergent Plate Boundary
(5) Continent-Continent Divergent Plate Boundary
(6) Transform Boundary
(7) No Plate Boundary

<u>Question 16.</u> Location **F** on Figure 12 corresponds to the following type of boundary (choose one from the following): (2 pts.)

(1) Continent-Continent Convergent Plate Boundary
(2) Continent-Ocean Convergent Plate Boundary
(3) Ocean-Ocean Convergent Plate Boundary
(4) Ocean-Ocean Divergent Plate Boundary
(5) Continent-Continent Divergent Plate Boundary
(6) Transform Boundary
(7) No Plate Boundary

Figure 12. Locations for questions 11-16.

(map is from https://www.cia.gov/library/publications/the-world-factbook/reference_maps/physical_world.html)

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Part IV: Fault Movement

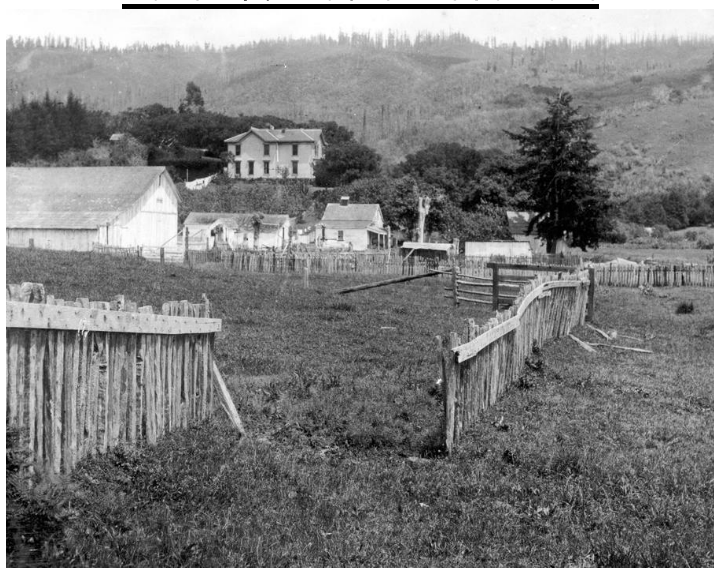

Figure 13. The above photograph was taken near Bolinas, CA, shortly after the San Francisco earthquake on April 18, 1906. The fence line was continuous before the earthquake.

(modified from U.S.G.S. Photographic Library, Gilbert, G.K., ggk02845, http://libraryphoto.cr.usgs.gov/index.html)

Questions

(partially accommodated from the Plate Movements Lab by Judson/Bonini/Rhodes/Rossbacher, Problem Solving in Geology, 2/e)

Question 17. Judging from the movement of the fence in Figure 13, what type of fault was this? (2 pts.).

A. Fault with mostly vertical movement (dip-slip fault)
B. Fault with mostly horizontal movement (transform, or strike-slip fault)
C. Fault with oblique horizontal movement (oblique-slip fault)

Question 18. Assume that the fence is 90 cm high. How far was the fence displaced horizontally? [Hint: Measure the height of the fence at the break line on the figure in order to determine the scale] (3 pts.)

Question 19. Using your estimate of the displacement, and given the duration of the event (60 seconds), how far would this fault move if the movement continued for a year? (2 pts.)

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Question 20. Is this a reasonable estimate for displacement velocity of plates? Why? (2 pts.)

Question 21. What is a reasonable estimate of the velocity of tectonic plates? (2 pts.)

Conclusions on the lab

1. Describe several natural phenomena that could be used as an evidence of the Plate Tectonics Theory. (5 points)

2. What is the source of energy that drives the motions of the tectonic plates? (5 points)

3. Where would you expect to find the youngest crust on Earth? The oldest? Explain. (5 points)