Student Name: ________________ **College:** ____________ **Grade:**

GEOLOGY 101 LABORATORY – LAB – Isostasy and Plate Tectonics

Understanding and Analyzing Vertical and Horizontal Plate Motion

Part I. Density and Isostatic Equilibrium

Introduction: Why does the Earth have continental areas and oceanic areas? Rephrasing the question a bit, why does the Earth's surface divide into two distinct regions of elevation: the **continents** (average elevation about 1 kilometer above sea level), and the **ocean basins** (average elevation about 4 kilometer below sea level)? The answer relates to the fact that Earth's surface is made up of two different types of crust: the **continental crust** and the **oceanic crust**. These two types of crust differ in **BOTH** their **Density and Thickness**. Today, you will see how these two properties control elevation of continents versus ocean basins.

Relationship between Volume, Mass, & Density

Density is a measure of mass per unit volume. To use water as an example, a gallon (a unit of volume) weighs about 8.33 pounds (a unit of mass). Therefore, the **density** of water is 8.33 pounds per gallon. We can use any measurement of mass and/or volume to express density. Water's density can also be expressed as 62.4 pounds per cubic foot (62.4 lbs/ft^3).

In the following lab exercise, we will use the standard Metric System unit for density, which is **grams** per **cubic centimeter** (**gm/cm^3**) to measure the **density** of water, wood and rock in **gm/cm^3**. So, we need to measure both the **mass (in grams)** and its **volume (in cubic centimeters)**. Measuring mass is easy; we just weigh the object on a scale. Measuring volume is more difficult. We will measure volume in two ways: by linear dimensions and by water displacement.

Question 1: Heft the pieces of oak and redwood in your two hands. Which one feels denser (heavier for a given amount)?

Answer: __________________

Determine the density of oak and redwood. Weigh the blocks to the nearest gram. Then use a ruler to measure, in centimeters, the length, width and height of the blocks. Make all measurements to the first decimal place (0.1). Write out the complete density calculation for blocks.

Hardwood (oak): Weight: _____gm **Length:** _____cm **Width:** _____cm **Height:** _____ cm

Volume: (length x width x height): ________ cm^3 **Calculation:**

Density: (weight / volume): ________ gm/cm^3 (round to nearest 0.01)

Softwood (redwood): Weight: _____gm **Length:** _____cm **Width:** _____cm **Height:** _____ cm

Volume: (length x width x height): ________ cm^3 **Calculation:**

Density: (weight / volume): _______ gm/cm^3 (round to nearest 0.01)

Determine the density of water. First weigh an empty graduated cylinder to the nearest gram. Take graduated cylinder off scale and then zero out the scale. Now fill the graduated cylinder with exactly 100 milliliters (cm^3) of water. Weigh the cylinder with water to the nearest gram. Write out the complete density calculation for water.

Water: Volume = 100 cm^3 **Weight:** _________ gm **Calculation:**

Density: (weight / volume): ________ gm/cm^3 (round to nearest 0.01)

Question 2: Comparing the density of water to the density of hardwood and redwood, predict what proportion (percent) of your blocks will stick up out of the water when the pieces of wood are floating.

Oak: _________ % of the block will be underwater, and ________ % will stick out of the water.

Redwood: _________ % of the block will be underwater, and ________ % will stick out of the water.

Question 3: Take the pieces of oak and redwood and float them in water. Do your predictions in #3 above fit with what you see?

Answer: ____________________

Directions: 1) Draw a simple side-view sketch of the two blocks across the waterline (shown below) as accurately as possible. 2) Label each block by name. And 3) List the %'s next to each block indicating how much of the block is above and below the waterline, respectively. (Note: Keep this observation in mind when you do the final part of the lab.)

____ ⇦ Waterline

Question 4: Think about what you saw with the blocks of wood floating. What effect did the difference in density between the two types of wood have on how high each one floated?

Answer: ____

Determining the Density of Granite and Gabbro. To determine the density of granite and gabbro, you will use the displacement method to measure the volumes of samples **of granite and gabbro**.

Directions: Follow steps below to complete the data tables below for the three samples of granite and gabbro.

a. Fill the plastic cylinder to between the 300 and 350 mL level. Tap the cylinder to get out air bubbles.
b. Weigh the first sample and record the **mass** in grams for "Sample 1."
c. Read the water level to the nearest 1 cm^3 (nearest 1 mL) and record it in the table under "start level" for "Sample 1".
d. Tilt the cylinder to ~ 45 degree angle and gently slide the sample in so that it slips into the water without splashing. Gently tap the cylinder to get out air bubbles.
e. Read the water level to the nearest 1 cm^3 and record it in the table under "end level" for "Sample 1."
f. Calculate the **volume** of the sample (in cm^3) by subtracting the start level from the end level.
g. Calculate the **density** of the sample (g/cm^3) by dividing the weight (in g) by the volume (in cm^3).
h. Without removing the water or rocks from the cylinder, repeat Steps b. – g. for the rest of the samples. *Note: the "start level" for each successive sample will be the same as the "end level" of the previous sample.*
i. Calculate the average density of the three samples of magnetite and the three samples of granite. By taking the average of three separate density measurements, we will hopefully cancel out some measurement errors and obtain a more accurate value for the density.

Granite Samples	Mass (g)	Start level (cm3)	End level (cm3)	Volume (cm3)	Density (g/cm^3)
Sample 1					
Sample 2					
Sample 3					

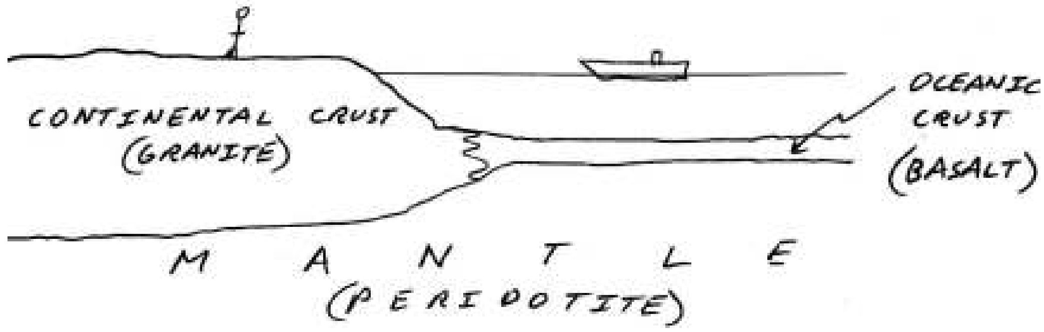
Average density of **Granite** samples = mass/volume = ______________ g/cm^3

Gabbro Samples	Mass (g)	Start level (cm3)	End level (cm3)	Volume (cm3)	Density (g/cm^3)
Sample 1					
Sample 2					
Sample 3					

Average density of **Gabbro** samples = mass/volume = ______________ g/cm^3

ISOSTATIC EQUILIBRIUM OF THE EARTH'S CRUST

In this part of the lab, we will see how differences in the density and thickness of rock control the elevations of the Earth's crust. We'll also see how the crust adjusts when loads of weight are added or taken away. The Earth is made up of two kinds of crust: continental crust and oceanic crust. **Continental crust**, which is mostly **granite** and rocks of similar density, makes up the continents. **Oceanic crust** is mostly the rock **basalt**, which makes up the floors of the ocean basins. Both types of crust lie on the Earth's **mantle**, which is mostly the rock **peridotite**. The illustration below shows that the continental crust and the oceanic crust have different thicknesses. Continental crust averages about 22 miles thick (more underneath mountains), while oceanic crust averages about 5 miles thick. The two types of crust, and the underlying mantle, also differ in their density. Most Earth rocks range in density from about 2.6 to about 3.3 gm/cm^3 -- even small differences in density can have important effects.



Density of the continental crust (put in your value for granite from above): ________ **gm/cm^3**

Density of the oceanic crust (basalt): 3.0 gm/cm^3

Density of the upper mantle (peridotite): 3.3 gm/cm^3

The geologist Clarence Dutton proposed decades ago that the Earth's two types of crust "float" buoyantly on the mantle, much in the way that an iceberg or a block of wood floats buoyantly in water. He called this condition **isostasy** (Greek for "equal standing"). When the crust floats in a balanced, stable manner in the mantle beneath, we have a condition called **isostatic equilibrium**. This turns out to be a very useful concept, as you will see.

Question 5: What is the connection between wood floating in water and the crust (either type) floating in the mantle? Use specific values of density for wood, water, crust and mantle in your answer.

Answer: ____

____

Question 6: Imagine a thick block of wood and a thin block of wood, both with a density of 0.5 gm/cm^3 floating in water next to each other. Would the tops be at the same level? Why or why not?

Answer: ____

Draw accurately a side-view sketch showing how these two blocks would look floating next to each other. Note: "accurately" here means that you need to consider the density of the wood relative to water.

____ ⇦ Waterline

Question 7: Geologists know that the continental crust is much thicker underneath mountain ranges than it is in low areas. Thinking about your answers above, Briefly explain why.

Answer: ____

Question 8: Thinking about all of your answers above, explain why the continental crust stands above sea level while the oceanic crust lies more than two miles (on average) below sea level. Your explanation should take into account both thickness differences and density differences.

Answer: ____

____

ISOSTATIC ADJUSTMENT

When the Earth's crust floats in a balanced, stable manner in the mantle, we have a condition called isostatic equilibrium. When this stability is changed by the addition or subtraction of weight, the crust adjusts by sinking down or rising up—a process called isostatic adjustment. Over human scales of time, this process is very slow; but over geologic time it can add up to a lot of change.

Question 9: A small iceberg is floating in the ocean. A group of polar bears jumps onto the iceberg. How does the iceberg adjust? The polar bears jump off. How does the iceberg adjust?

Answer: ____

Question 10: During the Pleistocene geologic period, ice sheets formed repeatedly over parts of Canada and the northern US. The latest ice sheet reached its maximum size about 21,000 years ago, and the ice accumulated nearly two miles thick in some places. How do you suppose the North American continent adjusted to the weight?

Answer: ____

Question 11: That big ice sheet has now mostly melted away. How do you suppose the North American continent has adjusted?

Answer: ____

Question 12: Antarctica is the highest continent, as measured by the average elevation of the surface of its ice sheet. But it is also the lowest continent, as measured by where the rock begins below all of that ice (ice that averages 6600 feet thick!). Explain the connection.

Answer: ____

____

Question 13: The Hawaiian Islands are volcanoes that have built upward from lava eruptions on the Pacific Ocean floor. The big island of Hawaii is actually the Earth's tallest mountain if you measure it from its base. Interestingly, the sea floor all around Hawaii is actually deeper than average for that region of the Pacific Ocean. Use the concept of isostatic adjustment to explain why.

Answer: ____

Part II. The Moving Tectonic Plates and their Dynamic Boundaries

This part of the lab studies the nature and dynamics of Earth's tectonic plates, and associated faulting and earthquake. In this part of the lab you will: 1) Evaluate the types of stress and associated faults of each of the three types of plate boundaries; 2) Become familiar with the global positions of the major tectonic plates; and 3) Measure and evaluate plate motions.

A. Characteristics of the Three Types of Plate Boundaries

Directions: Complete Columns "B", "C" and "E" on the incomplete chart below.

Column A: Block illustrations of three types of crustal faulting (type named in column D)

Column B: General type of crustal deformation associated with type of faulting.

Column C: The names of the major types of faults (see column "A").

Column D: The names of the major types of faults (already provided) (see column "A").

Column E: The type of plate boundary associated with "A", "B", "C", and "D").

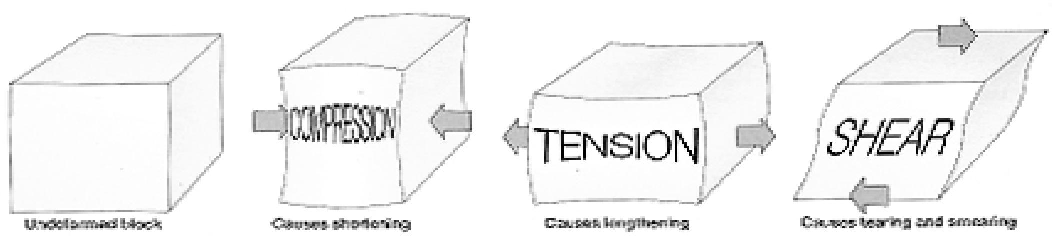


FIGURE 2.2 Three kinds of stress (applied force, as indicated by arrows) and the strain (deformation) that they cause in an undeformed block of rock.

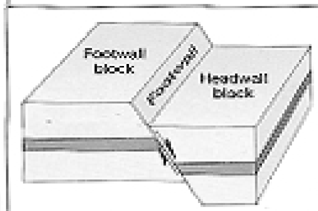
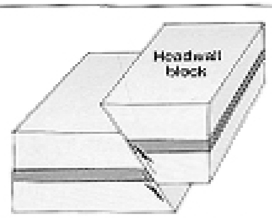
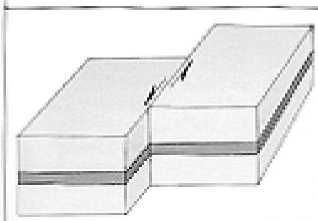
A. Block diagram	B. Has the crust: • Shortened? • Lengthened? • Neither? (Question 1)	C. Was the stress: • Shear? • Compression? • Tension? (Question 1)	D. Fault type	E. Is the plate boundary type: • Transform? • Divergent? • Convergent? (Question 4)
			Normal fault	
			Reverse fault	
			Strike-slip fault	

FIGURE 2.3 Chart for comparing fault types (columns A and D) to stress (column C) and strain (column B) in Question 1 and to plate boundary types (column E) in Question 4.

B. Measuring and Evaluating Plate Motions

Earth's lithospheric plates slowly move laterally over the asthenosphere – driven by a combination of heat, gravity, and differences in rock density. Geologists use several methods to establish plate velocities, which includes both speed and direction. One method is to analyze hot spot traces. Another method analyzes the age-dated magnetic strips patterns imbedded in the seafloor's basalt. Yet another method looks at the offset along transform faults. In all three cases, the two pieces of data that need to be collected to calculated plate motion are 1) distance and 2) time. To determine plate motion rate you divide distance (kilometers) by time (years). However, you will need to convert kilometers to centimeters (10^5 cm per km) to get a final rate of speed in centimeters per year.

Directions: Complete the following exercises on determining direction and speed of moving tectonic plates. Check the chapter on plate tectonics in your lab manual for figures and information for each specific plate motion exercise. Note that you need to write down all your complete math calculations, which must include units for all numeric values. Plate speeds are in centimeters per year.

1. The Hawaiian Islands and Pacific Plate Motion

a) What is the calculated average speed for the Pacific plate for the time period between the formations of the islands of Kauai and Molokai? Measure distances from the center of each island.

Calculation here: **Answer:** _________ cm/year

b) What is the interpreted plate movement direction for the Pacific plate for the time period between the islands of Kauai and Molokai formed? N? NE? E? SE? S? SW? W? NE?

Answer: Pacific Plate moving toward the _________ direction

c) What is the calculated average speed for the Pacific plate for the time period between which the islands of Molokai and the Big Island formed?

Calculation here: **Answer:** _________ cm/year

d) What is the interpreted plate movement direction for the Pacific plate for the time period between which the islands of Molokai and Big Island formed? N? NE? E? SE? S? SW? W? NE?

Answer: Pacific Plate moving toward the _________ direction

e) Compare the differences between the rate of speed and direction of the Pacific plate for the two different time periods you analyzed above.

Answer: Speed: ______________________________ Direction: ______________________________

f) Compare the Emperor Seamount chain and the Hawaiian Island chain in respect to their geographic extent and proximity to each other in the North Pacific basin, and their most likely volcanic origin. Based on your analysis, what can you say about these two volcanic chains, in terms of the following criteria?:

1) The plate(s) that the two volcanic chains are riding on?
2) The direction the plate was moving when each of the volcanic chain formed?; and
3) The hot spot origin (present day location) for where the volcanoes in each chain originally formed?

1) ____

2) ____

3) ____

2. The Juan de Fuca Spreading Center - Pacific Plate and Juan de Fuca Plate Motions

a) What is the calculated average speed for the Pacific Plate, based on the absolute age-dated paleo-magnetic seafloor anomalies between 0 and 10 million years? Measure the distances from the spreading center toward the NW on the Pacific Plate.

Calculation here: **Answer:** _________ cm/year

b) What is the interpreted plate movement direction for the Pacific plate, based on the orientation and age sequence of the paleo-magnetic seafloor stripes? N? NE? E? SE? S? SW? W? NE?

Answer: Pacific Plate is moving toward the _________ direction

c) What is the calculated average speed for the Juan de Fuca Plate, based on the absolute age-dated paleo-magnetic seafloor anomalies between 0 and 10 million years? Measure the distances from the spreading center toward the SE on the Juan de Fuca Plate.

Calculation here: **Answer:** _________ cm/year

d) What is the interpreted plate movement direction for the Juan de Fuca plate, based on the orientation and age sequence of the paleo-magnetic seafloor stripes? N? NE? E? SE? S? SW? W? NE?

Answer: Juan de Fuca is moving toward the _________ direction

e) Compare the differences between rates of speed and plate motion directions between the Pacific and Juan de Fuca Plates for the last 10 million years, based on your analyses above.

Answers:

Speed: ____

Direction: ____

f) Based on your analysis of the relative motion between the two plates, what can you say about the type of plate boundary between these two plates? Convergent? Divergent? Transform?

Answer: ___________________________

g) Note in Figure 4 that there are no paleo-magnetic seafloor anomalies older than 10 million years on the Juan de Fuca Plate, whereas, paleo-magnetic anomalies west of the spreading center on the Pacific plate are up to 14 million years old and older. Assuming that both plates have been growing equally on both sides of the spreading center, then what happened to the seafloor on Juan de Fuca Plate that was older than 10 million years? Hint: Check the plate boundary between Juan de Fuca and North American Plates.

Answer: ____

3. San Andreas Fault Motion

a) What is the calculated average rate of transform motion between the Pacific and North American plates along the San Andreas Fault over the past 25 million years, using the noted broken-apart Miocene volcanic bodies as an offset marker (shown in lab manual figure)?

Calculation here: **Answer:** _________ cm/year

b) What is the interpreted relative transform plate offset movement between the Pacific and North American plates using the noted Miocene volcanic body as an offset marker (shown in lab manual figure)? Right-lateral or left-lateral?

Answer: ____________________ transform motion

How did you arrive at your above answer? ____

Hawaiian Island Volcanic Hot Spot Chain Figures

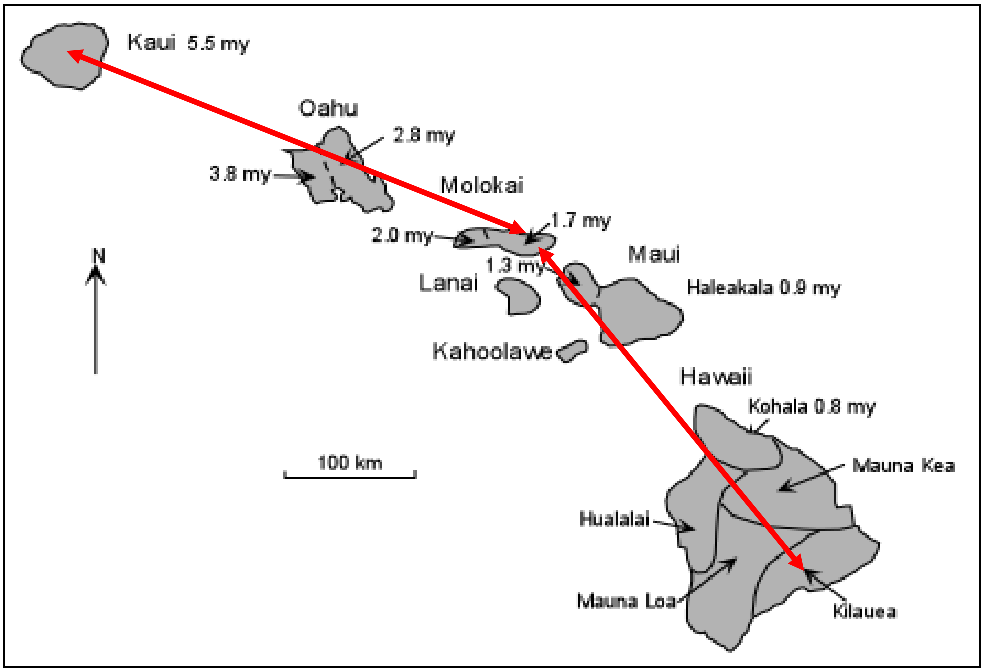


Figure 1

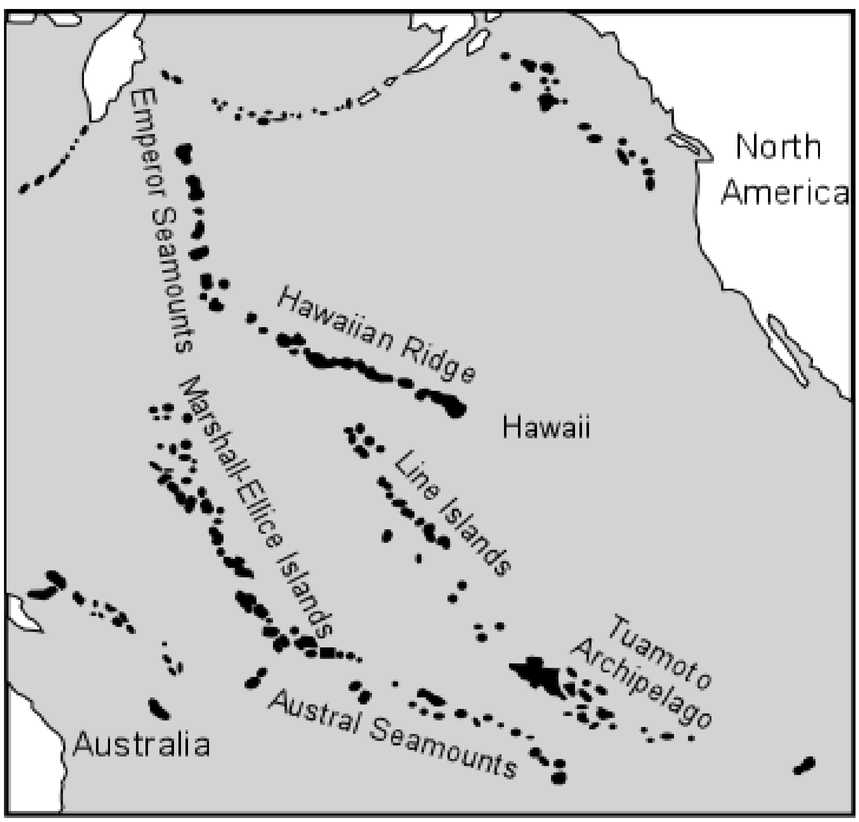
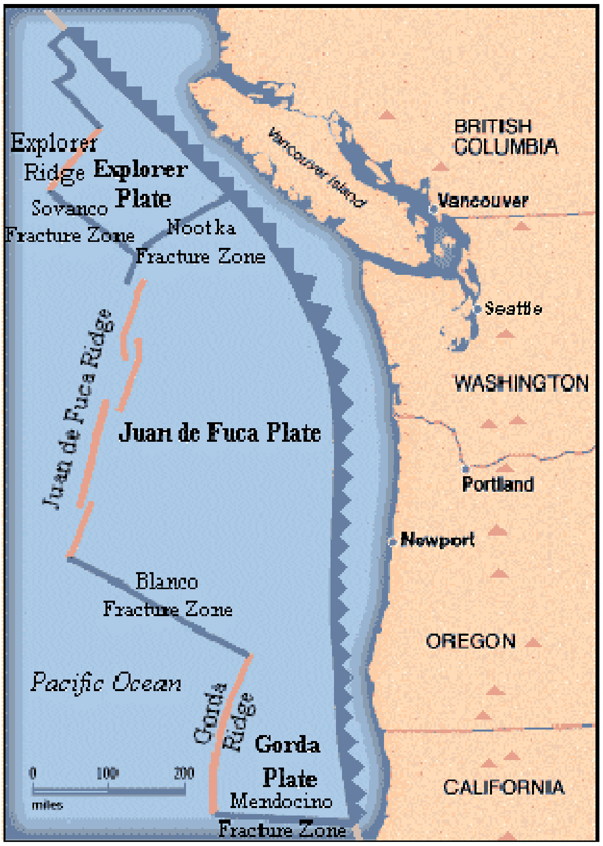
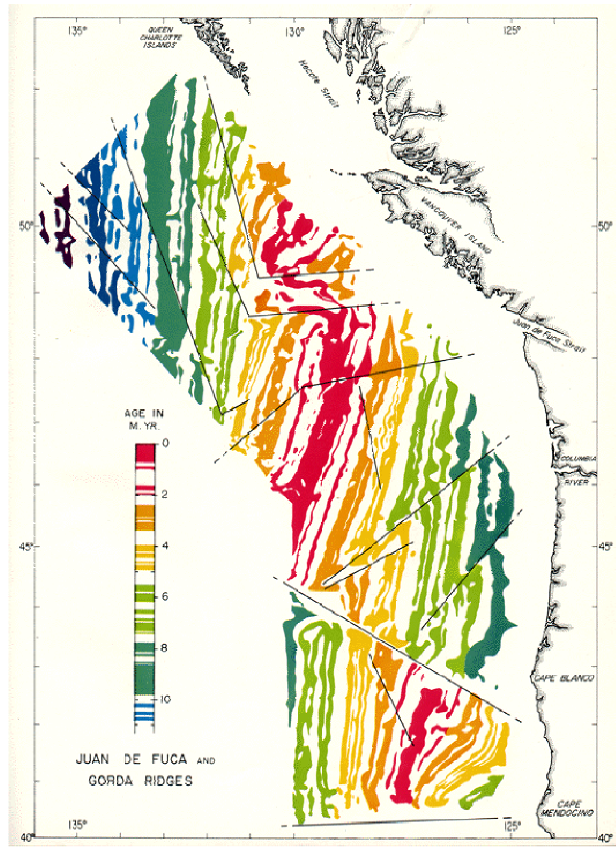


Figure 2.





Figures 3. and 4. The Juan de Fuca Spreading Center

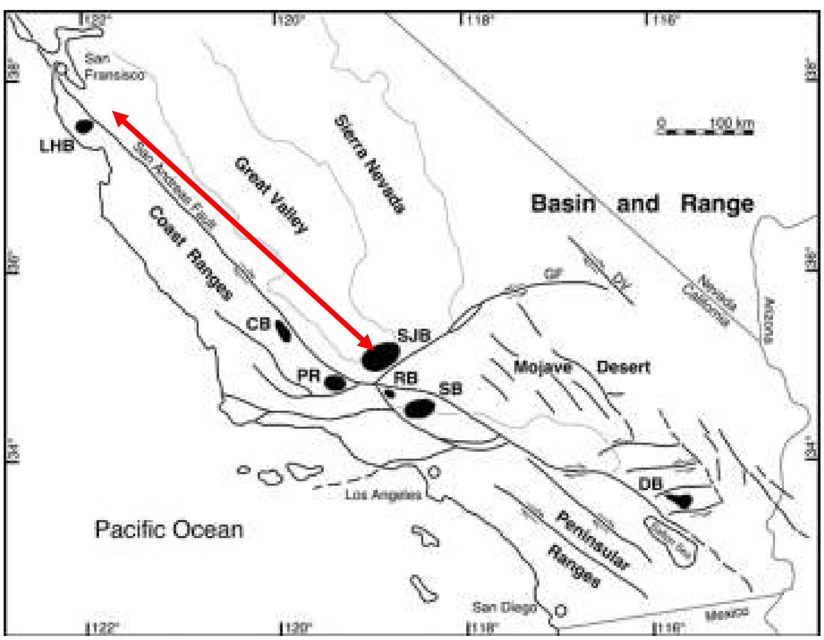


Figure 5. The San Andreas Fault. Note the 25 million year-old offset volcanic fields (LHB & SJB) at end of arrows. Length of arrow represents offset distance (km's)

Part III. Isostasy and Plate Tectonics Laboratory Reflection

Directions: Write a reflection of the lab activity, explaining its purpose, the methods used, the results obtained, and a brief personal reflection of what you enjoyed and learned about doing this lab (*3 points possible*). Answer the following 3-point question reflection set (fill in all the lines for full credit.)

1) *What was the purpose of this lab? What did you actually discover and learn during this lab?*

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2) *What did you enjoy most about this lab? Also, what was challenging or thought-provoking?*

____

____

3) *What are your constructive comments about the design and execution of this lab? What's good? What's bad? Offer suggestions for making the lab better.*

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