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## Lab # 5

### Plate Tectonics and Seafloor Spreading

**Instructions:** Numerical answers require units and appropriate numbers of significant digits. **Remember to show your work!**

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## PRELAB

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### 1 PART I: Plate Tectonics

#### 1.1 Introduction

The theory of Plate Tectonics explains most observable geological features on the surface of the Earth as the result of a major, unified pattern of large scale horizontal motions, involving the shallowest portions of the planet. In turns, motions of the “plates” thus defined at the surface of the Earth fits into a larger-scale pattern of convection due to the existence of large thermal gradients inside the planet, and involving at least a large part (probably the totality) of the Earth’s mantle.

In particular, major processes such as *mountain building* are interpreted as by-products (e.g., from collision) of larger-scale horizontal motions, rather than as resulting from purely vertical uplift. Ocean basins are caused by sea-floor generation and spreading at mid-ocean ridges, resulting in the drifting apart of continents, rather than by purely vertical subsidence and eventual “oceanization” of continental material. One of the ideas fundamental to the theory is the *youth* and *active* character of the oceans (at the most 200 million years old), as compared to the older continents (typically at least 2 billion years old), which play the *passive* role of *rafts*, drifting along, as they are driven by the motion of the more dynamic ocean floor.

Explaining vertical orogenies as by-products of horizontal motions is made possible by the orders of magnitude of the effects involved; while vertical motions at the surface of the planet (e.g. mountain building) take place at rates of typically a few millimeters per year, horizontal motion (e.g., the separation of Europe and America resulting from the opening of the Atlantic Ocean) involves rates of typically a few centimeters per year.

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## 1.2 Different Types of Plate Boundaries

As tectonic plates “move” on the surface of the earth, they collide, go away from, and rub against each other. As a result, there are three types of plate boundaries:

I. Convergent

II. Divergent

III Transform Faults

Figs. 1 and 2 shows these three basic types of plate boundaries. Warm material upwells at *spreading centers*, also known as mid-oceanic ridges, and then cools. Because the strength of rock decreases with temperature, the cooling material forms strong plates of new oceanic lithosphere. The cooling oceanic lithosphere moves away from the ridges, and eventually reaches *subduction zones*, where it descends in *downgoing slabs* back into the mantle, reheating as it goes. The direction of the relative motion between two plates at a point on their common boundary determines the nature of the boundary. At spreading centers both plates move away from the boundary, whereas at subduction zones the subducting plate moves toward the boundary. At the third boundary type, *transform faults*, relative plate motion is parallel to the boundary.

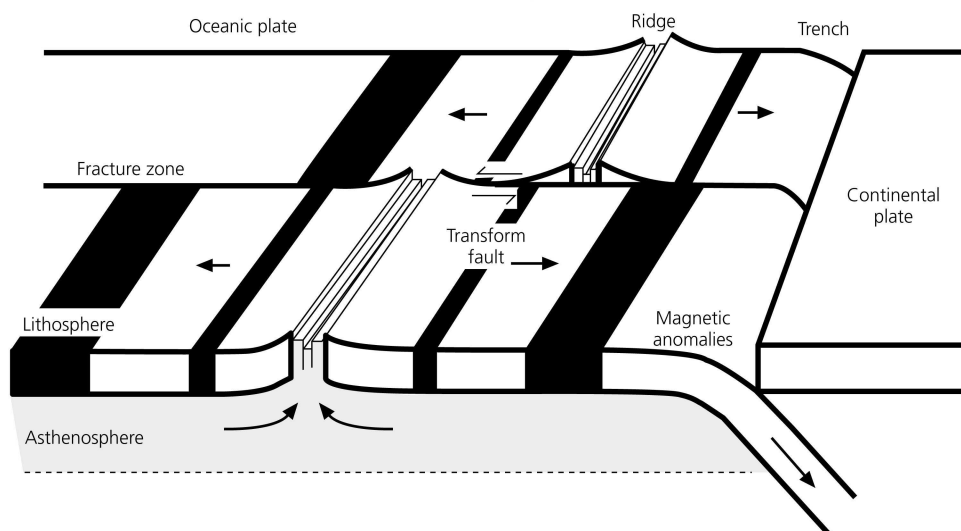
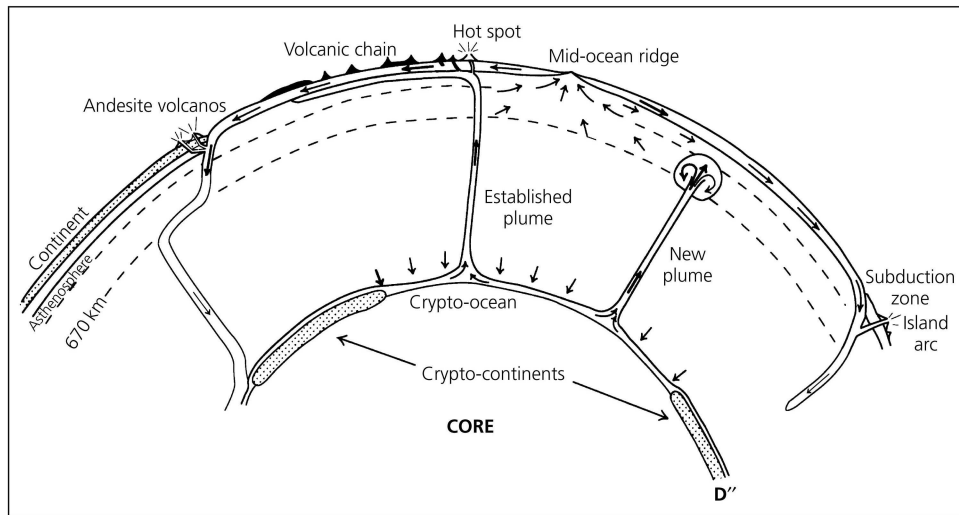


Figure 1: From Stein & Wysession (2003)

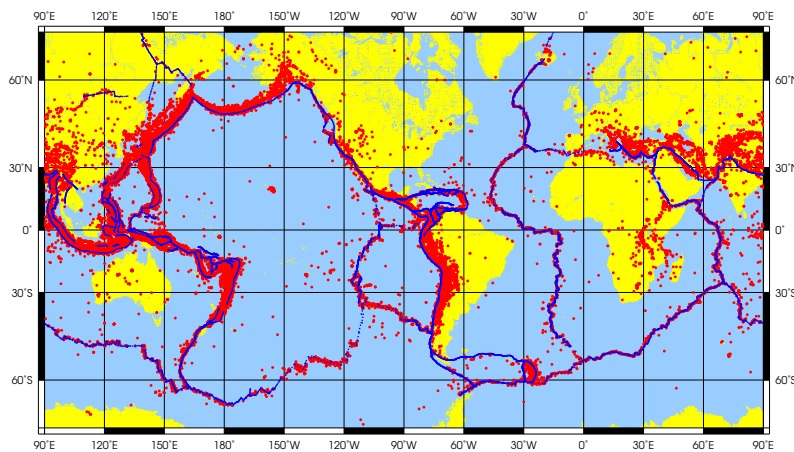
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**Figure 2:** From Stein & Wysession (2003)

Earthquakes mostly take place around plate boundaries as shown in Fig. 3. Most of our knowledge about the motions of tectonic plates is obtained through the study of distribution of earthquakes and the energy released by them.



**Figure 3:** Global distribution of earthquakes from the USGS catalog. The red dots represent earthquake epicenters, while blue lines show plate boundaries.

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### 1.2.1 GPS Data

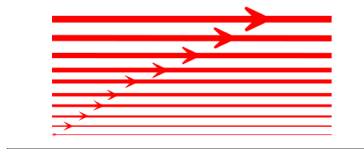
The Global Positioning System (GPS) is a constellation of navigation satellites used to pinpoint locations on the terrain. The GPS receiver helps determine locations on the Earth's surface by collecting signals from three or more satellites through a process called triangulation. Using a topographic map with the GPS receiver provides important information about features of the surrounding terrain. GPS is also another useful tool in studying plate kinematics through which we could measure the relative motion of plates with respect to each other.

There are many ongoing scientific projects on different scales dedicated to study tectonic plate motions. For instance, UNAVCO – a non-profit university-governed consortium that facilitates geoscience research and education using geodesy – conducts many of such projects.



**Figure 4:** A GPS satellite.

A famous example of such studies, is the *relative motion* of the Pacific plate with respect to the North American plate through the San Andreas fault. The San Andreas is a right-lateral strike-slip fault that is a result of the lateral, northward motion on the Pacific plate side. Consequently, the North American side of fault has a southward motion with respect to the Pacific side. Through a stick-slip mechanism, this results in *earthquakes* on the south-west coast. The displacement regime caused by the fault in a given fault region will increase as you go away from the fault plane (Fig. 5).



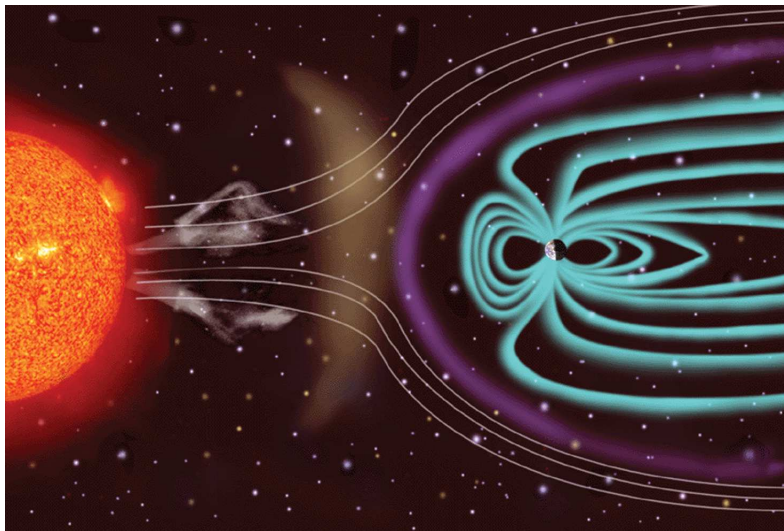
**Figure 5:** The amount of “motion” decreases as you go away from the fault. In this figure, the fault is shown by a black line and displacement in unit time is depicted by arrow size/line thickness.

## 2 PART II: Seafloor Spreading

### 2.1 Earth's Magnetic Field

The main part of the Earth's magnetic field originates in the planet's deep interior, but the field also reaches its surface and into the space (Fig. 6). Using this field, the compass has been used for orientation and navigation with the north-seeking tendency of its magnetized needle. This results from the common knowledge that the compass needle responds to the Earth's magnetic field, "always" pointing to the north.

It is fundamental to remember that the Earth's magnetic field is that of a **dipole**, and that the position of the magnetic poles on the planet varies with time. Obviously, the position of the North *magnetic pole* is different from the North geographic pole.



**Figure 6:** Earth's magnetic field interacting with radiation from the Sun (Links, 2008).

### 2.2 Ferromagnetism

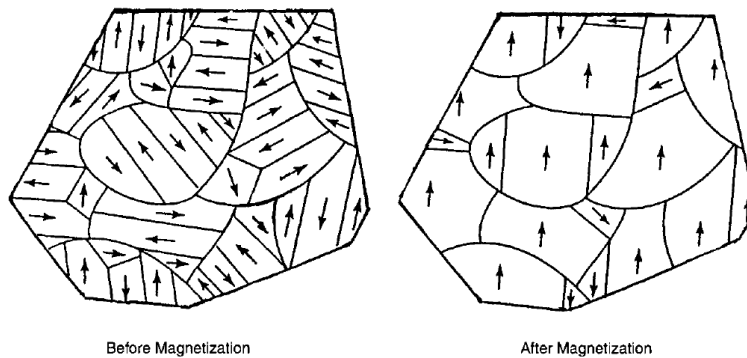
Ferromagnetism is the strongest form of magnetic properties which material can have. Even in the absence of an external magnetic source, ferromagnetic materials generate a magnetic field, and thus act like magnets. Most magnets are made of ferromagnetic material.

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Ferromagnetism can exist only below a critical temperature, called *Curie Temperature*,  $T_C$ , which is among the characteristics of materials.

Below  $T_C$ , the magnetic material is ordered in “domains”, inside which all atoms have their magnetic moments aligned parallel to each other. Such domains can be thought of tiny magnets. In general, in the absence of an external magnetic field, the domains are oriented at random and no macroscopic magnetic moment exists. Under the influence of an external magnetic field, the domains align themselves with the field, and this constructive interference results in a strong total magnetic moment (Fig. 7).



**Figure 7:** Areas enclosed by curved lines indicate the microscopic magnetic domains in a rock before and after magnetization. Arrows show the dipole field alignment within the domains (after Campbell, 2001).

When heated up above  $T_C$ , a ferromagnetic material loses its magnetic properties. However, if it is left to cool down through the Curie point, it becomes ferromagnetic again, and “if an external magnetic field is present”, it **aligns its magnetization with the there and then present magnetic field**. Igneous rocks are prime candidates for the acquisition of intense magnetization when they are rapidly cooled during their extrusion.

### 2.3 Paleomagnetism and Pole Reversals

Paleomagnetism is the study of the ancient mapping of the magnetic field of the Earth, as determined from samples of rock which have kept their magnetization, oriented in the direction of the Earth’s field, *where and when* they were formed.

Early in the twentieth century, it was noted that some igneous rocks presented a magnetization systematically *reversed* with respect to the polarity expected from the present-day

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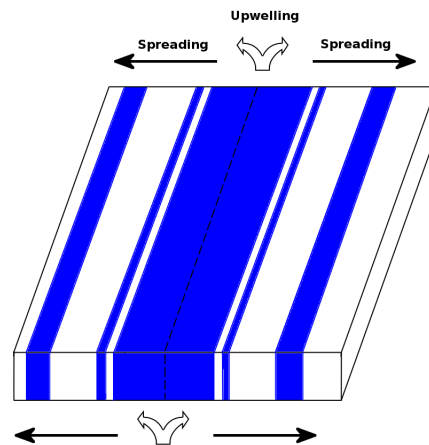
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field. Young igneous rocks (less than 3 Ma in age) sampled in different areas have a bimodal distribution of their azimuths of magnetizations, strongly centered at  $0^\circ$  and  $180^\circ$ . Given the slow rates of plate motions as discussed in PART I, the continents and the islands have only moved very slightly in 3 Ma, and so a change in their relative location cannot explain this pattern. If the interpretation of the origin of their magnetization is correct, the only explanation is that *Earth's magnetic field spends its time divided about equally between its present direction and the reversed direction (the North and South poles being exchanged)*.

## 2.4 Magnetic Anomalies on the Ocean Floor

The magma which form the igneous rocks in mid-ocean systems have temperatures exceeding the Curie temperatures for their minerals and thus are not ferromagnetic. However, as they reach the surface and upon cooling, as discussed above, they will *record* the direction of the present magnetic field.

During a period of *normal* magnetic polarization, they were subject upon formation to a field which for all practical purposes is similar to the present one. On the other hand, in *reverse* magnetic polarization (reversal episodes), their recorded fields will be reversed. As time goes by, rocks created during episodes alternatively normal and reversed, are pushed away from the ridge, and will create a pattern of *stripes*, of alternatively positive and negative anomalies, as shown in Fig. 8.



**Figure 8:** The striped pattern created as a result of “seafloor spreading” and magnetic reversals.

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## IN LAB

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### 3 Looking at Plate Motion in the GPS Data

Using your favorite internet browser, go to the “Data for Educators” center in the UNAVCO website, either by following the link below,

<http://www.unavco.org/education/resources/data-for-educators/data-for-educators.html>

On that page, there is a map of North America with green balloons on it which are permanent GPS stations. Zoom into the map focusing on the Los Angeles region until you reach the view shown in Fig. 9.

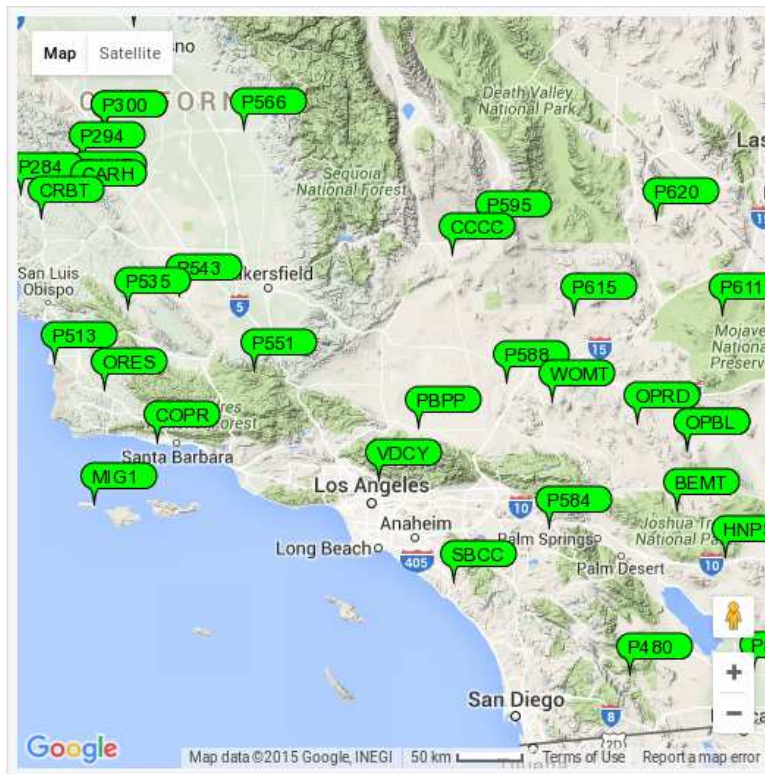


Figure 9: GPS station near Los Angeles.

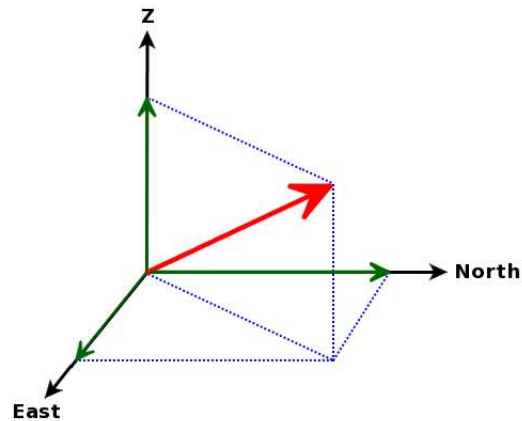


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By clicking on the individual balloons you will see dialog boxes containing information about the GPS time-series. Click on the the time series plot. You will see a detailed view of the position data over time. This data shows the position of every single station relative to the North American plate's frame of reference. These "motions" are recorded on three components, i.e., vertical, north-south, and east-west. In this way, you can reconstruct the 3D motion of the ground at any given station (Fig. 10).



**Figure 10:** 3D reconstruction of the motion vector, using the three recorded components.

On the detailed view, you will also see the calculated velocities for each of the component at each station. Fill in the following table using the information from the 30 stations in Fig. 9.

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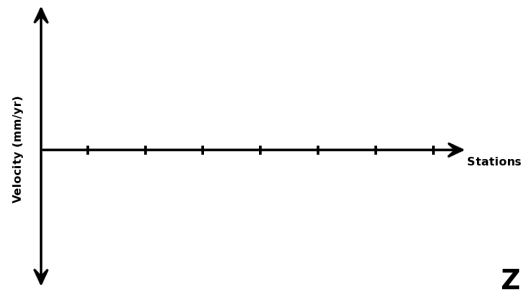
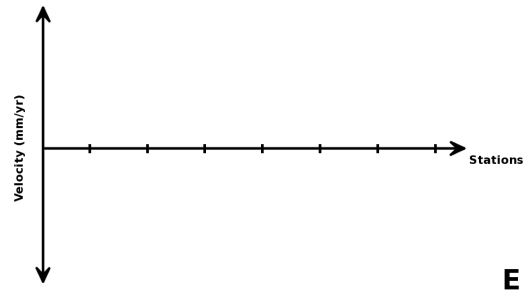
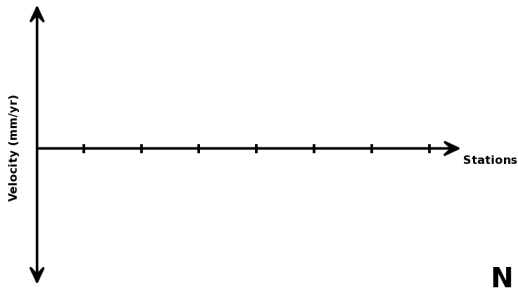
#	Station	N vel. (mm/yr)	E vel. (mm/yr)	Z vel. (mm/yr)	Total vel.
1					
2					
3					
4					
5					
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### Questions

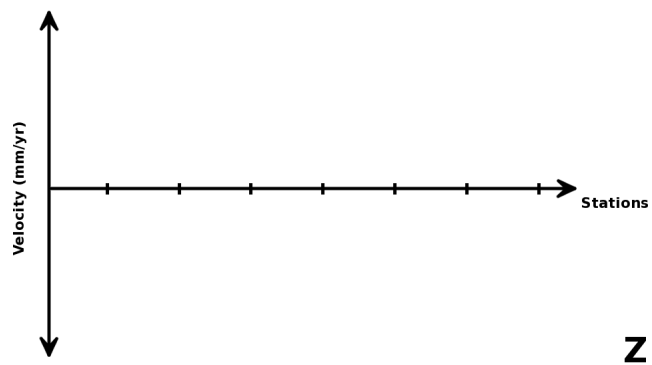
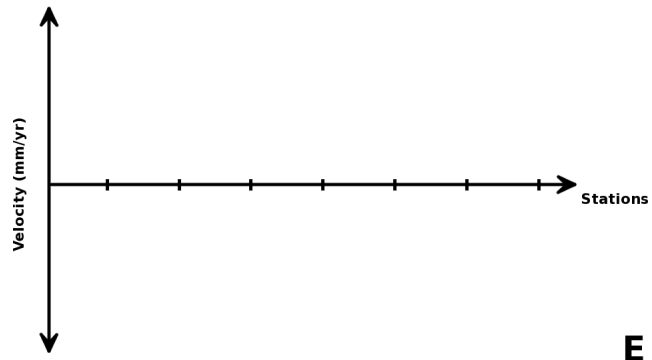
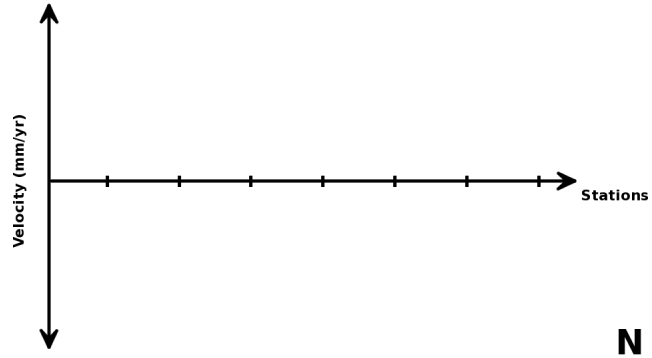
1. What are the minimum and maximum values for velocity? At which stations/components?
2. Draw velocity profiles for the three components along the following stations:
  - MIG1-COPR-P551-CCCC-P595



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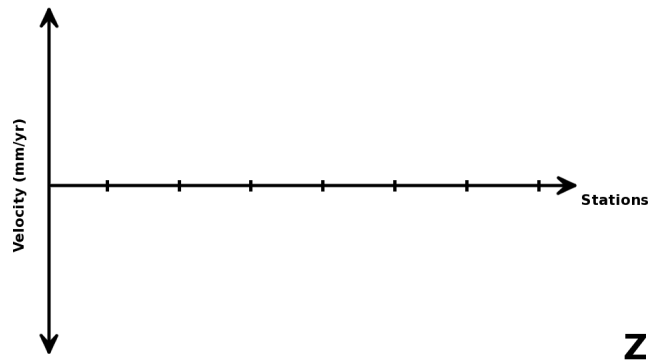
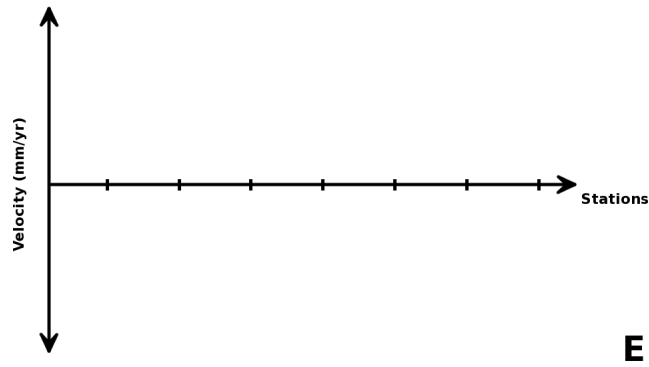
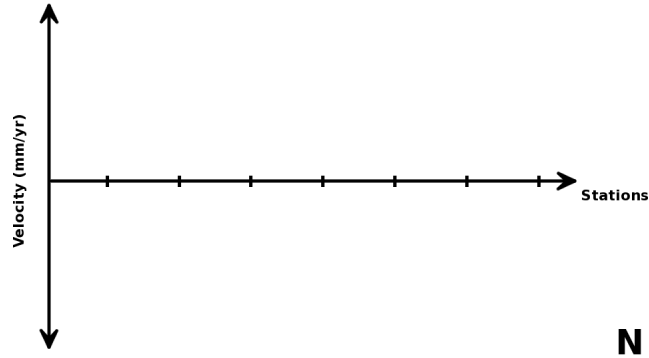
- VDCY-PBPP-P588-P615-P620



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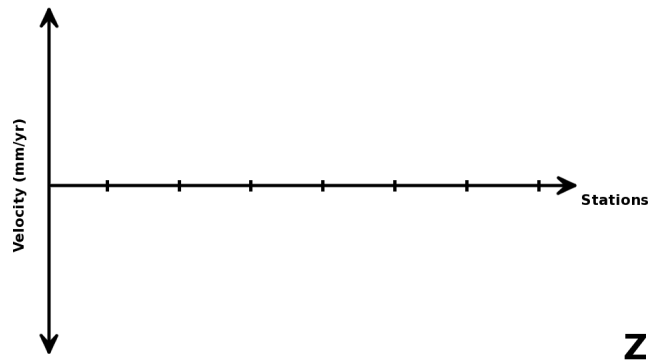
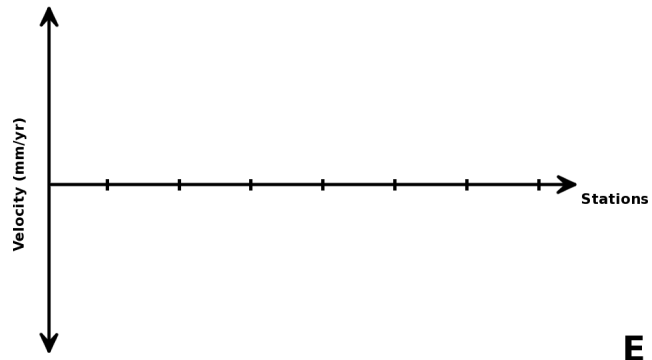
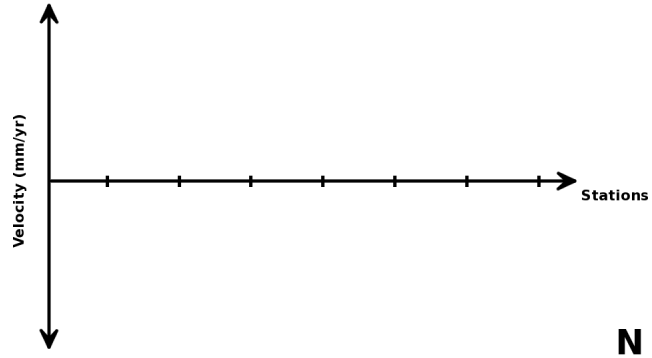
- SBCC-P584-BEMT-OPRD-P611



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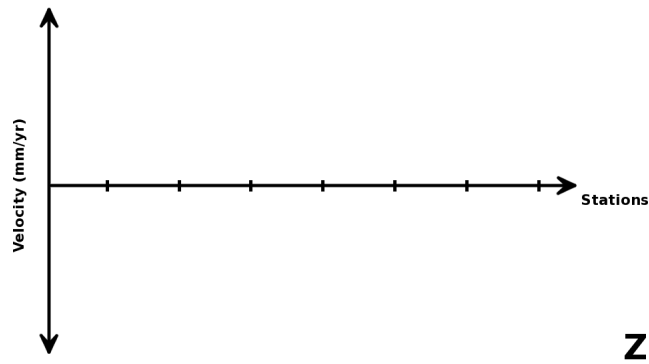
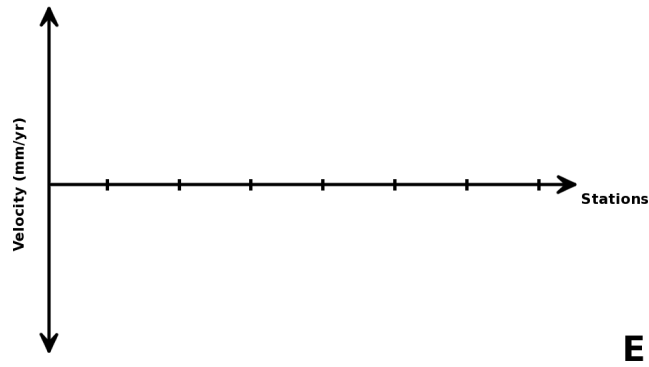
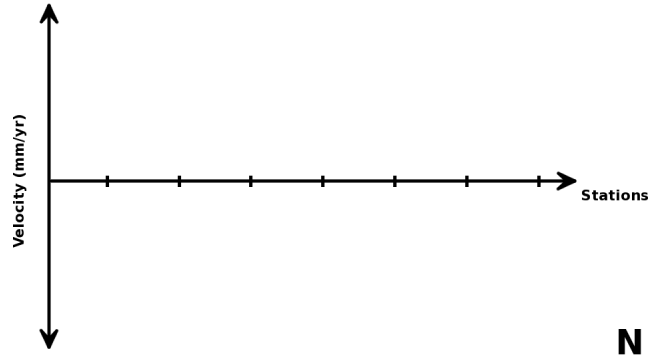
- HNPS-PBPP-P551-P535



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- P513-ORES-VDCY-P584



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3. Using your GPS data and from the profiles above, sketch the San Andreas fault on Fig. 9.
4. Is there a trend among the total values of velocities through the stations? Explain.

## 4 Activity: Global Tectonics

Look at Fig. 11 and answer the following questions.

1. Name four of the major plates.
2. Name three major subduction zones. Mark them on Fig. 11.



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3. Name three major spreading ridges. Mark them on Fig. 11.
4. How much is the African plate growing (in meters) on an east-west trend in 100 years (on average)?
5. By “reversing the clock” and considering the motion rates of tectonic plates, we can reconstruct their relative initial positions before they *drifted apart*. Cut out the continents on HANDOUT-B and try to fit them together like a puzzle to show how all of Earth’s continents once started out in a giant continent called Pangaea. Glue or tape them to the blank space below.

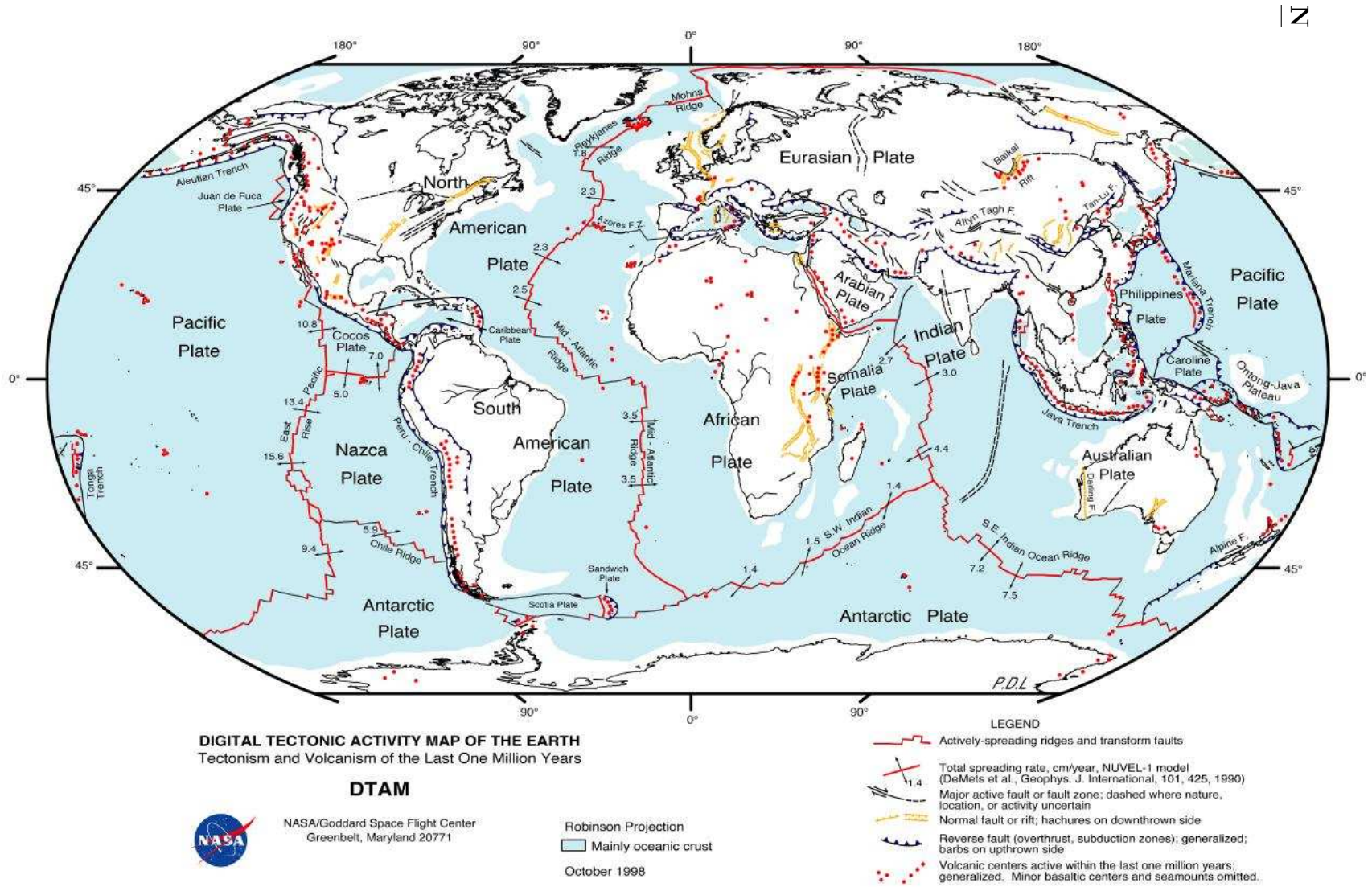


Figure 11: Tectonic plates and their average motion rates.

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## 5 Modeling Seafloor Spreading

The purpose of this part of the lab is to understand the concept of seafloor spreading and magnetic anomalies.

Follow through these steps:

1. Cut out the paper in HANDOUT-C with stripes that is labeled with millions of years (cut along the outside and then once down the middle so that you have two strips of paper that look exactly the same.)
2. Tape the two pieces of paper together.
3. (optional) Color the alternating strips so that the magnetic reversals are obvious.
4. Label the reversals with either North or South representing which direction the magnetic field was at the time.
5. On the next page, you will cut a slit where it says Mid-Ocean Ridge and Subduction Zones.
6. On the corresponding map, label “Mid-Ocean Ridges”, “Subduction Zones”, “Volcanoes”, “Where Earthquakes Occur”, “Lithosphere”, “Oceanic Crust”, and “Continental Crust”.
7. Pull the colored strips of paper through the Mid-Ocean Ridge slit.
8. Put the edges of the strips through the subduction zone strips.
9. Pull the slits through until the model shows what the seafloor looked like **6 MYA**. This is what you will turn in for grading.

### Questions

1. If you were to sample and date the rocks along the colored strip starting at the Mid-Ocean Ridge slit and moving toward the Subduction Zone slits, what change if any would you see in the age of the rocks.

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2. New seafloor rock is continually being formed at mid-ocean ridges and old seafloor is continually removed at ocean trenches. If the rock on the continents is continually formed but not removed, how would the age of the oldest rocks on the continents compare with the age of the oldest rocks on the seafloor?

3. On average, how many years are between each magnetic field reversal?

## 6 B-Spreading Rates

1. Color the ridge in Fig. 12.
2. Color the seafloor in Fig. 12 that is older than 50 million years (use Fig. 13 to match the anomaly number with the age in millions of years).
3. Using Fig. 13 and the distance scale in Fig. 12, calculate the spreading rate in the last 50 million years in centimeters per year (cm/yr).

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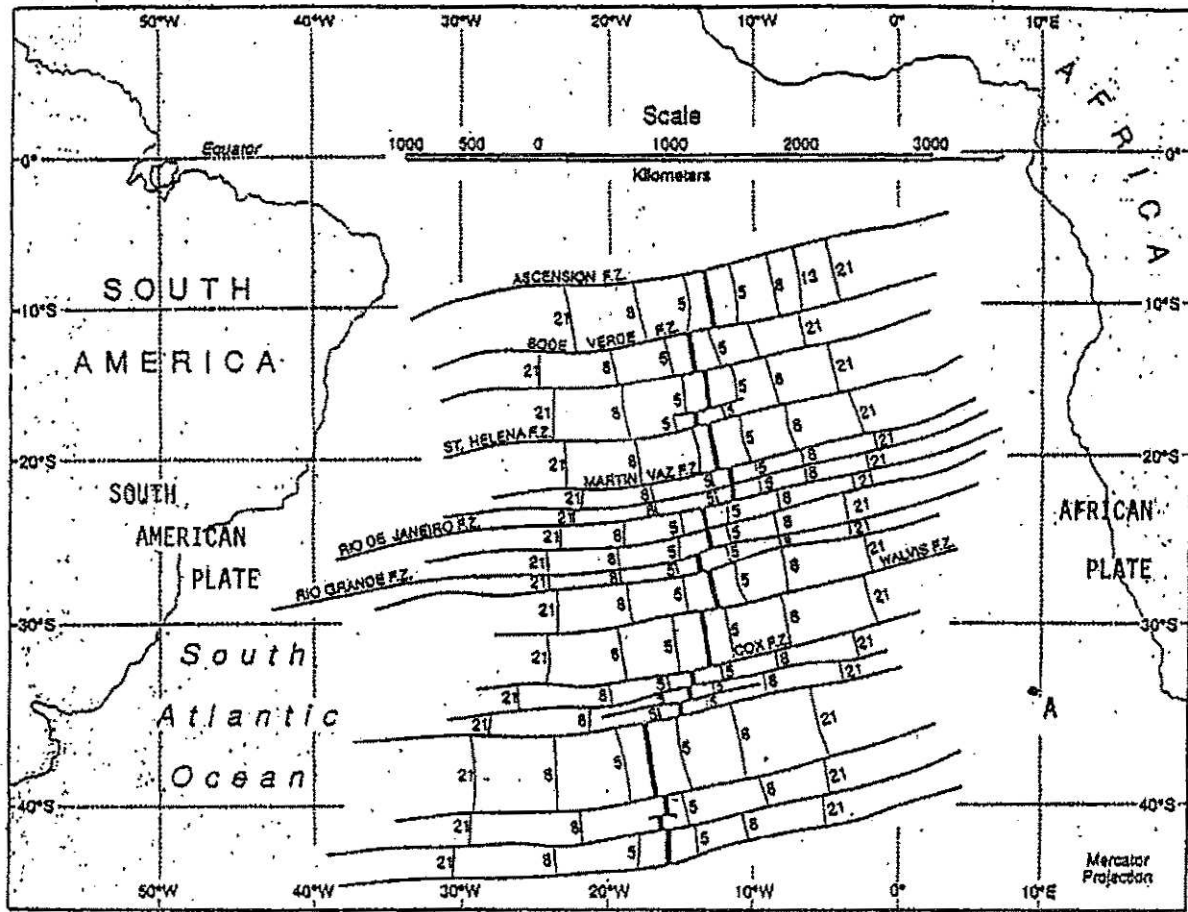


Figure 12: Map of the South Atlantic Ocean showing part of the Mid-Atlantic Ridge in black bars, the east-west fracture zones, and selected magnetic anomalies, labeled with anomaly numbers according to Fig. 13.

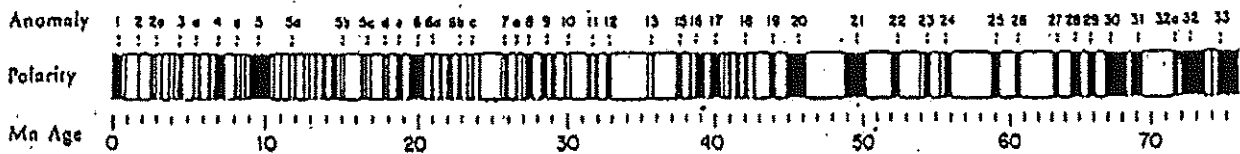


Figure 13: South Atlantic ocean floor magnetic anomalies. See Fig. 12.