Name____________________________

89.325 – Geology for Engineers
Plate Tectonics - Geomagnetism, Earthquakes, and Gravity

I. Geomagnetism

The earth's magnetic field can be viewed as a simple bar magnet located near the center of the earth and inclined from the geographic axis (Figure 1). The actual position of the magnetic pole changes with time due to drifting of the magnetic field.

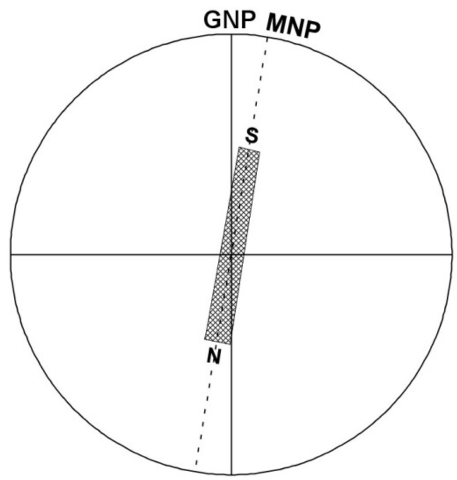


Figure 1. Representation of the earth's magnetic field as a simple bar magnet. The magnetic field is inclined with respect to the earth's rotational axis.

The north seeking end of a compass points towards the magnetic north pole (which must, therefore, be the south magnetic pole of our simple bar magnet), and the needle generally points either to the east or the west of the geographic north pole. This east or west deviation from true north is called magnetic declination - the angular variation between the geographic north pole and the magnetic north pole. Only in two special cases will true north and magnetic north correspond, a point to keep in mind when you are using a compass.

The instructor has provided you with a topographic map. On this map true north is up and parallel to the map boundary. The magnetic declination is given on the map. If you wanted to walk across country on a heading N20ºW, what compass heading should you use?

Map name_______________________________

Compass heading__________________________

Note that the magnetic declination does change with time, so the magnetic declination shown on an old topographic map would not be correct for the present day.

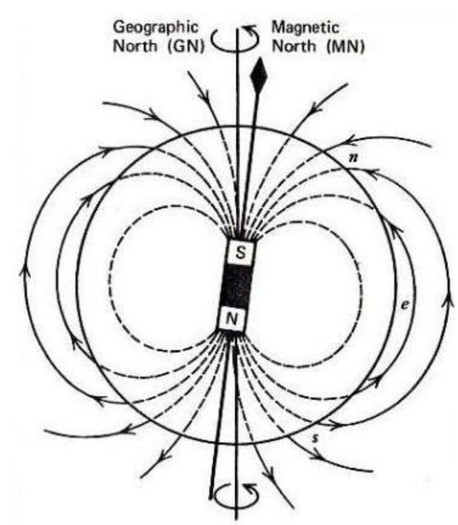


Figure 2. Lines of magnetic flux for the earth's magnetic field. From Wyllie, P. I., 1976. The Way the Earth Works. New York: Iohn Wiley & Sons, Inc., p. 105.

II. Polar Wandering

As a first approximation the Earth's magnetic field can be viewed as a simple bar magnet (Fig. 1). Notice that the angle the magnetic field makes with the earth's surface varies with latitude. This variation is referred to as inclination. If we make the assumption that the magnetic and geographic poles are at the same location (an assumption which is true when the position of the earth's magnetic field is averaged over thousands of years), latitude and inclination can be related by the simple formula

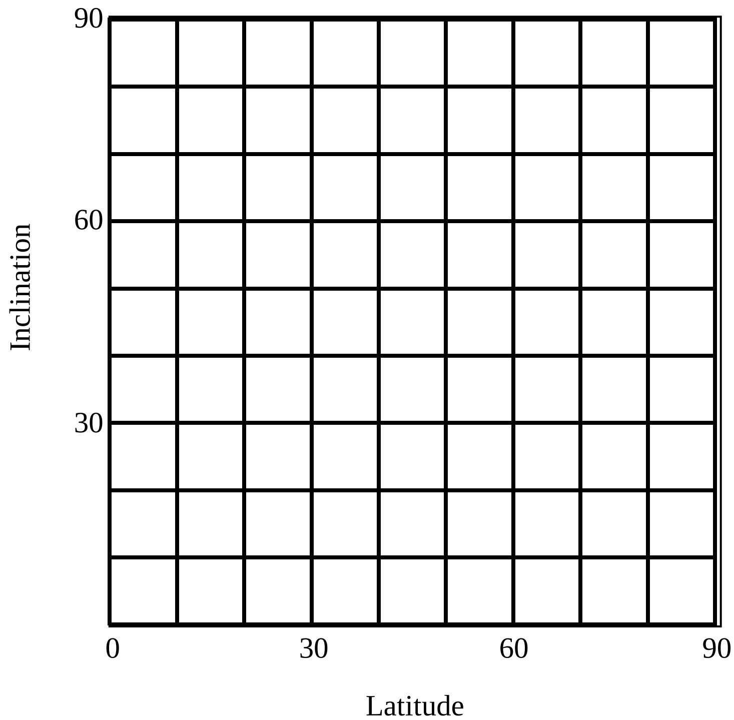
$$\tan \theta = 0.5 \tan i \qquad (1)$$

where θ = latitude and i = inclination.

Using the data given in Table 1, on the graph below plot inclination as a function of latitude.

Table 1. Latitude vs inclination of the earth's magnetic field

Latitude	Inclination
90N	90°
75	82
60	74
45	64
30	49
15	28
0	0



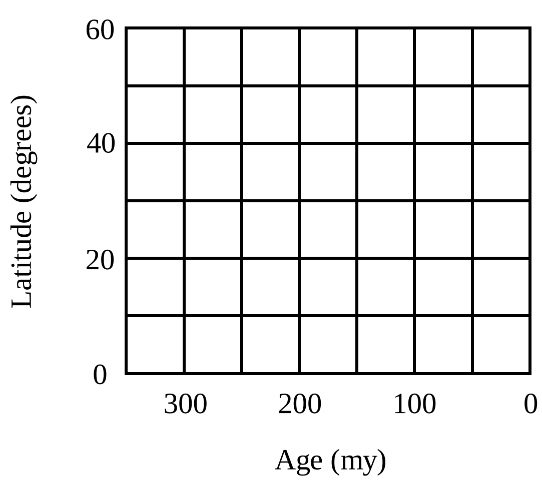
Certain minerals in a rock (particularly magnetite) are magnetic and their magnetic field is aligned with the magnetic field of the earth at the time the mineral is formed. It is possible to take a rock sample into the laboratory, artificially cancel out the earth's existing magnetic field, and measure the remnant magnetic field caused by these minerals. This remnant magnetism is referred to as paleomagnetism.

You are a geologist and have been busily at work collecting rocks of different ages from two continents, A and B. You take the samples into the laboratory and determine the fossil magnetic inclination. The data you collected are tabulated in Table 2. For each sample, calculate the paleolatitude at the time it was formed using either the inclination versus latitude curve or equation 1.

Table 2. Paleomagnetic inclination (in degrees) for Continents A and B

Continent A				Continent B		
Age (my)	i	θ		Age (my)	i	θ
0	64			0	35	
50	60			50	25	
100	45			100	20	
150	30			150	15	
200	10			200	10	
250	10			250	10	
300	0			300	5	
350	0			350	10	

On the graph below plot the positions of the two continents as a function of time. Use a different color for each continent.



1. How might you interpret the latitude versus age data? Geologists were very surprised when they first made this discovery in the 1950's.

III. Magnetic Reversals and Sea Floor Spreading

The greatest mountain chain on earth, 40,000 miles long, exists under the oceans. This mountain chain is referred to as the mid-ocean ridge system. Your instructor will show you maps of this system.

Geologists discovered in the early 1960's that if you towed a magnetometer (a device that measures the intensity of the earth's magnetic field) across the ocean's surface perpendicular to a mid-ocean ridge, the intensity of the earth's magnetic field varied in a regular manner. In fact, the variation in intensity was symmetrical about the mid-ocean ridge. It was also discovered that the polarity of the earth's magnetic field reverses through geologic time. It was suggested that the observed variations in magnetic intensity were due to sea floor rock that were formed at different times. If a particular piece of sea floor was formed when the magnetic polarity of the earth's field was the same as it is today (normal polarity) the measured magnetic field would be anomalously high. If a particular piece of sea floor was formed when the magnetic polarity of the earth's field was opposite from what it is today (reversed polarity) the measured magnetic field would be anomalously low. Using radiometric dating techniques it was possible to determine the age of the various magnetic anomalies.

The diagram below (Figure 3) shows the pattern of magnetic anomalies for ocean X. Open areas represent normal polarity, shaded areas represent reversed polarity.

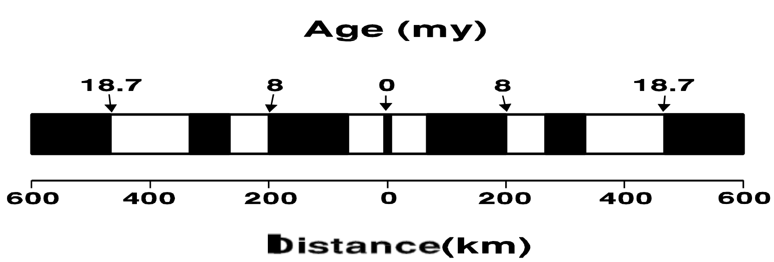


Figure 3. Sea-floor magnetic anomalies as a function of distance from the center of the mid-ocean ridge and age.

2. How did Vine and Matthews interpret the observed magnetic anomaly patterns?

3. Calculate the rate of sea-floor spreading between 0 and 8 my and between 8 and 18.7 my. Are the spreading rates constant?

   What is the age of the sea-floor located 1000 km from the mid-ocean ridge.

4. What does all of this suggest to you about the positions of continents? Are these positions fixed?

IV. Gravity

Variations in gravity reflect changes in the density of the material at depth. The difference in the measured gravity and the average gravity value for a particular region is referred to as the *gravity anomaly*. Gravity measurements are made in mGal (milliGals). The average value for the earth's gravity varies as a function of latitude because the earth is not a perfect sphere (and is rotating on its axis). For this problem the average gravity value is 980,000 mGal.

Measured gravity readings must be corrected for altitude from sea level (the Free Air Correction) and the contribution of mass between the location of the gravity measurement and sea level (the Bouguer Correction).

Free Air Correction = 0.3086 x distance above sea level (m)

Bouguer Correction = -0.04193 x density of material (g/cm^3) x distance above sea level (m)

Remember that we are using a Cartesian coordinate system so upwards is a positive direction and downwards is a negative direction. For continental crust average density = 2.7 g/cm^3 and for average sea floor basalt density = 3.0 g/cm^3. But remember that the ocean basins are already filled with water (density = 1.0 g/cm^3). Complete Table 3 with reference to Figure 4 and plot the results on the appropriate graph.

Table 3. Gravity data

Location (km)	Station Elevation (m)	Water Depth (m)	Measured Gravity (mGal)	Average Gravity (mGal)	Free Air Correction (mGal)	Bouguer Correction (mGal)	Gravity Anomaly (mGal)
0	1000	0	979,515	980,000			
50	1500	0	979,417	980,000			
100	1200	0	979,476	980,000			
150	1800	0	979,358	980,000			
200	1300	0	979,446	980,000			
250	1400	0	979,427	980,000			
300	500	0	979,602	980,000			
350	0	500	979,658	980,000			
400	0	2000	979,582	980,000			
450	0	2500	979,590	980,000			
500	0	3500	979,557	980,000			
550	0	4000	979,539	980,000			
600	0	6000	979,297	980,000			
650	0	4000	979,515	980,000			
700	0	3500	979,657	980,000			
750	0	3000	979,748	980,000			
800	0	3000	979,748	980,000			
850	0	3000	979,748	980,000			
900	0	3000	979,748	980,000			
950	0	3000	979,748	980,000			
1000	0	3000	979,748	980,000			

5. Interpret the gravity measurements. What can you conclude about the nature of the subsurface material?

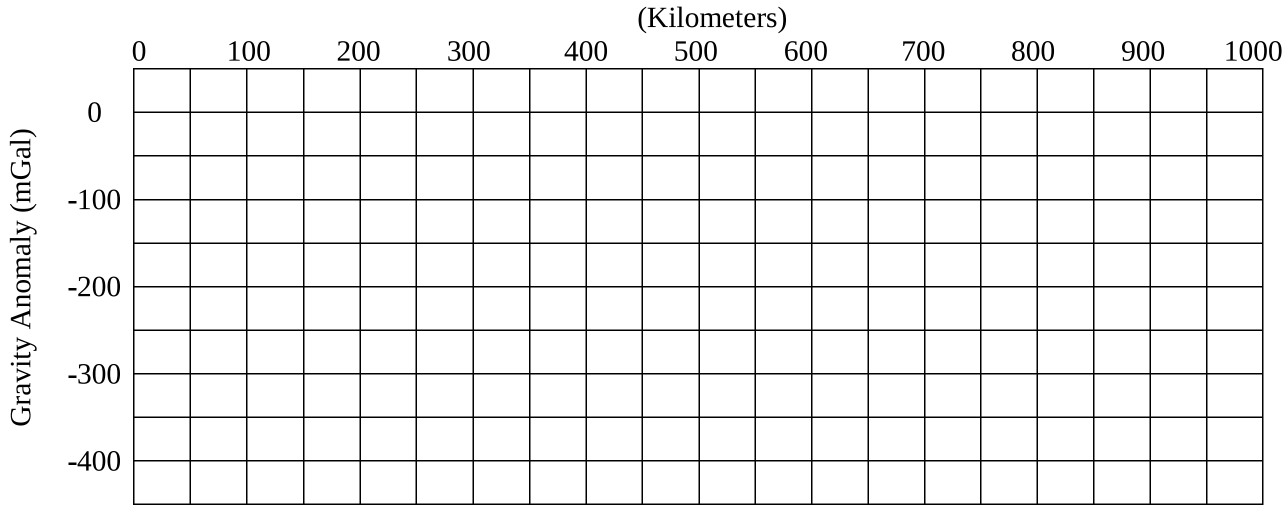
V. Earthquakes

In order for earthquakes to occur earth materials must behave as rigid solids. For average earth materials (rocks) at depths of greater than 70 km the material behaves plastically, not as a rigid solid. What we observe is that over most of the earth's surface earthquakes are confined to the top 70 km. However, very deep earthquakes are found in association with ocean trenches. With reference to Figure 4, plot the earthquake data (Table 4) on the appropriate graph.

Table 4. Earthquake data

Date	Location (km)	Depth (km)	Magnitude
September 1	200	250	6.1
September 15	435	145	4.7
October 2	680	10	3.2
October 24	250	225	5.9
November 5	600	70	3.7
November 10	540	80	4.0
December 1	340	175	5.5

6. Interpret the earthquake data. How might one explain the occurrence of earthquakes at great depths?



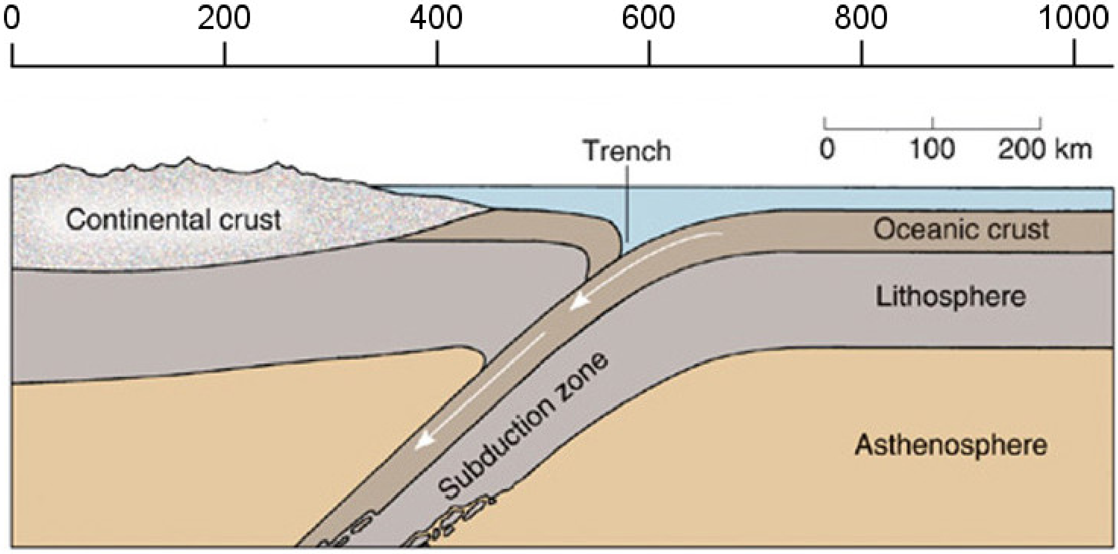


Figure 4. Cross-section of convergent ocean-continent margin.