Earthquake Lab

Introduction: Seismology is that branch of the geological sciences which is concerned with the study of earthquakes.

Purpose: The purpose of this exercise is to introduce some fundamental concepts of seismology including:

1) The calculation of the earthquake location
2) Earthquake magnitude, energy, and frequency

Method: Mathematical and graphical methods are used to determine the locations and the characteristics of earthquakes.

Equipment needed: USE a ***Pencil***, eraser (nobody is perfect!), compass, straightedge, and scratch paper.

Fundamental Concepts and Key Terms: underlined words

Much of what we know about the internal composition and structure of the earth (and now the moon) is obtained from earthquake records or **seismograms** which are collected at **seismograph stations**. In this lab, you will investigate how to interpret seismic data collected at a station located at Bowling Green State University.

Most earthquakes are caused by the sudden rupture of rock masses along fractures or **faults** in the crust. The movement may be visible at the surface (as in the San Andreas Fault) or may occur along faults buried deep in the earth's crust.

The location of the point of rupture of the earthquake is called the focus or hypocenter of the quake. The point on the earth's surface directly above the focus is called the **epicenter**. This is usually the place that has the greatest damage.

Elastic energy, movement, released at the focus of the earthquake is transmitted through the earth in the form of various seismic waves. Waves which travel, or propagate, through the interior of the earth are called **body waves**. Waves which propagate along the surface of the earth are called **surface waves**.

Body Waves: The motion of the vibrating particles of the rock may be parallel to the direction in which the wave is travelling, resulting in a compressional wave called the **primary wave** or a **P-wave**. If the motion of the particle is perpendicular to the direction of wave movement, a shear wave called the **secondary wave** or a **S-wave** is produced.

Surface Waves: The motion of the vibrating particles for surface waves is a lot more complex than for the body waves. There are two types, Rayleigh waves or **R-waves** and Love waves or **L-waves**. When the particles move in an elliptical, counterclockwise path within a vertical plane, up and down, while the direction of the wave moves horizontal, R-waves are created. When particles move back and forth in a plane, side to side, while the direction of the wave moves horizontal, L-waves are created. L-waves are the most destructive seismic waves.

The first waves to arrive at the seismograph station are the P-waves followed by the S-waves. The time lag between the arrival of the P and S waves indicates that their velocities are different. In other words, **P-waves travel faster than S-waves.** The difference in arrival time between the two waves increases with increasing distance from the focus, so this time lag may be used to calculate the distance from the seismograph station to the epicenter.

Earthquake Epicenter: Four partial records (seismograms) of the same earthquake, recorded at Bowling Green (BGO), San Francisco (SFC), Seattle (SEA), and Salt Lake City (SLC) are shown in Figure 1. On each line in **Figure 1**, the first (left) deflection marks the arrival of the P-waves, and the second deflection indicates the arrival of the S-waves. Using the information provided in **Figure 1**, answer the following.

1. Calculate the differences in the arrival times of the S and P-waves (S-P) for each station. **Round** to nearest minute or half minute.

   BGO ____________________________ minutes : seconds

   SFC ____________________________ minutes : seconds

   SEA ____________________________ minutes : seconds

   SLC ____________________________ minutes : seconds

2. Determine the arrival times of the S-waves at each station.

   BGO __________________________ EST

   SFC __________________________ PST

   SEA __________________________ PST

   SLC __________________________ MST

3. Using the differences in arrival times of the S and P waves determined above, and the time-distance table (**Table 1**), calculate the distance to the earthquake epicenter from each of the stations.

   BGO to earthquake ____________________________ miles

   SFC to earthquake _____________________________ miles

   SEA to earthquake _____________________________ miles

   SLC to earthquake _____________________________ miles

Figure 1

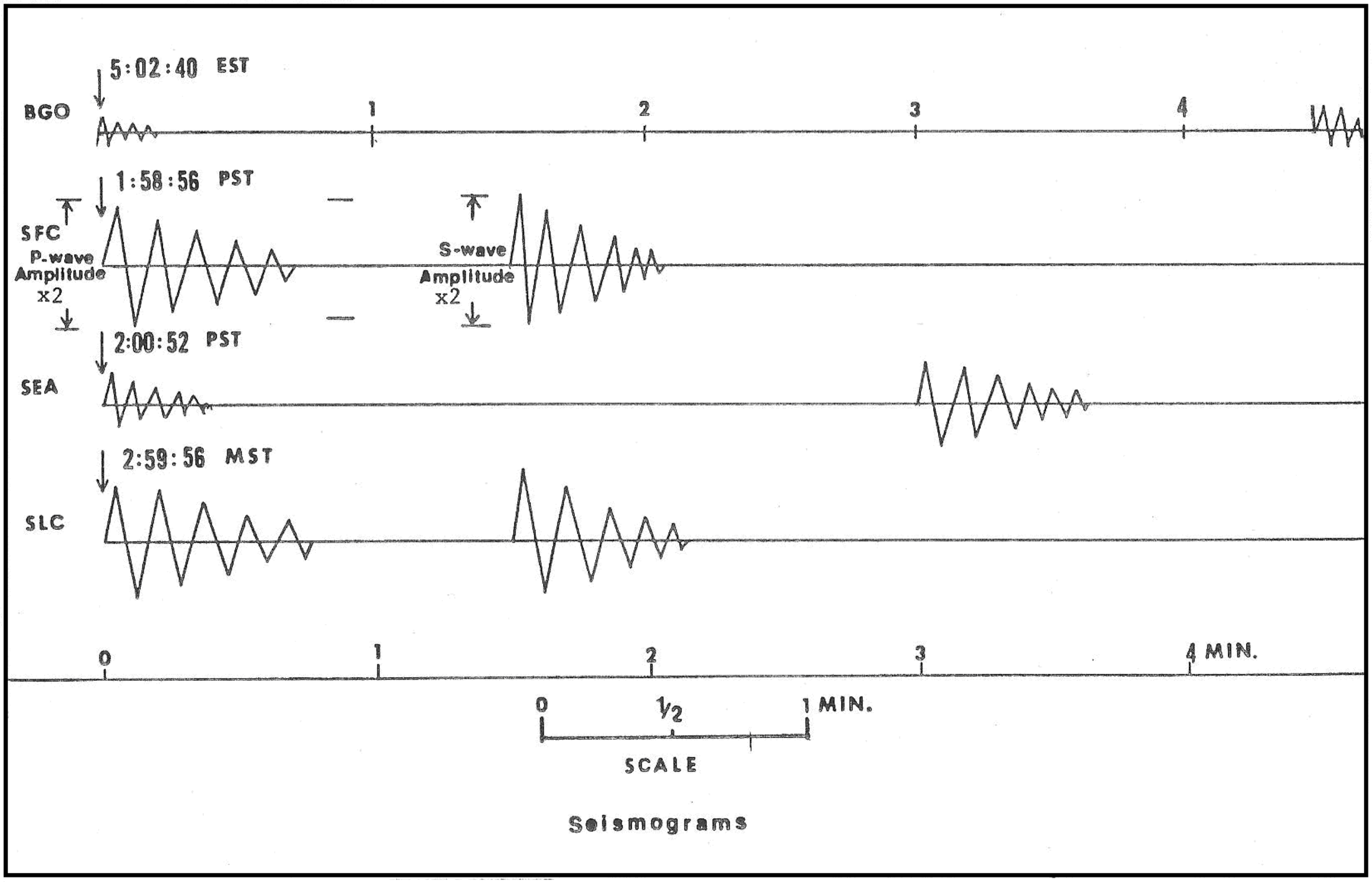

5:02:40 EST
BGO
1
2
3
4
1:58:56 PST
SFC
P-wave
Amplitude
x2
S-wave
Amplitude
x2
2:00:52 PST
SEA
2:59:56 MST
SLC
0
1
2
3
4 MIN.
0
1/2
1 MIN.
SCALE
Seismograms

Table 1

Travel Time vs Distance of P and S-waves

S-wave arrival time minus P-wave arrival time (hour:min:sec)	P-wave arrival time minus origin time (hour:min:sec)	Distance to epicenter km	miles
00:01:00	00:01:13	550	342
00:01:30	00:01:56	869	540
00:02:00	00:02:42	1199	745
00:02:30	00:03:18	1507	936
00:03:00	00:03:52	1804	1121
00:03:30	00:04:26	2123	1319
00:04:00	00:05:00	2475	1538
00:04:30	00:05:40	2926	1818
00:05:00	00:06:21	3421	2126
00:05:30	00:06:58	3894	2420
00:06:00	00:07:33	4356	2707
00:06:30	00:08:09	4840	3008
00:07:00	00:08:45	5357	3329

4. On the map of the United States (**Figure 2**), draw compass arcs with centers at the four stations and with radii corresponding to the calculated distances from **question 3**. Show the location of the epicenter on the map. Use the scale at the lower left of the map (**Figure 2**) to determine the compass arcs. **Helpful Hint:** 400 miles = 1 inch

5. The arrival time of the P-waves at each of the four stations is shown on the seismograms (Figure 1). Using the time-distance table (**Table 1**) and station BGO (**Figure 1**), determine the time the quake occurred (origin time of the quake). Show your calculations of how you arrived at your answer. **Helpful Hint:** Column 2 of Table 1

   Origin time of quake: ___________ EST.

Earthquake Magnitude: The Richter scale of earthquake magnitudes was developed to describe quantitatively the "strength" of an earthquake and the amount of energy released by the quake.

The Richter magnitude, M, is defined as

$$M = \log B - \log B_0$$

Lucky for us, *we don't* have to do the math to find the magnitude. To calculate the magnitude of an earthquake, a nomogram (**Figure 3**), derived from the above equation, may be used. For example, if the trace amplitude of the surface wave is 1mm and if the seismograph station is located at 800 km from the epicenter, a straight line drawn through these two points, on the nomogram in **Figure 3**, gives you a Richter magnitude (M) of 5.6.

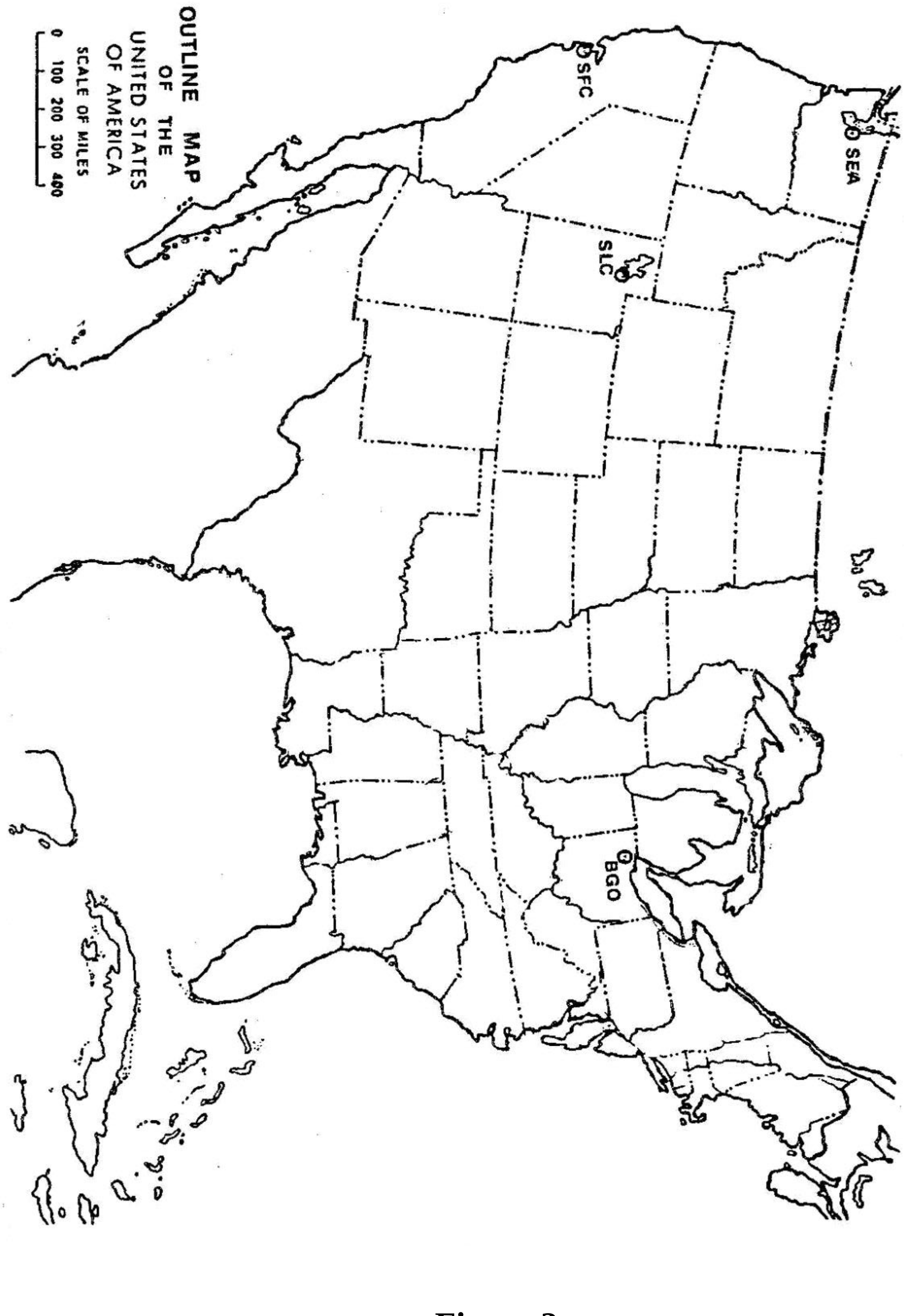
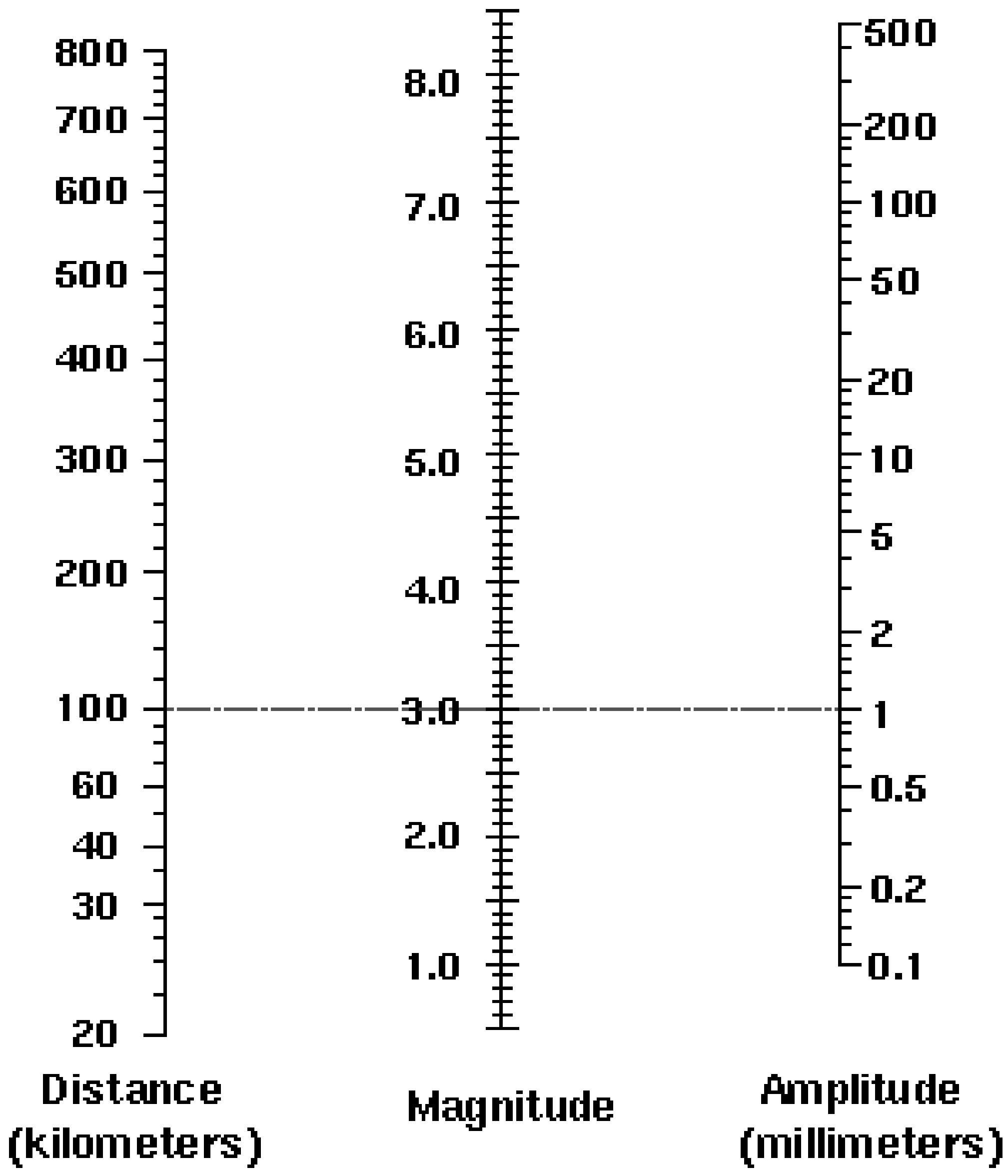

OUTLINE MAP
OF THE
UNITED STATES
OF AMERICA
SCALE OF MILES
0 100 200 300 400
SFC
SEA
SLC
BGO

Figure 2

Figure 3 - Nomogram



Let's say an earthquake occurred with its epicenter in southern Illinois. The seismograph station in Bowling Green (BGO), which is **600 km** (373 miles) away, records the quake with a maximum amplitude of the surface's waves of **.1mm**. Given this information, answer the following questions.

6. What is the Richter magnitude of the southern Illinois earthquake?

   Magnitude = ___________________________

7. If a seismograph station were located **200 km**, from the above quake, the amplitude would be what?

   Amplitude = __________________________

Once the magnitude of an earthquake has been determined, the approximate amount of energy released by the quake can be computed from the following formula:

$$\log E = 11.4 + 1.5M$$

where: E = energy in ergs
M = Richter magnitude of the quake

This is an <u>empirical</u> formula: that is, it was derived from the results of many observations, experiments, and related calculations.

Lucky for us, *<u>we don't</u>* have to do the math to find the amount of energy. The above equation is plotted in **Figure 4**. Note from this graph that, as the magnitude of a quake increases by 1 (from 3 to 4, for example), the energy released by the quake increases by more than a factor of 10.

8. Using **Figure 4**. calculate the amount of energy released by the southern Illinois earthquake. Try using the equation and **Figure 4** to get your answer.

   Energy released = ____________ ergs

To get a **"feeling"** for how much energy is released by a large earthquake, comparisons of quakes with nuclear explosions are often made. An atomic bomb of the Hiroshima type releases about 8×10^{20} ergs of energy while one of the largest earthquake ever recorded (M = 8.9) released $100{,}000 \times 10^{20}$ ergs of energy.

9. A quake of magnitude 8.9 is roughly equivalent to how many atomic bombs of the Hiroshima type? **Show** your calculations. **Hint**: $\frac{1 \text{ bomb}}{8 \times 10^{20} \text{ ergs}}$

   M (8.9) = _______________ atomic bombs

Frequency of Earthquake Occurrence: Although currently there are no reliable means of predicting where and when an earthquake will occur, an estimate of how frequently an earthquake of any magnitude occurs can be made. Based on data from all over the world, it has been determined that the frequency of occurrence of earthquakes of any given magnitude is approximately 8 to 10 times greater than that of earthquakes one magnitude higher. That is, a quake of magnitude 7 in general occurs 8 to 10 times more frequently than does a quake of magnitude 8.

One relationship which has been developed *strictly* for southern California is that

$$\log N = 4.77 - 0.85 M$$

where N = number of shocks of magnitude M or greater per year
M = Richter magnitude of the quake

Lucky for us, *we don't* have to do the math to find the frequency. The above equation is plotted in **Figure 5**.

10. In southern California, according to **Figure 5**, how many quakes of magnitude 4 or larger occur each year? Try using the equation and **Figure 5** to get your answer. Show calculations.

N = ________________ quakes per year.

11. How many quakes of magnitude 5 or larger occur each year? Try using the equation and **Figure 5** to get your answer. Show calculations.

N = __________________ quakes per year.

12. The ratio of the frequency of occurrence of a quake of magnitude 4 or greater to the frequency of occurrence of a quake of magnitude 5 or greater is:

N (4 or greater) : N (5 or greater) = ________________

13. What major geological feature in the United States is probably related to the earthquake that you calculated the epicenter in question 4 of this lab.

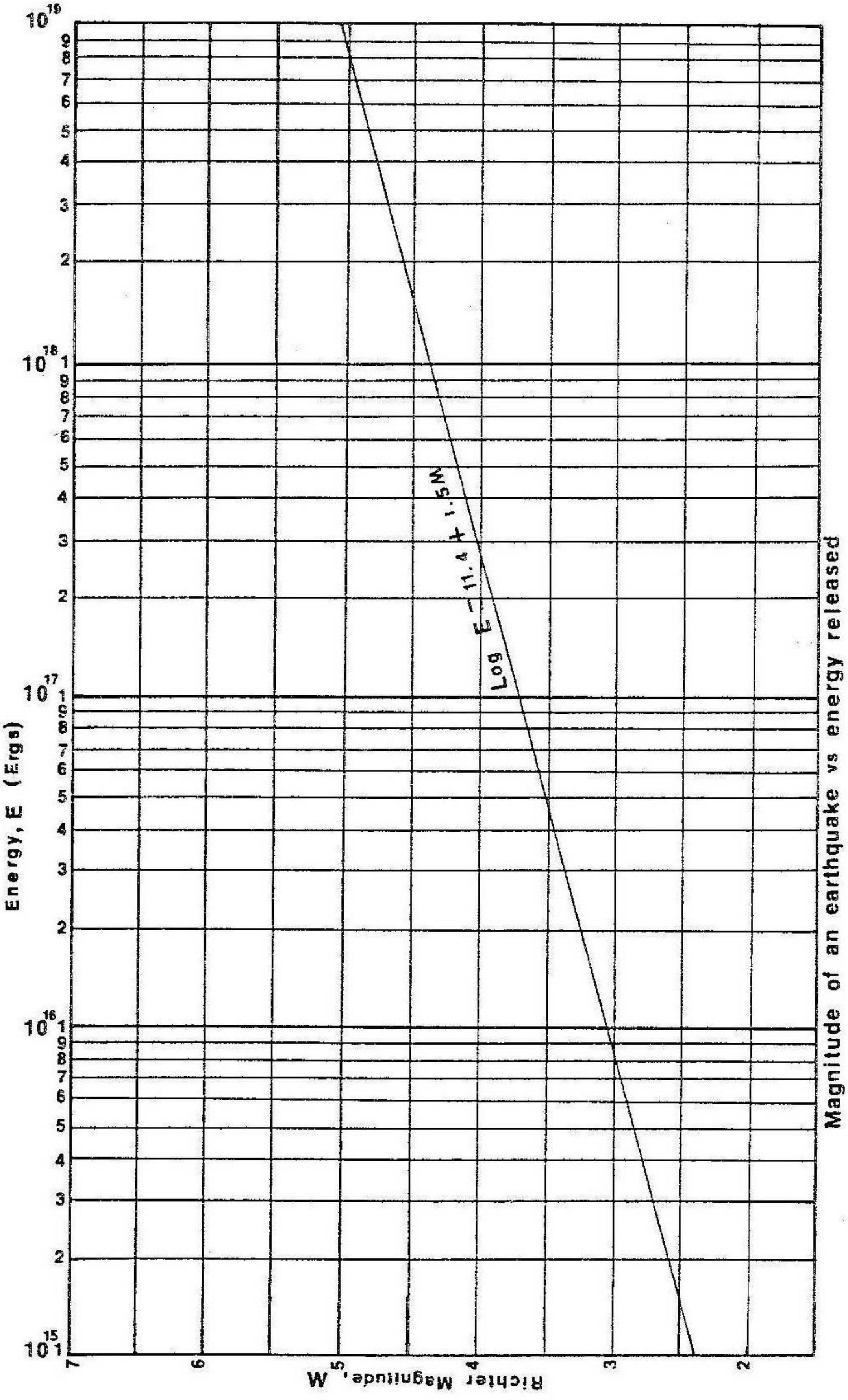

Magnitude of an earthquake vs energy released
Energy, E (Ergs)
Richter Magnitude, M
Log E = 11.4 + 1.5M
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
7
6
5
4
3
2

Figure 4

Magnitude of an Earthquake vs Frequency of Occurrence in Southern California.
(After C. F. Richter, 1958, Elementary Seismology, W. H. Freeman and Company, p. 360.)

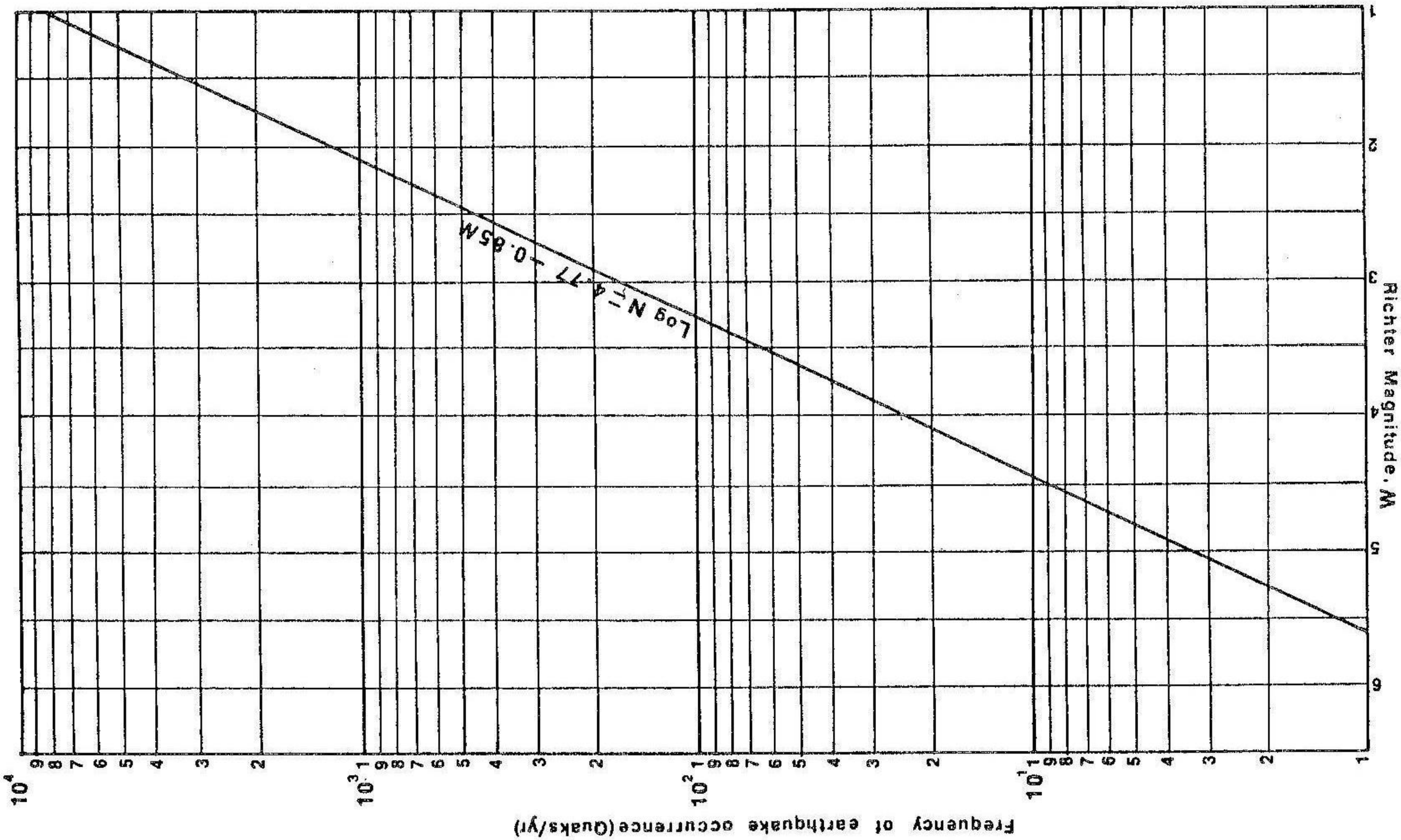


Figure 5

14. Place your ruler on the 100km mark on the left side of the nomogram. What would the amplitude be of an event of:

Magnitude 3.0 _______________ Magnitude 4.0 _______________ Magnitude 5.0 _______________

15. How would you summarize the relationship between amplitude and magnitude?

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____

16. In general terms, what happens to the amplitude as you get farther from the epicenter?

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17. What is the minimum number of seismographs needed to locate an earthquake? Why?

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18. Often the circles don't intersect perfectly at a point. List at least three reasons as you can for why this is so.

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