Natural Hazards and Disaster

Lab 5: Seismic Exercises

- Review terminology
- Earth structure
- Exercise 1: Loma Prieta 1989 epicenter and magnitude
- Exercise 2: Haiti 2010

http://earthquake.usgs.gov/eqcenter/recenteqsus/Maps/US10/32.42.-125.-115.php

Laboratory Exercise: Earthquakes

See Classes 4 and 5 on Earthquakes

Earthquakes are caused by the sudden release of stored energy when an active fault slips. Most faults are in the upper, brittle part of Earth's crust and are related to tectonic plate boundaries - such as:

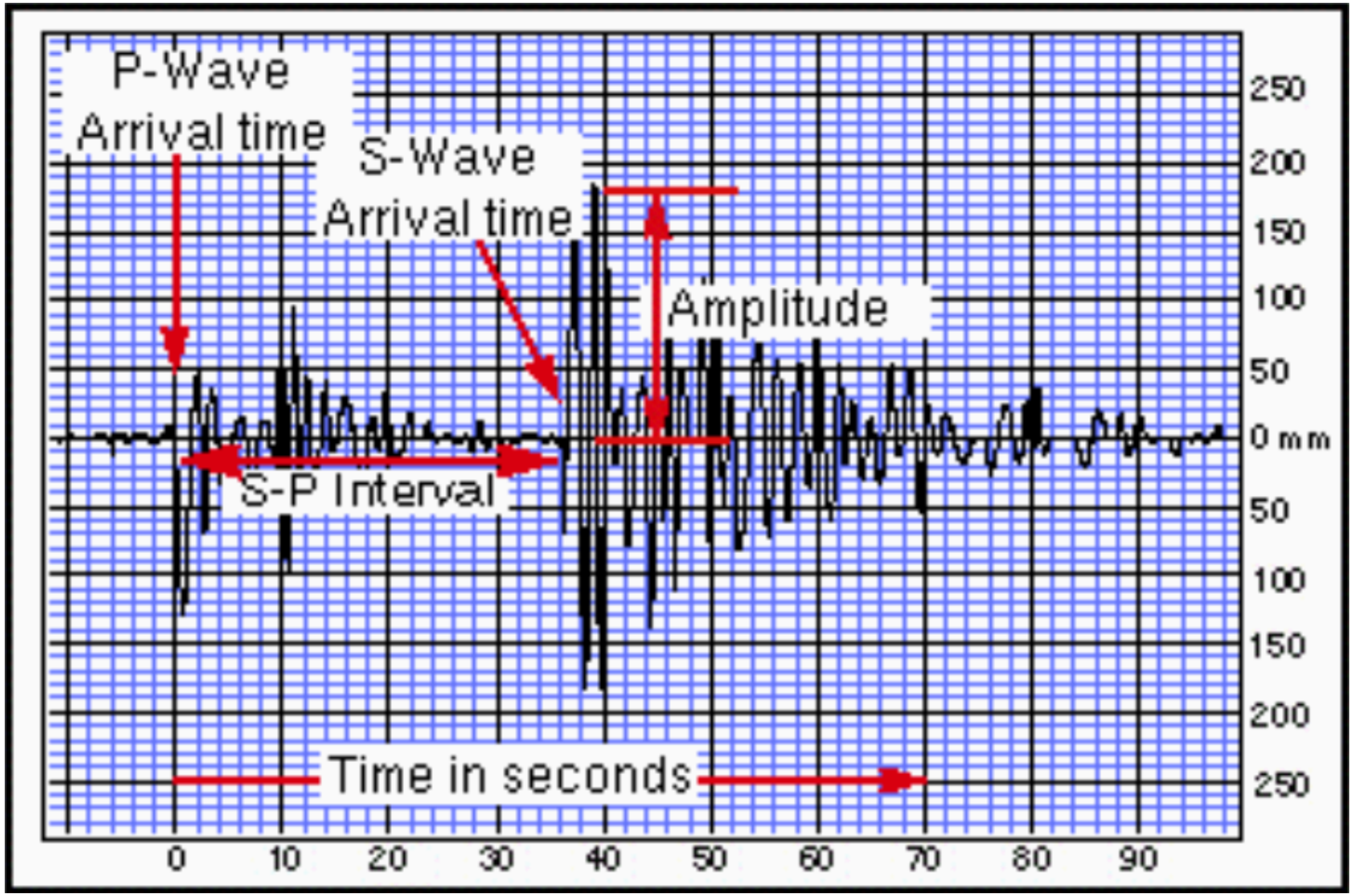
- Thrust and reverse faults that push crustal blocks upward (e.g., Himalayas)
- Strike-slip faults that have mostly horizontal motion (e.g., San Andreas)
- Extensional faults that allow crustal blocks to slide apart (e.g., Greece)
- Oblique-slip fault systems with displacement that is neither completely horizontal nor entirely vertical (e.g., Sumatra)
- Earthquakes are also caused by crustal flexing in plate interiors (e.g., New Madrid) and by the movement of magma beneath volcanoes. Large meteor impacts can also cause earthquakes, but these events are relatively rare.

Laboratory Exercise: Earthquakes

Earthquake terminology

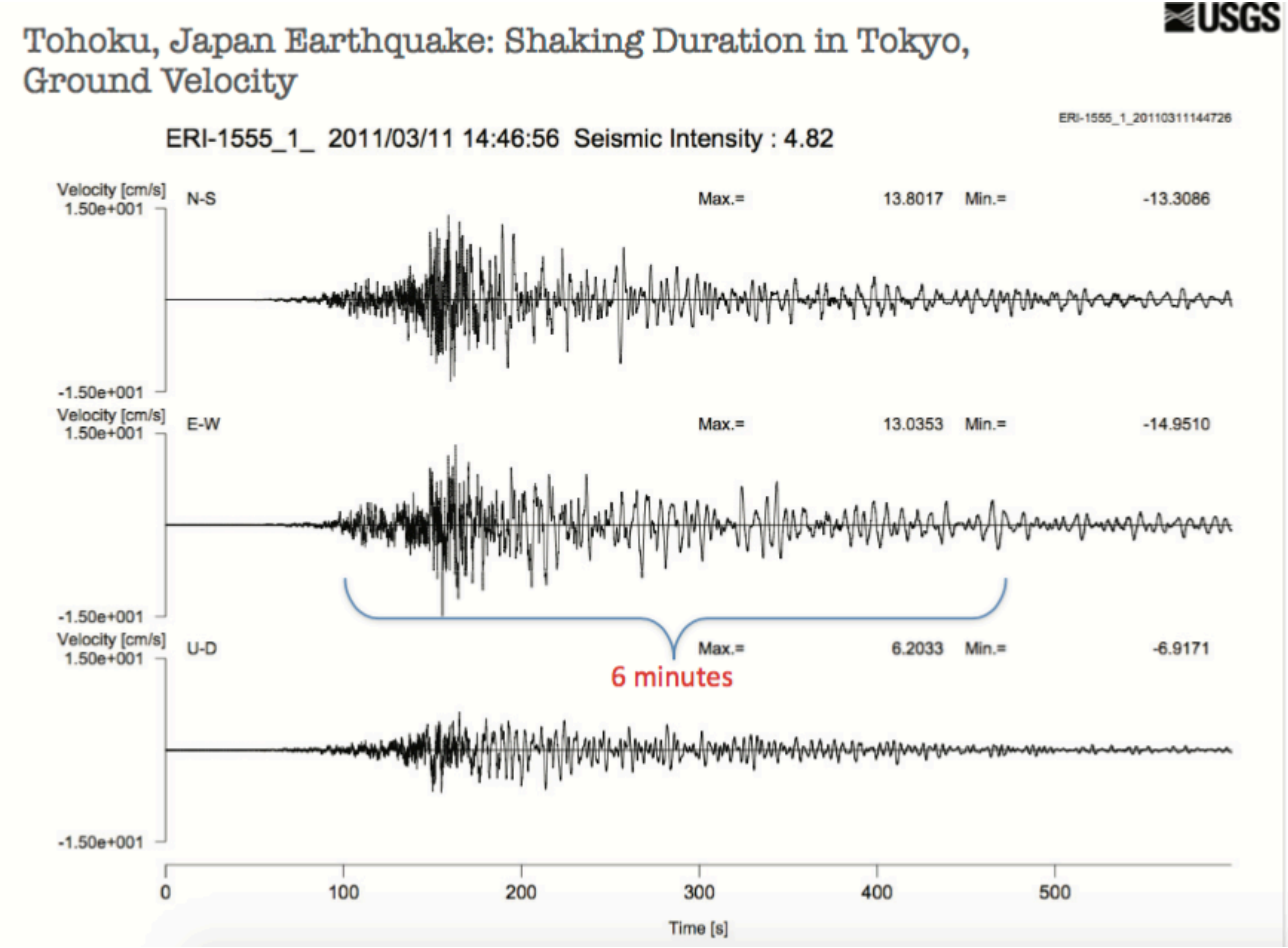
- When a fault ruptures because stresses across the fault plane exceed the strength of the material, the rupture point within the crust is called the **focus** (also known as focal point) of the released energy, which travels radially outward in the form of seismic waves. The point on Earth's surface above the focus is called the **epicenter**, and the vertical distance from the epicenter to the focus is called the **focal depth**.
- **P and S waves** - Seismic energy is released as compressional waves (P-waves), which can travel through both solids and liquids, and as shear waves (S-waves), which have a side-to-side motion and cannot travel through liquids. P-waves, and the vertical and horizontal planes of S-wave motion, are recorded by **seismograms** as **seismographs** at seismic stations around the world. The most damage to property is caused by large-amplitude surface shear waves that can violently shake the ground for several seconds or even minutes.
- **P waves travel faster than S waves.** Average P wave velocity in the upper part of the mantle is on the order of 8 km/s while S wave velocity is more like 5 km/s. Therefore it is possible to use their respective arrival times at different seismic stations around the world to estimate both the location and magnitude of the earthquake, a process known as First Motion study. Even though the speed of seismic waves varies according to the depth of an earthquake and the types of crustal rock that the waves travel through, the time interval between the first arrival of P and S waves, usually expressed in seconds, allows for a good estimate of the epicenter – provided that at least 3 different seismic station locations are used to triangulate the epicenter's location.
- **Earthquake magnitude** (expressed as M_W) is an estimate of the energy released, using a base 10 logarithmic scale (i.e., an M_W7.0 releases ten times more energy than an M_W6.0 earthquake). Magnitude can be roughly estimated from the maximum amplitude of S waves that are recorded at a known distance from the epicenter.

Laboratory Exercise: Earthquakes



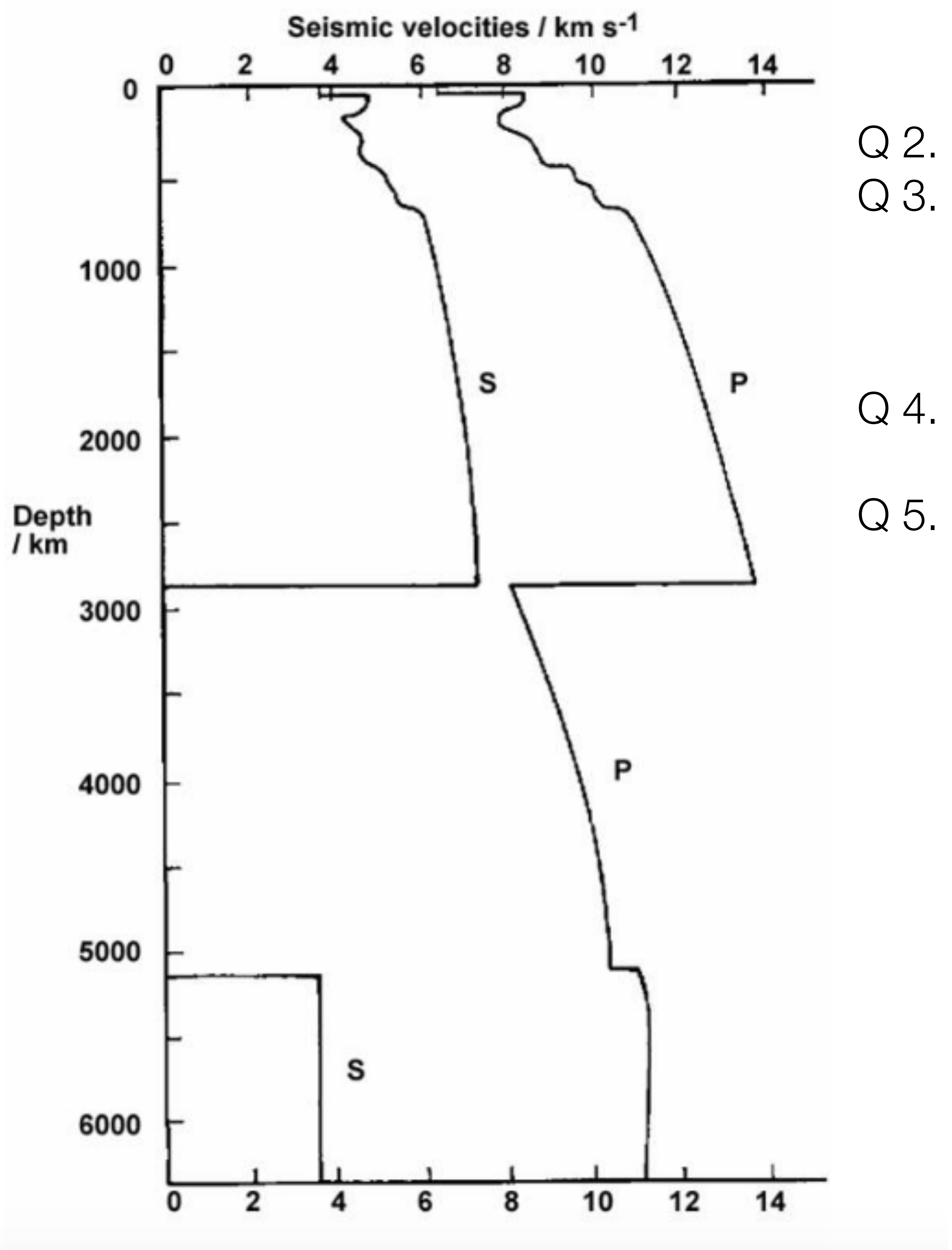
A simplified version of a seismogram, showing the first P-wave arrival time, the first S-wave arrival time, and the S-P time interval, all given in seconds. Also note that the amplitudes of P and S-waves is measured in millimeters on this graph.

Laboratory Exercise: Earthquakes



Real seismograms for the March 11, 2011 Tohoku, Japan, M_w=9.0 earthquake.

Laboratory Exercise: Earthquakes



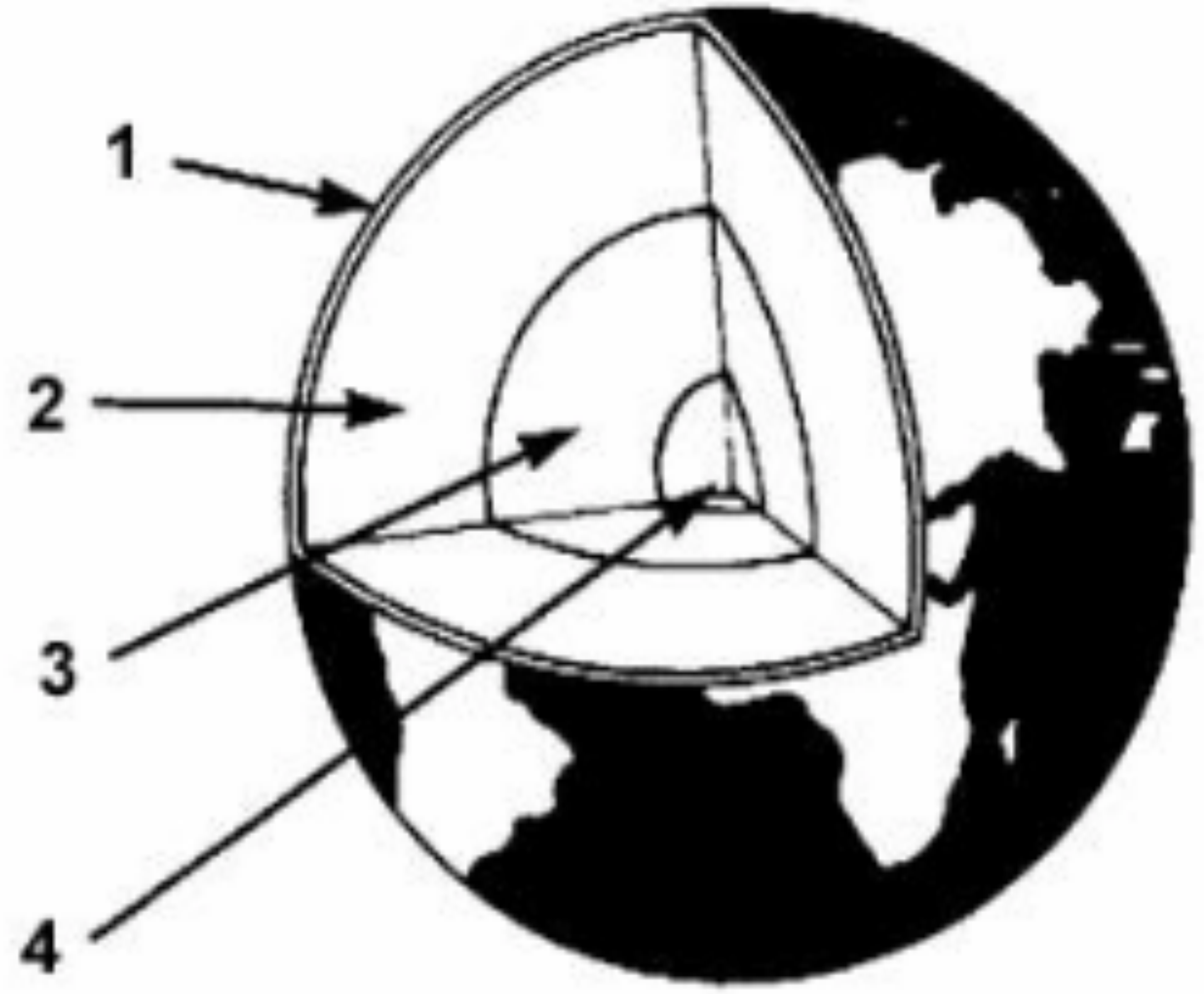
Q 1. (a) At which depths do the S and P-wave velocities change suddenly?
(b) How are the S-wave and P-wave velocities changing at these depth? (For example,'wave velocity decreasing').

Q 2. Why does the S-wave velocity drop to zero at a depth of 2900 km?

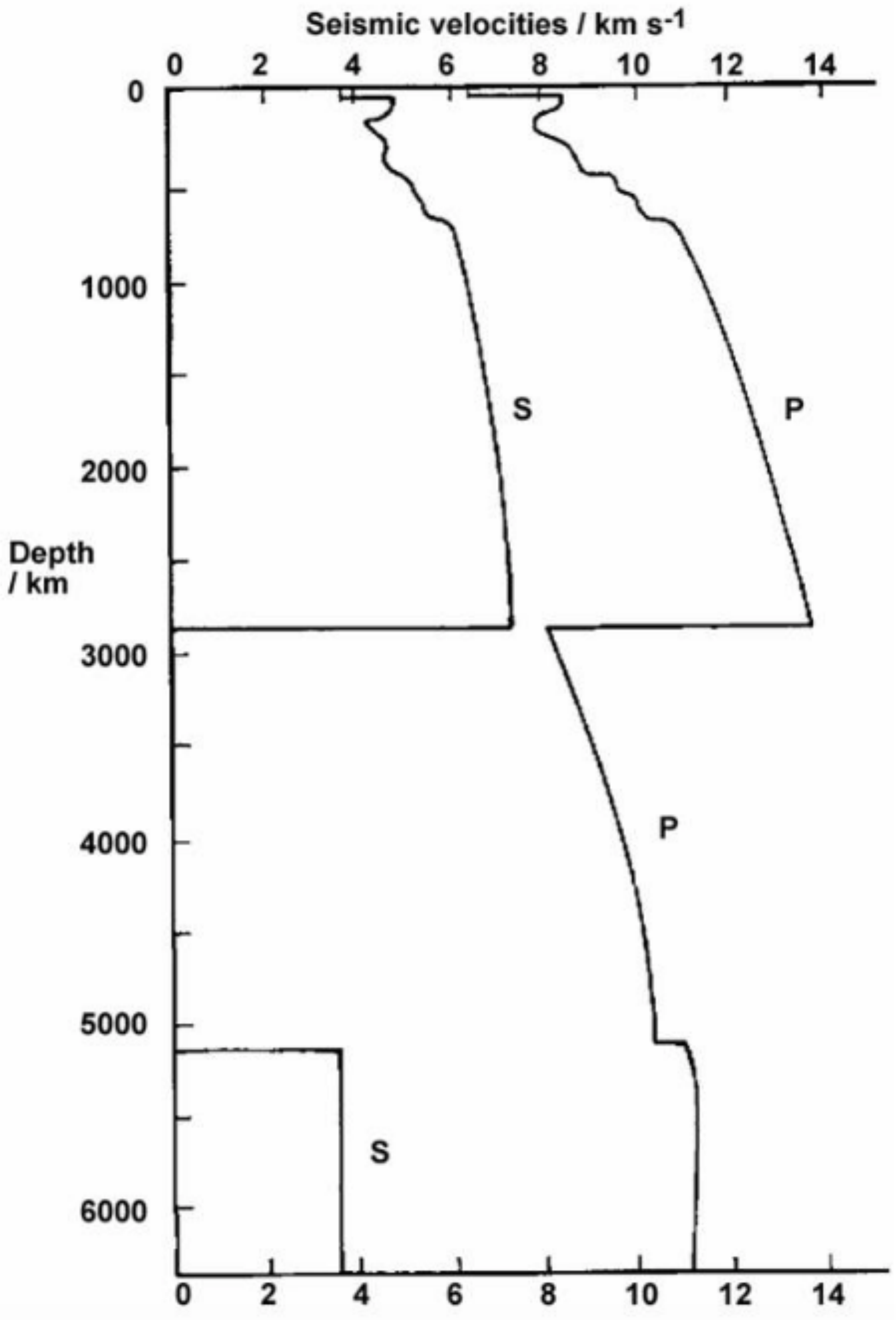
Q 3. (a) In what way is the P-wave velocity plot different from the S-wave velocity plot between the Earth's surface and 2900 km depth?
(b) In what way is the P-wave velocity plot similar to the S-wave velocity plot between the Earth's surface and 2900 km depth?

Q 4. Where on the graph are (1) the crust, (2) the mantle, (3) the outer core, (4) the inner core

Q 5. What are the properties of the different layers labelled 1-4 in the diagram below? On this diagram the crust is shown thicker than it really is, so that it can be seen. For layer 1, the answer is:
(1) 'P- and S-waves pass through the crust, so it is solid.'



Laboratory Exercise: Earthquakes



Q 1. (a) A little more than 0 km, at 2900 km and at about 5100 km.

(b) Both P- and S-waves show rapid increase in velocity just below the surface (beneath the crust), varying but rising velocities to almost 1000 km depth, then slowly increasing velocities to 2900 km. S- and P-wave velocities drop significantly between about 100 and 250 km depth. In the zone between 2900 km and 5100 km the S-wave velocity is zero

Q 2. Wave velocity drops to zero at 2900 km depth, as this is where liquid core starts, and S- (shear) waves cannot travel through liquids.

Q 3. (a) P-wave velocity has a higher value and a greater gradient than the S-wave velocity plot. P-wave velocity reduces sharply at 2900 km depth but not to zero as S-wave velocity does.

(b) The shape of the P-wave and S-wave velocity curve is very similar.

Q 4. 1 crust to 20 km, (2) mantle between 20–2900 km, (3) outer core between 2900–5100 km, (4) inner core between 5100–6500 km.

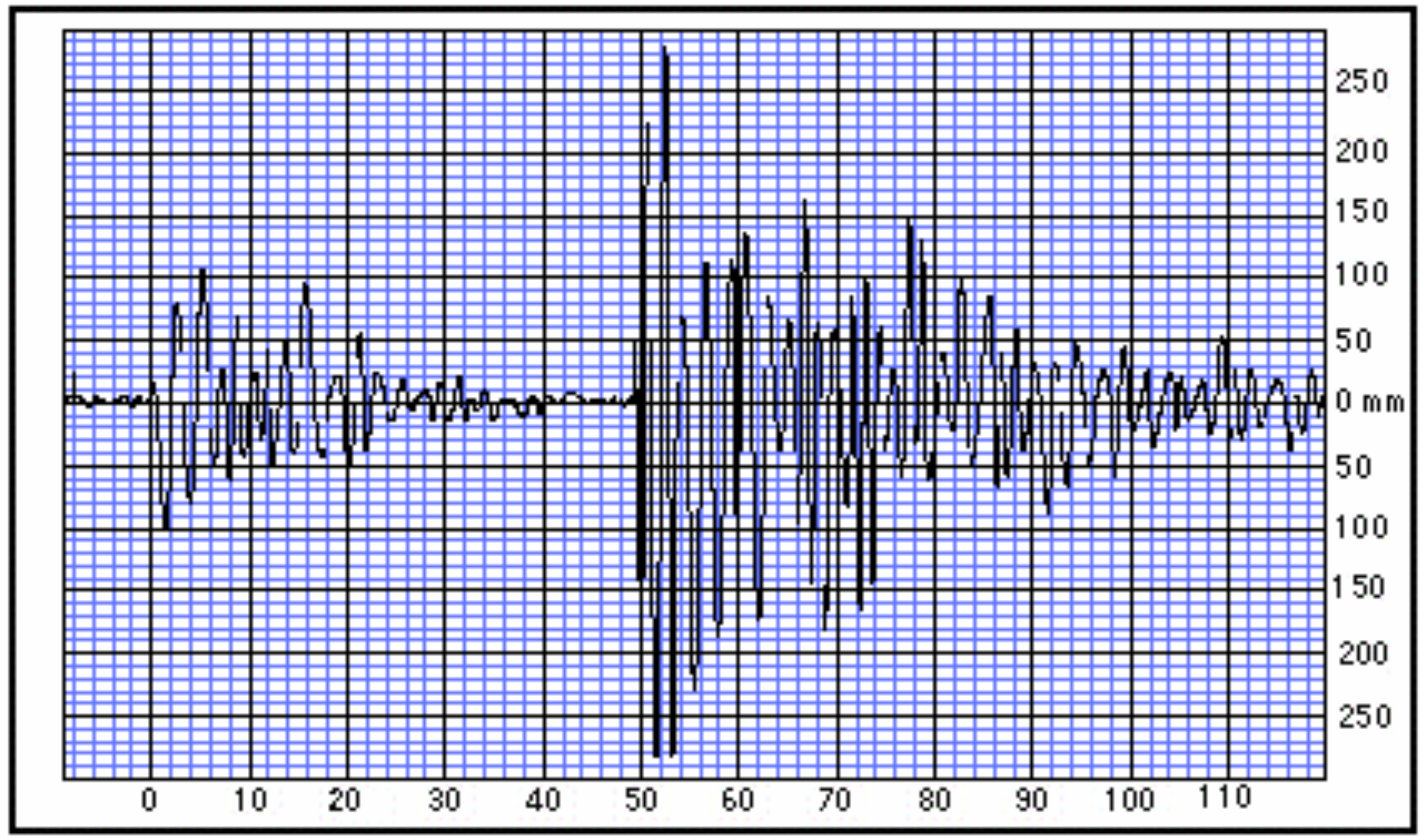
Q 5. 2 P-waves travel faster through mantle than S-waves. Mantle is solid

3 S-waves cannot travel through outer core so it is liquid

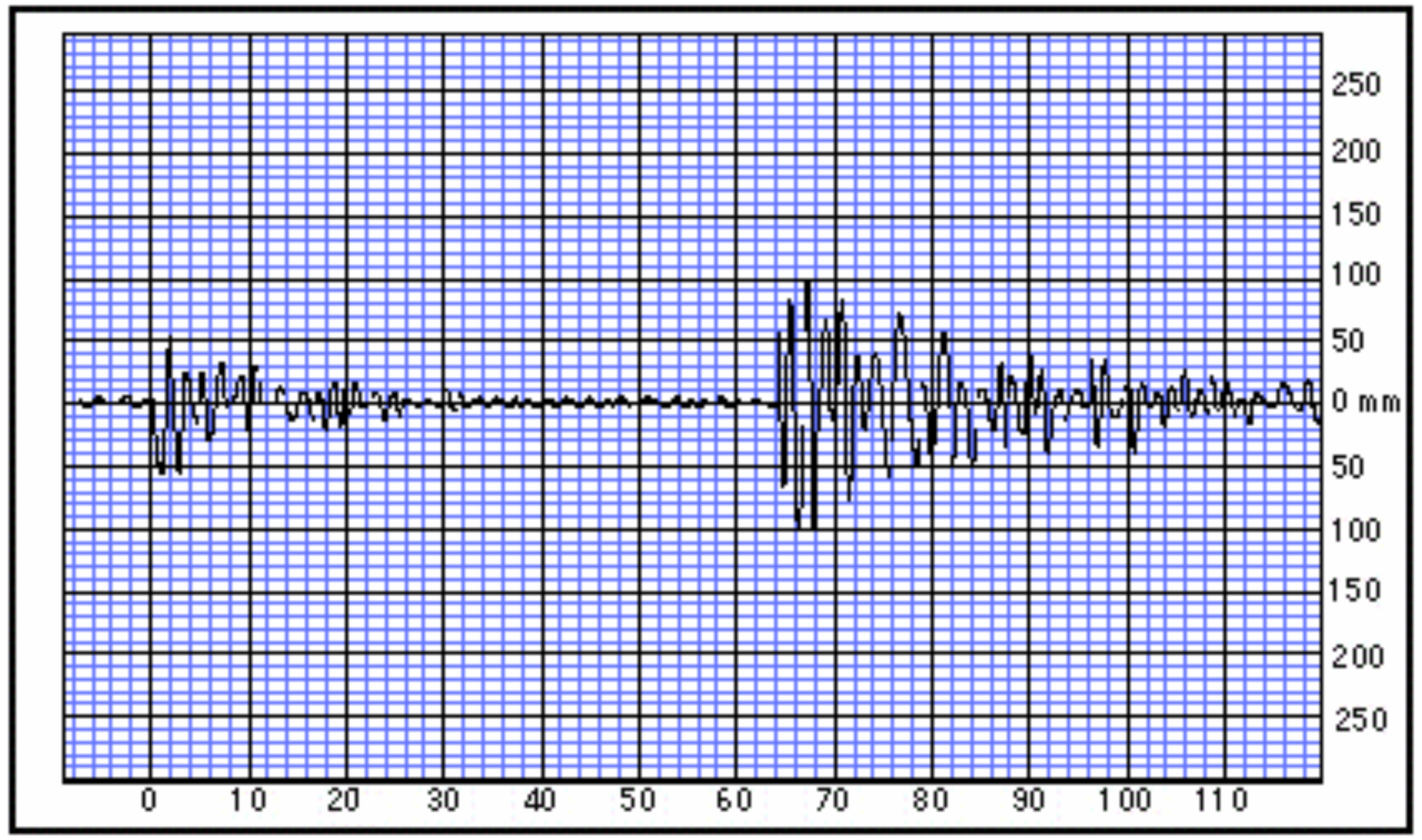
4 P-and S-waves travel through inner core so it is solid.

Laboratory Exercise: Earthquakes

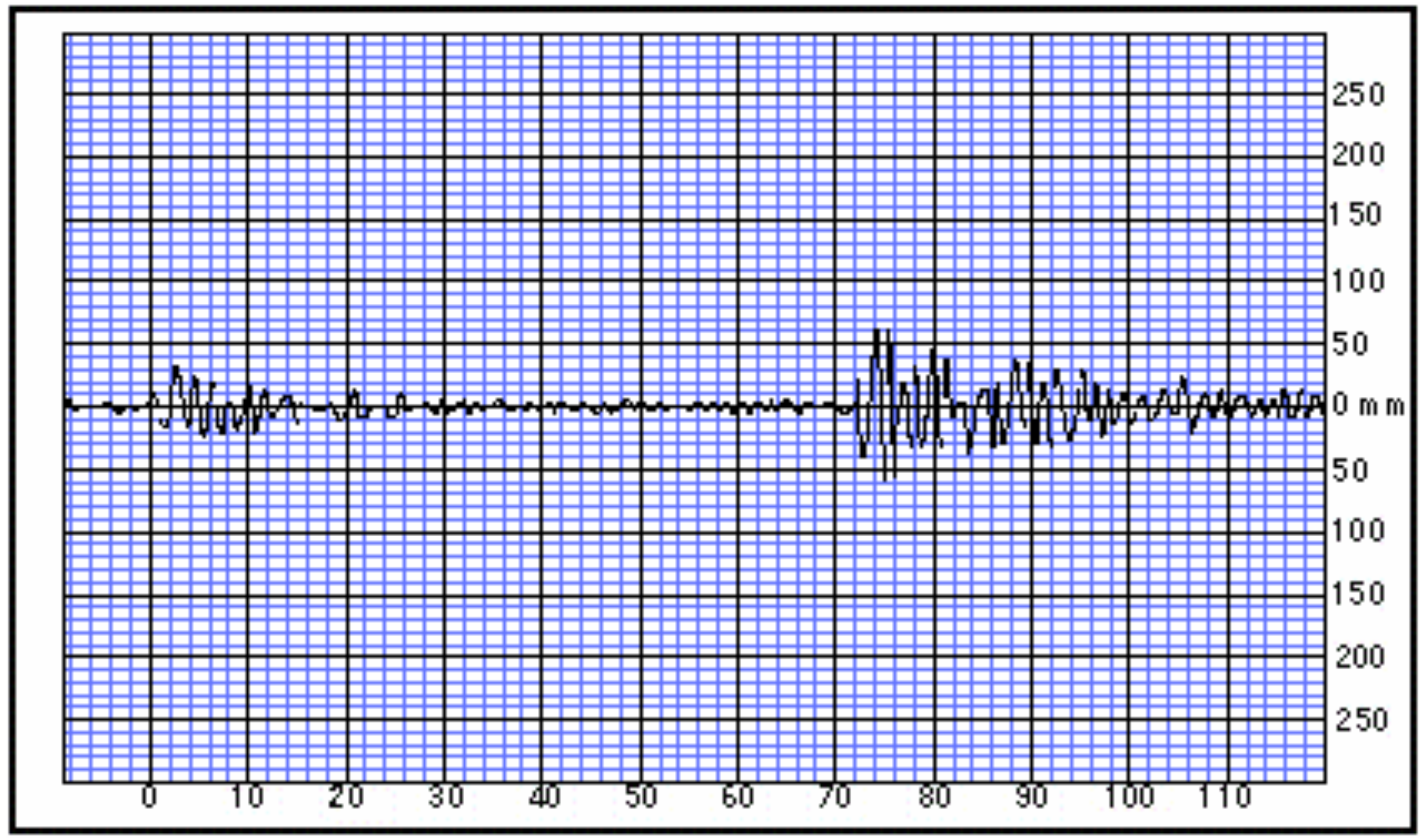
EXERCISE 1: Loma Prieta, California (Adapted from lab exercise of Dr. Gary Novak, Cal State University, Los Angeles)
This exercise uses seismic records obtained from three separate seismic stations to estimate (a) the epicenter, and (b) the magnitude of an earthquake that occurred near San Jose, California in 1989.



A. Seismogram from Eureka, California seismic station.



C. Seismogram from Las Vegas, Nevada seismic station.



B. Seismogram from Elko, Nevada seismic station.

P-waves travel faster than S-waves, therefore the time for P-waves to travel a specific distance (e.g., 200 km) is less than the time taken for S-waves to travel the same distance. S-wave minus P-wave (S–P) travel times as measured on a seismogram give the distance of the seismic station to the epicenter.

Laboratory Exercise: Earthquakes

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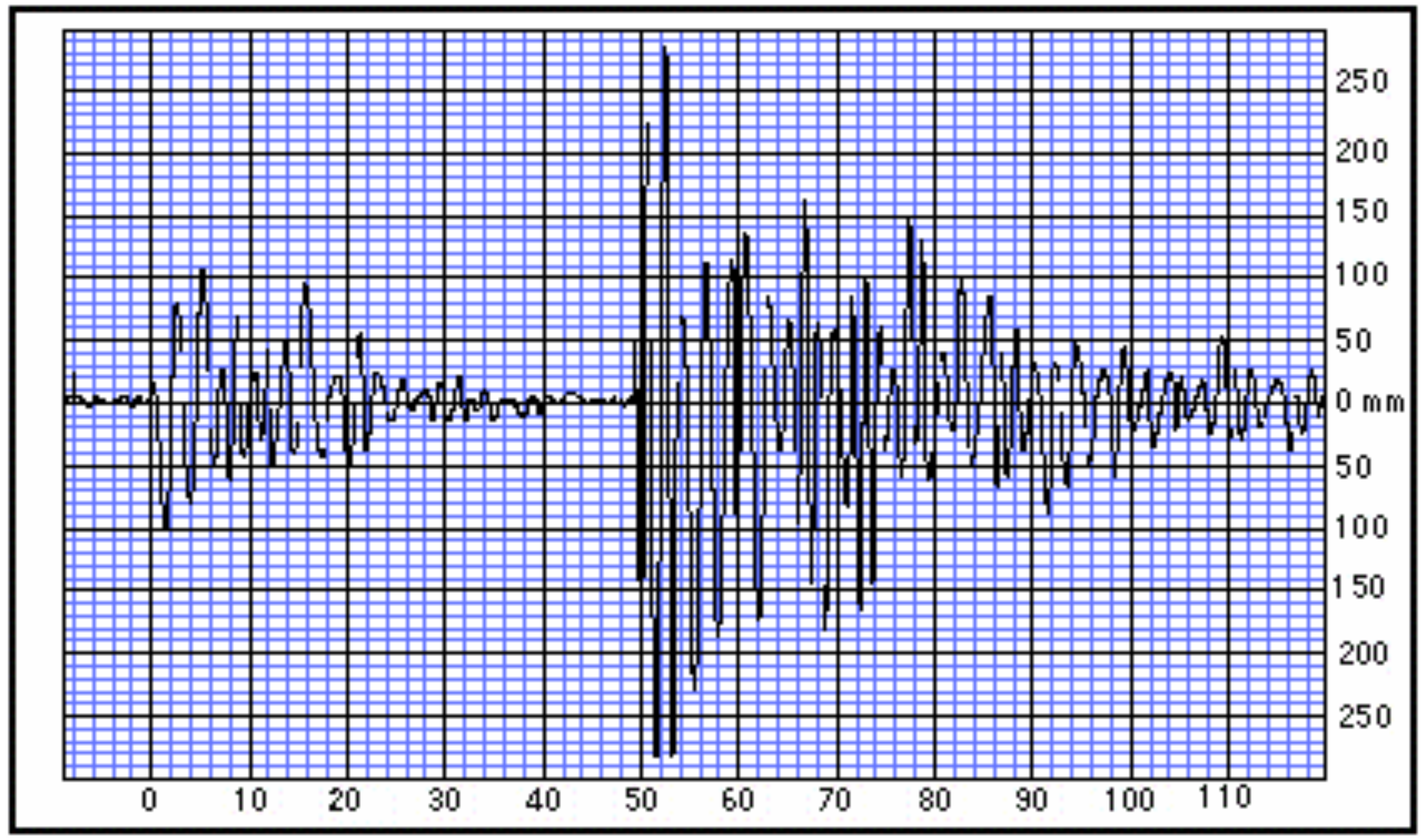
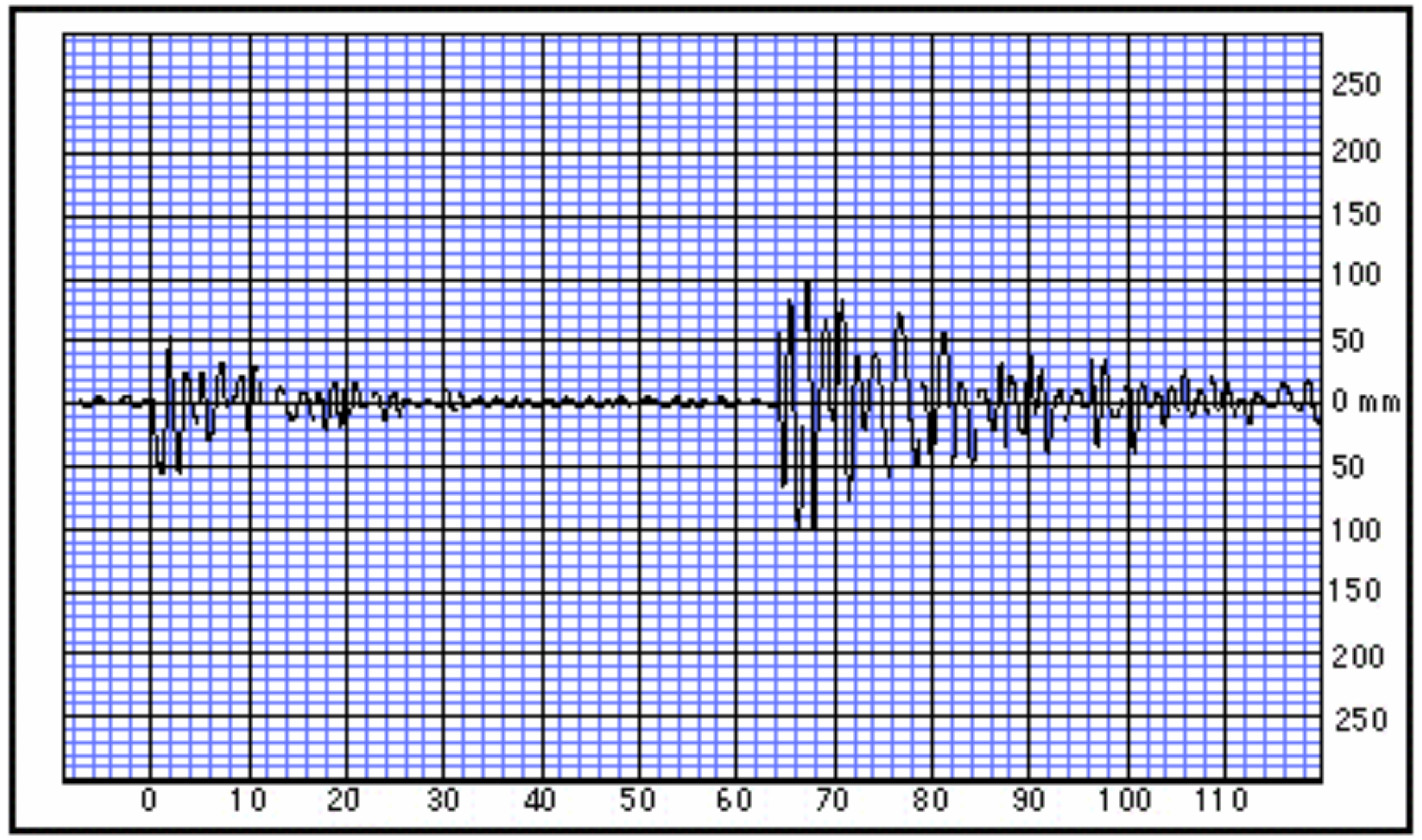
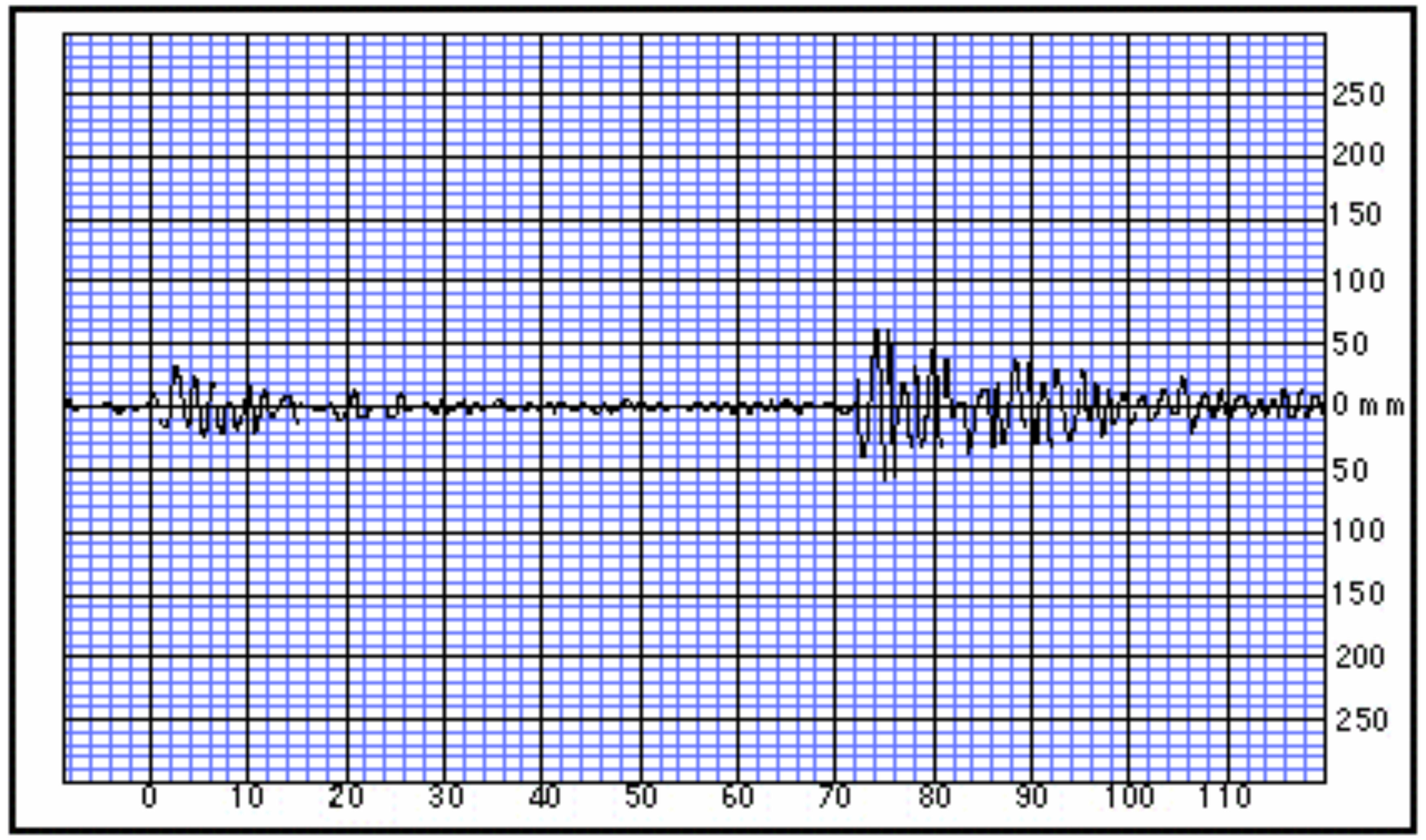


A. Seismogram from Eureka, California seismic station.



C. Seismogram from Las Vegas, Nevada seismic station.



B. Seismogram from Elko, Nevada seismic station.

Epicenter estimation

1. To obtain the earthquake's epicenter, first measure and record the S-P intervals on each of the three seismograms.

The S-P interval for:

Eureka: __________

Elko: ___________

Las Vegas: __________

Laboratory Exercise: Earthquakes

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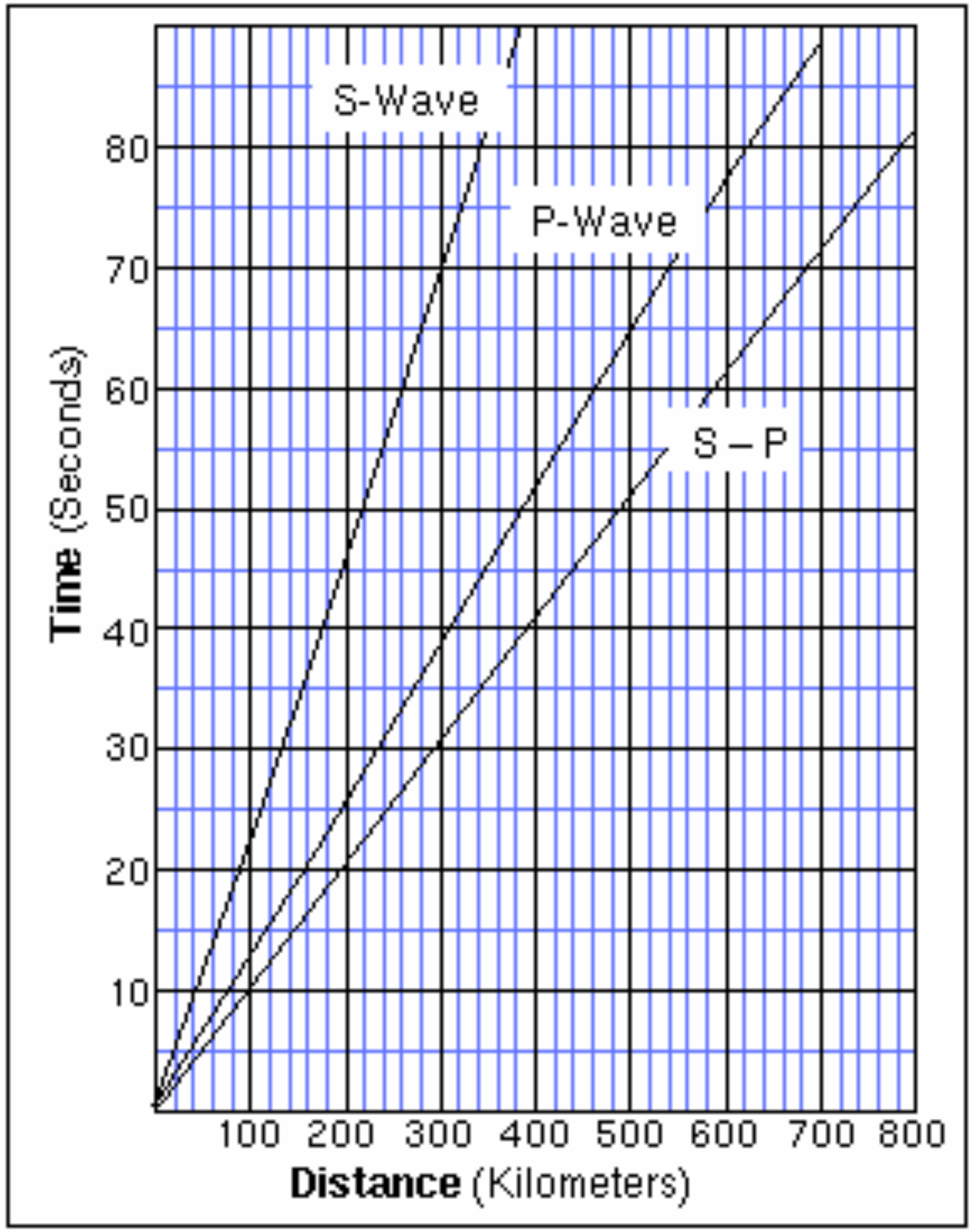
This exercise uses seismic records obtained from three separate seismic stations to estimate (a) the epicenter, and (b) the magnitude of an earthquake that occurred near San Jose, California in 1989.

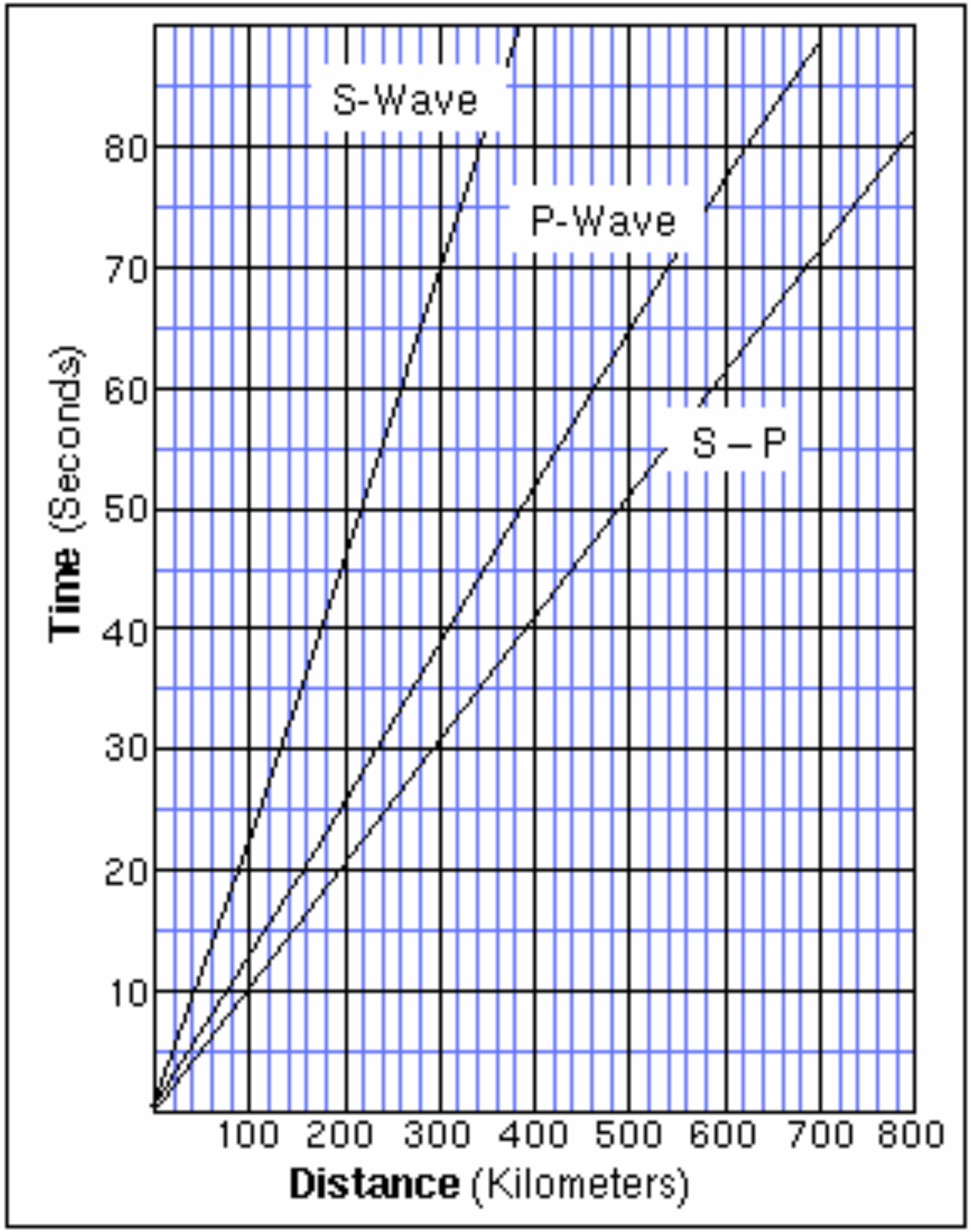


Epicenter estimation
1. To obtain the earthquake's epicenter, first measure and record the S-P intervals on each of the three seismograms.

The S-P interval for:
Eureka: __________
Elko: ___________
Las Vegas: __________

2. Use the data you just obtained, together with the S-P travel time graph, to estimate the distance from each seismograph to the epicenter.

The distance of the epicenter to:
Eureka: ________
Elko: _________
Las Vegas: _______



The S-P interval for:
Eureka: __________
Elko: ___________
Las Vegas: __________

The distance of the epicenter to:
Eureka: ________
Elko: _________
Las Vegas: _______

Laboratory Exercise: Earthquakes

EXERCISE 1: Loma Prieta, California (Adapted from lab exercise of Dr. Gary Novak, Cal State University, Los Angeles)
This exercise uses seismic records obtained from three separate seismic stations to estimate (a) the epicenter, and (b) the magnitude of an earthquake that occurred near San Jose, California in 1989.

Epicenter estimation

1. To obtain the earthquake's epicenter, first measure and record the S-P intervals on each of the three seismograms.

The S-P interval for:
Eureka: __________
Elko: ___________
Las Vegas: __________

2. Use the data you just obtained, together with the S-P travel time graph, to estimate the distance from each seismograph to the epicenter.

The distance of the epicenter to:
Eureka: ________
Elko: _________
Las Vegas: _______

3. Plot the three seismic stations on the map of California and Nevada.
For each station, draw a circle centered on the station with a radius equal to the epicentral distance you have calculated for that station.
In the ideal case, the three circles should intersect at the earthquake's epicenter. In reality, they may not all intersect at exactly the same point due to slight errors in measuring the S-P intervals from the seismograms and/or reading the distances from the S–P graph, or differences in rock types that the waves passed through on their way to the seismic stations. But you should be able to get a good idea of the epicenter's location.
The location of the Loma Prieta earthquake is close to: _____________________

Submit this Page with your results

The S-P interval for:
Eureka: __________
Elko: ___________
Las Vegas: __________

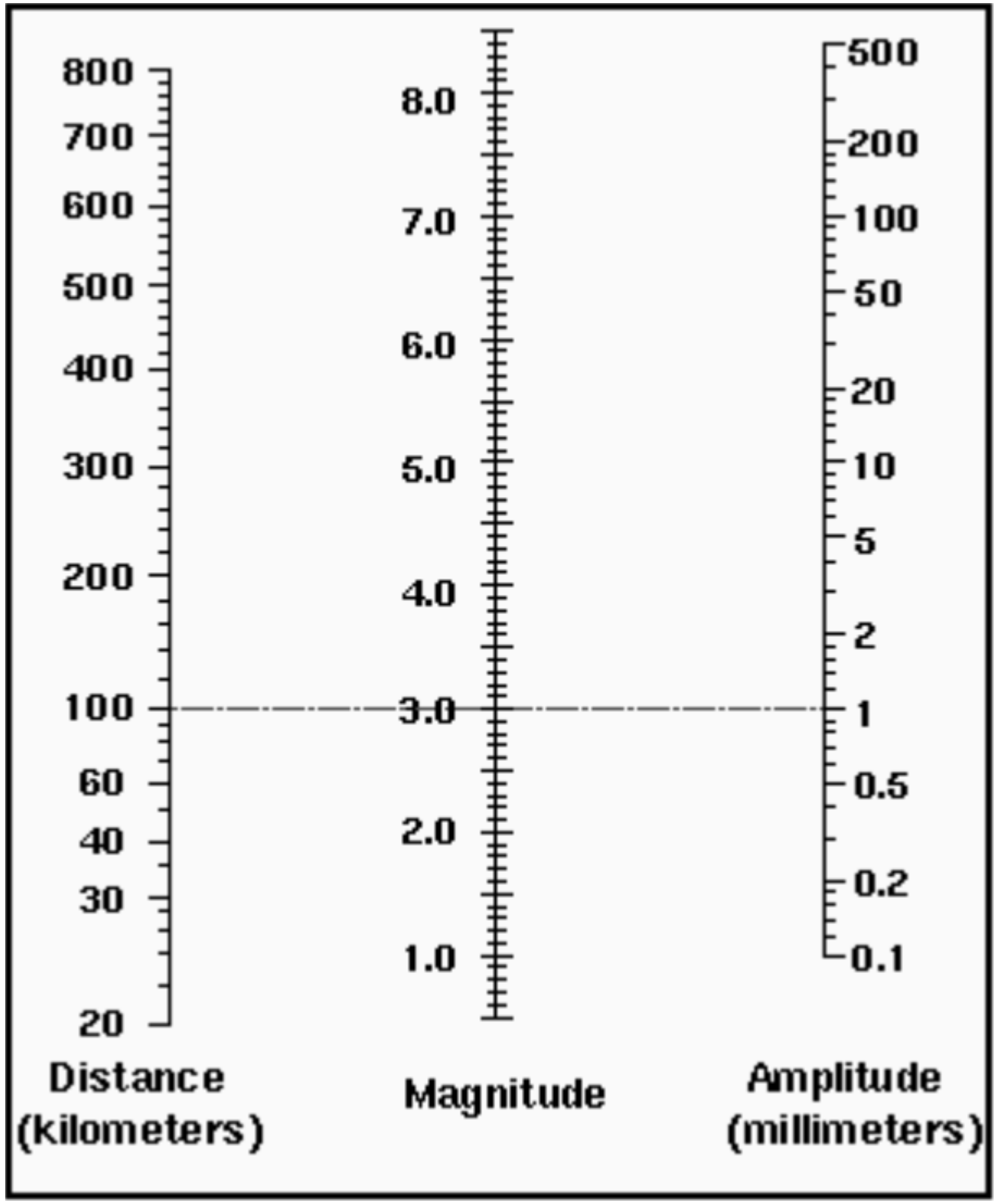
The distance of the epicenter to:
Eureka: ________
Elko: _________
Las Vegas: _______

The location of the Loma Prieta earthquake is close to:

____

Laboratory Exercise: Earthquakes

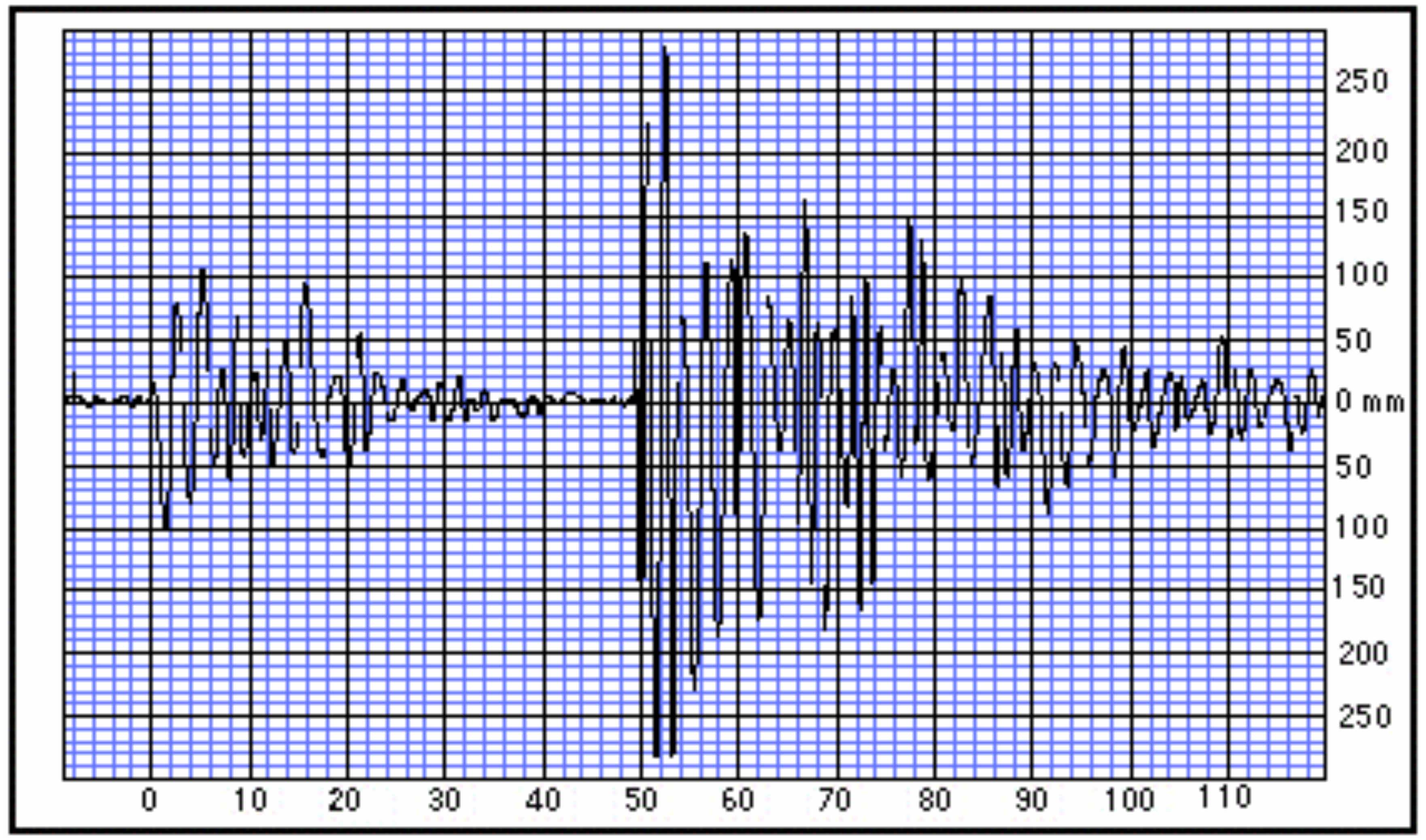
EXERCISE 1: Loma Prieta, California (Adapted from lab exercise of Dr. Gary Novak, Cal State University, Los Angeles)
This exercise uses seismic records obtained from three separate seismic stations to estimate (a) the epicenter, and (b) the magnitude of an earthquake that occurred near San Jose, California in 1989.



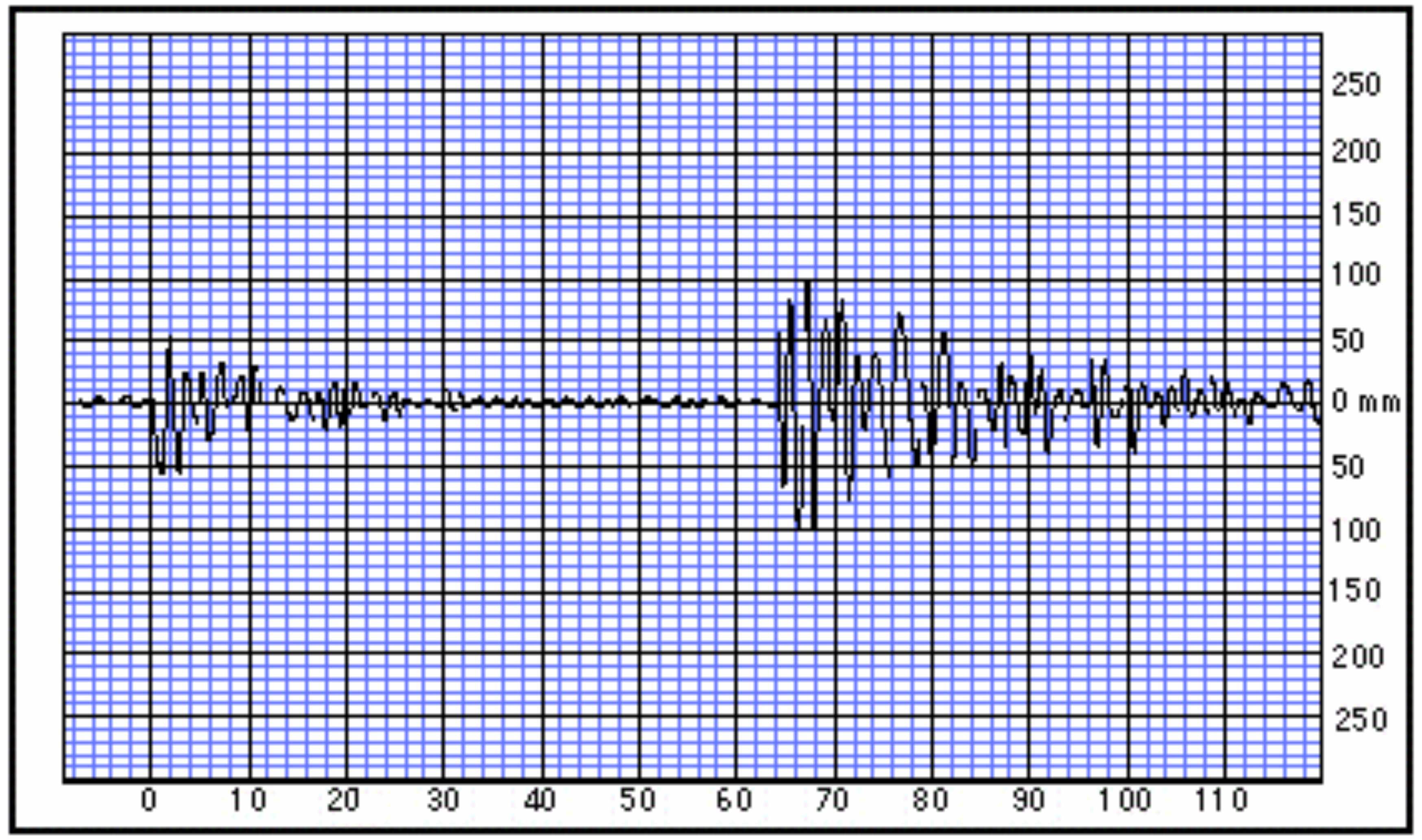
The Richter Earthquake Magnitude Nomogram.
The standard 'reference earthquake' used for this instrument is M=3.0. Although the Richter magnitude scale is nowadays replaced by the Moment Magnitude (M_W) scale (see your text for details), the nomogram gives a good first approximation of the magnitude of an earthquake. Additional data from multiple seismic stations, and incorporation of the known geology in the region to refine the P- and S-wave speeds, would allow more precise magnitude calculations.

4. To obtain the earthquake's magnitude, we can use an instrument called a nomogram, which is a simple graph that correlates the amplitude of the S-waves with distance from, and magnitude of, an earthquake (see figure on the left). A standard reference earthquake on the nomogram has M_W3.0 with 1.0 mm of maximum S-wave amplitude on a seismogram at an epicentral distance of 100 km. Using the nomogram, draw a line linking the maximum S-wave amplitude and computed distance from the epicenter for each of the three Loma Pieta seismograms. The three lines should all intersect in the same position on the magnitude scale. Errors in your measurements of amplitude and/or distance may cause the lines to intersect in a region of the nomogram instead of at a point.

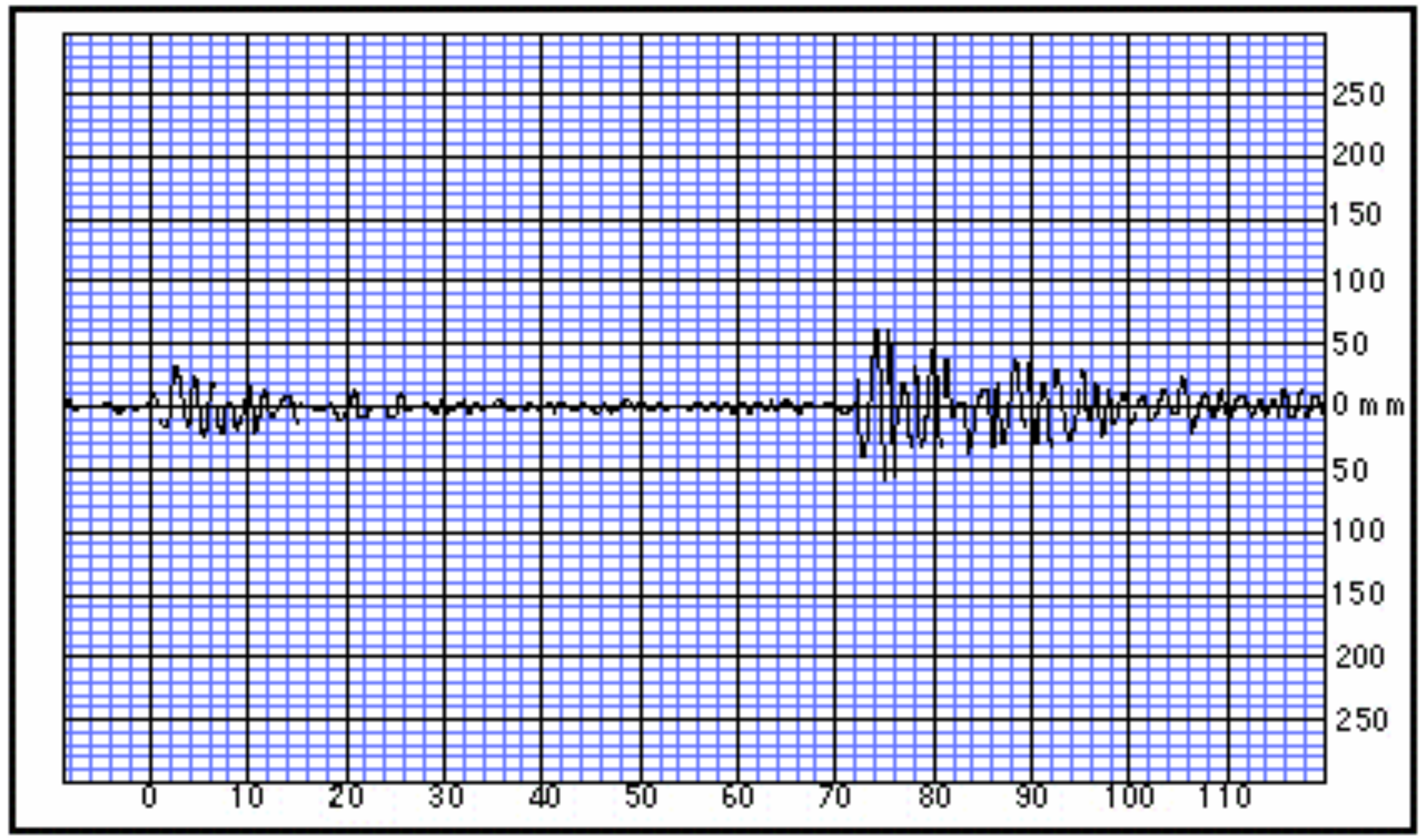
The 1989 Loma Prieta earthquake magnitude is estimated as: Mw _____.



A. Seismogram from Eureka, California seismic station.



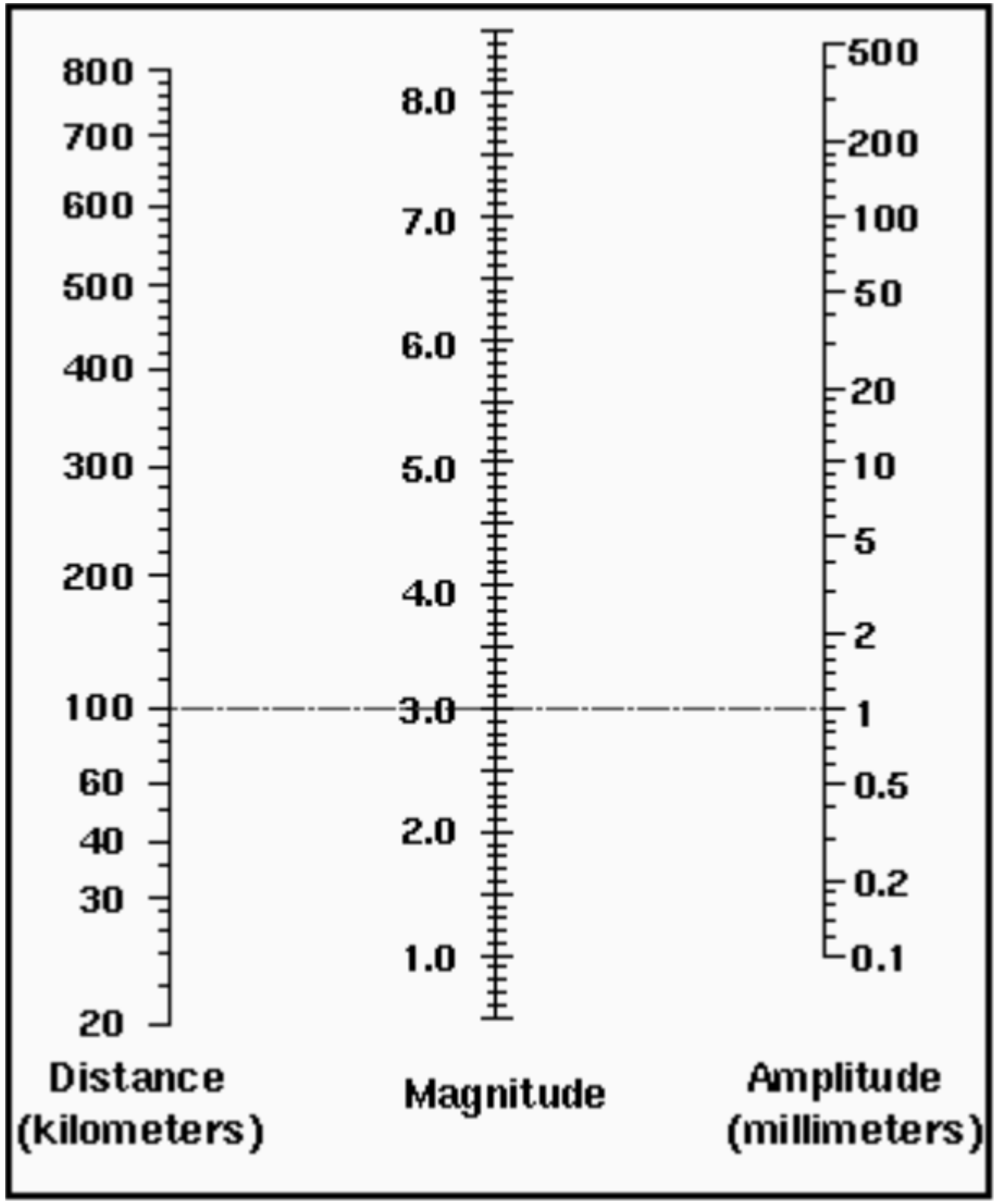
C. Seismogram from Las Vegas, Nevada seismic station.



B. Seismogram from Elko, Nevada seismic station.

The maximum s-wave amplitude is:
Eureka: __280________
Elko: ___________
Las Vegas: __________

Submit this Page with your results



The distance of the epicenter to:
Eureka: ________
Elko: _________
Las Vegas: _______

Maximum s-wave amplitude in mm:
Eureka: ________
Elko: _________
Las Vegas: _______

The 1989 Loma Prieta earthquake magnitude is estimated as: Mw _____.

Laboratory Exercise: Earthquakes

EXERCISE 2: HAITI, January 12, 2010
Complete the following exercises using the accompanying USGS poster.

1. The first figure on the poster illustrates the complex tectonic setting of the Caribbean Plate (strictly, a microplate) and the different types of plate boundary (i.e., compressional, extensional, or strike-slip) that exist around its margins. The red lines represent the location of plate boundaries as they intersect the Earth's surface.
• Examine the boundary between the Caribbean Plate and the South Atlantic Plate to the north of Trinidad and Tobago, and east of Puerto Rico. The teeth on the plate boundary line indicate that this is a predominantly compressional boundary, with the South American Plate subducting beneath the Caribbean Plate.
• (a) Give at least two pieces of evidence on the map (other than the red line with the teeth) that can justify the interpretation of a compressional plate boundary north of Trinidad-Tobago.
• (b) Now examine the Caribbean Plate boundary southwest of Nicaragua. What type of plate boundary is this?
• (c) What evidence is there on the map to support your answer in (b) above?

2. The epicenter of an earthquake on January 12, 2010 $M_W 7.0$ is indicated by the yellow star, near the city of Port-au-Prince, Haiti, on the island of Hispaniola. The more detailed map of Hispaniola and the small map beneath it show two major strike-slip fault zones that run more-or-less east-west through the island: the Septentrional fault zone (SFZ) in the north and the Enriquillo-Plantain Garden fault zone (EPGFZ) in the south. The main shock of January 2010 and its several aftershocks, including a $M_W 5.9$ event, are thought to have occurred along the EPFZ.
(a) Using the Significant Earthquake data from the poster, calculate the average Recurrence Interval (R) of earthquakes larger than M_W 6.5 that have affected Hispaniola during the recorded interval of 1902 to 1992.

$$R = N/n,$$

where *N* is number of years recorded and *n* is number of events in *N* years
(b) Was the January 2010 earthquake overdue, 'on-time,' or earlier than anticipated, based on your calculated *R*? What does this tell us about using the recurrence interval to predict when the next big earthquake will occur?

3. The January 12, 2010 earthquake was not the largest to have occurred in the region in the past century. Discuss why that one was particularly devastating for Haitians.

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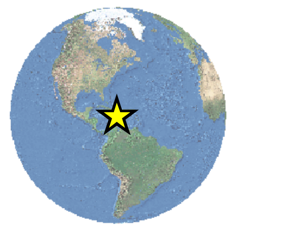
science for a changing world

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

EARTHQUAKE SUMMARY MAP

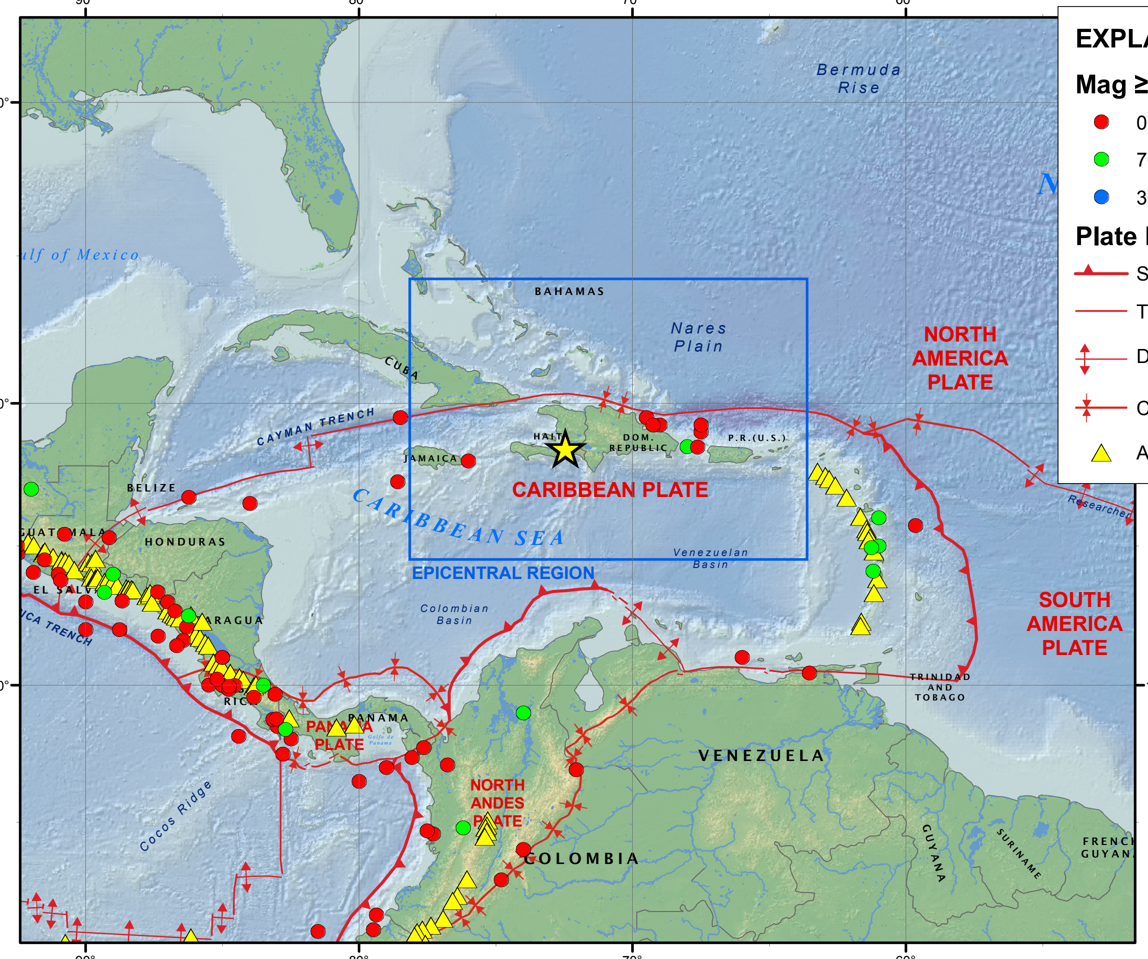


Prepared in cooperation with the Global Seismographic Network

GSN

M7.0 Haiti Earthquake of 12 January 2010

Tectonic Setting



EXPLANATION

Mag ≥ 7.0
- 0 - 69 km
- 70 - 299
- 300 - 600

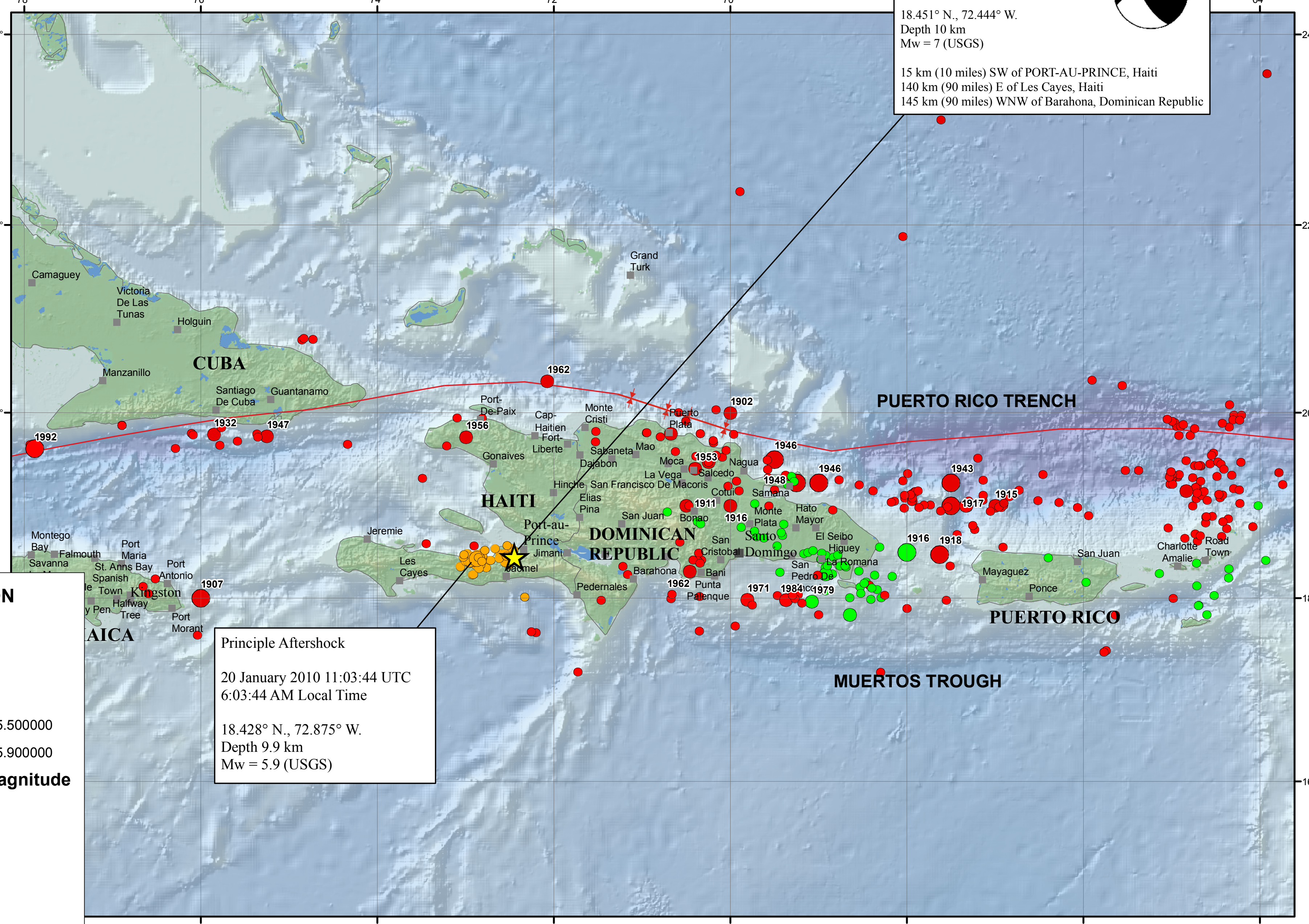
Plate Boundaries
- Subduction
- Transform
- Divergent
- Convergent
- Active Volcanoes

RELATIVE PLATE MOTIONS

In the region of this earthquake, earthquakes define the boundary between the North American and Caribbean Plates, which move past each other at about 20 mm/yr.

Scale 1:20,000,000

Epicentral Region



Port-Au Prince

12 January 2010 21:53:10 UTC
4:53:10 PM Local Time

18.451° N., 72.444° W.
Depth 10 km
Mw = 7 (USGS)

15 km (10 miles) SW of PORT-AU-PRINCE, Haiti
140 km (90 miles) E of Les Cayes, Haiti
145 km (90 miles) WNW of Barahona, Dominican Republic

Principle Aftershock

20 January 2010 11:03:44 UTC
6:03:44 AM Local Time

18.428° N., 72.875° W.
Depth 9.9 km
Mw = 5.9 (USGS)

EXPLANATION

Main Shock

Aftershocks

MAG
- 4.500000 - 5.500000
- 5.500001 - 5.900000

Earthquake Magnitude
- 5.50 - 5.99
- 6.00 - 6.99
- 7.00 - 7.99
- 8.00 - 8.99
- 9.00 - 9.99

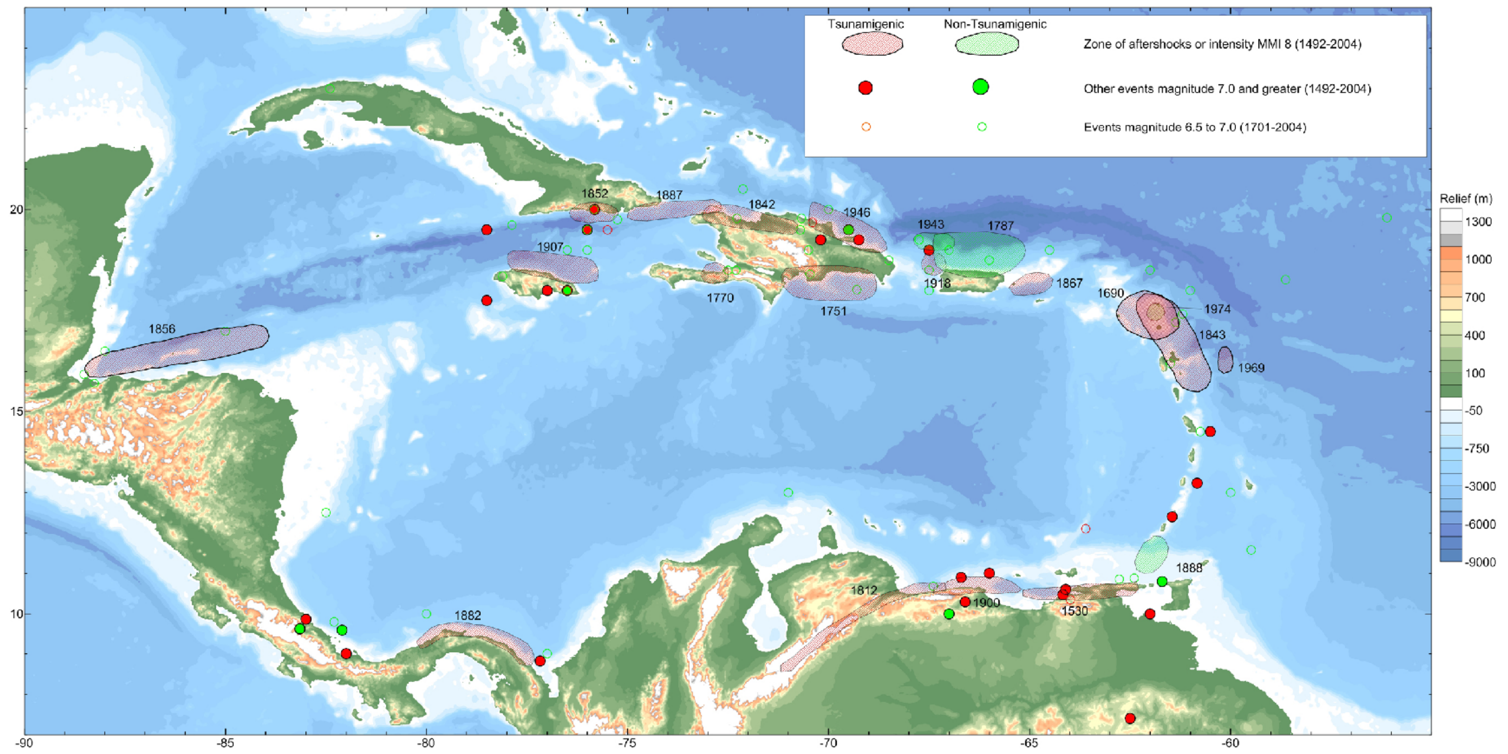
Earthquake Depth
- 0 - 69
- 70 - 299
- 300 - 700

Scale 1:4,500,000

0 125 250 500 Kilometers

Note on earthquakes: From 1900 - 1963, earthquakes shown are from Centennial Catalog, magnitudes greater than 5.5. From 1964 - 2002, earthquakes are from HDF catalog, magnitudes greater than 4.5. From 2003 to present, earthquakes are from NEIC, magnitudes greater than 4.5.

Historic Earthquakes and Tsunami 1492 - 2004



Note: Historic earthquakes in the interior and west coast of Central and South America are not included in this figure.

from McCann, 2006, Estimating the threat of tsunamigenic earthquakes and earthquake induced landslide tsunami in the Caribbean, in Caribbean Tsunami Hazard, Proceedings of the NSF Caribbean Tsunami Workshop, 2004, p.43-65.

TECTONIC SUMMARY

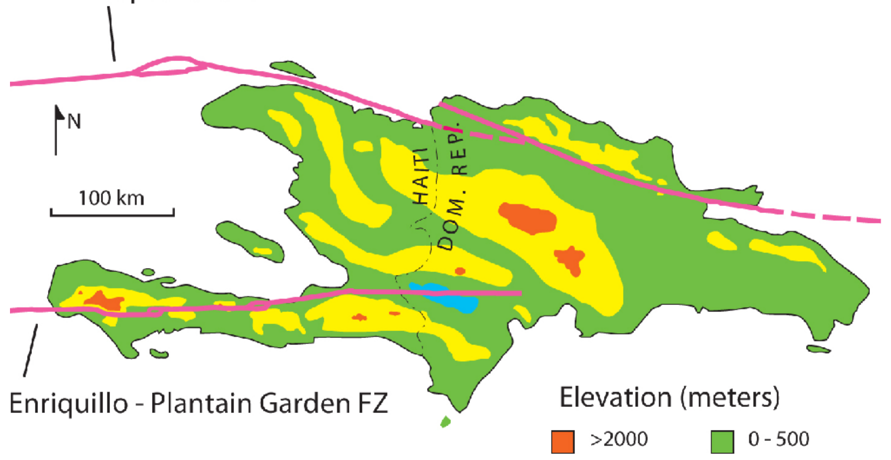
The Haiti earthquake of January 12, 2010, occurred in the boundary region separating the Caribbean plate and the North America plate. This plate boundary is dominated by left-lateral strike slip and compression, and accommodates about 20 mm/y slip, with the Caribbean plate moving eastward with respect to the North America plate.

Haiti occupies the western part of the island of Hispaniola, one of the Greater Antilles islands, situated between Puerto Rico and Cuba. At the longitude of the January 12 earthquake, motion between the two Caribbean and North American plates is partitioned between two major east-west trending, strike-slip fault systems -- the Septentrional fault system in northern Haiti and the Enriquillo-Plantain Garden fault system in southern Haiti.

The location and focal mechanism of the earthquake are consistent with the event having occurred as left-lateral strike slip faulting on the Enriquillo-Plantain Garden fault system. This fault system accommodates about 7 mm/y, nearly half the overall motion between the Caribbean plate and North America plate

The Enriquillo-Plaintain Garden fault system has not produced a major earthquake in recent decades. The EPGFZ is the likely source of historical large earthquakes in 1860, 1770, and 1751, though none of these has been confirmed in the field as associated with this fault.

HISPANIOLA



Prentice, USGS, 2003

from Prentice, et al, 2003, Journal of Geophysical Research, V 108, B3, p.2149

DISCLAIMER

Base map data, such as place names and political boundaries, are the best available but may not be current or may contain inaccuracies and therefore should not be regarded as having official significance.

USGS

USAID FROM THE AMERICAN PEOPLE

M 7.0, HAITI REGION

Origin Time: Tue 2010-01-12 21:53:09 UTC
Location: 18.45°N 72.45°W Depth: 10 km

PAGER
Version 5
Created: 17 hours, 10 minutes after earthquake

Estimated Population Exposed to Earthquake Shaking

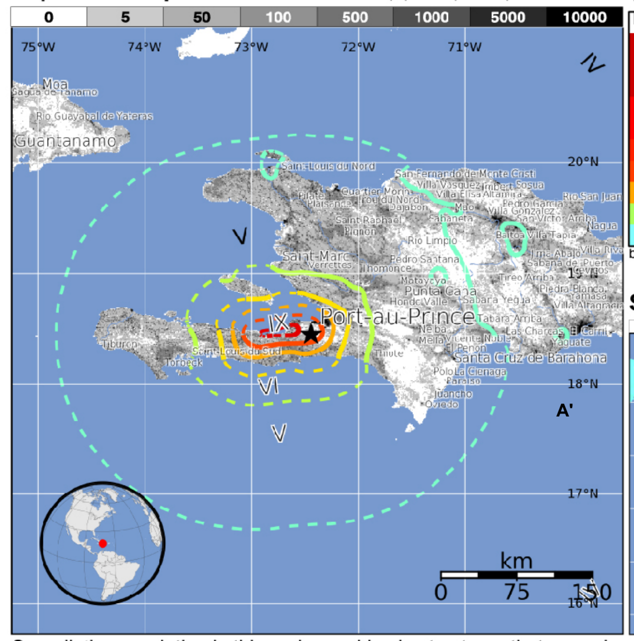
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	7,090k*	6,308k	777k	749k	1,884k	710k	137k
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

0 5 50 100 500 1000 5000 10000

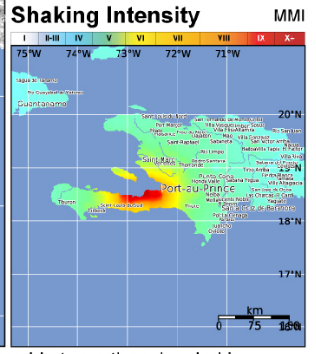


Selected City Exposure

MMI	City	Population
X	Petit Goave	15k
X	Leogane	12k
X	Grand Goave	5k
IX	Carrefour	442k
IX	Gressier	4k
VIII	Miragoane	6k
VIII	**Port-au-Prince**	**1,235k**
VII	Delmas 73	383k
V	**Verrettes**	**49k**
III	Santo Domingo	2,202k

bold cities appear on map (k = x1000)

Shaking Intensity MMI



Overall, the population in this region resides in structures that are vulnerable to earthquake shaking, though some resistant structures exist. On June 24, 1984 (UTC), a magnitude 6.7 earthquake 329 km East of this one struck the Dominican Republic with estimated population exposures of 320,000 at intensity VII and 2,964,000 at intensity VI, resulting in an estimated 5 fatalities. Recent earthquakes in this area have caused landslides that may have contributed to losses.

This information was automatically generated and has not been reviewed by a seismologist.

http://earthquake.usgs.gov/pager

Event ID: us2010rja6

Significant Earthquakes Mag >= 6.5

Year	Mon	Day	Time	Lat	Long	Dep	Mag
1902	02	17	0031	20.000	-70.000	0	6.9
1907	01	14	2136	18.000	-76.000	0	7.0
1911	10	06	1016	19.000	-70.500	0	6.8
1915	10	11	1933	19.000	-67.000	0	6.8
1916	04	24	0426	18.500	-68.000	80	7.0
1916	11	30	1317	19.000	-70.000	0	6.8
1917	07	27	0101	19.000	-67.500	50	7.0
1918	10	11	1414	18.473	-67.631	35	7.3
1932	02	03	0616	19.770	-75.850	25	6.8
1943	07	29	0302	19.250	-67.500	0	7.6
1946	08	04	1751	19.250	-69.000	0	7.9
1946	08	08	1328	19.500	-69.500	0	7.5
1947	08	07	0040	19.750	-75.250	50	6.8
1948	04	21	2022	19.250	-69.250	40	7.1
1953	05	31	1958	19.400	-70.400	33	6.9
1956	07	09	0956	19.737	-72.994	43.9	6.9
1962	01	08	0100	18.291	-70.461	32.6	6.7
1962	04	20	0547	20.339	-72.074	35	6.7
1971	06	11	1256	17.984	-69.808	59	6.5
1979	03	23	1932	17.964	-69.076	81.5	6.7
1984	06	24	1117	17.982	-69.369	44.1	6.7
1992	05	25	1655	19.618	-77.883	23.1	6.8

DATA SOURCES

EARTHQUAKES AND SEISMIC HAZARD
USGS, National Earthquake Information Center
NOAA, National Geophysical Data Center
IASPEI, Centennial Catalog (1900 - 1999) and extensions (Engdahl and Villaseñor, 2002)
HDF (unpublished earthquake catalog) (Engdahl, 2003)
Global Seismic Hazard Assessment Program

PLATE TECTONICS AND FAULT MODEL
PB2002 (Bird, 2003)

BASE MAP
NIMA and ESRI, Digital Chart of the World
USGS, EROS Data Center
NOAA GEBCO and GLOBE Elevation Models

REFERENCES

Bird, P., 2003, An updated digital model of plate boundaries: Geochem. Geophys. Geosyst., v. 4, no. 3, pp. 1027- 80.

Engdahl, E.R. and Villaseñor, A., 2002, Global Seismicity: 1900 - 1999, chap. 41 of Lee, W.H.K., and others,eds., International Earthquake and Engineering Seismology, Part A: New York, N.Y., Elsevier Academic Press, 932 p.

Engdahl, E.R., Van der Hilst, R.D., and Buland, R.P., 1998, Global teleseismic earthquake relocation with improved travel times and procedures for depth determination: Bull. Seism. Soc. Amer., v. 88, p. 722-743.

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