7 An **earthquake** is the perceptible shaking of the surface of the Earth, resulting from the sudden release of energy in the Earth's crust. This sudden motion causes shock waves (seismic waves) to radiate from their point of origin called the focus and travel through the Earth. It is these seismic waves that can produce ground motion which people call an earthquake.

Vibrations from an earthquake are categorised as P, S or L seismic waves. They travel through the Earth in different ways and at different speeds. They can be detected and analysed.

P-waves (P stands for **primary**) arrive at the detector first. They are *longitudinal waves*. These waves can travel through any type of material, including fluids, and can travel at nearly twice the speed of S waves.

S-waves (S stands for **secondary**) arrive at the detector of a seismometer seconds later. They are *transverse waves*. S-waves can travel only through solids.

L-waves (L stands for **long**) are the slowest, travel over the surface and causes the most damage.

The speed of an earthquake wave is not constant but varies with many factors. Speed changes mostly with depth and rock type. P waves travel between 6.0 and 13 km s^{-1} and S waves are slower and travel between 3.5 and 7.5 km s^{-1}.

In earthquake seismology, the time interval between the first arrivals of transverse (S) and longitudinal (P) waves, is proportional to the distance from the earthquake source.

In order to locate the epicenter of an earthquake you will need to examine its seismograms as recorded by at least three different seismic stations. On each of these seismograms you will have to measure the S - P time interval (in seconds). The S - P time interval will then be used to determine the distance the waves have traveled from the epicenter to that station.

(a) Distinguish between longitudinal and transverse waves. [2]

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(b) **Fig. 7.1** shows a structure of the Earth's interior and regions where P or S-waves may not be detected.

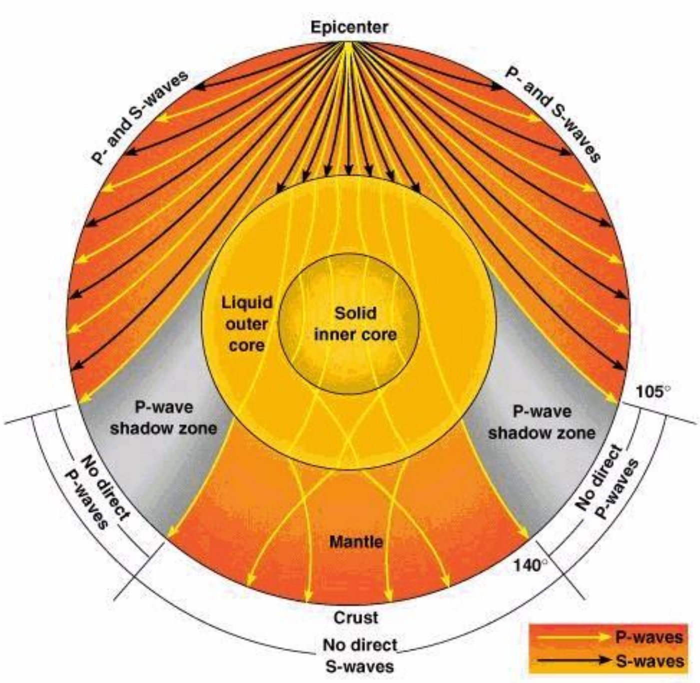

Fig. 7.1

Explain why no S-waves are detected directly opposite the epicenter. [1]

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(c) Fig. 7.2 shows the variation with distance (in kilometers) from the epicenter of the time (in seconds) taken for the S and P waves to reach the seismic station from the epicenter.

Fig 7.3 shows three seismographs from **Akita, Pusan and Tokyo Seismic Stations** of the earthquake that occurred in 1995, in the Kansai area of Japan near Kobe, called the Kobe earthquake. This earthquake took place near major population centers and caused significant loss of life and property damage.

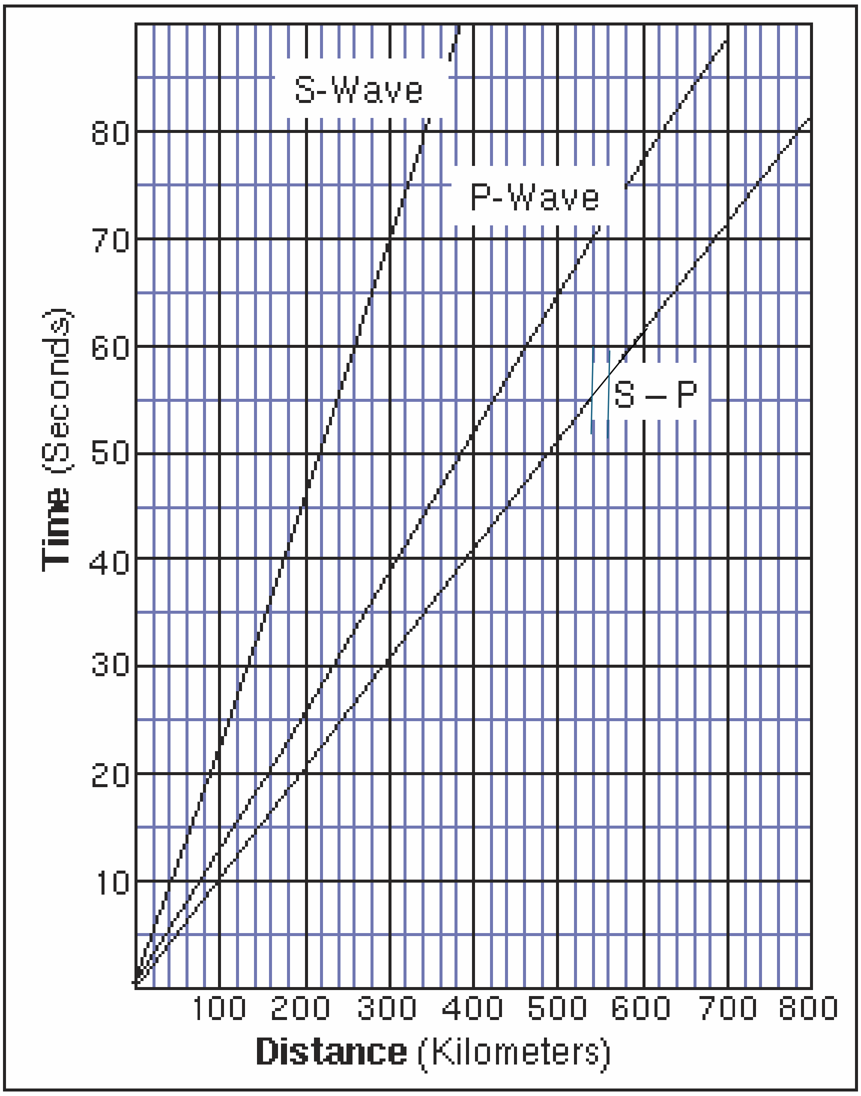
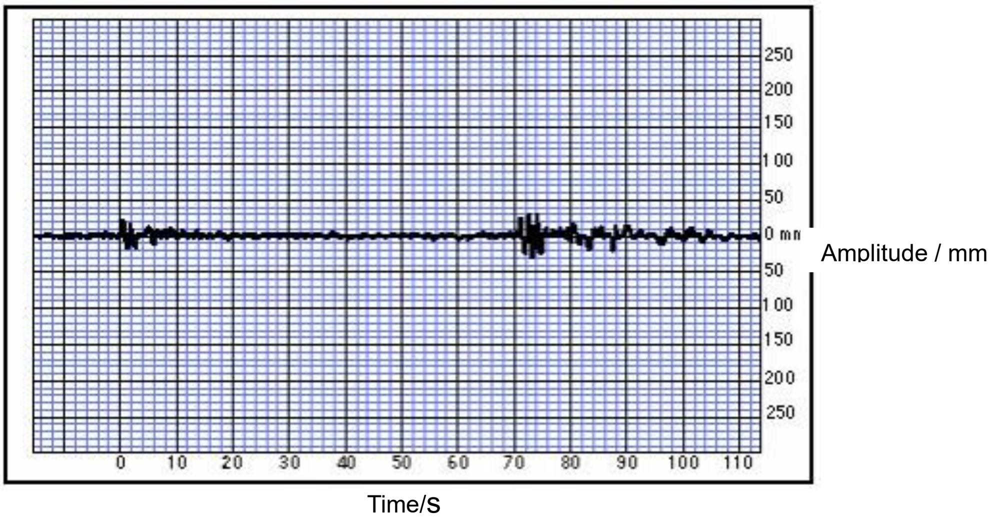
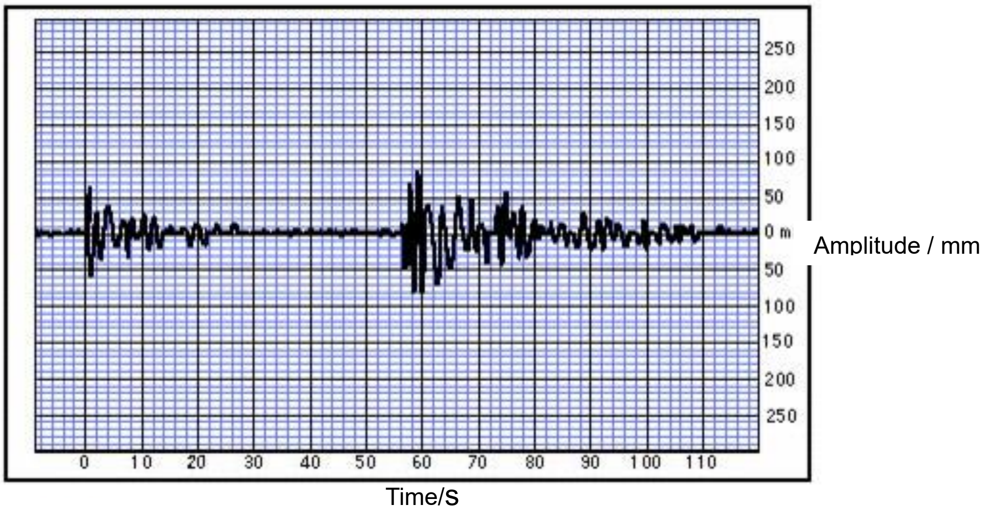


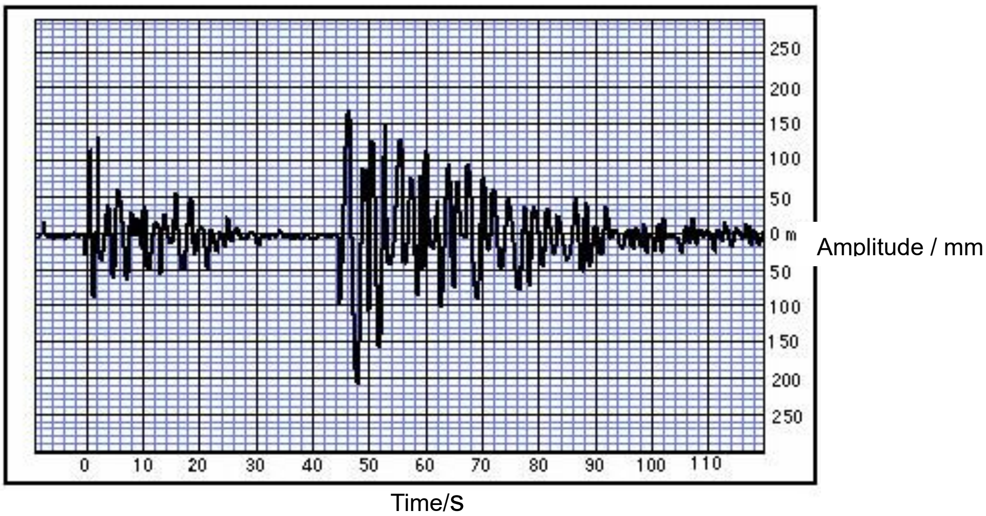
Fig. 7.2
(Source: http://engineeringseismologywithmearul.blogspot.sg/)



Akita Seismic Station



Pusan Seismic Station



Tokyo Seismic Station

Fig 7.3 Seismograms from Akita, Pusan and Tokyo Stations
(Source: http://www.geo.umass.edu)

(i) Using the data given in Fig. 7.2 and Fig. 7.3, complete Fig. 7.4 [3]

SEISMOGRAPH STATION	Difference in Arrival Time between P and S waves / s	Distance to Epicenter / km	Amplitude of the S wave /mm
AKITA	71	695	
PUSAN			90
TOKYO	44		

Fig. 7.4

(ii) Hence determine the approximate location of the epicenter of the earthquake on the location map in Fig. 7.5. Label your location "**X**". [3]

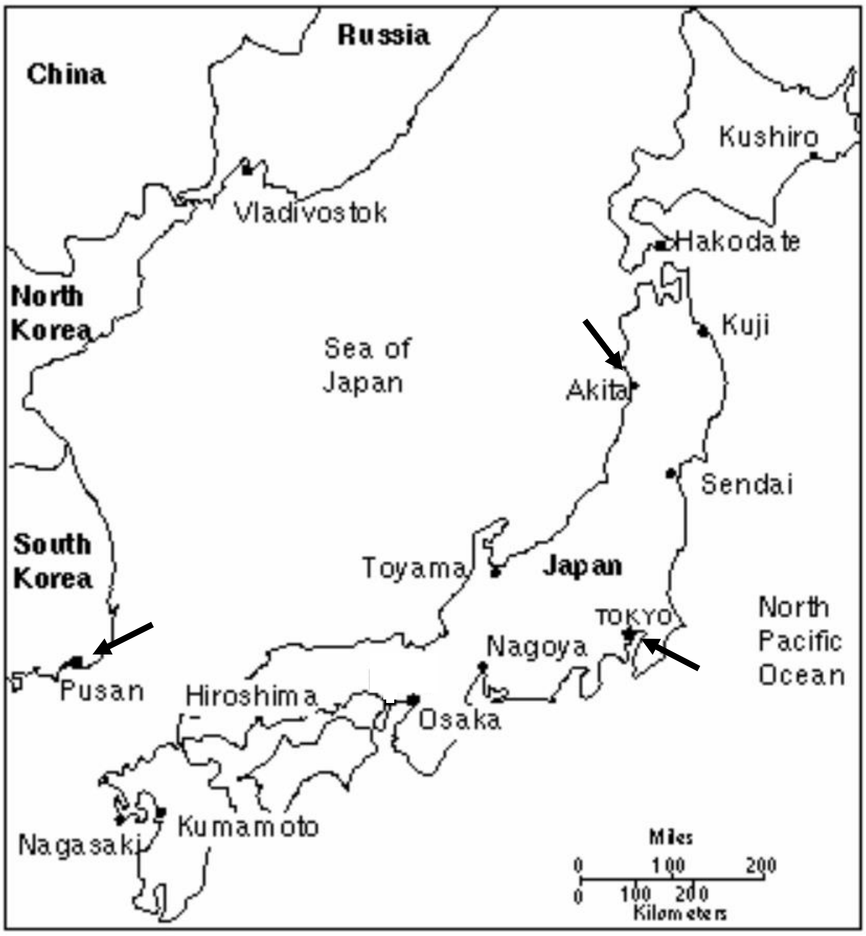


Fig. 7.5

(iii) The intensity of an earthquake on the Richter scale can be easily determined using a nomogram as shown in Fig. 7.6

For each station, connecting the distance on the Distance scale and the amplitude on the Amplitude scale with a straight line, the intersection on the Magnitude scale is the Richter scale reading for the earthquake.

If distance of the station from the earthquake's epicenter is 100 km and amplitude of the earthquake recorded at the station is 1 mm, the magnitude of the earthquake is 3.0 on the Richter scale, as shown in the sample line drawn in Fig. 7.6.

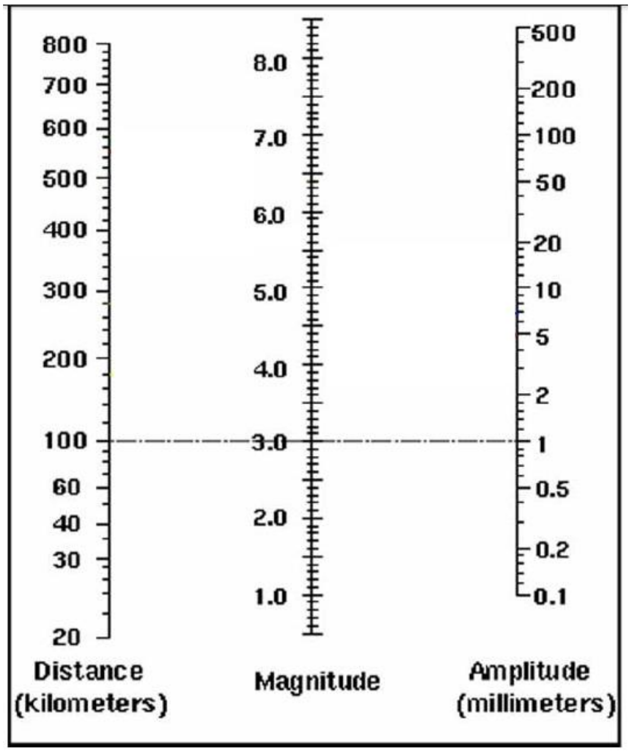


Fig 7.6

1. State one other factor that may affect the amplitude of the S-wave recorded besides the intensity of the Earthquake. [1]

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2. Using your answers from Fig. 7.4 and the nomogram in Fig 7.6, construct and determine the magnitude of the earthquake on the Richter scale. [2]

Magnitude = ……………………..

(d) The Richter magnitude scale used in (c) was developed in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. The magnitude of an earthquake on a Richter Scale M is related to the intensity (I) of the S-wave according to the equation

$$M = \log\left(\frac{I}{I_o}\right)$$

where I_o is a reference intensity.

The amount of energy radiated by an earthquake is a measure of the potential for damage to man-made structures. The Richter magnitude M, is related to the energy released E in ergs (1 erg = 10^{-7} J) through the equation

$$\log E = 1.5\,M + 4.8$$

(i) On 26 Dec 2004, an underwater 9.0-magnitude earthquake off the coast of Aceh, Indonesia, sent giant tidal waves into coastal areas in Indonesia, Thailand, Malaysia, Sri Lanka, Bangladesh, India, Myanmar, the Maldives and Somalia, resulting in at least 159 000 people dead. This is known as the great Sumatra Earthquake

1. Determine the ratio of the intensity of the Sumatra Earthquake to the Kobe Earthquake [1]

Ratio = …………………….

2. Hence explain why we use the Richter scale, which is a logarithmic scale, instead of just a normal scale based on the intensity I. [1]

(ii) Determine the ratio of the energy released from the Sumatra Earthquake to the Kobe Earthquake.

Ratio = …………………… [1]

(e) The death toll in the 2015 Chile Illapel Earthquake with magnitude 8.3 was 14 whereas that from the 2015 Nepal Earthquake with magnitude 7.8 was almost 9000.

Suggest a possible reason why higher magnitude earthquakes may not always lead to higher death tolls. [1]

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End of paper