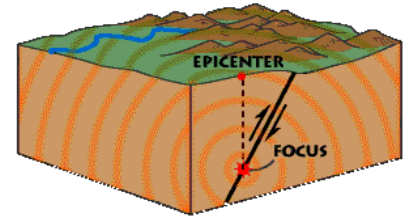


Seismic Waves

When the rupture of a rock occurs, the release of energy causes seismic waves to be produced. Just as wind energy causes waves in water to move across a lake or ocean, seismic waves move through the layers of the Earth.

1) Geologically speaking, what is the difference between a joint and a fault (check notes from previous class)?

As movement occurs along a fault most parts of the fault generally will creep along at a steady pace. Certain locations will lock up. This may be a result of the type of rock involved or the fault might take a change in direction at that point. What ever the reason, as the rest of moves along, rock around the locked up point gets stretched or compressed and stores elastic energy. At some moment, the elastic forces exceed the forces holding the fault in place and the rock gives way. This is referred to as the rupturing of the fault. The point of rupture is referred to as the focus or hypocenter of the earthquake. It may be tens to hundreds of kilometres underground. The epicenter is the point at the earth's surface directly above the focus.



2) a) What is the maximum speed of the rock at the rupture point when the fault gives way? (check notes)
b) To what wave speed does this correspond?

3) If you live near where a fault intersects the surface, does this mean that your home is going to be near the epicenter when an earthquake occurs on your part of the fault?

Because the rocks move so fast, they overshoot their equilibrium position (where they would be if the fault had not locked up), they rebound, and they end up vibrating back and forth like a spring that has been plucked. These vibrational seismic waves are what produces the destruction that can accompany an earthquake by heaving, shaking, and cracking the ground as they pass through an area. The seismic waves spread out in all directions from the focus.

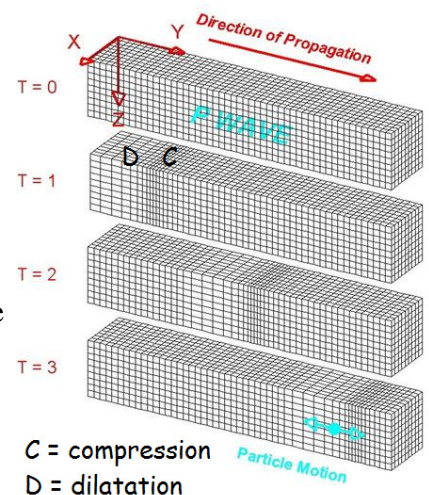
P Waves

Compression waves are one type of seismic wave. They are the first to arrive at the surface of the Earth. Because of this they are given another name, P or Primary waves.

P waves are the fastest of the seismic waves. They travel at incredible speeds, 6.5 km/s (more than half the escape speed of the earth's gravity) at the surface to over 11 km/s through the core of the Earth. P waves are able to pass all the way through the entire Earth.

When P waves strike an object they push and pull the object, like a train engine bumping into a railroad car which then bumps into another and so on all the way through the whole length of the train. This jackhammer movement is the first sign that an earthquake is occurring.

P-waves are the first waves to arrive at any location, but they generally are the least destructive as well.



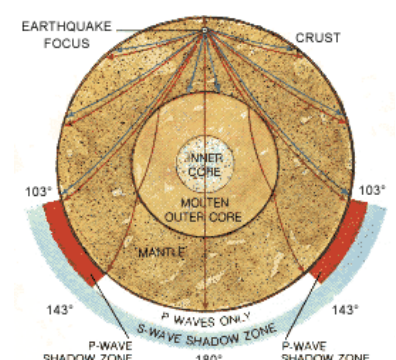
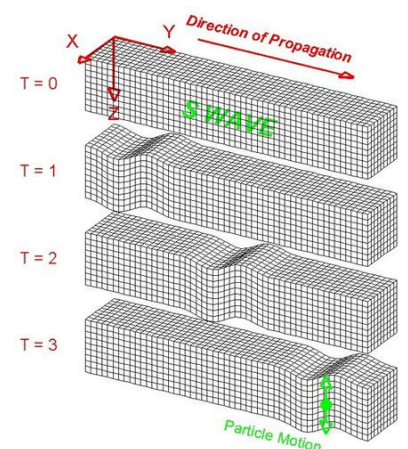
S Waves

Shear waves reach the surface shortly after the P waves and are given the name S or Secondary waves. S waves travel at about half the speed of P waves. They move objects in their paths in an up and down motion in the direction that the wave is moving.

S waves can only move through solids and because of this can travel only through the crust and mantle of the Earth. When S waves strike the outer core, which is made of liquid iron and nickel, the waves stop.

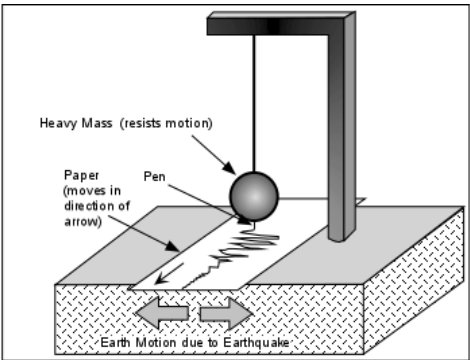
S waves typically have a greater amplitude and more destructive force than P waves.

The actual nature of the seismic waves that arrive at any point along the surface of a planet are a little more complicated than shown in the simple S and P wave shadow zones on the previous page. This is because S and P waves can reflect off the surfaces between the various rock layers in a planet. When they do, they usually reflect both S and P waves. So, an incident P wave bouncing off the mantle-core boundary will produce a reflected P wave and a reflected S wave. However, with a little experience, seismographers can identify these different reflected waves and still identify the two primary shadow zones.



Seismographs and Seismograms

Seismographs are devices that record seismic waves. In the simplest case, they are a mass suspended by a wire which holds a pen. The pen makes a mark on a spool of paper which is attached to the earth. When the earth shakes, the mass with the pen does not move because it is suspended from its wire. Thus, the pen makes a wavy line on the paper. The bigger the amplitude of the wave, the stronger the seismic wave.

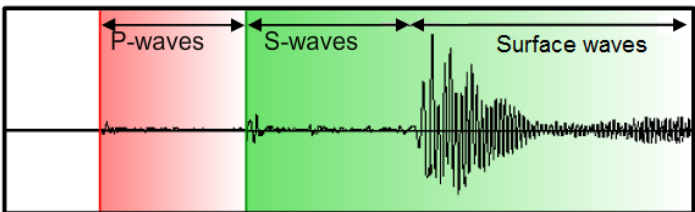


Modern seismographs are more complex and most now are solid state accelerometers such as those in a car’s airbag crash sensor. There are two varieties. Short period sensors are sensitive to small ground motion (they can detect a person’s footfalls) but go off-scale with large amplitude waves. Strong motion sensors are less sensitive, but will accurately record large waves up to many centimetres in amplitude. There is a limit to any sensor however. For this reason, sensors near the actual epicenter are not all that useful for measuring ground motion.

There are three sensors per recording station: one to record E-W vibrations, one to record N-S vibrations, and one to record vertical vibrations. This is particularly important for distinguishing between the types of surface waves (see below).

Seismograms

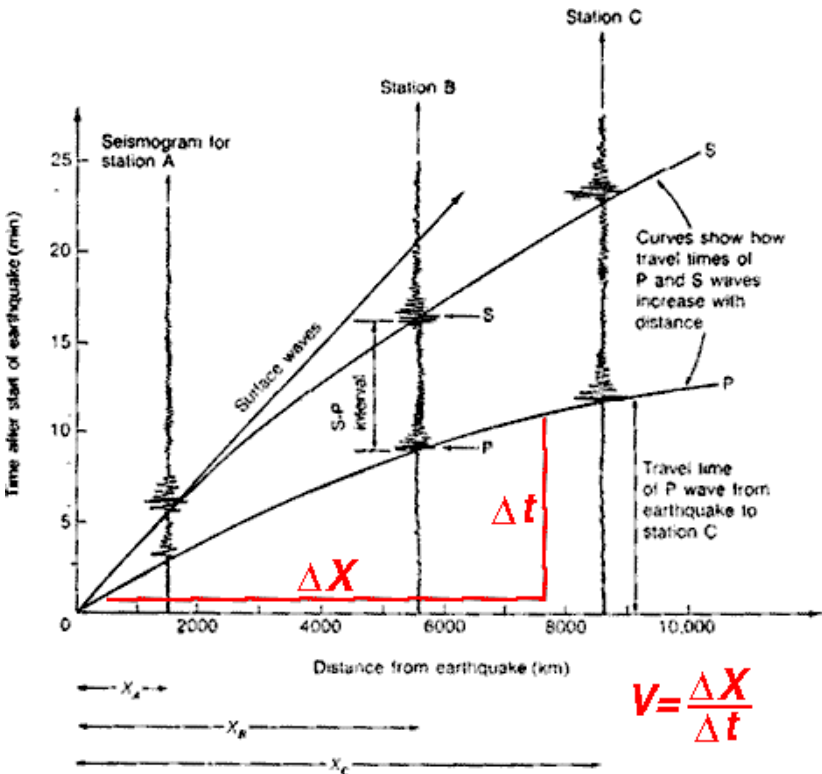
A seismogram is the record produced by the seismograph. Each seismic wave type produces a characteristic wave pattern and has a characteristic arrival time that depends on its speed through the earth.



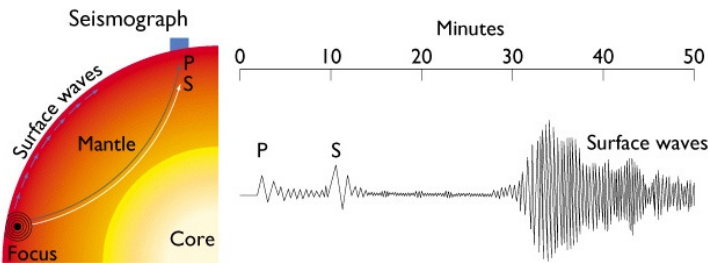
First Seismic Wave Arrival Time

S Waves are slower than P waves. Near the surface, they travel at 4 km/s. Therefore, they arrive at any location away from the location of the seismic event after the P waves. The farther away you are from the location of the seismic event, the greater the span of time between the P wave and S wave arrival. As long as we have a good idea of the P-wave and S-wave speeds, we can use the difference in the arrival time of the first P waves and S waves to determine how far away we are from the location of the seismic event.

Surface waves are slower and only move along the earth’s surface.



4) Consider the figure to the right. Why, on the arrival time vs distance from epicenter graph above, do surface wave arrival times form a straight line, while the S and P wave arrival times form a curve that gets more horizontal as the recording stations get farther away from the epicenter?



5) Read paragraph 2 on both page 1 and 2 as well as the graph of wave arrival time versus distance. Give three reasons why seismograph stations near to the epicenter would be useless for pinpointing the location of the epicenter.

Surface Waves

Surface waves are the third type of wave. These are the waves that produce the most destruction. They originate from the arrival of P and S waves at the surface. They are much slower than both P and S waves. Surface waves are limited to travel along only the surface of the Earth, just as waves in a body of water are limited to travel along only the surface of the water.

There are two types of surface waves: Love waves and Rayleigh waves. Love waves move in a manner very similar to S waves but the movement to objects in it's path is side to side instead of up and down. Rayleigh waves travel much in the same way as waves in water. Rayleigh waves have an almost circular pattern to their wave motion.

Surface waves are even slower than S waves. They are, however, typically more damaging and show up on a seismogram as having much larger amplitudes than the P and S waves.

Surface waves also typically have a lower frequency than S and P body waves. Much of the time, however, it takes considerable experience to identify each of these wave arrivals on a seismogram. The general approach is to identify the P-wave arrival time by the first vibrations that are significantly larger in amplitude than the background. The S-wave arrival time is identified by a sudden increase in the wave amplitude. The P-wave amplitude may decay to almost nothing before this if the earthquake is far enough away. The surface wave arrival time is marked by another sudden increase in amplitude as well as an increase in the wavelength of the vibrations.

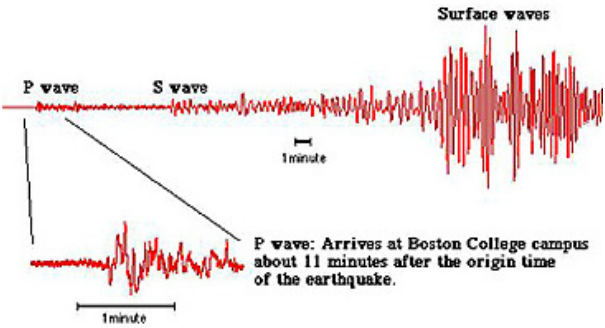
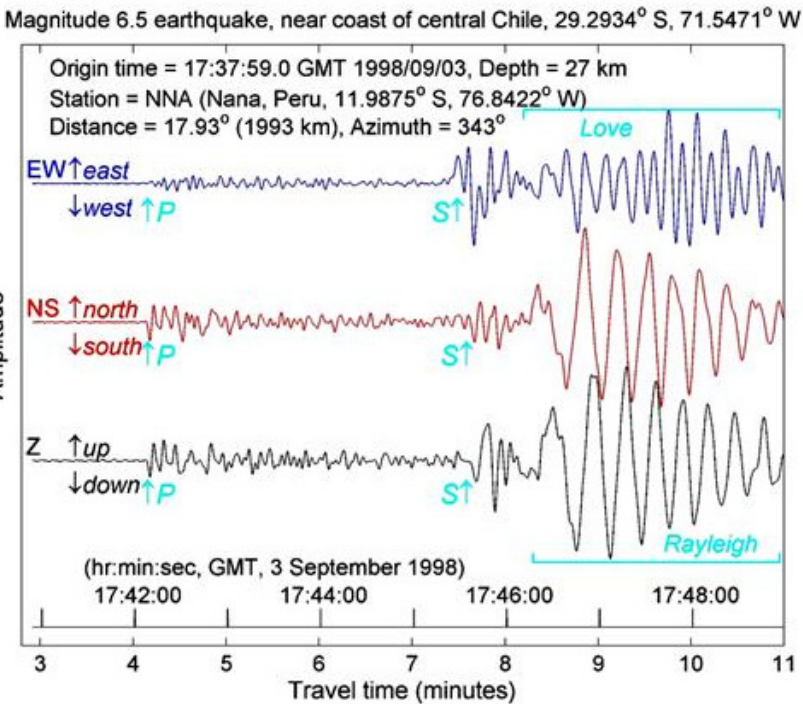
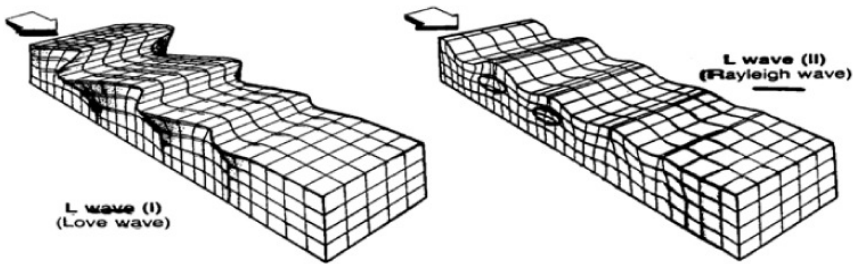
Richter Magnitude

The Richter Magnitude is a number that is used to measure the size of an earthquake. The magnitude is a measure of the amplitude of the seismic waves that have been sent out from the focus.

Each number on the Richter Scale represents an earthquake that has ten times the wave amplitude as the number below it. An earthquake measuring 6 has waves with ten times the amplitude than those of a magnitude 5 quake. An earthquake of a magnitude 9 has wave amplitudes 10,000 times larger than a 5.

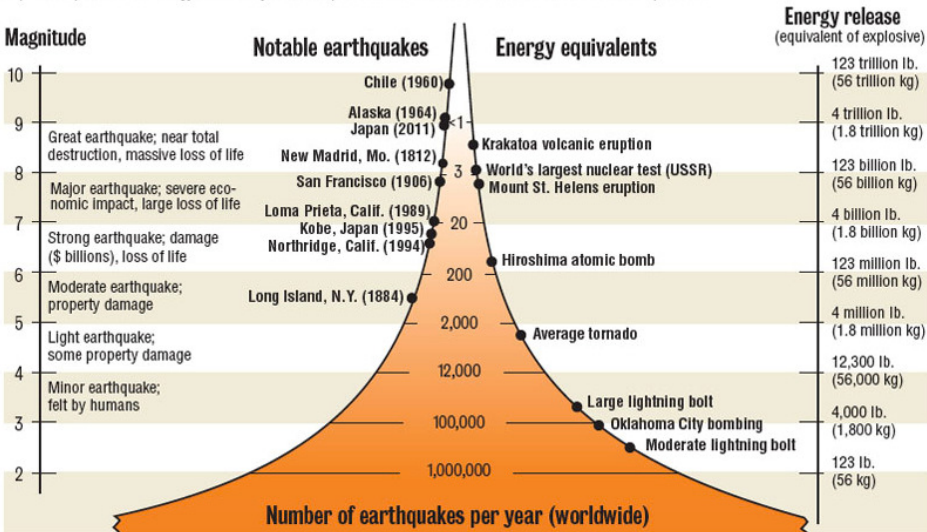
6) Consider the consequences listed for each of the magnitudes on the left-hand side of the figure to the right. What additional factor plays into how much damage would occur from earthquakes of these magnitudes?

7) How much larger was the wave amplitude of the largest earthquake ever measured than the amplitude of an earthquake that is just perceptible to a person.



Earthquake frequency and destructive power

The left side of the chart shows the magnitude of the earthquake and the right side represents the amount of high explosive required to produce the energy released by the earthquake. The middle of the chart shows the relative frequencies.



The energy released by an earthquake is related to the amplitude of the waves. Each ten-fold increase in wave amplitude represents a 31-fold increase in earthquake energy.

8) *How much more energy is released by a magnitude 8 earthquake versus a magnitude 5 earthquake?*

Calculating the Distance and Magnitude of an Earthquake

To determine the magnitude of an earthquake from a seismogram, it is necessary to know both:

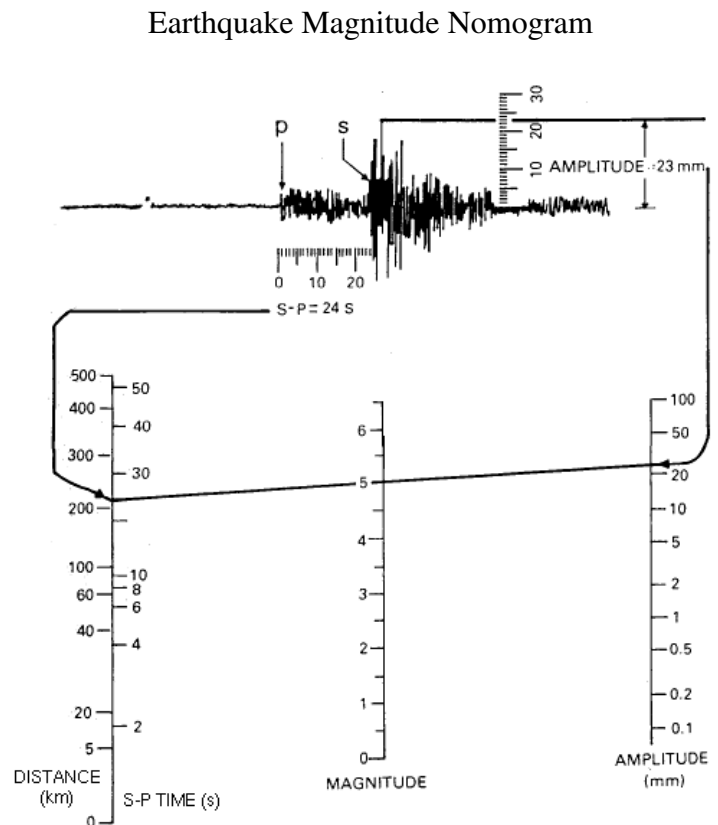
A) the distance of the seismograph station from the focus of the earthquake (the epicenter will do, if you are farther than a couple hundred kilometres) and

B) the maximum amplitude of the S waves.

Both of these can be calculated from the seismogram.

A) The distance to the epicenter can be calculated from the difference in arrival time of the S and P waves. Calculate this time difference and use the Arrival Time vs Distance graph on page 2 to determine the distance (find the distance for which the S and P arrival lines are that number of seconds apart: **see the video**). You also can use a graph that plots S-P times already calculated (see assignment).

B) The maximum S wave amplitude can be read off of the seismogram. Be sure to find the greatest amplitude either above or below the centre line.



On the nomogram, put a dot on the right hand axis for the maximum amplitude and a dot on the left axis for the distance (some nomograms, like this one, have S-P time on the left axis, but most do not). Connect these two dots with a straight line and where this crosses the middle axis gives you the earthquake magnitude.

The nomogram can give you any of the three variables: distance, amplitude, or magnitude; if you know the other two.

- 9) a) *What is the magnitude of an earthquake that produces maximum amplitudes of 5 mm at a distance of 20 km from the epicenter?*
b) *What amplitude of shaking would be expected at a distance of 400 km from a magnitude 5.5 earthquake?*
c) *If you experience 75 mm amplitude shaking from an earthquake that you know to be a magnitude 4, how far from the epicenter are you?*

10) *The nomogram becomes less reliable as you get closer to the epicentre. Extend the amplitude axis of the nomogram on your assignment sheet far enough to calculate the shaking amplitude of a magnitude 8.5 earthquake if you were 20 km away. Keep in mind to preserve the log scale of this axis when you extend it (the distance up from 500 to 5000 is the same as the distance from 50 to 500, ect.). How realistic is the shaking amplitude that you get for an 8.5 magnitude event 20 km away?*

11) *If you are a city hazard manager, how might you use the period of time between the arrival of the fairly low-energy P-waves and the arrival of more damaging S-waves and surface waves? What activities might you want to halt with respect to industries such as transportation and health care when P waves are detected? One might realistically have earthquake alarms attached to sensors all over a city at risk of earthquakes.*

12) *Use the earthquake frequency and destructive power chart on page three to estimate how often (in terms of seconds) a perceptible earthquake occurs anywhere on the earth.*

13) *You will be given one of three different earthquake data sheets. Each has three seismograms from three different stations. Measure a S-P arrival time and a maximum amplitude for each seismogram. Use the S-P time vs distance graph and the nomogram on each sheet to calculate the magnitude and epicenter distance for each of the seismographs. Use a compass to draw distance circles on the map for each of the seismograph stations and use these to pinpoint the location of the earthquake epicenter.*