

How Do We Know Where an Earthquake Originated?

Teacher's Guide

Standard Addressed:

<u>Grades 6-8:</u>	Scientific Inquiry	1 B/1, 2
	Mathematical Inquiry	2 C/2
	Technology and Science	3 A/2
	Processes that shape the Earth	4 C/ 1, 2

<u>Grades 9-12:</u>	Scientific Inquiry	1 B/2
	Technology and Science	3 A/3
	Processes that shape the earth	4 C/5
	Symbolic Relationships	9 B/3
	Common themes: Models	11 B/3

Objectives: By the end of this activity, the student will be able to:

1. Identify P and S waves on seismograms,
2. Determine the distance of an epicenter from a seismic station using travel time curves,
3. Locate the epicenter of an earthquake by triangulation, and
4. Calculate the time of origin of an earthquake based on seismic data

Materials Needed:

- 3 component seismograms,
- Travel time curve,
- Globe or map for locating epicenter,
- String (with globe) or compass (with map)
- Map with Tectonic Plates illustrated.

Time Management:

Teacher Background:

A tremendous number of earthquakes occur every year around the world. The vast majority of these earthquakes are too small to be felt by humans. The larger ones, having a magnitude greater than 5, can effect human property and life if they originate near a populated area. However, populated areas do not make up a very large portion of the earth's surface. For this reason, most of the earthquakes that occur each year are not felt either because they are too small, or they are in an area where no one is around to make a direct observation of their movement.

To understand Plate Tectonic processes on the Earth, and to better understand where future earthquakes are likely to occur, it is important to know how to locate earthquakes as they occur. The primary tool seismologists use to locate an earthquake's point of origin is a network of seismometers. Seismometers are designed to be sensitive enough to feel even the smallest motion of the waves coming from distant locations on Earth. By combining measurements of wave arrival times at several seismograph stations, the earthquake's source can be located.

There are several hundred seismic stations around the world; each one continuously monitoring the Earth's surface for shaking caused by an earthquake. Organizations such as the Incorporated Research Institutions for Seismology (IRIS) gather and archive data from these stations in a central database. These data can then be accessed by anyone interested in learning more about earthquakes.

Some other things to be aware of are that:

- Modern seismic stations produce a 3 component seismogram simultaneously. One seismogram is a vertical motion, one is of east to west motion, and another is of north to south motion (**FIGURE 1**)
- Because body waves come up from below the surface, P wave motion is usually greatest on a vertical component seismogram, while the S wave usually registers a stronger signal on the horizontal component seismograms (**FIGURE 1**).
- Students will need help in identifying P and S waves on seismograms. The P wave is the first signal to appear on the seismogram, and is best identified on the vertical component. The S wave arrives later, and should be the first signal to arrive with its amplitude on the horizontal components larger than that on the vertical component. The S wave may be a broader pulse than the P wave (longer period, or lower frequency). There may be several arrivals of P waves before the S wave arrives; students will interpret only the **FIRST** P wave and **FIRST** S wave.

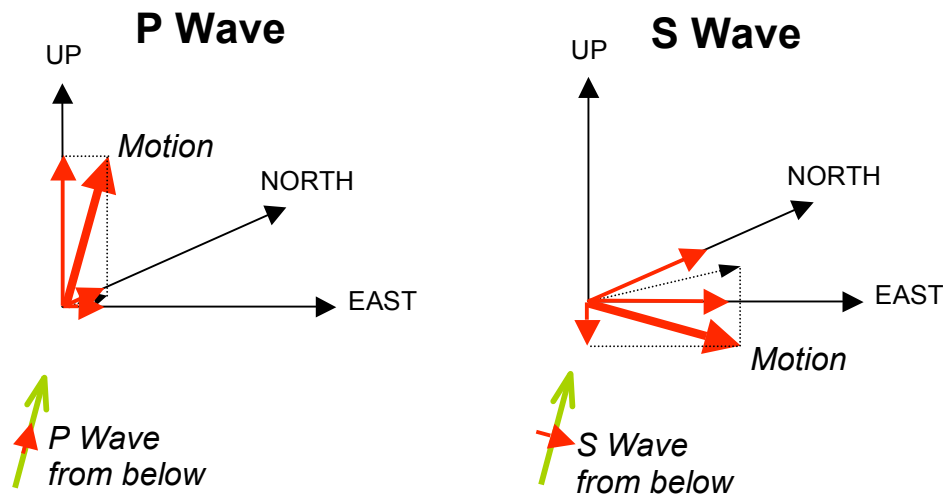


FIGURE 1 – Since the motion of a P wave is in the direction the wave travels, for a wave coming up from below the seismograph station, the motion of the ground will be mostly vertical (up and down), with a smaller amount of motion on the horizontal components (North and East). By contrast, since the S wave motion is perpendicular to the direction of wave travel, an S wave coming up under the station will produce larger motion in a horizontal direction which may be some combination of the North and East component directions, and smaller motion on the vertical component.

- Travel time curves indicate the arrival times of various waves with increasing distance from the earthquake source. Time is plotted in minutes and distance is plotted in degrees (the opposite side of the Earth is at a distance of 180°). The P wave curve and the S wave curve should be indicated, and these are the ones the students will use. There are many other P and S wave curves, representing reflections and refractions from layers within the Earth. These will not be used, but will help students see what the later-arriving P waves and S waves represent.
- Measuring the S wave and P wave arrival times from only one station gives the station's distance (the radius of a circle) away from the epicenter. An estimate of the time of origin is also calculated.
- Measuring arrival times at two stations should give you two possible locations of the epicenter, where the two circles intersect.
- Arrival times measured at three stations, minimum, are needed to triangulate epicenter location to a single point. Using more than three stations supplies redundant information, which is helpful if any errors in measurement or interpretation occur with the data from any one of the stations.

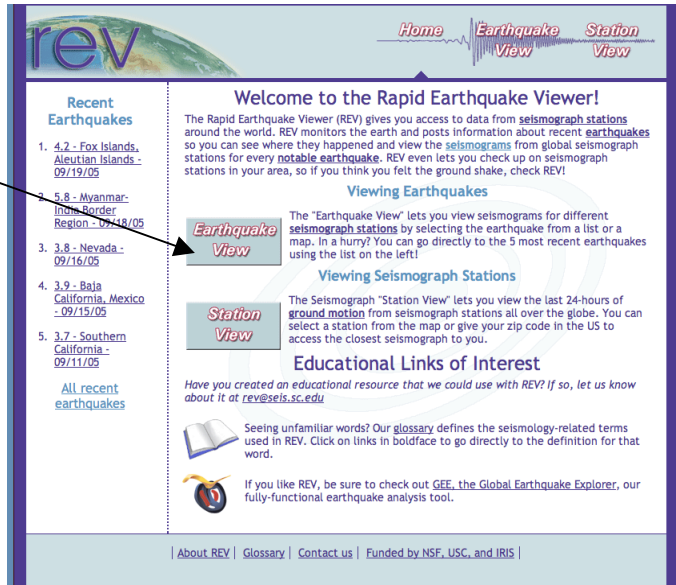
- Each student should work on seismograms from one station. Only by cooperating with other students who have worked on the same earthquake, but at different stations, can the earthquake be located. By teaming up, sharing data, and discussing interpretations and procedures, students can find their own mistakes in calculations.
- Due to the inherent distortion in most maps, caused by making a 3 dimensional object into 2 dimensions, the scale changes as you move north or south of the equator. In order to triangulate for earthquake location, it is important that both distance and angle from each station to the earthquake epicenter be accurate. This is possible only for carefully chosen map projections centered near the earthquake location. Of course, this gives away the answer; the earthquake will be near the center of the map.
- By using a globe, the problems of map projection is eliminated. The shortest path between seismograph station to earthquake epicenter is often over the North or South pole, and this is easily measured (and seen) on a globe. To measure distance on a globe, students should measure a length of string along the equator (a great circle). Placing one end of the string at the seismograph station location, the circle swept out by rotating the string around this gives all possible locations for the earthquake source.
- It can be a bit unwieldy having three or four students simultaneously measuring distances on a single globe, but this enables them to find and visualize the intersection point needed for triangulation. It will be necessary to have several globes or to schedule their use so that groups who have interpreted seismograms for the same earthquake can access the globe together.

What the Student Should Know:

1. The student should be aware of the basic differences between P and S waves, and how to identify them on a seismogram.
2. The student should be familiar with travel time curve, and what it represents. They should be able to identify the P and S wave travel time curves.
3. The idea that different time and distance scales are used on seismograms, travel time curves, globes and/or maps.

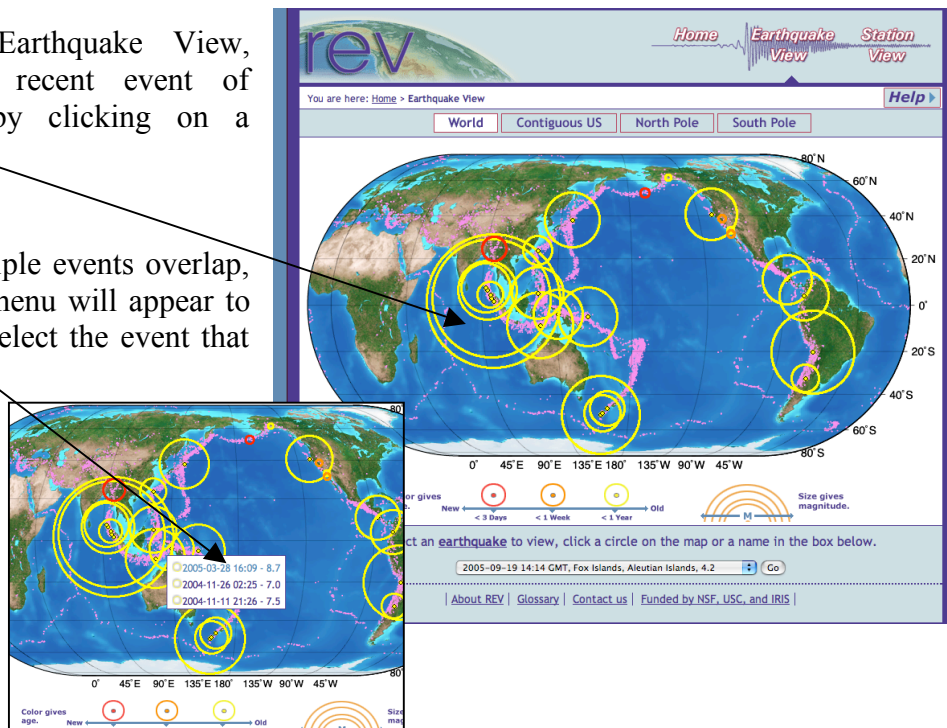
Instructions for Retrieving Data:

1. Visit the Rapid Earthquake Viewer (REV) at <http://rev.seis.sc.edu/>. Select "Earthquake View"

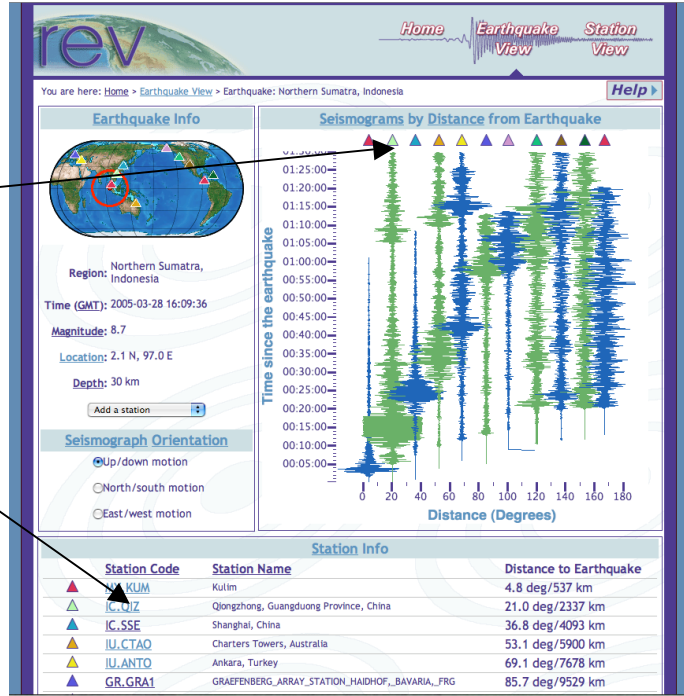


2. In the Earthquake View, select a recent event of interest by clicking on a circle.

Note: If multiple events overlap, a drop down menu will appear to allow you to select the event that interests you.

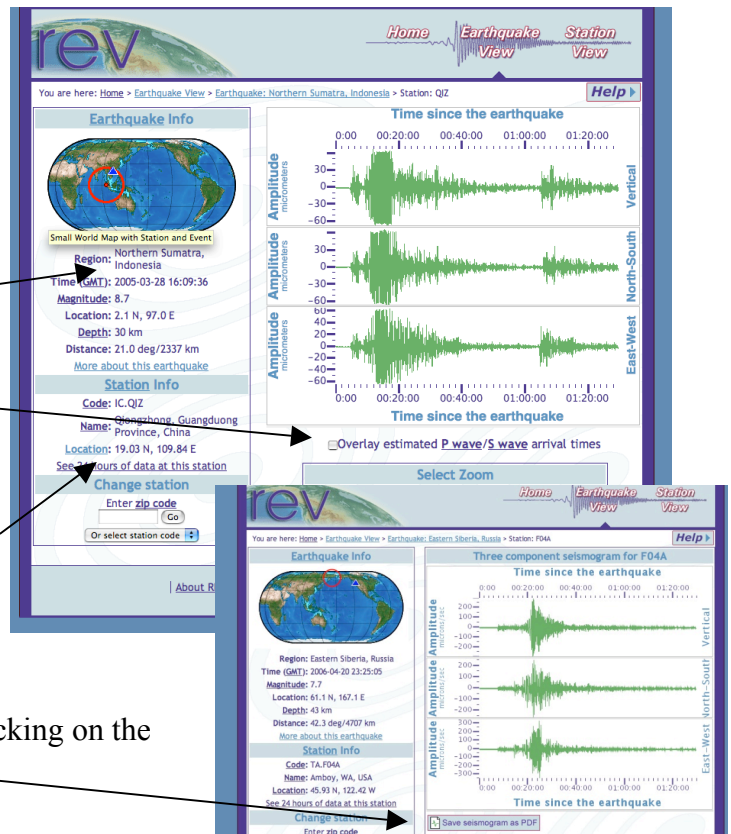


- From the Record Section window, you will be able to select which stations you want to get data from. Do this by noting the station symbol (colored triangles at the top of the record section) and clicking on corresponding station code in the table below the seismograms.



- This will open a three-component view of the seismograms for the earthquake. From this window you can do the following;

- Get the time and date of the event (you will need to write this on the seismograms for the students).
- Toggle the calculated p/s wave arrivals on and off (This is useful to help you check your P and S picks.)
- Get the latitude and longitude for the station (you will need to write this on the seismograms for the students).



- Save or print the seismograms by clicking on the Save seismogram button.

6. Use your browsers back button to return to the Record Section view to select additional stations (See step #3) so that each group has 3 to 4 stations' recordings of the same event.
7. Once you have enough stations for that event, use your browsers back arrow to return to the Earthquake View to select additional earthquakes as needed for rest of the class.

Possible Pitfalls:

1. Students may fail to realize that the three components of the seismograms indicate ground motion simultaneously in three directions. They sometimes think that one component follows the others in time.
2. Students may have trouble identifying P and S waves. Rather than interpreting the first P wave and the first S wave, they may be drawn to the largest waves.
3. Students may not measure the difference in time between the S wave arrival and the P wave arrival. Instead, they may simply measure the arrival time of one or the other wave. Students may also have difficulty with measurements on the time scale of the seismograms.
4. Students may not realize that the travel time curve likely has a different time scale than the seismograms. After measuring the time difference appropriately, students may not keep their measurements on the travel time curve aligned with the time axis. This is necessary in order to measure time difference at a single distance. Finally, students may have difficulty reading this distance from the travel time curves.
5. Students may have difficulty measuring angular distance on a globe. They may try to measure distance along lines of latitude which are not great circles. They may confuse the latitude and longitude of their station with the angular distance determined from travel time curves.
6. Students may have difficulty locating their seismograph station on a globe. They may confuse latitude and longitude, or may neglect whether these are N, S, E or W. This is a useful learning exercise. The seismograph stations have letter names which indicate the nearest town or region, but these may not be labeled on the globe.
7. Even with no apparent errors in procedure, students' triangulations may not meet at a point. The most likely cause is that the earthquake occurred at a depth significantly different than assumed for the travel time curve. With the expected level of measurement error in time and distance in the various stages of this exercise, it is not unusual to have a gap of a few degrees in triangulating. Larger misfits probably indicate misunderstandings in interpretation or incorrect procedure. If more than three students interpret seismograms from a single earthquake, some sets of three may find consistent results, while others have discrepancies. This indicates an error by one of the students in the group with discrepancies.

Answers to Questions:

Procedure 6:

Q: How many possible locations are there for the epicenter using the data from one station?

A: The epicenter could be at any one of an infinite number of locations along the circumference of the circle, with its radius being the calculated distance from the epicenter.

Procedure 7:

Q: How many possible locations are there for the epicenter using the data from two stations?

A: There are one or two locations, depending on if/where the circles intersect.

Procedure 8:

Q: How many possible locations are there for the epicenter using data from 3 stations?

A: There is only one location now that fits the data from three stations (assuming all calculations have been done correctly).

Procedure 9:

Q: Does a fourth station help to further pinpoint the epicenter?

A: The fourth data set should confirm the location of the epicenter.

QUESTIONS:

1. **Q:** Describe how you were able to calculate origin time of event.

A: Once the distance is determined from the travel time curve, the travel time of the P wave can read from the curve. Subtracting this from the arrival time of the P wave on the seismogram gives the origin time of the earthquake.

2. **Q:** Describe what two things you learned from your data alone.

A: The student learned the distance from the epicenter and the origin time of the event.

3. **Q:** Describe step by step how using more data narrowed down the possible epicenter locations.

A: With one data set, the epicenter could be anywhere on the circle, two data sets narrow the possible locations to two (where the circles intersect), and three or more data sets pinpoint the location of the epicenter being where all of the circles intersect.

4. **Q:** How were you able to use your calculation of the origin time to double check the "distance from epicenter" calculations?

A: As long as the origin times all came out to be the same time for the same event, then the distance to the epicenter calculations must be correct.

5. **Q:** The vast majority of earthquake hypocenters (foci) are too deep to show any surface rupture. Aside from that reason, why do we depend on indirect methods to locate earthquake epicenters rather than personal observation? (HINT: Most earthquakes occur along plate boundaries. Where are most plate boundaries located?)

A: It is exceedingly rare to be located directly over a focus during an actual event. Most earthquakes occur below oceans, further obscuring them.

6. **Q:** Discuss the advantages of having a network of seismic stations similar to that of IRIS.

A: The data is in one location and is convenient to access.

7. **Q:** Locate the epicenter on a map showing Earth's tectonic plates. Based on the map, would you expect an earthquake in this area to be fairly common or rare? Explain your answer fully.

A: It depends on the event. Most likely the event is located in close proximity to a plate boundary. Earthquakes are common near most plate boundaries due to the motions of one plate with respect to the adjacent plate.