WHOSE FAULT IS IT?

A hands-on approach to seismology

ART BY CHARLES BEYL

by Eric Muller

When a geological fault slips, the amount of energy released can equal that of a hydrogen bomb. Students find this fact both frightening and awe-inspiring, especially if they happen to live in a tectonically active area such as San Francisco. To capitalize on my students' fascination with earthquakes, I developed "Whose Fault Is It?," a seismic simulation that I incorporated into my Earth science curriculum.

Depending on curricular goals, the game can be adapted for use in an elementary school science class or even a college level geology course. There are also mathematical applications that can be used in courses ranging from second grade mathematics to calculus. This game can be used to "break the ice" or to develop positive group dynamics. Groups with a wide range of skills, ages, and coordination levels can easily learn to play this game.

This who-dunnit activity uses students as the source, carriers, and detectors of earthquake waves. The group determines who the secret starter of an earthquake is by applying some basic principles of seismology. Students are introduced to the concept of a seismic wave lag and use data from the activity to create a seismic wave travel-time graph.

EARTHQUAKE ESSENTIALS

Some of the main events that cause earthquakes are fault rupture and slippage, magma movement and volcanic events, and nuclear explosions. When an earthquake does occur, seismic waves radiate outward in a spherical pattern from its *focus* or *hypocenter*. People often mistakenly use the term epicenter to refer to the point of origin of seismic waves, but this term actually refers to a point on the surface of the Earth's crust directly above the focus.

There are two types of seismic waves that propagate within the Earth. The faster of the two types of waves is known as a *P-wave*. P-waves, also referred to as primary or pressure waves, travel as longitudinal compression waves. The second type of seismic wave is known as the *S-wave*. These waves, also known as secondary or shear waves, travel noticeably slower than P-waves. S-waves travel as a transverse wave. This difference in seismic speed is very useful to seismologists. The farther seismic waves travel, the greater the lag or delay is between the arrival of the P-wave and the S-wave.

Devices known as seismometers are located throughout the world. These instruments are sensitive pieces of equipment that detect and record the arrival of seismic waves. With data provided by three or more seismic stations, a seismologist can determine how far away each station is from a seismic event. Using a method known as triangulation, seismologists can pin-point the origins of an earthquake.

By locating the source of seismic waves, geologists are better able to understand our planet. By plotting epicenter locations on maps, they are able to define tectonic plate boundaries and locate faults more efficiently. Numerous lives have been saved by a tsunami warning system that can detect undersea earthquakes. The more seismic information that can be garnered from earthquakes, the better our chances are of developing a system for accurately predicting earthquakes and volcanic eruptions.

PLAYING THE GAME

This activity usually takes two to three class periods to complete. The first class period is spent introducing the game, practicing the necessary hand motions, and working out the bugs. I advise teaching this game in a step-by-step manner. Skills, rules, and roles should be brought up and taught as needed. The following is a description of the basic mechanics of the game.

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Object of the game—To correctly locate the origin of an earthquake. (The Earthquake will be a member of your group.)

Players and assignments—There are three different roles that students will play. A brief description of the roles is provided below. Students will assume various roles during the exercise, so they should pay close attention to each role description:

The Earthquake—Generator of the seismic waves;

The Seismometers—Detectors, collectors, and informers of seismic activity; and,

The Mediums—Carriers of seismic waves (analagous to the Earth's interior).

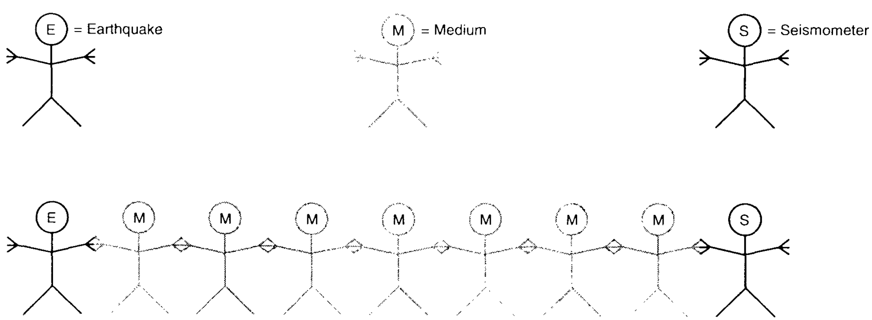
Line-up—Students should stand in a line and hold hands. The person at one end of this pattern will play the role of the Earthquake. The person at the other end will be the Seismometer. All players in between are the Mediums (Figure 1).

The P-Wave—It is important to let players know that since people are used to transmit seismic waves during this game, the waves are quite different than those found within the Earth. This wave is a single squeeze of the hand sent from player to player that always originates with and moves away from an Earthquake. The Earthquake starts a P-wave moving by squeezing the hand of his/her neighbor.

As soon as a player receives a P-wave in one hand, he/she transmits it immediately by squeezing the hand of his/her neighbor. This process of having your hand squeezed, then squeezing the hand of your neighbor should continue until the P-wave has been transmitted all the way to the Seismometer.

It is important to send this wave as fast as possible. Once the P-wave reaches the Seismometer, the student playing that role should shout, "P-wave!" Several practice P-waves should be sent from the Earthquake, to the Seismometer.

FIGURE 1. Positioning of the players.



The S-wave—After the P-wave is mastered, the teacher can introduce the S-wave to the players. The S-wave will also be a wave sent from player to player. Like a P-wave, an S-wave can only originate and move away from an Earthquake.

An S-wave differs from a P-wave in two ways. First, it is not a squeeze, but a single shake of a player's hand. Second, before transmitting an S-wave, a player must wait *two seconds*. This delay is mandatory in order to make the game work.

The Earthquake starts an S-wave by counting silently, "ONE-one thousand, TWO-one thousand." The Earthquake, must then, shake the hand of his/her neighbor. As soon as this player receives an S-wave, he/she must also count silently, "ONE-one thousand, TWO-one thousand." Once the count is complete, that player can then send the S-wave on to his/her neighbor, and so on.

The process of waiting two seconds before shaking the next player's hand should continue until the S-wave has been transmitted to the Seismometer. When the S-wave reaches the Seismometer, the Seismometer should immediately shout, "S-wave!" Several practice S-waves should be sent from the Earthquake to the Seismometer. It is important that all players count at the same rate.

Combining the waves—For the next stage of the game, P-waves and S-waves are combined. The Earthquake begins by sending a P-wave, waiting two seconds, then sending an S-wave. The Earthquake's neighbor transmits the P-wave immediately after he/she feels it, but delays sending the S-wave. This process should be repeated until the both waves finally reach the Seismometer. There should be a significant time gap between the shouting of "P-wave!" and "S-wave!"

The Seismometer—At this stage, the Seismometer is given an additional responsibility. The Seismometer must time, in

It is important that all players count at the same rate.

seconds, the lag between the arrival of the P-wave and the S-wave. It is no longer necessary for the Seismometer to shout, "P-wave!" Now, when the P-wave arrives, the Seismometer needs to begin counting to him/herself. The rate of counting should be the same as that used for the S-wave delay, but the count may go well above two seconds. For example: ONE-one thousand, TWO-one thousand, THREE-one thousand, FOUR-one thousand, and so forth. Depending on the size of the group playing, the count may go very high.

After the S-wave arrives, the Seismometer stops counting and shouts, "S-wave!" The Seismometer then informs the rest of the group the number of seconds that the S-wave lagged behind the P-wave.

The combining of P-waves and S-waves is critical to the success of this game. This section should be practiced several times and lag times should be checked by the teacher or group leader.

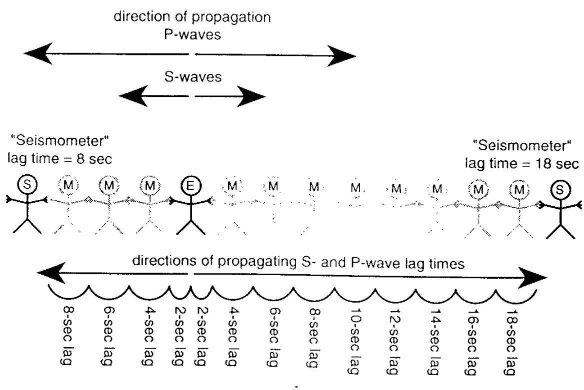
Checking lag times—Lag times should correspond to the number of people participating in the delay. Each person delays an S-wave by two seconds. This obvious relationship between time and players can be expressed as:

Distance (in persons) between Earthquake and Seismometer = Duration of lag divided by 2 seconds

For example, if there are 19 Mediums and one Earthquake (20 people total) then the Seismometer should observe a 40-second delay.

20 people x 2 second lag/person=
40 second lag

FIGURE 2. The two-seismometer set up.



ALTERING THE HYPOCENTER

Once the lag-time is mastered, the group can be introduced to a slightly more complicated version of the pattern. A new Earthquake should be chosen, but this one should be located near the center of the line. Two new Seismometers should also be picked and located at opposite ends of the line (Figure 2).

In this configuration, as well as many other configurations to come, an Earthquake will have two neighbors, and must squeeze both of their hands simultaneously to send out a P-wave, then wait two seconds before shaking both their hands to send out an S-wave.

The two Seismometers now have the same responsibilities as the one Seismometer did in the original set up. However, because of the Earthquake's location in the line, it is possible for each Seismometer to note a different lag time.

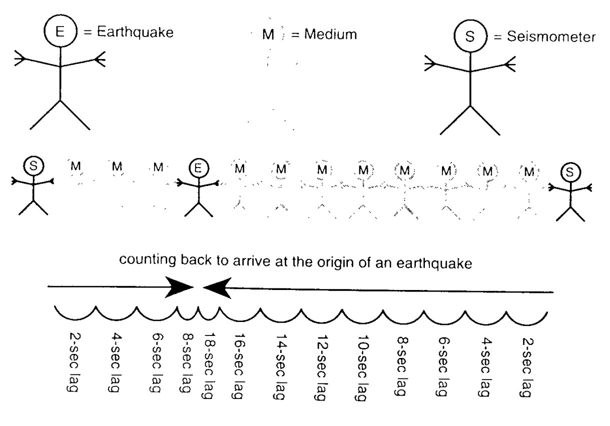
This is a good point to begin a more in-depth discussion and description of Earthquake locating. The lag times obtained by the two Seismometers will vary with the distance (number of mediums/students) away from the Earthquake. The farther the Seismometer, the greater the lag time (Figure 3).

> *"Whose Fault Is It?" lends itself to numerous graphing exercises.*

To figure out who the Earthquake is, the players need the lag time data from the each Seismometer. The players can use the equation on page 31 to determine how many people the seismic waves had to have traveled through in order to get from the Earthquake to each Seismometer. Once this distance (number of players) is known, the group needs only to count that number of people away from the corresponding Seismometer to find the Earthquake.

For this pattern, two Seismometers are redundant, but each serves as a checking mechanism for the other. Often, with a large group, the results may not pin-point an Earthquake exactly, but may narrow the possibilities down to a few people. If the possible seismic source is larger than three people per 25 players, then your students may need more practice with the "sending" process. Future patterns may be more complex and require additional Seismometers (see Note at end of article). If players have not yet mastered how to locate an Earthquake by this step, do not go on, but continue to practice.

FIGURE 3. Lag times between sensors and earthquake.



YOUR FIRST QUAKE

Before starting your quake, you should stress the importance of the following rules to your students.

1. Only the chosen Earthquake can initiate seismic waves.
2. An Earthquake must only be uncovered by using the lag time information provided by the Seismometers.
3. Nobody is to shout out an answer, especially the neighbor of an Earthquake.
4. This game is done by consensus and cooperation.
5. The Earthquake should never divulge his/her identity until he/she is uncovered as the Earthquake.

To begin, you will use the same student pattern as shown in Figure 2, but choose new Seismometers. You will also secretly select another student to serve as a new Earthquake. This is done by having all the players close their eyes and tapping one student on the head to play the Earthquake.

THE TRAVEL/TIME GRAPH

"Whose Fault Is It?" lends itself to numerous graphing exercises. I use this game to create a graph known as a P-wave and S-wave travel/time graph. This graph provides a means for visualizing the rate of speed of each wave and its arrival time.

The graph is created by first obtaining data from the game, recording this data in a table format, and then drawing the graph. Begin by placing an Earthquake at one end of a line of students. The teacher can then add Seismometers to the line at regularly spaced intervals. The Seismometers will detect seismic waves as they pass between Mediums by gently placing their hands on top of the clasped hands of the Mediums. For an average-sized class, one Seismometer spaced every five players is adequate.

The Earthquake should announce when he/she is going to start the P-wave. Each Seismometer should count the time it takes the wave to travel from the Earthquake to his/her hand. The same method is used to determine S-wave speed.

A data table is completed using information collected from each Seismometer (see example in Figure 4). This data is then used to complete a travel-time graph (Figure 5). Distance in people-lengths is plotted on the x-axis and time in seconds on the y-axis.

20 seconds represents a distance of ten people.

The graph helps in determining the distance that seismic waves travel before being received by the Seismometer. This is done by comparing the vertical difference of S-wave and P-wave arrival times to the corresponding horizontal distance. In the example below, an S-P wave arrival time difference of 20 seconds represents a distance of ten people.

Non-linear graphs can also be created by altering the speeds of seismic waves. In a line of players, each person can be assigned additional delays to slow down the rate of P-wave and/or S-wave transmission. Conversely, large delays can be assigned to waves at first. These delays can then be successively decreased away from the Earthquake. This modification is analogous to delays caused by the layers within the Earth. Real P- and S-waves travel faster as they penetrate deeper into the Earth.

Real applications and exercises related to earthquake locating are included in many geology textbooks. A good text should provide an explanation of seismic station triangulation as well as data that can be plotted on a map.

NOTE
Advanced patterns that require three or more sensors and triangulation will appear in the Idea Bank section of an upcoming issue of *TST*.

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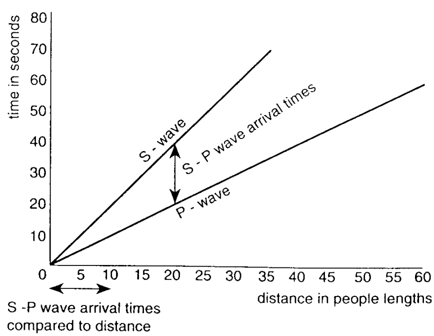
FIGURE 4. A sample data table.

P- and S-wave travel-time table		
Distance in "people lengths"	Wave times in seconds	
	P-wave	S-wave
0	0	0
5	5	10
10	10	20
15	15	30
20	20	40
25	25	50
30	30	60
35	35	70

FIGURE 5. The time-travel graph.



ADVANCED FAULT FINDING

In an article I wrote recently for *The Science Teacher* called "Whose Fault Is It?" (November 1993) I described a game in which students locate a "mystery" earthquake by holding hands and transmitting imaginary seismic waves. The following is a continuation of that article describing a more advanced earthquake pattern.

Advanced patterns—If the group is successful at locating the mystery *Earthquake* (the student initiating the seismic waves) in a linear pattern, the group should move on to more challenging patterns. Figure 1 shows one example of a more complex pattern, but any number of patterns could be created. Pattern configurations are only limited by group size and your imagination. However, some guidelines should be followed if an original pattern is being used:

1. All players, except *Seismometers*, may hold hands in two ways, either clasping the hand of one other player or the hands of two other players.
2. Many patterns will require three *Seismometers* to locate an *Earthquake.*
3. *Seismometers* can only receive seismic waves, they may not transmit them. *Seismometers* may only be situated in one of two ways:

 a. to receive seismic waves at the edges of a pattern by holding the hand of someone at the end of a line, or

 b. to feel seismic waves pass from one player to another by gently placing his or her hand over the clasped hands of other players.
4. It is important for a player to send a p-wave and an s-wave only once. This rule must be emphasized especially when using a pattern in which players hold hands in a closed loop configuration.

Figuring out advanced patterns—Nonlinear patterns are more challenging to solve. Since there is more than one seismic station and more than one direction for seismic waves to travel, there may seem to be many possible solutions. Yet if all rules and guidelines are followed, the puzzle can be easily solved.

Since only the distances from each *Seismometer* to an *Earthquake* can be determined, the *Earthquake* can only be discovered by the process of elimination. The person who can satisfy the distance requirements for each *Seismometer* is the *Earthquake* (Figure 2).

Figure 2 shows that, by using data only from *Seismometer 1*, four possible solutions exist. Likewise, *Seismometer 2* can base a solution on six possibe *Earthquakes.* If the data from two *Seismometers* are used, such as *Seismometers 2* and *3*, then the possible solutions are narrowed down to only two locations. However, when the data for all three stations are used, only one person could be responsible for generating the initial seismic waves.

Additional applications—This game will also lend itself to lessons and analogies in earthquake intensity and seismic wave shadow zones. With continued and

FIGURE 1. Sample pattern for advanced earthquake-finding activity.

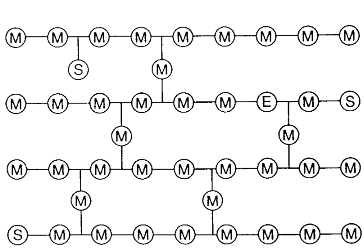
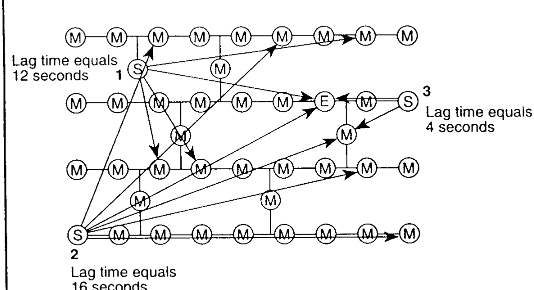


FIGURE 2. Possible solution using sample pattern diagramed in Figure 1.



creative experimentation, a teacher may see many other possible applications for this classroom activity.

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