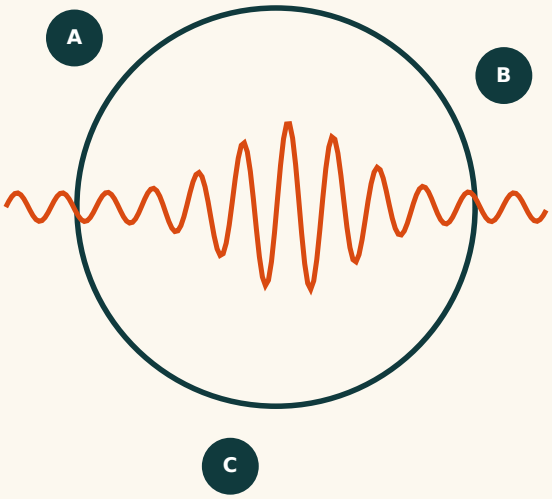
EARTH SCIENCE ACTIVITY PACK

EARTHQUAKE DETECTIVE

Find it. Measure it. Explain it.



Use seismic waves, arrival times and station data to investigate where earthquakes happen - and why locating them is more complicated than drawing three circles on a map.

STUDENT ACTIVITY PACK

Works with the free Earthquake Detective at Dig Earth Studio.

Name: _____ Class: _____ Date: _____

OPEN EARTHQUAKE DETECTIVE

digearthstudio.com/earthquake-detective/

Dig Earth Studio

ORIENTATION

MEET THE P AND S WAVES

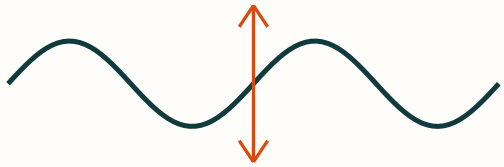
Earthquakes release energy as seismic waves. Two important body waves are P waves and S waves.

P WAVE - COMPRESSION



Particle motion parallel to travel

S WAVE - SHEAR



Particle motion perpendicular to travel

P WAVES - PRIMARY

Fastest body waves, so they arrive first.
Compressional motion: particles move back and forth roughly parallel to wave travel.

Can travel through: solids, liquids and gases.

Simplified speed: about 6 km/s.

S WAVES - SECONDARY

Travel more slowly than P waves, so they arrive later.
Shear motion: particles move perpendicular to wave travel.

Can travel through: solids, but not liquids.

Simplified speed: about 3.4 km/s.

WHY THE P-S GAP MATTERS

P and S waves start at the earthquake source at about the same time. Because P waves travel faster, the P wave gets farther ahead as both waves travel. A larger P-S arrival-time gap usually means a greater source distance.

Model simplification: the interactive uses approximate, constant wave speeds. Real seismic-wave speeds vary through the Earth.

QUICK CHECK

1. The first wave to arrive is the _____ wave.
2. The slower wave is the _____ wave.
3. A larger P-S gap usually means the source is _____ away.
4. S waves travel through _____ but not liquids.

THINK

Why would the P-S arrival-time gap become larger as the earthquake gets farther away?

SKILL 01

HOW TO PICK P AND S ARRIVAL TIMES

Before you can calculate earthquake distance, you need to identify when each seismic phase first arrives.

THE RULE

A wave arrival is the beginning of a new change in the seismogram. It is not the biggest wiggle. Read the trace from left to right and ask: Where does this new motion begin?

STEP 1 - FIND P

Follow the quiet background trace from left to right. The first clear departure from the background is your P-wave arrival.

STEP 2 - FIND S

Continue farther right. Look for a second clear change, usually followed by stronger motion. Pick the start of that change.

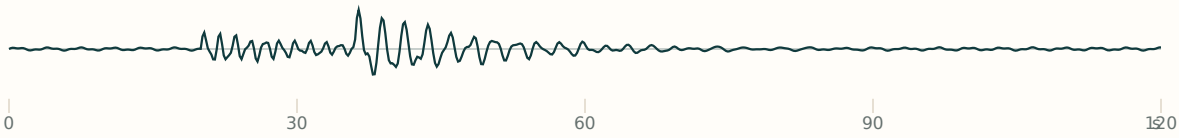
PRACTICE EXAMPLE



P = 24 s | S = 39 s | P-S gap = 15 s | source distance ≈ 120 km

Important: 8 km/s is a simplified P-S distance conversion factor, not the speed of either seismic wave.

YOUR TURN



P-wave arrival: _____ s

S-wave arrival: _____ s

P-S gap: _____ s

Estimated source distance: _____ km

MEASUREMENT UNCERTAINTY

Your pick may differ slightly from someone else's. That is normal. A 1 s difference changes estimated source distance by about 8 km. Aim for a reasonable interpretation of where the wave begins.

THINK

Why should you not choose the largest peak as the arrival time?

INVESTIGATION 01

SCENARIO A: FIND YOUR FIRST EARTHQUAKE

Scenario A is intentionally simple: an idealized surface-source case for learning the basic distance-circle method.

1 - START THE EARTHQUAKE

Select Scenario A, click Start Earthquake, and wait for the three seismic traces. Do not reveal the source yet.

2 - PICK THE ARRIVALS

Station	P arrival (s)	S arrival (s)	P-S gap (s)
A	_____	_____	_____
B	_____	_____	_____
C	_____	_____	_____

3 - CALCULATE SOURCE DISTANCE

D ≈ (P-S gap) × 8 km/s

Station	P-S gap (s)	Estimated source distance (km)
A	_____	_____
B	_____	_____
C	_____	_____

4 - USE THE DISTANCE CIRCLES

A single station tells you the source could be anywhere on one circle. Two stations narrow the possibilities. Three stations should bring the circles together near one location.

Did all three circles meet at exactly the same point? ☐ Yes ☐ No

5 - REVEAL AND COMPARE

Now reveal the earthquake source. How close was your location estimate?

☐ Very close ☐ Close ☐ Some distance away

If the circles did not meet exactly, give one possible reason: _____

THINK

Why can one seismic station give you a source distance but not an exact location?

MODEL NOTE

Scenario A uses an idealized 0 km depth so source distance can be treated as a surface-map distance. Real tectonic earthquakes usually begin below the surface.

INVESTIGATION 02

SCENARIO D: WHEN THE CIRCLES DO NOT MEET

Select Scenario D, click Start Earthquake, and do not reveal the source yet.
Use the same arrival-picking method to investigate an earthquake that begins below the surface.

1 - MEASURE THE EVIDENCE

Station	P arrival	S arrival	P-S gap	Source distance
A	_____ s	_____ s	_____ s	_____ km
B	_____ s	_____ s	_____ s	_____ km
C	_____ s	_____ s	_____ s	_____ km

2 - LOOK AT THE MAP

Use your source distances to display the three raw distance circles. What happens?

- ☐ The circles meet neatly at one point
- ☐ The circles come close, but do not meet perfectly
- ☐ The circles clearly do not agree

3 - MAKE A HYPOTHESIS

You used the same method as in Scenario A. Why might the circles behave differently now? Write one possible explanation before continuing.

THINK IN THREE DIMENSIONS

The map shows the Earth's surface. But the earthquake begins at the hypocenter below the surface. The P-S measurement gives a source-to-station distance. Is that the same as a horizontal map distance?

SKETCH IT

In the space below, sketch the surface, one station, the epicenter, the hypocenter and the source-to-station path.

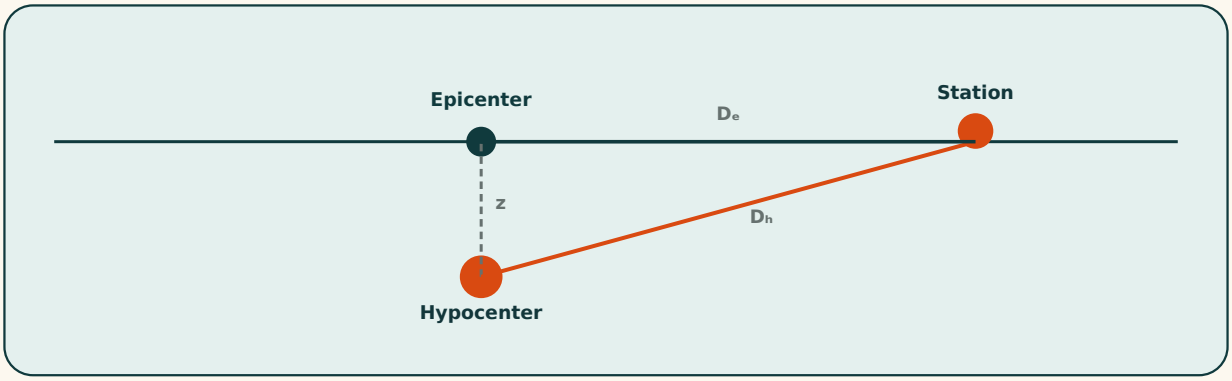
THE MYSTERY

If the earthquake source is deep underground, could the source-to-station distance and the horizontal map distance be different? Explain.

CONCEPT

EPICENTER, HYPOCENTER AND DEPTH

The raw circles fail because the P-S gap estimates distance to an underground source, while the map is two-dimensional.



HYPOCENTER

The point inside the Earth where the earthquake begins. P-S timing estimates the station-to-hypocenter distance, D_h.

EPICENTER

The point on the surface directly above the hypocenter. The horizontal station-to-epicenter distance is D_e.

$$D_h^2 = D_e^2 + z^2 \rightarrow D_e = \sqrt{(D_h^2 - z^2)}$$

EXAMPLE

If D_h = 100 km and z = 60 km:

$D_e = \sqrt{(100^2 - 60^2)} = \sqrt{6400} = 80$ km.

The station is 100 km from the hypocenter, but only 80 km horizontally from the epicenter.

RETURN TO SCENARIO D

Test different assumed depths and watch the circles change. At approximately what depth do they come closest together?

Estimated depth: _____ km

EXPLAIN

Why does increasing the assumed depth make the surface circles smaller?

KEY IDEA

Locating an earthquake is a three-dimensional problem: P-S timing gives source distance, and depth must be accounted for before that distance is used correctly on a surface map.

INVESTIGATION 03

SCENARIO E: LOCATE A DEEPER EARTHQUAKE

This time, carry out most of the investigation yourself.

1 - MEASURE

Station	P arrival	S arrival	P-S gap	Hypocentral distance
A	_____ s	_____ s	_____ s	_____ km
B	_____ s	_____ s	_____ s	_____ km
C	_____ s	_____ s	_____ s	_____ km

2 - TEST THE RAW CIRCLES

Do the uncorrected circles converge neatly? What does the pattern suggest?

3 - ESTIMATE THE DEPTH

My estimated depth: _____ km

Why did you choose this value?

4 - LOCATE THE EPICENTER

At your estimated depth, use the corrected circles to locate the epicenter in the interactive. Do not reveal the source yet.
Do the corrected circles converge closely near one point? ☐ Yes ☐ No

5 - REVEAL AND COMPARE

Actual depth: _____ km Difference from estimate: _____ km

- ☐ Epicenter estimate: very close
- ☐ close
- ☐ some distance away

EXPLAIN YOUR METHOD

In your own words, explain how you went from a seismogram to an estimated earthquake location. Use: P wave, S wave, P-S gap, hypocenter, depth, epicenter.

UNCERTAINTY

Could two students choose slightly different arrival times and still both produce scientifically reasonable locations? Explain why.

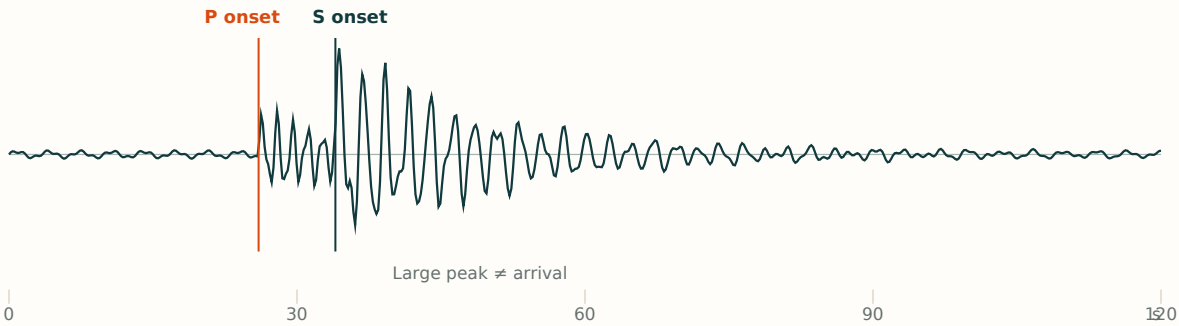
SKILL 02

WHEN P AND S WAVES OVERLAP

A nearby source can produce a small P-S gap. The S wave may arrive while P-wave motion is still visible.

DO NOT WAIT FOR P TO STOP

After you pick P, keep following the trace. The S arrival is where a new phase of motion begins - often a change in amplitude or pattern - even if earlier P-wave motion is still present.



CHALLENGE CASE

Use Scenario C - Station C with Firm ground selected. Make your best P and S picks.

P-wave arrival: _____ s

S-wave arrival: _____ s

P-S gap: _____ s

Estimated source distance: _____ km

WHAT MADE THIS TRACE HARDER?

- ☐ The P-S gap was smaller
- ☐ P-wave motion was still visible when S arrived
- ☐ The largest peak was not the S-wave arrival
- ☐ The change between phases required interpretation

COMPARE YOUR PICK

Another student's S pick: _____ s

Difference: _____ s

Effect on source distance: _____ s × 8 km/s = _____ km

EXPLAIN

Why is arrival picking more difficult when P and S motion overlap?

INVESTIGATION 04

SAME EARTHQUAKE, DIFFERENT GROUND

Keep the earthquake fixed. Change only the local ground condition and watch how the recorded motion responds.

SITE RESPONSE

Earthquake Detective uses three simplified site types: Bedrock | Firm ground | Soft sediment. Changing the site affects recorded amplitude and duration, but does not change the earthquake source.

1 - COMPARE THE THREE SITE CONDITIONS

Ground	Relative amplitude	Duration	P arrival changed?	S arrival changed?
Bedrock	_____	_____	Yes / No	Yes / No
Firm ground	_____	_____	Yes / No	Yes / No
Soft sediment	_____	_____	Yes / No	Yes / No

2 - WHAT CHANGED?

Smallest recorded motion: _____

Largest recorded motion: _____

Longest-lasting motion: _____

3 - WHAT DID NOT CHANGE?

Changing ground condition changed the P arrival time. ☐ Yes ☐ No

Changing ground condition changed the S arrival time. ☐ Yes ☐ No

MAGNITUDE IS NOT RECORDED AMPLITUDE

Magnitude describes the size of the earthquake source. The height of the wiggles at one station is the recorded amplitude, which can also be influenced by distance, wave path and local site conditions.

THINK

Station X is on bedrock. Station Y is on soft sediment and records larger motion from the same earthquake. Does the earthquake have a larger magnitude at Station Y? Explain.

KEY IDEA

Magnitude belongs to the earthquake. Recorded shaking belongs to the earthquake-path-site combination.

INVESTIGATION 05

MAGNITUDE, DISTANCE AND AMPLITUDE

A large trace does not automatically mean a large earthquake.

PART A - SAME EARTHQUAKE, DIFFERENT DISTANCES

Choose the scenario assigned by your teacher and keep all stations on Firm ground. Compare the three stations.

Station	Source distance (km)	Relative trace amplitude
A	_____	Small / Medium / Large
B	_____	Small / Medium / Large
C	_____	Small / Medium / Large

Closest station: _____ Largest amplitude: _____

ATTENUATION

For the same earthquake and similar site conditions, recorded motion generally becomes weaker with distance as seismic wave energy spreads and is attenuated.

PART B - COMPARE TWO EARTHQUAKES

Compare Scenario C - Station C with Scenario G - Station B. Keep both sites on Firm ground. Examine the traces before revealing the source information.

	Earthquake 1	Earthquake 2
Scenario	_____	_____
Station used	_____	_____
Source distance	_____ km	_____ km
Relative amplitude	_____	_____
Your guess: larger magnitude?	☐	☐

REVEAL AND EXPLAIN

Earthquake 1 magnitude: _____ Earthquake 2 magnitude: _____

Why might a smaller earthquake produce a larger-amplitude trace at one station than a larger earthquake produces at another?

KEY IDEA

Magnitude ≠ amplitude at one station. Recorded amplitude is influenced by source magnitude + distance + wave path + local site conditions.

FINAL INVESTIGATION

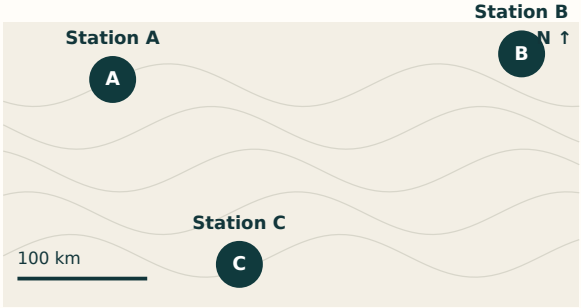
FINAL CASE: SOLVE THE EARTHQUAKE

Use everything you have learned. Set all stations to Firm ground, select Scenario G, and do not reveal the source yet.

1 - MEASURE THE SEISMIC EVIDENCE

Station	P arrival	S arrival	P-S gap	Hypocentral distance
A	_____ s	_____ s	_____ s	_____ km
B	_____ s	_____ s	_____ s	_____ km
C	_____ s	_____ s	_____ s	_____ km

2 - ESTIMATE DEPTH AND EPICENTER



DEPTH

Adjust the assumed depth until the corrected circles agree as closely as possible.

Estimated depth: _____ km

EPICENTER

On the map, mark your estimated epicenter with a large X.

3 - MAKE YOUR FINAL PREDICTION

Recorded motion looks: ☐ relatively small ☐ moderate ☐ relatively large

Can you determine the earthquake's exact magnitude from the height of these traces alone? Explain.

4 - REVEAL AND COMPARE

Actual depth: _____ km Actual magnitude: _____ Depth error: _____ km

After revealing the source, mark the actual epicenter on your map with a ●. How close was your X?

- ☐ Very close
- ☐ Close
- ☐ Some distance away

5 - COMPLETE THE REASONING CHAIN

P and S arrivals → _____ → distance to the _____ → account for _____ → estimate the _____

CASE CONCLUSION

In two or three sentences, explain how several seismic stations can be used to locate an earthquake.

FINAL CHECK

EARTHQUAKE DETECTIVE QUIZ

Try these without looking back. The goal is to apply the ideas, not memorize wording.

1 - FIRST ARRIVAL

Which seismic wave normally arrives first?

☐ P wave ☐ S wave

2 - WHY FIRST?

Why does that wave arrive first?

☐ Faster ☐ Larger ☐ Starts earlier

3 - ARRIVAL PICKING

What should you look for when picking a wave arrival?

☐ Largest peak ☐ Start of a clear change ☐ End of shaking

4 - P-S CALCULATION

P arrives at 18 s and S at 32 s. a. Calculate the P-S gap. b. Use the Earthquake Detective approximation to estimate source distance.

5 - DISTANCE CLUE

What happens to the P-S gap as source distance generally increases? Why?

6 - EPICENTER VS HYPOCENTER

Define hypocenter and epicenter in one sentence each.

7 - DEPTH GEOMETRY

Why can't the full hypocentral distance always be drawn directly as a radius on a surface map?

8 - DEPTH CALCULATION

A station is 100 km from the hypocenter and the earthquake is 60 km deep. Use $D_e = \sqrt{(D_h^2 - z^2)}$. What is D_e?

9 - CIRCLE MISMATCH

Three raw distance circles do not meet neatly for a deep earthquake. Give one likely reason.

10 - MAGNITUDE

Two stations record the same earthquake; one trace is larger. Does the earthquake have a larger magnitude there? Explain.

11 - SITE RESPONSE

Which ground condition in Earthquake Detective generally produces the strongest and longest-lasting response? What is this effect called?

12 - 8 KM/S

Why is this statement incorrect: “8 km/s is the speed of the earthquake wave”?

13 - SIMPLIFICATION

Why are simplified constant wave velocities useful for this activity?

14 - REAL SEISMOLOGY

Why is Earthquake Detective still only an approximation of real earthquake location?

FINAL REFLECTION The most important thing I learned about locating earthquakes is...