ANSWER KEY

EARTHQUAKE DETECTIVE

Expected answers, calculations and likely outcomes for the Earthquake Detective Student Activity Pack. Because students make their own arrival picks, numerical results can vary slightly. Mark the **reasoning and phase interpretation** rather than requiring identical clicks.

ARRIVAL-PICK TOLERANCE

A difference of about **1 second** can be reasonable on a trace. In the simplified model, 1 second of P-S separation changes the calculated source distance by about **8 km**. Treat decimal values below as **reference onsets / typical expected picks**, not exact clicks.

PAGE 2 - MEET THE P AND S WAVES

1. P wave **2.** S wave **3.** farther away **4.** solids

Think: P waves travel faster than S waves. As the waves travel farther, the faster P wave gets progressively farther ahead, so the arrival-time gap increases.

PAGE 3 - HOW TO PICK ARRIVAL TIMES

Worked example: P = 24 s, S = 39 s. $\Delta t = 39 - 24 = 15$ s -> $D \approx 15 \times 8 = 120$ km.

Your turn: accept a reasonable onset-based P pick and S pick from the printed practice trace. Check that the student calculates **P-S gap = S - P** and then **source distance ≈ gap × 8 km**. Apply the ±1 s picking tolerance where appropriate.

Think: the arrival is the onset of the phase; the largest peak may occur after the wave has already arrived.

PAGE 4 - SCENARIO A

Station	P arrival	S arrival	P-S gap	Source distance
A	≈ 37.3 s	≈ 59.3 s	≈ 22.0 s	≈ 176 km
B	≈ 45.3 s	≈ 73.3 s	≈ 28.0 s	≈ 224 km
C	≈ 32.0 s	≈ 50.0 s	≈ 18.0 s	≈ 144 km

Did all three circles meet exactly? They should converge very closely, but small mismatch is acceptable because of manual picking and rounding.

Reveal and compare: “Very close” is the expected outcome for a good set of picks. Accept “Close” if the student’s picks are reasonable. Possible mismatch reasons: slightly different P/S onset picks or rounding.

Why can one station not locate the earthquake? One station gives a distance, but the source could lie anywhere at that distance around the station. Additional stations narrow the location.

DEPTH INVESTIGATION

PAGES 5-6

PAGE 5 - SCENARIO D: WHEN THE CIRCLES DON'T MEET

Scenario D: true depth 80 km, magnitude M6.0.

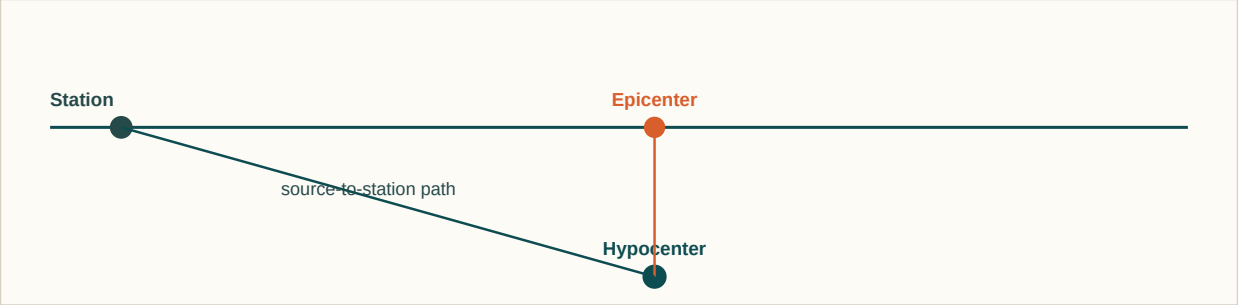
Station	P arrival	S arrival	P-S gap	Hypocentral distance
A	≈ 50.8 s	≈ 82.9 s	≈ 32.1 s	≈ 257 km
B	≈ 48.4 s	≈ 78.7 s	≈ 30.3 s	≈ 242 km
C	≈ 33.5 s	≈ 52.6 s	≈ 19.1 s	≈ 153 km

Expected observation: the raw source-distance circles do not converge neatly when treated as horizontal map radii.

Why? The P-S gap estimates the three-dimensional distance to the **hypocenter**, while the map requires horizontal distance to the **epicenter**.

Where does the earthquake begin? At the hypocenter below the surface. **Could the two distances differ?** Yes; for a deep earthquake the hypocentral distance is larger.

SKETCH IT - REFERENCE



PAGE 6 - EPICENTER, HYPOCENTER AND DEPTH

Hypocenter: point inside the Earth where the earthquake begins. **Epicenter:** point on the surface directly above the hypocenter.

$$Dh^2 = De^2 + z^2 \quad -> \quad De = \sqrt{(Dh^2 - z^2)}$$

Worked example: De = $\sqrt{(100^2 - 60^2)}$ = 80 km.

Scenario D best-fit depth: approximately **80 km**. A modest range around this can be accepted if the student's manual picks make the corrected circles converge well.

Why do circles shrink as assumed depth increases? Part of the measured source distance is vertical; once depth is removed, the remaining horizontal distance is smaller.

Which is larger for a deep earthquake? Hypocentral distance.

INDEPENDENT CASE

PAGES 7-8

PAGE 7 - SCENARIO E

Scenario E: true depth 120 km, magnitude M6.5.

Station	P arrival	S arrival	P-S gap	Hypocentral distance
A	≈ 38.6 s	≈ 61.6 s	≈ 23.0 s	≈ 184 km
B	≈ 46.8 s	≈ 76.0 s	≈ 29.2 s	234 km
C	≈ 45.4 s	≈ 73.4 s	≈ 28.0 s	≈ 224 km

Raw circles converge neatly? No. **Expected depth estimate:** approximately 120 km.

Why choose this value? Around 120 km, the depth-corrected horizontal circles converge most closely near one point.

Do corrected circles converge closely near one point? Yes, approximately. **Actual depth:** 120 km. **Difference from estimate:** |student estimate - 120 km|.

Epicenter estimate: usually very close or close with reasonable picks. Accept some variation from manual onset selection.

Method explanation: identify P and S arrivals, calculate the P-S gap, convert the gap to hypocentral distance, test assumed depth values, then use corrected horizontal distances to estimate the epicenter.

Uncertainty: yes. Arrival picking involves interpretation, so slightly different reasonable picks can still produce scientifically reasonable locations.

PAGE 8 - WHEN P AND S WAVES OVERLAP

LOCKED CASE

Scenario C - Station C - Firm ground

P arrival	S arrival	P-S gap	Source distance
≈ 20.9 s	≈ 30.6 s	≈ 9.7 s	≈ 77.6 km

Acceptable classroom range: use the general ±1 s onset-pick tolerance when the phase interpretation is reasonable. Rounded answers of about **21 s, 31 s, 10 s and 80 km** are appropriate.

Expected observations: the P-S gap is small; P-wave motion is still visible when S arrives; the largest peak is not the S arrival; identifying the onset requires interpretation.

Why is it harder? There is no quiet interval between phases. Students must identify a change in the character or amplitude of the trace.

Compare your pick: difference between S picks × 8 km/s gives the change in estimated source distance. Examples: 1 s -> about 8 km; 2 s -> about 16 km.

SITE RESPONSE & MAGNITUDE

PAGES 9-10

PAGE 9 - SAME EARTHQUAKE, DIFFERENT GROUND

Ground	Relative amplitude	Duration	P changed?	S changed?
Bedrock	Lowest	Shortest	No	No
Firm ground	Intermediate	Intermediate	No	No
Soft sediment	Highest	Longest	No	No

Smallest recorded motion: Bedrock. **Largest recorded motion:** Soft sediment. **Longest-lasting motion:** Soft sediment.

Effect name: site response or site amplification.

Think: No. Station Y does not have a larger earthquake magnitude. It is the same earthquake; soft sediment changes the recorded response, not the source magnitude.

PAGE 10 - MAGNITUDE, DISTANCE AND AMPLITUDE

Part A - teacher-assigned scenario. The worksheet does not lock this part to one scenario. Mark the student's distances and Small / Medium / Large classifications against the scenario actually assigned. The intended pattern is: **closest station -> generally largest trace; farthest station -> generally smallest trace**, with all stations on Firm ground.

OPTIONAL REFERENCE IF SCENARIO D IS ASSIGNED

Station	Source distance	Relative motion	Worksheet label
A	≈ 257 km	≈ 0.74×	Small
B	≈ 242 km	≈ 0.78×	Medium
C	≈ 153 km	≈ 1.15×	Large

Part B - locked comparison, both Firm ground

Case	Magnitude	Source distance	Relative motion
Scenario C - Station C	M6.2	≈ 78 km	≈ 2.33×
Scenario G - Station B	M6.7	≈ 345 km	≈ 0.90×

Your guess: larger magnitude? This is a pre-reveal prediction; do not mark it for correctness.

EXPECTED CONCLUSION

The **smaller M6.2 earthquake** produces the larger trace at the chosen station because it is much closer. Trace height alone does not determine earthquake magnitude.

Magnitude belongs to the source. A single earthquake has one magnitude; recorded amplitude varies from station to station.

FINAL INVESTIGATION

PAGE 11 - SCENARIO G

Scenario G: true depth 220 km, magnitude M6.7.

Station	P arrival	S arrival	P-S gap	Hypocentral distance
A	≈ 48.0 s	≈ 77.9 s	≈ 29.9 s	239 km
B	≈ 65.6 s	≈ 108.7 s	≈ 43.1 s	≈ 345 km
C	≈ 55.8 s	≈ 91.7 s	≈ 35.9 s	≈ 287 km

Raw circles: should not converge correctly because the distances are to the hypocenter. **Expected depth estimate:** approximately 220 km.

Epicenter: students mark an **X** on the printed worksheet map before reveal. After revealing the source, they add the actual epicenter with a ● and judge how close the X was. Exact marks may vary with picks.

Recorded motion looks: accept a defensible qualitative choice based on the displayed traces; this is an observation rather than a magnitude measurement. **Can exact magnitude be determined from trace height alone?** No.

Actual revealed magnitude: M6.7. **Actual depth:** 220 km. **Depth error:** |student estimated depth - 220 km|.

INVESTIGATION CHAIN

P and S arrivals -> P-S gap -> distance to hypocenter -> account for depth -> estimate epicenter

CASE CONCLUSION

A strong answer explains that each station provides an estimated source distance from its P-S gap. Several stations constrain the location, and earthquake depth must be accounted for to convert those 3-D source distances into horizontal surface distances.

WHY MIGHT CIRCLES NOT CONVERGE PERFECTLY?

- small differences in P- or S-wave picks;
- rounding of calculated distances;
- an assumed depth that is not quite correct.

FINAL QUIZ

PAGE 12 - ANSWERS

1. Which wave arrives first?
P wave.

2. Why?
It travels faster.

3. What should you look for when picking an arrival?
The beginning of a clear new change in the trace.

4. P = 18 s, S = 32 s
a. $\Delta t = 14$ s. b. $D \approx 14 \times 8 = 112$ km.

5. What happens to the P-S gap with increasing distance?
It becomes larger because the faster P wave gets progressively farther ahead of the slower S wave.

6. Define hypocenter and epicenter.
Hypocenter: point inside the Earth where the earthquake begins. Epicenter: point on the surface directly above the source.

7. Why can't full hypocentral distance always be used as a surface-map radius?
It includes vertical depth; a surface map needs the horizontal distance to the epicenter.

8. Dh = 100 km, z = 60 km
De = 80 km.

9. Why might raw circles fail to meet for a deep earthquake?
The measured distances are to the hypocenter and need a depth correction before being used as horizontal map radii.

10. Does a larger trace mean a larger magnitude at that station?
No. Magnitude belongs to the source; recorded amplitude varies with distance, site response and other effects.

11. Strongest and longest-lasting site response?
Soft sediment. Effect: site response / site amplification.

12. Why is “8 km/s is the speed of the earthquake wave” incorrect?
8 km/s is the simplified P-S distance conversion factor, not the velocity of either P or S waves.

13. Why use simplified constant velocities?
They make the timing-distance relationship easy to calculate so students can focus on the main concepts.

14. Why is the model still an approximation?
Real seismic velocities vary, the Earth is layered and heterogeneous, wave paths can bend, and professional location uses many stations and velocity models.

FINAL REFLECTION

No single required wording. Look for evidence that the student understands at least one major relationship: P-S timing -> source distance; hypocenter + depth -> epicenter; magnitude ≠ recorded amplitude; or local ground conditions affect recorded shaking.