

Racing Across the Ocean: Does Depth Set a Tsunami's Speed?

Learning target: I can use tide-gauge travel-time data to argue what controls a tsunami's speed, and use that claim to forecast when waves will reach a coast and how much warning people will have.

Claim, evidence, reasoning

About 45 min

Individual

MS-ESS3-2 · assesses

writing

data analysis

Name _____

Date _____

Period _____

Directions

Read the background and study both datasets. Complete the warm-up calculations first, because they become your evidence. Then write your Claim, Evidence and Reasoning. Strong evidence uses specific numbers from both datasets. Strong reasoning explains why the pattern happens, not only what it is. Finish with the two forecasts in q4 and q5.

You will need: This worksheet, Pencil, Calculator

The question

A tsunami warning center keeps records from tide gauges, instruments that measure sea level at harbors around an ocean. For past tsunamis from one undersea fault, scientists know where each tsunami started, how far the waves traveled to each gauge, how long they took, and how high the water rose. A new forecaster asks a simple question: what sets how fast a tsunami travels? One coworker says it is the size of the earthquake. Another says it is the depth of the ocean along the path. Your job is to decide from the data.

Background you can use — A tsunami moves the whole column of water from the seafloor to the surface. Its crests are often more than 100 km apart, which is far longer than the ocean is deep (about 4 km on average). Ordinary wind waves have crests only meters apart and move only water near the surface.

Dataset 1: One tsunami reaching six tide gauges (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Tide gauge	Path mostly over	Average depth along path (m)	Distance from source (km)	Travel time to first wave (h)
A	Deepest open-ocean basin	5000	4000	5.0
B	Open ocean	4000	2850	4.0
C	Ocean with undersea ridges	3000	1850	3.0
D	Edge of the basin and continental slope	1000	700	2.0
E	Wide continental shelf	200	320	2.0
F	Shallow inland sea	50	120	1.5

Simulated data for teaching. Distances and times are realistic for a large ocean basin; average depth is the typical depth along each path.

Dataset 2: Two different earthquakes on the same fault, measured at gauge B (teaching dataset)

Simulated teaching dataset: the numbers are invented to be realistic, not measured.

Earthquake	Magnitude	Travel time to gauge B (h)	Highest water rise at gauge B (m)
Earthquake 1	7.7	4.0	0.2
Earthquake 2	8.9	4.0	1.8

Simulated data for teaching. Both tsunamis followed the same 2,850 km path averaging 4,000 m deep.

Warm-up: organize the evidence

1. Calculate the average speed to each gauge: $\text{speed} = \text{distance} \div \text{time}$. Round to the nearest whole number and show one calculation below the table.

Average depth (m)	Average speed (km/h)
Gauge A	
Gauge B	
Gauge C	
Gauge D	
Gauge E	
Gauge F	

2. Describe the pattern between depth and speed in your table. Does each extra 1,000 m of depth add the same amount of speed? Use gauges A, C and D to check.

3. Using Dataset 2, calculate the speed of each tsunami to gauge B. Then calculate how many times higher the water rose for Earthquake 2 than for Earthquake 1.

Your argument

CLAIM

Claim: What sets how fast a tsunami travels: the depth of the ocean along its path, the size of the earthquake, or both? Also state what the size of the earthquake does change.

EVIDENCE

Evidence: Give at least three specific pieces of evidence with numbers. Use at least one comparison among the six gauges and the comparison between the two earthquakes.

REASONING

Reasoning: Explain why ocean depth would control the speed of a wave that moves the whole column of water and whose crests are far longer than the ocean is deep. Explain why a bigger earthquake makes a taller tsunami but not a faster one. Finish by explaining how your claim lets a warning center forecast arrival times.

Use your claim to forecast

4. A large earthquake strikes on this fault at 2:00 a.m. A harbor town lies 3,600 km away across open ocean averaging about 4,000 m deep. Use the speed you found for gauge B to forecast when the first wave should arrive. Show your calculation and give the arrival time to the nearest 5 minutes.

5. A second town is only 120 km from the fault, across water averaging about 2,000 m deep. Use your table to estimate the tsunami's speed on that path, then estimate how many minutes the town would have before the first wave. Explain what that means for how the town must prepare **before** any earthquake happens.

6. The warning center can forecast tsunami arrival times very well, but it cannot forecast the date of the next tsunami. Explain why, using what starts a tsunami.

Evidence sentence frames

Try these frames for your Evidence box: 'Over a path averaging ___ m deep, the tsunami traveled at about ___ km/h, but over a path averaging ___ m deep it traveled at only ___ km/h.' 'Earthquakes 1 and 2 had magnitudes of ___ and ___, yet both tsunamis took ___ hours to reach gauge B, a speed of ___ km/h.' 'The bigger earthquake made the water rise ___ times higher.' For q5, find the two gauges whose depths are on either side of 2,000 m and choose a speed between theirs.

Find the rule

Physicists have found that for waves much longer than the water is deep, speed in meters per second equals the square root of $(9.8 \times \text{depth in meters})$. Use a calculator to test this rule for gauges A, D and F (multiply meters per second by 3.6 to get km/h). How close are the results to your table? Then use the rule to explain why the tsunami that reached Crescent City, California, about 10 hours after the 2011 earthquake off Japan traveled about 7,500 km in that time.