

Counting Quakes: Frequency, Magnitude and a 30-Year Forecast

Learning target: I can calculate how often earthquakes of different magnitudes happen, compare their energy on a logarithmic scale, and use the record of past quakes to write a forecast that gives a chance, not a date.

Data and graphing

About 50 min

Individual

MS-ESS3-2 · assesses

data analysis

independent practice

writing

Standards connections

MS-ESS3-2 (assesses, the data-analysis and forecasting half): Students analyze the magnitudes, frequencies and timing of past earthquakes, the kinds of data the clarification statement names, to forecast future large quakes as a likelihood over a time window and to recommend a mitigation. The forecast they write in q10 is direct evidence toward the PE.

Purpose: practice · **Time:** about 50 minutes · **Format:** individual

Answers with reasoning

Part A: How often, and how strong?

Seismometers have recorded every earthquake of magnitude 3 or larger along the Redrock Fault Zone for 50 years (1976 to 2025). The town of Millbrook sits 10 km from the fault. The table counts the quakes in each magnitude group.

Earthquakes recorded on the Redrock Fault Zone, 1976-2025 (teaching dataset)

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

Magnitude group	Number of quakes in 50 years
3.0 to 3.9	1240
4.0 to 4.9	118
5.0 to 5.9	13
6.0 to 6.9	2
7.0 or larger	0

Simulated data for teaching. The counts follow the real pattern of roughly ten times fewer quakes for each step up in magnitude, but no real fault is described.

Real reference: earthquakes worldwide in an average year

Magnitude group	Average number per year worldwide
8.0 or larger	1
7.0 to 7.9	15
6.0 to 6.9	134
5.0 to 5.9	1319

U.S. Geological Survey, Earthquake Facts and Statistics: average number of earthquakes per year worldwide (magnitude 7 and larger based on observations since 1900; magnitude 5 to 6.9 based on observations since 1990).

1. Calculate the frequency of each Redrock magnitude group. Write one full calculation under the table. 3 pts

Answer: Magnitude 4: $118 \div 50 = 2.36$ per year; $50 \div 118 = 0.42$, about one every 0.42 years (about every 5 months). Magnitude 5: $13 \div 50 = 0.26$ per year; $50 \div 13 = 3.85$, about one every 3.85 years (about every 4 years). Magnitude 6: $2 \div 50 = 0.04$ per year; $50 \div 2 = 25$, about one every 25 years.

Why: Frequency is events per unit time; the recurrence interval is its reciprocal. Students must divide in the correct order for each column.

Also acceptable: Accept 0.4 or 5 months for magnitude 4 and 3.8 or 4 years for magnitude 5.

2. Divide each Redrock count by the count in the next group up ($1,240 \div 118$, then $118 \div 13$, then $13 \div 2$). Round to one decimal place. Then do the same for the world table, starting with $1,319 \div 134$. In one sentence, describe the pattern the two tables share. 3 pts

Answer: Redrock: $1,240 \div 118 = 10.5$; $118 \div 13 = 9.1$; $13 \div 2 = 6.5$. World: $1,319 \div 134 = 9.8$; $134 \div 15 = 8.9$; $15 \div 1 = 15.0$. Pattern: in both tables, each step up in magnitude has roughly ten times fewer earthquakes (the ratios cluster around 10, with more scatter where the counts are small).

Why: This is the frequency-magnitude pattern described in the lesson's data on frequency and magnitude. The scatter at the top of each table comes from small counts, which students may notice.

Also acceptable: Accept a pattern statement such as 'bigger quakes are about 10 times rarer per step' or 'the counts drop by about a factor of 10'.

- All six ratios correct to one decimal place
- States that each step up has about ten times fewer quakes in both tables

3. (a) How many times more energy does one magnitude 6 quake release than one magnitude 4 quake? Show the multiplication. (b) Treat each quake in a group as if it were exactly 5.0 or exactly 6.0. Did the 2 magnitude 6 quakes or the 13 magnitude 5 quakes release more energy in total? About how many times more? Show your work. 3 pts

Answer: (a) Two steps: $32 \times 32 = 1,024$, so about 1,000 times more energy. (b) One magnitude 6 releases about 32 times the energy of one magnitude 5. The 2 magnitude 6 quakes released about $2 \times 32 = 64$ magnitude-5 'units' of energy, compared with 13 units for the 13 magnitude 5 quakes. $64 \div 13 = 4.9$, so the two magnitude 6 quakes released about 5 times more energy than all 13 magnitude 5 quakes together.

Why: Students apply the logarithmic energy factor and discover that the rare large quakes dominate the total energy. Treating each group as its lower bound is a stated simplification.

Also acceptable: Accept 'about 5 times' or 'about 4.9 times'. A student who uses amplitude (10 times per step) instead of energy should be redirected to the energy rule in the directions.

4. Use your answers to q2 and q3. Which magnitude group shakes Millbrook most often, and which group releases most of the fault's energy? Why does the answer matter for planning? 2 pts

Answer: The magnitude 3 group happens most often (1,240 in 50 years, about 25 a year), but the rare largest quakes release most of the energy (q3 shows two magnitude 6 quakes outweigh all the magnitude 5 quakes about five to one). Planning has to focus on the rare large quakes, because they cause the strong shaking that damages buildings, even though residents mostly feel small ones.

Why: This connects frequency and magnitude: frequent small events and rare large events must both be considered, but mitigation is driven by the rare, high-magnitude ones.

Also acceptable: Accept 'the 4s are felt most often' if the student reasons that magnitude 3 quakes are often too small to feel.

- Names the smallest group as most frequent
- Names the largest groups as releasing most energy, using q3
- Explains that mitigation must target the rare large quakes

Part B: Reading the trench

Fifty years of seismometer records contain no magnitude 7 quakes, so geologists dug a trench across the Redrock Fault. In the trench wall, soil layers that were torn and offset show eight large earthquakes (about magnitude 7 or larger). Dating plant remains in the layers gives the approximate year of each one.

Large earthquakes found in the Redrock Fault trench (teaching dataset)

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

Event	Approximate year
1	1030
2	1160
3	1220
4	1390
5	1480
6	1680
7	1750
8	1870

Simulated data for teaching. Each date is uncertain by about 20 years, as real trench dates are.

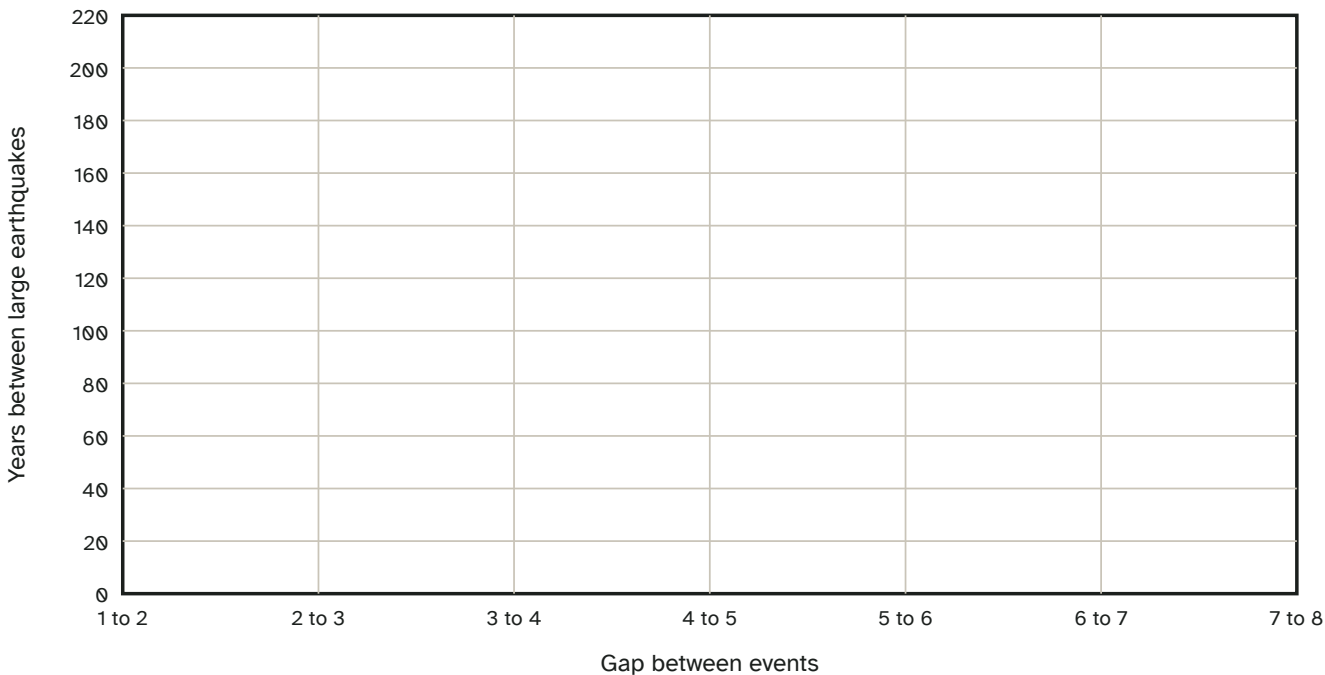
5. Subtract to find the number of years between each pair of large earthquakes. 3 pts

Answer: 1 to 2: $1160 - 1030 = 130$ years. 2 to 3: $1220 - 1160 = 60$. 3 to 4: $1390 - 1220 = 170$. 4 to 5: $1480 - 1390 = 90$. 5 to 6: $1680 - 1480 = 200$. 6 to 7: $1750 - 1680 = 70$. 7 to 8: $1870 - 1750 = 120$.

Why: Straight subtraction of consecutive dates; these values are graphed next.

Also acceptable: No alternatives; check arithmetic.

Years between large Redrock earthquakes



6. Find the average (mean) gap between large earthquakes, the shortest gap and the longest gap. 3 pts
Show how you found the average.

Answer: Sum: $130 + 60 + 170 + 90 + 200 + 70 + 120 = 840$ years. Average: $840 \div 7 = 120$ years. Shortest gap: 60 years. Longest gap: 200 years.

Why: The average is the same as $(1870 - 1030) \div 7 = 840 \div 7 = 120$. The longest gap is more than three times the shortest.

Also acceptable: Accept $(1870 - 1030) \div 7$ as the method.

7. How many years have passed since event 8, counting to 2026? In how many of the seven past gaps did the next large quake come **sooner** than that? 2 pts

Answer: $2026 - 1870 = 156$ years. The next quake came sooner than 156 years in 5 of the 7 gaps (130, 60, 90, 70 and 120). Only 2 gaps (170 and 200) were longer.

Why: The fault has now been quiet longer than in most past gaps, but not longer than every past gap.

Also acceptable: Accept '5 out of 7' or about 71 percent.

8. A Millbrook resident says: 'The average gap is 120 years and it has been 156, so the fault is 36 years overdue. The big one will hit this year.' Use your graph to explain what is reasonable and what is not reasonable about this statement. 3 pts

Answer: Reasonable: the fault has been quiet for 156 years, longer than the average gap and longer than 5 of the 7 past gaps, so a large quake in the coming decades is a serious possibility and the town should prepare. Not reasonable: the average is not a schedule. The graph shows gaps from 60 to 200 years, so the next quake could come this year or decades from now. Nothing in the data can pick 'this year', and 'overdue' wrongly suggests the fault must break on time.

Why: This targets the most common forecasting error: treating an average recurrence interval as a timetable. The irregular bars are the evidence.

Also acceptable: Accept an answer noting that two past gaps (170, 200) were longer than 156 years, so the fault has gone this long before without breaking.

- Acknowledges that 156 years is longer than the average and most gaps
- Uses the range of gaps (60 to 200) from the graph as evidence against a fixed schedule
- States that no year can be named

9. Assume the rates stay the same. (a) Using Part A, how many magnitude 6 quakes would you expect in the next 30 years? (b) Using the average gap from q6, what fraction of an average gap is 30 years? Use it to estimate the chance of a large (magnitude 7 or larger) quake in the next 30 years as 'about 1 in ____'. 3 pts

Answer: (a) $2 \text{ quakes} \div 50 \text{ years} = 0.04 \text{ per year}$; $0.04 \times 30 = 1.2$, so about 1 magnitude 6 quake expected in 30 years. (b) $30 \div 120 = 0.25$, one quarter of an average gap, so roughly a 1 in 4 chance of a magnitude 7 or larger in the next 30 years.

Why: This is a simple rate-based estimate. It ignores the time already elapsed since 1870 and the irregularity of the gaps; real forecasts use more complex models. Its purpose is to express likelihood as a chance over a window.

Also acceptable: Accept 'about 25 percent' or 'about one in four'. For (a), accept 'about one' or 1.2.

10. Write a three- to five-sentence forecast for the Millbrook town council. Include: where the hazard comes from, the sizes of quakes to expect, how likely they are over the next 30 years (use your numbers), and one thing the data **cannot** tell the council. End with one mitigation the town should fund and the number from this sheet that justifies it. 5 pts

Answer: Example: 'Millbrook sits 10 km from the Redrock Fault, which produces frequent small quakes and rare large ones. In the next 30 years, the town should expect many magnitude 4 quakes (about 2 a year) and about one magnitude 6. The trench shows large quakes of about magnitude 7 every 60 to 200 years, averaging 120, so there is roughly a 1 in 4 chance of one in the next 30 years. The data cannot tell us the year or day of the next large quake. We recommend strengthening the elementary school and the fire station first, because a magnitude 7 releases about 32 times the energy of a magnitude 6 and the fault has been quiet for 156 years, longer than 5 of its 7 past gaps.'

Why: This is the PE in miniature: data on location, magnitude and frequency become a probabilistic forecast that informs a mitigation decision.

Also acceptable: Any mitigation that reduces harm (retrofitting, building codes, early warning sensors, emergency supplies at schools, land-use limits near the fault) earns credit when it is justified with a number.

- Names the source of the hazard (the Redrock Fault) and Millbrook's distance
- Gives expected sizes and a likelihood over 30 years using numbers from q1, q6 or q9
- States one thing the data cannot tell (the date or exact time)
- Recommends one mitigation and supports it with a specific number from the sheet
- No exact date or 'it will happen in year X' claim

Teacher notes

Both Redrock datasets are simulated. The world table is real (USGS Earthquake Facts and Statistics yearly averages). The 32-times energy factor is 10 to the 1.5 power; ground-motion amplitude on a seismogram increases about 10 times per whole step, so watch for students mixing the two factors. In q3(b) the 'exactly 5.0 or 6.0' simplification keeps the arithmetic manageable; real totals depend on the decimals. The q9(b) estimate ($30 \div 120$) is a deliberately simple rate model; real forecasts such as UCERF3 combine fault slip rates, GPS data and models of stress build-up, and some account for time since the last quake. Use q8 to discuss why scientists avoid the word 'overdue'. Graph key: seven bars at 130, 60, 170, 90, 200, 70 and 120 years with a dashed line at 120 labeled 'average'; three bars sit below the line (60, 70 and 90), three above it (130, 170 and 200) and only one on it (120), which is the visual evidence for q8. Accept a dot plot if the heights are correct.

Scaffold offered to students: Three calculation patterns

Frequency: $\text{count} \div \text{number of years} = \text{events per year}$. Recurrence: $\text{number of years} \div \text{count} = \text{about one every } __ \text{ years}$. Energy: for each whole-number step up in magnitude, multiply by 32 (two steps: $32 \times 32 = 1,024$, about 1,000). Average gap: add all seven gaps, then divide by 7. For q8, look at how tall and how short your bars are compared with the dashed average line.

Extension: How much do the error bars matter?

Each trench date could be off by about 20 years in either direction. Pick the shortest gap (events 2 to 3). What are the smallest and largest that gap could really be if each date is 20 years off in opposite directions? Do the same for the longest gap. Write a paragraph explaining whether this uncertainty changes the main conclusion that large Redrock quakes do not arrive on a regular schedule, and why scientists still report forecasts as probabilities.