

Cliff, Continent and Cave: Measuring Rates of Change

Learning target: I can calculate a rate of change from measurements, graph it, convert rates to a common unit so that processes at different scales can be compared, and explain what a rate can and cannot tell me about a sudden event.

Data and graphing About 45 min Individual MS-ESS2-2 · practice data analysis independent practice

Standards connections

MS-ESS2-2 (practice): Rates measured today are the quantitative bridge between present processes and past changes. Computing and comparing them across scales is the data practice behind explanations of how long a canyon, a cliff retreat or a continent's journey took.

Purpose: practice · **Time:** about 45 minutes · **Format:** individual

Answers with reasoning

Part A: A retreating sea cliff

A park ranger drove a steel post into the ground on a grassy bluff and, once a year, measured the distance from the post to the edge of the sea cliff. Waves undercut the cliff, and chunks of it fall to the beach. The ranger's six measurements are below.

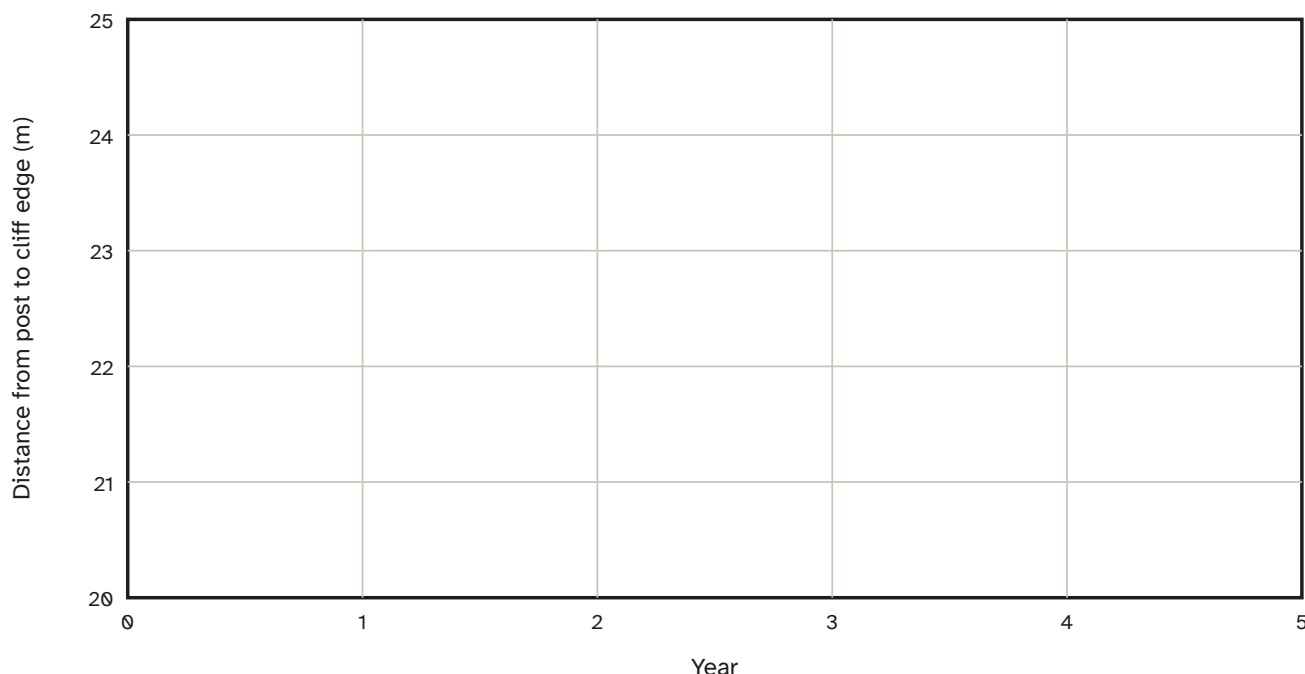
Distance from the post to the cliff edge (teaching dataset)

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

Year	Distance from post to cliff edge (m)
0	24.0
1	23.4
2	22.9
3	22.1
4	21.6
5	21.0

Simulated data for teaching; realistic for a soft-rock sea cliff.

Distance from post to cliff edge versus year



1. How many meters of bluff were lost between year 0 and year 5? Calculate the average rate of cliff retreat in meters per year. Show your work.

Answer: Lost: $24.0\text{ m} - 21.0\text{ m} = 3.0\text{ m}$. Rate: $3.0\text{ m} \div 5\text{ years} = 0.6\text{ m per year}$.

Why: Distance at the start minus distance at the end gives the bluff lost; dividing by the 5-year span gives the average rate. Students sometimes divide by 6 (the number of readings) instead of 5 (the number of years).

Also acceptable: Accept 0.60 m per year or 60 cm per year .

2. If the cliff keeps retreating at the average rate, how many years after year 5 will the cliff edge reach the post? Show the calculation.

Answer: Distance remaining at year 5: 21.0 m . $21.0\text{ m} \div 0.6\text{ m per year} = 35\text{ years}$.

Why: Time equals distance divided by rate; the units of meters cancel, leaving years.

Also acceptable: Accept 35 years; if a student starts from year 0 ($24.0\text{ m} \div 0.6 = 40\text{ years from year 0}$), that is 35 years after year 5 and should be credited if explained.

3. Describe the shape of your graph. Then look at the year-by-year changes: one year lost noticeably more than the others. Which year was it, how much was lost, and what kind of event could explain a bigger loss in a single year?

Answer: The points fall close to a straight line sloping down to the right: the distance shrinks by a similar amount each year. Year-by-year losses: 0.6, 0.5, 0.8, 0.5, 0.6 m. Year 3 (between year 2 and year 3) lost the most, 0.8 m. A single big storm with large waves, a very wet winter that soaked the cliff, or one large chunk breaking off could explain the extra loss.

Why: The graph is roughly linear, which supports an average rate, but the year-3 jump shows the rate is an average of uneven events, which prepares Part C's point about sudden events.

Also acceptable: Accept 'the line slopes downward' for shape; accept any storm, flood or rockfall explanation.

- Describes a roughly straight, falling line
- Identifies year 3 and 0.8 m
- Proposes a plausible one-time cause

Part B: A creeping continent

A satellite-positioning station bolted to bedrock records its position to the nearest millimeter. Each year, the station's eastward position is compared with where it started. The movement is the whole plate, carrying the station and the continent with it.

Eastward movement of a positioning station (teaching dataset)

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

Year	Eastward movement since year 0 (mm)
0	0
1	24
2	51
3	74
4	101
5	125

Simulated data for teaching; realistic for a slowly moving plate.

4. Calculate the station's average rate of movement in millimeters per year, then convert it to centimeters per year. Show your work.

Answer: $125 \text{ mm} \div 5 \text{ years} = 25 \text{ mm per year}$. $25 \text{ mm} \div 10 = 2.5 \text{ cm per year}$.

Why: Total movement divided by total time; 10 mm in a centimeter.

Also acceptable: Accept 25 mm/yr and 2.5 cm/yr.

5. At that rate, how far would the continent move in one million years? Give the answer in kilometers and show each conversion step (mm to m to km). Then calculate how many years it would take to move 1,000 km.

Answer: 25 mm per year $\times$ 1,000,000 years = 25,000,000 mm. 25,000,000 mm $\div$ 1,000 = 25,000 m. 25,000 m $\div$ 1,000 = 25 km in one million years. Time for 1,000 km: 1,000 km $\div$ 25 km per million years = 40 million years.

Why: The conversions move through meters to kilometers; the final step divides a distance by a rate expressed per million years.

Also acceptable: Accept 25 km and 40,000,000 years. If a student converts 1,000 km to mm (1,000,000,000 mm $\div$ 25 mm/yr = 40,000,000 years), that is equally correct.

Part C: Putting every rate on the same ruler

Rates are hard to compare when they use different units. Convert each rate below to **millimeters per year** so they can be lined up. Two of the rates come from your own answers above.

Six rates of change (teaching values)

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

Process	Rate as measured
Cave formation (stalactite) growing	0.1 mm per year
Continent moving (your Part B answer)	? cm per year
Sea cliff retreating (your Part A answer)	? m per year
Dune crest moving downwind	12 cm per month
Glacier front flowing	0.5 m per day
Landslide (moved 300 m, then stopped)	300 m in 2 minutes

Teaching values chosen to be realistic for each kind of process; convert each one to mm per year.

6. Complete the table. Useful facts: 1 cm = 10 mm, 1 m = 1,000 mm, 1 year = 12 months = 365 days = 525,600 minutes.

Answer: Stalactite: 0.1 mm per year (no conversion). Continent: 2.5 cm $\times$ 10 = 25 mm per year. Sea cliff: 0.6 m $\times$ 1,000 = 600 mm per year. Dune crest: 12 cm per month $\times$ 12 months = 144 cm per year = 1,440 mm per year. Glacier front: 0.5 m per day $\times$ 365 = 182.5 m per year = 182,500 mm per year. Landslide: 300 m $\div$ 2 min = 150 m per minute; 150 $\times$ 525,600 min = 78,840,000 m per year = 78,840,000,000 mm per year (about 7.9×10^{10} mm per year).

Why: Each row is one or two unit changes. The landslide value is enormous because a two-minute rate is being stretched over a whole year the slide never ran.

Also acceptable: Accept 7.9×10^{10} or 'about 79 billion mm per year' for the landslide; accept 182,000 or 183,000 for the glacier if the rounding is shown.

7. Rank the six processes from fastest to slowest using your mm-per-year values. Then explain why the landslide's number is misleading, even though the arithmetic is correct.

Answer: Fastest to slowest: landslide (79 billion mm/yr), glacier front (182,500), dune crest (1,440), sea cliff (600), continent (25), stalactite (0.1). The landslide's number is misleading because the slide lasted two minutes and then stopped; it will not keep moving for a year. A rate in 'per year' only makes sense for a process that keeps going. Sudden events are better described by how much moved and how long the event lasted.

Why: Ranking is mechanical; the explanation is the learning goal: rates describe continuing processes, while sudden events need a size and a duration.

Also acceptable: Accept 'the landslide happens once, the others keep happening.'

- Correct order
- Explains that the landslide stopped, so a per-year rate does not apply

8. The landslide moved 300 m of rock in two minutes. How many years would the sea cliff need to retreat 300 m? How many years would the continent need to move 300 m? Show both calculations.

Answer: Sea cliff: $300 \text{ m} \div 0.6 \text{ m per year} = 500 \text{ years}$. Continent: $300 \text{ m} = 300,000 \text{ mm}$; $300,000 \text{ mm} \div 25 \text{ mm per year} = 12,000 \text{ years}$ (or $300 \text{ m} \div 0.025 \text{ m per year} = 12,000 \text{ years}$).

Why: Both are distance divided by rate with matching units. The contrast (two minutes versus 500 and 12,000 years) sets up q9.

Also acceptable: Accept 500 years and 12,000 years with work shown in any consistent unit.

9. Using numbers from this sheet, explain why a very slow process can still produce a bigger total change than a very fast one. Then explain why a scientist describing any change needs to report both how much space it covered and how long it took.

Answer: Model answer: The continent moves only 25 mm a year, slower than the landslide by billions of times, yet in one million years it moves 25 km, and in 40 million years 1,000 km, which is far more than the 300 m the landslide moved. A slow process wins on total change because it never stops; the small yearly change multiplied by a huge number of years adds up. That is why a scientist must report both rulers: the size of a change (300 m, 25 km, 1,000 km) says how much happened, and the time (2 minutes, one million years) says how it happened. The same 300 m means a catastrophe if it took two minutes and ordinary slow change if it took 500 years.

Why: Full credit requires at least two numbers from the sheet, the 'adds up because it keeps going' reasoning, and the two-rulers conclusion.

Also acceptable: A student who uses the stalactite (0.1 mm/yr for 10,000 years = 1 m) instead of the continent has the same idea.

- Uses at least two numbers from the sheet
- Explains that slow processes accumulate because they continue
- States why both size and time are needed, with an example

Teacher notes

All three datasets are simulated. The cliff rate (0.6 m per year) is realistic for soft coastal bluffs; the station rate (25 mm per year) matches the textbook's 'one to three centimeters per year' for continents and the average Mid-Atlantic spreading rate (about 2.5 cm/yr, USGS); real plates range from under 2 to about 7 cm per year or more, which is why the sheet states its own value. The stalactite rate (0.1 mm/yr) is a teaching

value; the National Park Service gives about 1 mm per year as a maximum for widening cave stream passages, so growth of formations is slower still. The most common errors: dividing by 6 readings instead of 5 years in q1, and forgetting the $\times 1,000$ in q5. The landslide row is deliberately absurd; let students discover that the arithmetic is right and the meaning is wrong, which is the lesson's point about sudden events. Suggested emphasis for q9: 'slow plus long beats fast plus short.'

Scaffold offered to students: Rates in three lines

Write every rate calculation in three lines: (1) the total change with its unit, (2) the total time with its unit, (3) $\text{change} \div \text{time} = \text{rate}$, with the unit written as 'per' (for example, $3.0 \text{ m} \div 5 \text{ years} = 0.6 \text{ m per year}$). To convert a rate, change one unit at a time and write the new unit after each step: $0.5 \text{ m per day} \rightarrow 0.5 \times 365 = 182.5 \text{ m per year} \rightarrow 182.5 \times 1,000 = 182,500 \text{ mm per year}$. To find a time from a rate, divide the distance by the rate and check that the distance units cancel.

Extension: When the rate is not constant

The cliff lost 0.8 m in year 3 but only 0.5 m in years 2 and 4. Suppose that from now on a big storm like year 3's hits once every five years and ordinary years lose 0.5 m. Recalculate how long the cliff will take to reach the post under this pattern, compare it with your q2 answer, and write two sentences about why planners who build near cliffs should use the storm pattern rather than a single average. Then find out how scientists measure present-day plate movement to the millimeter, and write one sentence on why a five-year record is enough to measure a rate that will run for millions of years.