

# The Paper Seafloor: Pull a Ridge Apart and Read Its Age Bands

**Investigation question:** If new seafloor forms at a ridge and moves outward, what pattern of ages should the seafloor show, how does the pattern change when one side spreads faster, and why does the ocean not get wider forever?

Physical model

Groups of 3

1 session

Setup 10 · Activity 40 · Cleanup 5 min

MS-ESS2-3 · practice

MS-ESS2-2 · supports

## Scientific purpose

Students build a working model of a spreading ridge from two paper strips fed up through a slot in a cardboard base. Each pull stands for one million model years; a line drawn at the ridge after each pull becomes an age band that travels outward. Students measure where each band ends up, graph distance against age, read the spreading rate from the graph, convert it to a real-world rate, then change the pull rule to see what uneven spreading does to the pattern. Because the strips exit through two more slots, the model also shows why adding seafloor at the ridge does not make the ocean, or Earth, grow.

## Why this helps students with this chapter

Seafloor spreading is usually shown as a finished diagram, which hides the prediction inside it. When students draw a line at the ridge, pull, and watch the line move away while a newer line appears behind it, the age pattern stops being a fact to memorize and becomes a consequence they produced. Measuring and graphing it turns the pattern into a rate, and the uneven-pull run shows that the rule 'older with distance from the ridge' survives even when the ridge is not in the middle of the ocean. The trench slots answer the question students always ask: if the ocean keeps growing, why is Earth not getting bigger?

## Standards connections

**MS-ESS2-3** (practice, the seafloor-structure half: the age pattern that ridges and trenches produce):

Students generate the age-with-distance pattern themselves and state what the real seafloor data must look like if spreading is real. This builds the interpretation skill the PE requires; Lab 3 then applies it to a dataset, which is where the PE is assessed.

**MS-ESS2-2** (supports, the slow, large-scale end of the time-and-space scale): Converting a model rate of 2 cm per tick into 20 km per million years and 2 cm per year gives students the scale sense that a process too slow to see can open an ocean; the fuller explanation of surface change at many scales belongs to Lesson 11 and Lesson 17.

## Roles (rotate each session)

- **Puller:** Sits below the base and pulls each strip down through its trench slot by exactly the distance called for each tick, using the ruler marks on the strip's underside.

- **Marker:** Draws a straight line across both strips at the ridge slot after each tick, labels it with the tick number, and calls out when the line is drawn.
- **Measurer and recorder:** After the last tick of each run, measures the distance from the ridge slot to every labeled line on both sides, records it, and plots the points on the graph.

## Materials

| Item                                                                                            | Quantity    | Per     | Note                                                                                                   |
|-------------------------------------------------------------------------------------------------|-------------|---------|--------------------------------------------------------------------------------------------------------|
| Corrugated cardboard base, about 36 cm by 20 cm, with three slots cut by the teacher (see prep) | 1           | group   | A flattened shipping box works. Cereal-box board is too flimsy; it buckles when the strips are pulled. |
| Adding-machine or receipt paper strips, 60 cm long                                              | 2           | group   | Standard 57 mm (2.25 inch) tape. Mark one strip WEST and one EAST at one end.                          |
| Washable markers in two colors, plus a pencil                                                   | 1 set       | group   |                                                                                                        |
| Ruler marked in centimeters                                                                     | 2           | group   | One for the Puller under the base, one for the Measurer on top.                                        |
| Two equal stacks of books or two desks pushed close with a gap                                  | 1 setup     | group   | The base rests across the gap so the strips hang below and can be pulled.                              |
| Masking tape                                                                                    | about 30 cm | group   | To hold the base on the books.                                                                         |
| Recording sheet and calculator                                                                  | 1 set       | student |                                                                                                        |

**Estimated cost:** 5 to 8 per class, mostly reusable (an estimate; Estimate. One roll of adding-machine paper (about \$3) gives more than 30 strips; cardboard comes from recycled boxes; markers, rulers and tape are classroom stock. The bases can be reused for years.)

## Safety

- The craft knife is used only by the teacher during prep; students never cut the cardboard.
- Paper edges can cut; pull strips slowly and keep fingers away from the slot edges.
- The elevated base can slide off its supports; tape it down and keep the Puller's head clear of the underside.
- No chemicals, heat or glass are used.

## Teacher preparation and setup

1. Cut one base per group from corrugated cardboard, about 36 cm by 20 cm. With a craft knife (teacher only), cut three slots, each 7 cm long and about 4 mm wide, running across the short direction of the base: a RIDGE slot at the center (18 cm from each end) and two TRENCH slots 4 cm in from each end. Each trench slot is 14 cm from the ridge slot. Label the slots RIDGE, WEST TRENCH and EAST TRENCH, and draw an arrow on each side pointing from the ridge toward the trench.

2. Before class, mark the underside of each strip with pencil ticks every 1 cm for the Puller to use, or give the Puller a ruler and have the group mark the strips in step 1.
3. Thread one set yourself: feed the WEST strip up through the ridge slot from below, lay it flat toward the west trench slot and push its end down through that slot so about 10 cm hangs beneath; do the same with the EAST strip through the same ridge slot toward the east trench slot. Pull each strip from below the trench and confirm that fresh paper rises smoothly from the ridge slot. If the ridge slot binds with two strips, widen it slightly.
4. Write the scale on the board: 1 cm on the model = 10 km of real seafloor; 1 tick (one pull) = 1 million model years.
5. Set up two stacks of books or a desk gap so each base can sit about 15 cm above the table with room for the Puller's hands beneath.
6. Do one full run (six ticks of 2 cm) to confirm your measurements match the expected values on the recording sheet key: lines 0 to 6 at 12, 10, 8, 6, 4, 2 and 0 cm.

## Investigation design

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|                             |                                                                                                                                                                                                                                                |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Independent variable</b> | The pull rule: the length pulled per tick on each side (run 1: 2 cm west and 2 cm east; run 2: 3 cm west and 1 cm east)                                                                                                                        |
| <b>Dependent variable</b>   | Distance of each labeled age line from the ridge slot after the run, in centimeters, on each side                                                                                                                                              |
| <b>Controlled</b>           | One tick stands for one million model years in both runs; Model scale of 1 cm = 10 km in both runs; Distances measured from the center of the ridge slot to the center of each line; Same base, same strips and same slot positions throughout |
| <b>Trials</b>               | One run of each rule per group; the class compares run 1 rates across groups and should get the same 2 cm per tick within measurement error.                                                                                                   |
| <b>Comparison</b>           | Run 1 (equal pull) against run 2 (uneven pull): does 'older with distance from the ridge' still hold, and what changes?                                                                                                                        |

## Student procedure

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1. Build the model: rest the base across the two book stacks and tape it down. Feed the WEST strip up through the RIDGE slot from below, lay it flat toward the WEST TRENCH slot and push its end down through that slot. Do the same with the EAST strip toward the EAST TRENCH slot. Both strips come up through the same ridge slot, back to back. Pull each strip from below until about 2 cm of each shows above the ridge slot.
2. Run 1, equal spreading. Marker: with the first color, draw a straight line across both strips exactly at the ridge slot and label it 0 on both strips. Puller: pull the WEST strip down through its trench slot by exactly 2 cm, then the EAST strip by exactly 2 cm. Marker: draw a new line at the ridge, label it 1. Repeat pull-then-draw until line 6 has been drawn. Alternate the two marker colors so the bands are easy to see.
3. Measure run 1. Without pulling further, the Measurer measures the distance from the center of the ridge slot to each labeled line on the west strip and on the east strip, and records them in the run 1 table. Fill in the age column: a line's age is the number of ticks since it was drawn (line 6 is age 0; line 0 is age 6).

4. Graph run 1: plot distance from the ridge (vertical axis) against age in ticks (horizontal axis) for both sides, using different symbols for west and east. Draw a best-fit straight line through each side's points.
5. Keep pulling: do two more 2 cm ticks on each side without drawing new lines. Watch what happens to lines 0 and 1 at the trench slots. Write what you saw in question 2.
6. Run 2, uneven spreading. Before you start, predict in the run 2 table where each line will end up if the WEST strip is pulled 3 cm per tick and the EAST strip 1 cm per tick for five ticks. Then switch to pencil, draw a line at the ridge labeled A0, and run five ticks: west 3 cm, east 1 cm, draw and label A1 through A5 at the ridge after each tick.
7. Measure run 2 exactly as in step 3 and compare each measurement to your prediction.
8. Measure the distance from the ridge slot to each trench slot. Compare it with the total length of paper you pulled through on each side during the whole lab. Write both numbers beside your side-view drawing; you will use them in analysis question 6.
9. Draw the side view of the model on the recording sheet, then answer the analysis questions individually before comparing in the group.

## Expected observations

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- Run 1: lines 6, 5, 4, 3, 2, 1 and 0 sit at about 0, 2, 4, 6, 8, 10 and 12 cm from the ridge on both sides, within about half a centimeter. The graph is a straight line through the origin with a slope of 2 cm per tick for each side.
- Step 5: lines 0 and 1 slide down into the trench slots and disappear from view; the visible seafloor between ridge and trench stays 14 cm long.
- Run 2: lines A5 to A0 sit at about 0, 3, 6, 9, 12 and 15 cm on the west side (A0 may already be at or into the west trench slot) and at 0, 1, 2, 3, 4 and 5 cm on the east side. Both sides still get older outward; the west bands are spaced three times as widely.

## Likely difficulties

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- The two strips jam in the ridge slot. Widen the slot slightly or wax the slot edges with a candle stub; feeding the strips back to back rather than overlapped also helps.
- The Puller overshoots. Have the Puller use the pencil ticks on the strip's underside and call out 'two' each time; the Marker should not draw until the Puller confirms.
- Students label a line's age with its label number instead of the ticks since it was drawn. The table's first row (line 6, age 0) is there to anchor this; check it before groups graph.
- In run 2 some students expect the east side to stop aging because it moves slowly. Ask whether age depends on distance or on time: a band drawn five ticks ago is five ticks old no matter how far it moved.

## Structured debrief

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1. Pool run 1 rates on the board. Every group should get close to 2 cm per tick; ask why small differences appear (the pull was not exactly 2 cm; lines were not drawn exactly at the slot). Then do the conversion together: 2 cm per tick, 1 cm = 10 km, 1 tick = 1 million years, so 20 km per million years, which is

2,000,000 cm per 1,000,000 years, or 2 cm per year. Real ridges spread at about 0.5 to 8 cm per year on each side, so the model's rate is realistic.

- 2. Ask what the model predicts for the real ocean: the youngest rock at the ridge, ages rising in matching steps on both sides, and the oldest at the far edges. Then ask how anyone could check it. Students should land on drilling and dating the seafloor at different distances, which is exactly what the Glomar Challenger did across the South Atlantic in 1968-69 and what Lab 3 simulates.
- 3. Use run 2 to break the idea that ridges must sit in the middle of oceans. Uneven spreading is real; the rule that survives is 'older with distance from the ridge,' not 'symmetric about the center of the ocean.' Then ask where the oldest seafloor on each side went: into the trench slots in run 1. In a real ocean with a trench, the oldest seafloor is at the trench; in the Atlantic, which has almost no trenches, the oldest seafloor lies against the continents.
- 4. Close on q8 and what the model cannot show: the paper does not cool, thicken or get denser as it ages, nothing melts at the ridge, and a hand pulled the strips. Say plainly that what moves real plates is still studied and is not part of what students are assessed on; the pattern of ages is.

Recording sheet: what students fill in

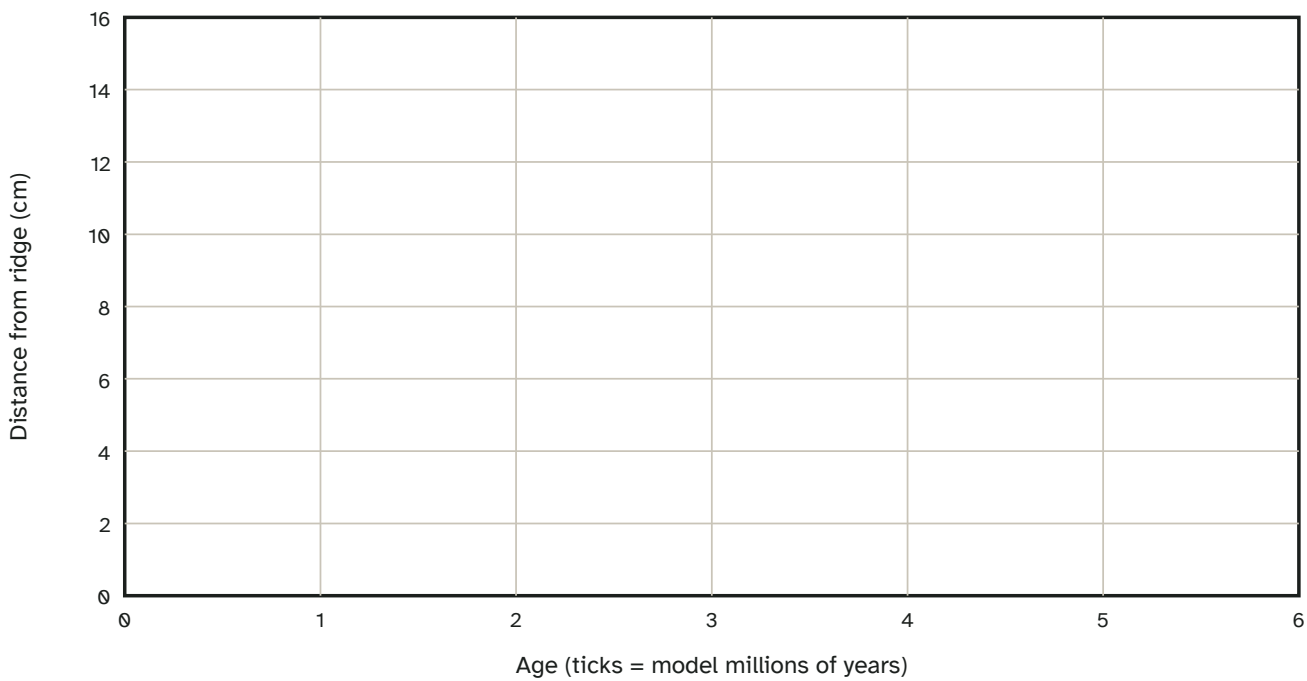
Lab 2 recording sheet: The paper seafloor

**Model scale** — 1 cm on the model stands for 10 km of real seafloor. One tick (one pull) stands for 1 million model years. A line's **age** is the number of ticks since it was drawn at the ridge.

Run 1: equal spreading, 2 cm per tick on each side

| Line label | Age (ticks since drawn) | Distance from ridge, WEST (cm) | Distance from ridge, EAST (cm) |
|------------|-------------------------|--------------------------------|--------------------------------|
| 6          | 0                       |                                |                                |
| 5          |                         |                                |                                |
| 4          |                         |                                |                                |
| 3          |                         |                                |                                |
| 2          |                         |                                |                                |
| 1          |                         |                                |                                |
| 0          |                         |                                |                                |

Run 1: distance of each age line from the ridge



Run 2: uneven spreading, 3 cm per tick WEST and 1 cm per tick EAST

| Line label | Age (ticks) | Predicted WEST (cm) | Measured WEST (cm) | Predicted EAST (cm) | Measured EAST (cm) |
|------------|-------------|---------------------|--------------------|---------------------|--------------------|
| A5         | 0           |                     |                    |                     |                    |
| A4         |             |                     |                    |                     |                    |
| A3         |             |                     |                    |                     |                    |
| A2         |             |                     |                    |                     |                    |
| A1         |             |                     |                    |                     |                    |
| A0         |             |                     |                    |                     |                    |

-  Draw the model from the side: the base, the ridge slot with both strips rising through it, the two trench slots with the strips going down, and the age lines on top. Label the ridge, both trenches, the youngest seafloor and the oldest seafloor still visible.

**Answer:** A side view showing the base with the ridge slot at the center, both strips rising through it and lying outward, each strip going down through a trench slot near its end, labeled lines on top with the lowest numbers farthest from the ridge, and labels: ridge, west trench, east trench, youngest seafloor (at the ridge), oldest visible seafloor (next to each trench).

**Why:** The drawing checks that students can turn the model into a cross-section with the age gradient and the two removal points labeled.

- Ridge and both trenches labeled correctly
- Youngest at the ridge and oldest near the trenches
- Strips shown going down at the trenches

1. Describe the pattern in the run 1 table in one sentence: where are the youngest lines, where are the oldest, and how do the two sides compare?

**Answer:** The youngest line (6) is at the ridge, the oldest visible line (0) is farthest away at about 12 cm, ages rise steadily outward, and the two sides mirror each other with the same line at the same distance.

**Why:** This is the seafloor spreading prediction in the student's own words. Look for 'youngest at the ridge,' 'older with distance' and 'same on both sides.'

- Youngest at the ridge, oldest farthest out
- Both sides mirror each other

2. What happened to lines 0 and 1 when you kept pulling in step 5? What real-world process does the trench slot stand for?

**Answer:** Lines 0 and 1 slid into the trench slots and disappeared beneath the base. The trench slot stands for a deep-sea trench, where old seafloor bends down and sinks into the mantle (subduction).

**Why:** Students should connect disappearance in the model to removal of seafloor in the real world; naming subduction or 'sinks into the mantle' earns full credit.

*Also acceptable: Accept 'the old seafloor is destroyed or recycled at the trench.'*

## Analysis questions: answer key

3. Use your run 1 graph to find the spreading rate of one side in cm per tick. Then convert it to a real rate using the model scale: give the answer in kilometers per million years and in centimeters per year. Show every step.

**Answer:** Slope of the run 1 line: 12 cm over 6 ticks = 2 cm per tick. Real rate: 2 cm per tick  $\times$  10 km per cm = 20 km per 1 million years. In cm per year: 20 km = 2,000,000 cm, divided by 1,000,000 years = 2 cm per year.

**Why:** Both conversions must be shown. Groups whose measured slope is 1.8 to 2.2 cm per tick should carry their own value through (18 to 22 km per million years, 1.8 to 2.2 cm per year).

*Also acceptable: Accept any correct chain from the group's own measured slope.*

4. At the run 1 rate, how far from the ridge would seafloor that is 25 million years old be in the real world? How long would that be on the model, and what would have happened to it in your setup?

**Answer:** 25 million years  $\times$  20 km per million years = 500 km from the ridge. On the model that is 500 km  $\div$  10 km per cm = 50 cm, which is far beyond the 14 cm trench slot, so in this setup that seafloor would already have gone down the trench and been removed.

**Why:** The twist checks whether students see the trench as a limit on how old visible seafloor can be in a basin with a trench.

*Also acceptable: Accept 'it would have been subducted' or 'it would be off the model' with the 500 km and 50 cm shown.*

5. In run 2 the west side was pulled three times as far per tick as the east side. Did 'older with distance from the ridge' still hold on both sides? What was different, and what would an age map of a real ocean that spreads unevenly look like?

**Answer:** Yes. On both sides every line was older the farther it was from the ridge. What changed was the spacing: west lines were 3 cm apart and east lines 1 cm apart, so a band of a given age sat three times farther from the ridge on the west. An age map of a real ocean spreading unevenly would still show the youngest seafloor along the ridge with ages rising outward on both sides, but the bands would be wide on the fast side and narrow on the slow side, and the ridge would not be in the middle of the ocean.

**Why:** Students must separate the rule (age rises with distance) from the symmetry (equal spacing), and recognize that asymmetry does not break the rule.

- States the rule still holds on both sides
- Describes the spacing difference
- Describes the real map: ridge off-center, bands wide on one side

6. The ridge-to-trench distance stayed 14 cm on each side even though you pulled far more than 14 cm of paper through during the lab. Explain how the model shows why Earth does not grow, and what happens to real seafloor at the feature the trench slot represents.

**Answer:** Every centimeter of paper added at the ridge was matched by a centimeter leaving through a trench slot, so the visible seafloor stayed 14 cm per side no matter how much was pulled (groups will have pulled roughly 16 cm on the west and 16 cm on the east in run 1 plus 15 cm and 5 cm in run 2). The trench slot stands for a deep-sea trench, where old, cold, dense seafloor bends down beneath another plate and sinks into the mantle. Because seafloor is removed about as fast as it is made, Earth stays the same size.

**Why:** This is the conservation argument. Full credit requires both the model observation (constant visible length) and the real process (subduction at trenches) with the consequence (Earth does not grow).

- Visible length constant while much more paper passed through
- Names subduction at trenches
- Concludes that creation and destruction balance

7. Suppose seafloor spreading were not happening at all. Describe what age lines on the real seafloor would look like instead, and what a drill ship sampling at different distances from the ridge would find.

**Answer:** There would be no age pattern tied to the ridge: the seafloor would be the same age everywhere, or ages would be scattered with no trend, and the oldest ocean floor could be as old as the continents. A drill ship would find no steady increase of age with distance and no young rock at the ridge.

**Why:** Stating the opposite prediction is what makes the spreading hypothesis testable; this question prepares Lab 3.

- No trend of age with distance
- States what a drill ship would find instead

8. Name two ways the paper model is unlike the real seafloor, and for each say whether the difference matters for the age-pattern prediction you tested.

**Answer:** Any two of: the paper does not cool, thicken or become denser with age (does not affect the age pattern, but it is why real seafloor sinks at trenches); a hand pulled the strips, whereas the force that moves real plates is still studied (does not affect the age pattern; the pattern follows from new material at the ridge, whatever moves it); the ridge is a slot rather than a rift valley with volcanoes (does not affect the pattern); the model rate is fixed, while real rates vary between oceans and over time (affects the spacing of bands but not the rule); the model has a trench on both sides, while many real oceans such as the Atlantic have none, so their oldest seafloor lies against the continents (changes where the oldest seafloor is found, not the rule).

**Why:** Accept any two accurate differences with a defended judgment; the key idea is that the age-with-distance prediction does not depend on the details the model leaves out.

- Two accurate differences named
- Each judged for its effect on the age-pattern prediction

## Individual evidence of learning

Each student submits their own run 1 and run 2 tables, the run 1 graph with best-fit lines, the side-view drawing, and written answers to q1 through q8. The graph and q3 are the primary evidence for the age-pattern and rate targets; q6 and q7 are the evidence for understanding what the pattern predicts and what its absence would look like.

## Assessment criteria

| Criterion                  | Proficient looks like                                                                                                                                                                                           |
|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Data and graph</b>      | All lines measured on both sides within about half a centimeter of expected values, ages assigned as ticks since drawing, points plotted correctly with a best-fit line through the origin.                     |
| <b>Rate and conversion</b> | Reads 2 cm per tick from the graph and converts correctly to 20 km per million years and 2 cm per year with the scale factors shown.                                                                            |
| <b>Pattern reasoning</b>   | States that age increases with distance from the ridge on both sides in both runs, that uneven spreading changes spacing but not the rule, and that a drill ship should find this pattern if spreading is real. |

|                                      |                                                                                                                                                                                        |
|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Conservation and model limits</b> | Explains that seafloor leaving at the trench slots balances seafloor added at the ridge, names subduction at trenches as the real process, and gives two accurate limits of the model. |
|--------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## Accessibility adaptations

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- Let a partner pull while a student with limited fine-motor control calls each tick and reads the ruler with a hand lens; provide a run 1 table with the age column already filled.
- Provide a graph with axes already scaled and the first two points plotted for students who need more support, and a worked conversion chain (cm per tick to km per million years to cm per year) as a reference strip.
- Accept q5 through q8 as a recorded spoken explanation while pointing at the model, and provide a picture glossary for ridge, trench, age band and spreading in the student's home language.
- For students who need movement, run one large-scale version with a 2 m strip across the classroom floor, with students walking the age bands outward one step per tick.

## Low-cost alternative

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Use strips cut from newspaper margins or a roll of paper towel cut lengthwise, and a shoebox lid with slots instead of flat cardboard. If paper strips are not available at all, run the model on paper only: have students compute and draw where each line should sit after six ticks at 2 cm per tick and after five ticks at 3 cm and 1 cm, then answer the same questions.

## Model limitations

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The paper strip is a model of position and age only. Real oceanic lithosphere cools, thickens and becomes denser as it moves away from the ridge, which the paper does not; real ridges have a rift valley and volcanism rather than a slot; real plates are not pulled by hands, and what drives their motion is still an area of research and is not assessed here; real spreading rates vary from about 0.5 to 8 cm per year per side and can change over time; and real oceans have fracture zones that offset the ridge, which a single straight slot cannot show. Many real oceans, including the Atlantic, have no trench on one or both sides, so the oldest seafloor there lies against the continents rather than entering a trench. This activity has not been physically tested by the authors; the slot widths and the expected measurements were worked out on paper, so run one base before class and adjust the slot width if the strips bind.

## Teacher notes

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Expected values assume lines are drawn exactly at the ridge slot and pulls are exactly 2 cm; a half-centimeter scatter is normal. If a group's run 1 slope is far from 2, check whether they labeled ages as ticks since drawing. Keep the mechanism out of the assessment: the model shows what happens to new seafloor, not why plates move, and MS-ESS2-3 does not assess driving forces. The run 2 asymmetry is real on Earth, and the Atlantic's lack of trenches is why its oldest seafloor lies along the continental shelves.