

Plan the Drilling Voyage: Six Holes to Test a Spreading Ridge

Learning target: I can define the criteria and constraints of a seafloor-drilling expedition, choose drill sites that would test seafloor spreading, predict the ages the cores should show, and justify my plan.

Transfer and design

About 50 min

Pairs

MS-ETS1-1 · practice

MS-ESS2-3 · practice

engineering design

data analysis

writing

Standards connections

MS-ETS1-1 (practice, sorting and stating criteria and constraints for a data-collection design problem): Students separate the requirements of a drilling plan (criteria) from its limits (constraints) and write their own, using real limits such as ship time, water depth and ship speed. The problem is given to them rather than defined from scratch, so this practices rather than fully assesses the PE.

MS-ESS2-3 (practice, predicting the seafloor age pattern that would count as evidence of plate motion): To choose sites, students must know what pattern of seafloor ages spreading predicts and what pattern would reject it. Designing the test builds the interpretation the PE assesses in Worksheets 5 and 6.

Purpose: extend · **Time:** about 50 minutes · **Format:** pairs

Answers with reasoning

The scenario

Ocean K is 2,400 km wide from the continental shelf on its west side to the shelf on its east side. Sonar shows a mid-ocean ridge running down the middle, 1,200 km from each shelf. Nobody has dated the seafloor of Ocean K. If the ridge is spreading at the rate suggested by satellite measurements of the two coasts, the seafloor should be moving away from the crest at about **3 cm per year on each side**. Your drill ship starts at the port on the west coast, must finish at the port on the east coast, and may drill at any site along the straight line between them.

Rules of the voyage — 1. You have **24 days** of ship time in total. 2. Drilling, coring and dating one site takes **3 days**. 3. The ship moves at most **400 km per day** when it is not drilling. 4. The drill pipe can reach the seafloor only where the water is **no deeper than 4,600 m**. 5. A core counts only if it reaches the volcanic rock under the sediment; the age of the oldest sediment resting on that rock is the age of the seafloor. 6. The crossing itself (2,400 km) must be paid for out of the 24 days.

Water depth and sediment thickness in Ocean K (teaching dataset)

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

Distance from ridge crest (km)	Water depth (m)	Sediment thickness (m)
0	2600	0
200	3200	80
400	3700	160
600	4100	250
800	4500	340
1000	4800	430
1200	5100	520

Simulated for teaching. The trends are real: seafloor sinks deeper as it cools and ages, and sediment piles up the longer the seafloor has existed. The numbers are invented and the same on both sides of the ridge.

Part A: Criteria or constraint?

A **criterion** is something the plan must achieve to count as a success. A **constraint** is a limit the plan cannot break. Sort these eight statements.

1. Label each statement a criterion or a constraint and give a short reason.

Answer: a criterion (needed to test symmetry); b constraint (time limit); c criterion (what a successful core must achieve); d constraint (physical limit of the drill); e criterion (what the data must allow); f constraint (speed limit); g criterion (a required feature of the data); h constraint (fixed route).

Why: Criteria describe what the result must achieve; constraints describe limits the plan cannot cross. Students sometimes call c a constraint because it 'limits' which cores count; the key treats it as a criterion because it defines success, but accept either with a reason that shows the distinction.

Also acceptable: Accept c as a constraint if the reason says it restricts which cores are acceptable.

- At least seven of eight sorted as in the key
- Reasons that use the achieve-versus-limit distinction

2. Write **one more** criterion and **one more** constraint of your own for this voyage. Each must be something not already in the list.

Answer: Examples. Criterion: the sites should include at least one far enough from the crest to give an age over 20 million years, so the line is long enough to measure a rate; or each core must be dated by the same method so the ages can be compared. Constraint: the drill pipe is long enough for a fixed total length (water plus sediment); or the ship cannot drill in storms above a certain wave height; or the budget allows only one set of drill bits.

Why: Any new, relevant statement correctly labeled earns credit.

Also acceptable: Any sensible pair.

- One criterion not already listed
- One constraint not already listed
- Both correctly labeled

Part B: What the rules allow

3. How many days does the 2,400 km crossing use at 400 km per day? How many days are left for drilling? How many sites can you drill at 3 days each? Show each step.

Answer: Crossing: $2,400 \text{ km} \div 400 \text{ km/day} = 6 \text{ days}$. Drilling days left: $24 - 6 = 18 \text{ days}$. Sites: $18 \text{ days} \div 3 \text{ days per site} = 6 \text{ sites}$.

Why: The crossing must be paid for first (rule 6); the sites then fit exactly. Note that the ship can drill at sites along its crossing without extra transit, since all sites lie on the straight line between the ports.

Also acceptable: Accept 6 sites with the three steps shown.

4. Using the depth table, how far from the ridge crest, on each side, is the farthest point where the drill can still reach the seafloor? Explain how you decided.

Answer: 800 km on each side. The table gives 4,500 m at 800 km (allowed, under 4,600 m) and 4,800 m at 1,000 km (not allowed). So drilling is possible only within 800 km of the crest; the outer 400 km on each side is too deep.

Why: Students must compare each table row with the 4,600 m limit. The exact crossover lies somewhere between 800 and 1,000 km, but with the table given, 800 km is the farthest usable row.

Also acceptable: Accept 'somewhere between 800 and 1,000 km, so 800 km is the last safe site in the table.'

5. Convert the expected one-side rate of 3 cm per year into kilometers per million years. Show every step. Then write the formula you will use to predict the age of seafloor at any distance from the crest.

Answer: $3 \text{ cm/yr} \times 1,000,000 \text{ yr} = 3,000,000 \text{ cm per million years}$. $3,000,000 \text{ cm} \div 100,000 \text{ cm/km} = 30 \text{ km per million years}$. Formula: predicted age (millions of years) = distance from crest (km) $\div$ 30 km per million years.

Why: The conversion mirrors Worksheet 5. The formula is age = distance $\div$ rate.

Also acceptable: Accept age = distance $\div$ 30 with the units stated, or distance = 30 $\times$ age rearranged.

Part C: Your plan

6. Choose your six sites. Use distances that appear in the depth table (0, 200, 400, 600 or 800 km) so you can read the depth directly. Fill in every column and show one age calculation below the table.

Answer: Model plan (one of several good ones): Site 1 crest, 0 km, 2,600 m, allowed, 0 Ma. Site 2 west 400 km, 3,700 m, allowed, $400 \div 30 = 13.3$ Ma. Site 3 west 800 km, 4,500 m, allowed, $800 \div 30 = 26.7$ Ma. Site 4 east 400 km, 3,700 m, allowed, 13.3 Ma. Site 5 east 800 km, 4,500 m, allowed, 26.7 Ma. Site 6 east (or west) 200 km, 3,200 m, allowed, $200 \div 30 = 6.7$ Ma. Other predicted ages students may use: 600 km gives 20.0 Ma.

Why: Any plan earns full credit if every site is within 800 km (depth $\leq 4,600$ m), both sides are sampled, a crest or near-crest site is included, the spacing allows a line, and every age equals distance $\div 30$ (0, 6.7, 13.3, 20.0, 26.7 Ma for 0, 200, 400, 600, 800 km). A plan with a site at 1,000 or 1,200 km breaks the depth constraint.

Also acceptable: A plan with three sites on each side and no crest site, such as west 200, 400, 800 km and east 200, 400, 800 km, is acceptable if the student notes that the 200 km sites anchor the young end of the line.

- Six sites, all within 800 km
- Both sides sampled
- A crest or 200 km site included
- Ages computed correctly from distance $\div 30$
- One calculation shown

7. Justify your plan. Explain how your six sites satisfy every criterion in Part A, stay inside every constraint, and will let you draw an age-versus-distance graph for both sides of the ridge. Say which site you would drop first if the voyage lost three days to a storm, and why.

Answer: A full justification states: both sides are sampled (criterion a); every site is within 800 km so the water is 4,600 m or shallower (constraint d); a crest or 200 km site anchors the youngest age (criterion g); the sites are spread between 0 and 800 km so the ages can be graphed as a line on each side (criterion e); six sites fit the 18 drilling days after the 6-day crossing (constraints b, f, h); and every core will be drilled to volcanic rock (criterion c). Drop first: the site that adds the least new information, usually the 200 km site (its age is close to the crest's) or one of a matched pair if the other side keeps the same distance; keep the far sites because they set the rate and the crest site because it sets the zero.

Why: The justification must touch every criterion and constraint, not just list the sites. The drop decision is a judgment; look for a reason tied to what the graph needs.

Also acceptable: Dropping a far site to protect symmetry on the remaining distances is also defensible if explained.

- Each criterion in Part A addressed
- Each constraint shown satisfied
- Explains how the sites give a line for both sides
- Names a site to drop with a reason

8. Describe the result that would **support** seafloor spreading at Ocean K's ridge and the result that would **reject** it. Be specific about the ages and the two sides.

Answer: Support: the crest core is close to 0 Ma and the ages rise with distance on both sides by about the same amount, near the predicted 13.3 Ma at 400 km and 26.7 Ma at 800 km (a different rate would still support spreading, as long as ages rise steadily and symmetrically). Reject: the ages are the same at every site, or random, or oldest at the crest, or rise on one side but not the other.

Why: Students should separate 'spreading is happening' (steady, symmetric increase) from 'spreading at exactly 3 cm per year' (the specific ages). A steady rise at a different rate still supports spreading.

Also acceptable: Accept 'a steady rise but at a different rate would mean spreading is real but the satellite rate is off.'

- Supporting result: youngest at crest, ages rising on both sides
- Rejecting result: same ages everywhere, random, or oldest at the crest

9. A teammate proposes drilling all six sites on the east side, 100 km apart, starting at the crest, 'to get a really detailed line.' Using the criteria, explain what that plan would gain and what it would lose.

Answer: Gain: a very detailed line on the east side with six points between 0 and 500 km, which would show clearly whether age rises smoothly. Lose: criterion a (both sides) fails completely, so the plan cannot show that the ridge makes seafloor evenly in both directions, which is the key sign of spreading at the crest; it also leaves the west side's older seafloor (up to 800 km) untested. Six closely spaced points add less than three well-spread points on each side.

Why: This is a criteria trade-off; the strongest answers note that symmetry is the distinctive prediction and that a one-sided line cannot test it.

Also acceptable: A student who proposes 4 east and 2 west as a compromise is reasoning well.

- Names the gain (detail on one side)
- Names the loss (no symmetry test; criterion a unmet)
- Judges that the loss outweighs the gain

10. Rule 5 says a core counts only if it reaches the volcanic rock. Using the sediment column of the table, explain why the sites far from the ridge are the slowest to drill and why that matters when you plan the order of your stops.

Answer: Far from the ridge the sediment is thicker (340 m at 800 km versus 0 m at the crest), so the drill must cut through more mud before it reaches the volcanic rock that gives the age; those sites take the longest and carry the most risk of the core not reaching rock. That matters for the order of stops because the far sites should be drilled when there is still time to redrill if a core fails, and the 3-day allowance is tightest there.

Why: This connects the dataset's sediment column to a practical planning decision; real drilling programs budget more time for thick-sediment sites.

Also acceptable: Accept 'drill the far sites first so a failure can be fixed.'

- Thicker sediment far from the ridge
- More drilling to reach rock
- A planning consequence

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
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Criteria and constraints (Part A)	All eight statements sorted correctly with reasons that use the achieve-versus-limit distinction; one original criterion and one original constraint that are relevant and correctly labeled.	Seven of eight correct; original statements present but one is a restatement of a listed item.	Several statements swapped; original statements missing or mislabeled.	Sort largely incorrect or incomplete.
Calculations (Part B and the age column)	Crossing days, drilling days, site count, depth limit and rate conversion all correct with units; every predicted age equals distance $\div$ 30.	One arithmetic or unit slip; method correct throughout.	Two or more slips, or the rate conversion missing.	Calculations missing or without units.
Design decision (Part C plan)	Six sites that meet every criterion and constraint; both sides sampled with a crest anchor and spacing that gives a line on each side.	Plan meets the constraints and most criteria; one weakness (for example, no crest site, or sides unevenly covered).	Plan breaks a constraint (a site beyond 800 km, or seven sites) or ignores a key criterion (one side only).	No plan, or a plan unrelated to the rules.
Justification and prediction (q7-q9)	Justification addresses every criterion and constraint; supporting and rejecting results stated specifically; trade-offs in the storm case and the one-sided plan explained with reasons.	Justification covers most items; predictions correct; one trade-off thinly explained.	Justification lists sites without linking to criteria; predictions vague.	Justification missing or contradicts the plan.

Teacher notes

The scenario is invented but every trend in it is real: oceanic lithosphere deepens as it cools (ridge crests at roughly 2,500 m, old basins at 5,000 m or more), sediment thickens with seafloor age, and real drilling programs plan around water depth, drill-string length, ship time and sediment thickness. The 3 cm per year one-side rate gives 30 km per million years, so predicted ages are 0, 6.7, 13.3, 20.0 and 26.7 Ma for 0, 200, 400, 600 and 800 km. The 4,600 m rule is set so that the depth constraint bites at 1,000 km; a real drill string can reach deeper, but the constraint keeps the problem tractable. Students sometimes forget that the crossing is paid from the 24 days or that the drill ship can drill sites along its route without extra transit; both are stated in the rules. The extension at 15 days gives $15 - 6 = 9$ days, so 3 sites; a transit speed of 600 km per day would save 2 days but buys no extra site on its own (11 drilling days still fit only 3 sites), while a 2-day site time would allow 4 sites in 9 days, one extra.

Scaffold offered to students: A plan that always works

If you are stuck choosing sites, start from symmetry. Put one site at the crest (0 km). Then choose the same two distances on both sides, using only distances that appear in the depth table, for example 400 km and 800 km. That gives crest, west 400, west 800, east 400, east 800, and one site left over; put it at 200 km on either side to fill in the line. Check each site against the 4,600 m rule, then compute each age as distance divided by 30 km per million years.

Extension: The budget is cut to 15 days

The funding agency cuts the voyage to 15 days. Recalculate how many sites you can afford, choose them, and write a two-paragraph memo to the agency explaining which criterion you had to weaken and why your reduced plan can still test seafloor spreading. Then propose one change to the ship (for example a faster transit speed or a shorter drilling time per site) and calculate exactly how many extra sites it would buy.