

Roll the Rock Cycle: Where Does Earth's Material Spend Its Time?

Investigation question: If every rock-cycle change is a roll of the dice, where does rock material pile up, which routes does it take, and how do the results change when we rewrite the rules for a different place on Earth?

Collaborative systems modeling

Groups of 4

1 session

Setup 5 · Activity 42 · Cleanup 3 min

MS-ESS2-1 · assesses

Scientific purpose

Students run the rock cycle as a system of five stations (magma, igneous rock, sediment, sedimentary rock, metamorphic rock) with a dice table at each station that decides whether the material stays or moves and, if it moves, by which process and with which energy source. Each roll is logged as a data row, group tallies are pooled into class data, and students compare the fraction of turns spent at each station with the probabilities written into the rules. They then choose a geologic setting, rewrite the rules of one or two stations to fit it, predict the effect and run the model again. The lab turns the cycle diagram into a system students can measure and modify.

Why this helps students with this chapter

A cycle diagram shows what can happen; a dice model shows what tends to happen and how often. Students discover that material sits at a station for many turns before moving, that two travelers starting in the same place take different routes, that the class data settle toward the rule probabilities while a single traveler's record does not, and that changing a local condition such as nearness to a plate boundary changes where material collects. Those are the ideas behind stability and change and energy and matter, made countable.

Standards connections

MS-ESS2-1 (assesses, developing and using a model of cycling materials with the energy source for every process): The recording sheet is itself a model: every logged transition names the process (melting, crystallization, weathering and erosion, deposition and burial, heat and pressure) and the energy that drives it, and the modified-rules run requires students to revise the model for a new setting and explain the change. This produces direct evidence for the PE; no minerals are identified.

Roles (rotate each session)

- **Roller:** Rolls the die for the current traveler, announces the number, and keeps the die on the desk between rolls.
- **Table reader:** Finds the current station's table, reads the outcome aloud in full (process, energy source, destination or stay), and confirms the traveler's new station.
- **Recorder:** Writes one row per roll in the roll log: traveler, station before, roll, process, energy source, station after. Checks that each row's energy source matches the process.

- **Tally keeper and reporter:** Keeps the running tally of turns at each station, posts the group totals on the class chart, and leads the choice of setting for the modified-rules run.

Materials

Item	Quantity	Per	Note
Six-sided die	1	group	Two dice let two travelers run at once if time is short.
Station tables sheet (five tables, A4, one per group)	1	group	Table text is given in the prep notes.
Four traveler tokens (coins, buttons or counters)	4	group	Tokens sit on the station tables sheet so the group can see where each traveler is.
Recording sheet	1	student	
Class tally chart on the board or a shared spreadsheet	1	class	
Calculator	1	group	
Blank station table template for the modified-rules run	2	group	

Estimated cost: 0 to 5 per class (an estimate; Estimate. Dice and counters are usually in the classroom games box; a pack of 12 dice costs about \$4 if not. Everything else is printed paper.)

Safety

- No physical hazards. Keep dice on the desk, not thrown across the room; a dropped die is a trip hazard on a hard floor.
- If the lab is run as a floor game with taped stations, clear bags and chairs from the walking paths and walk, do not run, between stations.

Teacher preparation and setup

1. Print the station tables. **MAGMA:** 1-2, cools slowly deep underground and crystallizes (intrusion), energy: heat flows out of the melt into cooler rock; interior budget, go to **IGNEOUS ROCK**. 3, erupts and cools quickly at the surface (extrusion), energy: interior made the melt, surface takes the heat; go to **IGNEOUS ROCK**. 4-6, stays molten, energy: interior heat keeps it liquid; stay at **MAGMA**.
2. **IGNEOUS ROCK:** 1-2, uplifted and exposed (Earth's interior does the lifting), weathered and eroded into pieces, energy: Sun and gravity; go to **SEDIMENT**. 3, buried or caught in a plate collision, changed by heat and pressure without melting, energy: interior; go to **METAMORPHIC ROCK**. 4, heated until it melts, energy: interior; go to **MAGMA**. 5-6, stays as rock, energy: none needed; stay at **IGNEOUS ROCK**.
3. **SEDIMENT:** 1-3, deposited, buried, compacted and cemented, energy: gravity and the weight of overlying layers (surface budget); go to **SEDIMENTARY ROCK**. 4, carried farther by wind, water or ice, energy: Sun and gravity; stay at **SEDIMENT**. 5-6, sits in a dune, riverbed or seafloor, energy: none needed; stay at **SEDIMENT**.

4. SEDIMENTARY ROCK: 1-2, uplifted (Earth's interior does the lifting), weathered and eroded, energy: Sun and gravity; go to SEDIMENT. 3-4, buried deeply or squeezed in a plate collision, changed by heat and pressure, energy: interior; go to METAMORPHIC ROCK. 5, heated until it melts, energy: interior; go to MAGMA. 6, stays as rock; stay at SEDIMENTARY ROCK.
5. METAMORPHIC ROCK: 1, uplifted (Earth's interior does the lifting), weathered and eroded, energy: Sun and gravity; go to SEDIMENT. 2, heated until it melts, energy: interior; go to MAGMA. 3, more heat and pressure change it again into a different metamorphic rock, energy: interior; stay at METAMORPHIC ROCK (record 'changed again'). 4-6, stays as rock; stay at METAMORPHIC ROCK.
6. Draw the class tally chart with five station columns and one row per group plus a totals row and a percent row. Work out beforehand that the long-run fractions built into the tables are roughly magma 18 percent, igneous 13 percent, sediment 28 percent, sedimentary rock 17 percent and metamorphic rock 24 percent (exactly 16, 12, 25, 15 and 21 parts out of 89), so you can compare the class result with the rules.
7. Decide the starting stations: traveler 1 at Magma, 2 at Sediment, 3 at Sedimentary rock, 4 at Metamorphic rock, so the class samples every station from the first roll.
8. Prepare two or three settings for the modified-rules run on a slide: a desert basin far from any plate boundary; the edge of a plate collision building mountains; a chain of active volcanoes. Each group picks one.

Investigation design

Independent variable	The starting station of each traveler (run 1) and the rule set used, standard or modified for a chosen setting (run 2)
Dependent variable	The number of turns each traveler spends at each station, the route each traveler takes, and the group and class percent of turns at each station
Controlled	Ten rolls per traveler in every group; The same five station tables for run 1 in every group; A fair six-sided die read exactly as the table says; The same starting stations in every group
Trials	Four travelers per group in run 1 (40 turns), pooled across the class; two travelers per group in run 2 (20 turns) with modified rules.
Comparison	Group percents versus class percents versus the probabilities built into the tables; run 1 (standard rules) versus run 2 (rules modified for a setting).

Student procedure

1. Read all five station tables aloud as a group. For each table, check that every outcome names a process and an energy source, and say which outcomes are 'stay' and which are 'move.' Note that moving and staying are both allowed results.
2. Place the four traveler tokens on their starting stations: Magma, Sediment, Sedimentary rock, Metamorphic rock. Each traveler will make 10 rolls, one traveler at a time.
3. Run traveler 1. The Roller rolls; the Table reader reads the outcome for the traveler's current station; the Recorder writes the row (traveler, station before, roll, process or 'stays', energy source, station after); the

- Tally keeper adds a mark under the station where the traveler ends the turn. Move the token. Repeat until 10 rolls are logged.
4. Run travelers 2, 3 and 4 the same way. Rotate the Roller role after each traveler so everyone rolls at least once.
 5. Total the tally: how many of the group's 40 turns ended at each station. Calculate each station's percent of the 40 turns and post the group's five counts on the class chart.
 6. Trace each traveler's route on the recording sheet as a chain of station names with the process on each arrow. Mark any traveler that never visited Magma and any traveler that skipped from one rock type directly to another rock type.
 7. When the class chart is complete, copy the class totals and percents into your sheet and compare them with your group's percents and with the rule probabilities the teacher posts.
 8. Choose a setting from the slide. Decide which one or two station tables would be different there and why. On a blank template, rewrite those tables (keep six outcomes, each with a process and an energy source). Write a prediction: which station will gain turns, which will lose.
 9. Run two travelers for 10 rolls each with the modified tables, log the rows on the second roll log, and tally. Compare with your prediction.
 10. Answer the analysis questions individually.

Expected observations

- Travelers spend several consecutive turns at Sediment and Metamorphic rock; stays of three to six turns in a row are common.
- Group percents vary widely (a group may record 35 percent at one station and 5 percent at another); class percents land within a few points of the rule probabilities when 30 or more travelers are pooled.
- At least one traveler per group usually completes 10 rolls without visiting Magma, and at least one skips directly from igneous or sedimentary rock to metamorphic rock.
- In run 2, groups that chose the plate-collision setting typically shift turns toward Metamorphic rock and Magma; groups that chose the desert basin shift turns toward Sediment; volcano settings shift toward Magma and Igneous rock.

Likely difficulties

- Recorders write the station but not the process or the energy, which loses the point of the model. Require every row to have all six columns before the next roll.
- Groups treat 'stays' as a wasted turn and want to re-roll. Insist that stays count; they are the model's way of showing time.
- Percent arithmetic with 40 turns trips some students (divide by 40, multiply by 100). Post the formula and one worked example.
- Modified tables sometimes drop the energy source or make a station impossible to leave. Check each rewritten table for six outcomes, an energy source per outcome and at least one 'move' outcome.
- Time runs short for run 2. If so, have groups write and justify the modified tables and prediction in class and run the 20 rolls at the start of the next period.

Structured debrief

1. Finish the class chart and compute the class percents together. Post the rule probabilities (about 18, 13, 28, 17 and 24 percent for magma, igneous, sediment, sedimentary and metamorphic) and ask why the class line sits closer to them than any single group's line: more turns smooth out the luck of the die, which is why geologists want many samples, not one.
2. Collect routes on the board: ask for a traveler that never melted, a traveler that went igneous straight to metamorphic, and a traveler that sat at one station for five or more turns. Each one disproves a piece of the fixed-loop misconception: no required order, shortcuts exist, and staying put is normal.
3. Have two groups with different settings present their modified tables side by side (for example the desert basin with sediment that rarely gets buried fast, versus the plate collision with more heat-and-pressure and melting outcomes). Ask what changed in the counts and whether that matches where those rock types are actually common.
4. Close on the model itself. List on the board what the dice model shows well (many routes, no order, long stays, energy on every arrow) and what it hides (unequal timescales, the fact that only part of a rock body moves at a time, conditions that depend on depth and location). Ask students to say which of the three labs modeled the rock cycle best and for what purpose.

Recording sheet: what students fill in

Lab 3 recording sheet: Roll the rock cycle

Log every roll as one row. If the traveler stays, write 'stays' in the process column and the reason the table gives. The energy source must match the process: Sun and gravity for surface processes, Earth's interior for melting, uplift and heat-and-pressure changes, and 'none needed' when the material simply sits.

Roll log, run 1 (standard rules). Continue on the back for all 40 rolls.

[illegible]

Traveler	Station before	Roll	Process (or stays)	Energy source	Station after
2	Sediment				
2					

Station tally

Station	Group turns (of 40)	Group percent	Class turns	Class percent	Rule probability the teacher posts
Magma					
Igneous rock					
Sediment					
Sedimentary rock					
Metamorphic rock					
Total	40	100		100	100

Routes

Traveler	Route as a chain of stations (write the process on each arrow)	Ever visited Magma? (yes/no)	Skipped from one rock type straight to another? (which)
1			
2			
3			
4			

Run 2: our modified rules

Setting chosen	Station table(s) we changed	What we changed and why	Prediction: station that gains, station that loses	Result after 20 turns

- Which station held your group's travelers for the most turns, and which for the fewest? Give the counts.

Answer: Group-specific. Typically Sediment or Metamorphic rock holds the most turns (often 10 to 15 of 40) and Igneous rock or Sedimentary rock the fewest (often 3 to 7), but any honest counts that match the tally earn credit.

Why: Checks that the tally was kept and read correctly. The teacher can confirm against the posted group totals.

- Names the highest and lowest stations
- Gives counts that match the group's tally

2. Did any of your four travelers complete all 10 rolls without ever visiting Magma? Copy that traveler's route and explain why this is possible in the real rock cycle.

Answer: Group-specific; in most groups at least one traveler never reaches Magma (for example Sediment, Sediment, Sedimentary rock, Sedimentary rock, Metamorphic rock, Metamorphic rock, Metamorphic rock, Sediment, Sediment, Sedimentary rock). This is possible on Earth because weathering, burial and heat-and-pressure changes happen to solid rock at or near the surface and in the crust without any melting; a sandstone can become quartzite and then erode back to sand while never getting hot enough to melt.

Why: Direct evidence against the fixed loop. If no traveler avoided Magma, accept a route copied from another group or an explanation of why such a route is allowed by the tables.

- Reports whether a no-magma traveler occurred and copies a route
- Explains that surface and crust processes change solid rock without melting

Analysis questions: answer key

3. A group's 40 turns ended at Metamorphic rock 11 times and at Igneous rock 4 times. Calculate the percent of turns at each of these stations and show the arithmetic.

Answer: Metamorphic rock: $11 \div 40 = 0.275$, which is 27.5 percent. Igneous rock: $4 \div 40 = 0.10$, which is 10 percent.

Why: Percent of turns is the count divided by the total number of turns, multiplied by 100. Both calculations must be shown.

Also acceptable: Accept 28 percent rounded for metamorphic rock.

4. Look at the Metamorphic rock table. On what fraction of rolls does material stay at that station (including 'changed again')? Convert the fraction to a percent and explain why the rule was written that way, using what you know about how long real rock stays metamorphic.

Answer: Stays on rolls 3, 4, 5 and 6, which is 4 out of 6 rolls, or $4/6 = 2/3 \approx 0.667$, about 67 percent. The rule was written that way because once rock is deep enough to be metamorphosed it is usually far from the surface and not hot enough to melt, so it tends to remain metamorphic rock for a very long time, often hundreds of millions of years; a roll of 3 shows that it can be changed again by more heat and pressure while remaining at the station.

Why: Reading a probability from the table and connecting it to residence time. Full credit requires the fraction, the percent and the reason.

Also acceptable: Accept $3/6 = 50$ percent if the student explicitly counts 'changed again' as a change rather than a stay and says so.

- Fraction $4/6$ (or $2/3$) and about 67 percent
- Explains long residence of deep rock
- Counts 'changed again' as a stay

5. Compare your group's percents with the class percents and with the rule probabilities. Which was closer to the rules, your group or the class? Explain why, using the number of turns in each.

Answer: The class percents are almost always closer to the rule probabilities than any one group's. A group has only 40 turns, so a few lucky or unlucky rolls shift a station's percent by 5 or 10 points; the class has several hundred turns, so the effects of single rolls cancel out and the percents settle toward what the tables say. More trials give a result closer to the built-in probabilities, which is the same reason scientists collect many samples before drawing a conclusion.

Why: Sample size and variability. Full credit requires the comparison, the numbers of turns, and the cancelling-out idea.

- States that the class was closer (or honestly reports the exception and explains it as chance)
- Cites the number of turns in group versus class
- Explains that more trials reduce the effect of chance

6. Pick one row from your roll log where the material moved. Write the process, the energy source and the station it moved to, then explain in one or two sentences what that same change looks like on Earth and roughly how long it takes.

Answer: Example: 'Traveler 3, Sedimentary rock, roll 4, heat and pressure (buried or squeezed in a plate collision), Earth's interior, to Metamorphic rock.' On Earth this is a layered sandstone buried kilometers deep or caught between colliding plates, where heat and pressure fuse and regrow its grains into quartzite without melting; it takes millions of years. Any logged move earns credit if the process, energy and station match the table and the Earth description and timescale are reasonable (weathering and erosion: thousands to millions of years; a lava flow cooling: days to years; an intrusion cooling: thousands to millions of years; melting: thousands to millions of years).

Why: Links a model event to a real event with an order-of-magnitude time. Exact numbers are not expected; the point is that times differ by process and that the model hides this.

- Row copied with process, energy and destination matching the table
- Earth version described correctly
- A reasonable timescale given

7. Describe the rules your group wrote for run 2, the prediction you made, and what happened. Did the material pile up where you expected? Use your counts.

Answer: Group-specific. Example for the plate-collision setting: the Sedimentary rock table was changed so rolls 2-5 go to Metamorphic rock (heat and pressure, interior) and roll 6 melts (interior), and the Igneous rock table gained a second heat-and-pressure outcome; prediction, Metamorphic rock and Magma gain turns and Sediment loses; result, of 20 turns, Metamorphic rock rose from 25 percent in run 1 to about 45 percent. Full credit requires rules that fit the setting with a reason, an energy source on every outcome, a prediction stated before the run and a comparison with counts.

Why: This is the revise-the-model evidence. A prediction that failed is fine if the student says so and offers a reason (small sample, rules not changed enough).

- Rules described and justified by the setting
- Every new outcome has a process and an energy source
- Prediction stated and compared with counts from run 2

8. The model treats a turn at Magma and a turn at Sedimentary rock as the same length of time, and it never lets material be at two stations at once. Name two more ways the dice model is unlike the real rock cycle and one thing the model shows well.

Answer: Any two of: the same probabilities everywhere, while real chances depend on depth, climate and distance from a plate boundary; no sense of depth or location, so a traveler can be 'at the surface' one roll and 'melted' the next with no journey between; no dissolved route or shell-building; no partial change, so a whole rock body changes at once; every roll is independent, while on Earth one process (uplift) makes others (weathering) far more likely. Something the model shows well: there is no required order and shortcuts between rock types are normal; material stays put for long runs; every change is tied to an energy source; pooled data reveal where material tends to collect.

Why: Students must evaluate the model as a model. Full credit requires two limits beyond the two given in the prompt and one genuine strength.

- Two additional limits named, each specific
- One strength named that connects to the lesson's model ideas

Individual evidence of learning

Each student submits a complete roll log with process and energy source on every row, the station tally with group and class percents, the routes table, the run 2 rules and result, and written answers to q1 through q8. The roll log and routes table are direct evidence for the model with energy sources (MS-ESS2-1); q7 shows whether the student can revise the model for a setting and reason about the result.

Assessment criteria

Criterion	Proficient looks like
Model with energy	Every logged move names the correct process and the correct energy budget; stays are recorded with the table's reason; routes are written as station chains with processes on the arrows.
Data analysis	Group and class percents computed correctly from the counts; the student explains that the larger class sample lands closer to the rule probabilities.
Revising the model	Modified tables fit the chosen setting with a stated reason, keep an energy source on every outcome, include a testable prediction, and the result is compared with the prediction using counts.
Model evaluation	Names at least three specific limits of the dice model (equal turn lengths, one station at a time, no depth or location, fixed probabilities) and at least one strength (no required order, long stays, energy on every arrow).

Accessibility adaptations

- Run the lab as a floor game with five taped stations and large printed tables for students who need movement; each student walks as a traveler while a partner logs the rows.
- Provide a roll log with the station names as a drop-down or checklist and the energy sources as two stamps or stickers (Sun and gravity; Earth's interior) for students who need more support or are multilingual.

- Allow a partner to roll and read the table while a student with limited fine-motor control records on a tablet or dictates rows.
- Supply a pre-computed class chart to groups who need to focus on interpretation rather than arithmetic, and a calculator for all.

Low-cost alternative

If dice are unavailable, use six numbered slips drawn from a cup and returned, or a spinner cut from card. The whole lab can be run with one die per class if groups take turns rolling at the front while everyone logs the same traveler.

Model limitations

The dice model gives every turn the same length, while real changes range from hours (lava cooling) to hundreds of millions of years (a mountain range eroding). It moves all of a traveler's material at once, while in reality only the exposed part of a rock body weathers and only the deepest part melts. It uses the same probabilities everywhere, while real chances depend on depth, climate and nearness to a plate boundary, which is exactly what the modified-rules run begins to fix. It leaves out hot fluids, partial melting and the dissolved route to rock. This activity has not been physically tested with students; the expected station percents come from the rule probabilities and a small simulation, and the timing is an estimate.

Teacher notes

Spot-check roll logs against the tables: a row that says 'Igneous rock, roll 3, melting' is a reading error (roll 3 at Igneous rock is heat and pressure). The rule probabilities to post are 18, 13, 28, 17 and 24 percent (magma, igneous, sediment, sedimentary, metamorphic), the long-run fractions of the five tables (exactly 16, 12, 25, 15 and 21 out of 89). In simulated classes of 28 to 32 travelers with 10 rolls each, each station landed within 5 points of its value about 8 or 9 times in 10 (all five at once about 6 times in 10), and the class result was closer to the rules than a single group's about 95 percent of the time. For q3 and q4 check the arithmetic, not the wording. For run 2, the most common flaw is a table with no 'move' outcome, which traps the traveler; treat that as a teaching moment about systems that must keep cycling.