

Rock Detectives at Red Mesa: An Evidence Jigsaw

Learning target: I can work with a team to combine evidence cards from one site into an ordered history of its rocks, naming the rock-cycle process and energy source behind each event, and defend that history to another group.

Collaborative investigation

About 55 min

Jigsaw

MS-ESS2-1 · practice

MS-ESS2-2 · supports

collaboration

discussion

visual modeling

Standards connections

MS-ESS2-1 (practice): Building a site history from evidence requires students to recognize melting, crystallization, weathering, deformation and sedimentation from their traces and to tie each to the Sun or Earth's interior. The group's timeline is a model of the cycle at one place, built toward the PE.

MS-ESS2-2 (supports): The timeline mixes very slow events (intrusion, uplift, tilting) with fast ones (a lava flow, a rockfall), which previews the varying time scales of surface change that MS-ESS2-2 addresses in Lessons 11 and 26.

Purpose: practice · **Time:** about 55 minutes · **Format:** jigsaw

Answers with reasoning

The site. Red Mesa is a flat-topped hill in a dry region. A river has cut a canyon into its side, exposing everything from the hill's dark cap down to the pink rock at the canyon floor. Your class visited, and the cards below are the field notes and lab results, split among four experts. Nobody has the whole story until the group puts the cards together.

Twelve evidence cards from Red Mesa

1 Card 1 (Set A): The river today

The river in the canyon carries sand after storms. The sand on its bars is pink, white, gray and black, and the grains are rounded. Upstream, the river flows across the pink rock at the canyon floor.

2 Card 2 (Set A): The pebbly layer

The lowest of the tilted layers is a rock made of rounded pebbles cemented together. Most pebbles are pink-and-gray with interlocking crystals about 5 mm across, exactly like the pink rock at the canyon floor. The pebbly layer rests directly on top of the pink rock.

3 Card 3 (Set A): The stack of layers

Above the pebbly layer come, in order: tan sandstone in layers with ripple marks on some surfaces; gray shale in very thin layers; and a pale limestone full of shell fossils. All of these layers are tilted 20 degrees toward the east.

4 Card 4 (Set B): The pink rock at the canyon floor

The pink rock has no layers. It is made of interlocking pink, white, black and gray crystals 4 to 8 mm across. It forms the floor and lowest walls of the canyon over a width of at least 2 km.

5 Card 5 (Set B): The banded rock beside the pink rock

At the east edge of the pink rock is a dark rock whose crystals are flattened and lined up in wavy bands. The pink rock cuts straight across the bands. Within about 30 m of the pink rock, the banded rock's crystals are noticeably larger than they are farther away. No fossils are found in it.

6 Card 6 (Set B): Lab report on the banded rock

The banded rock's chemical makeup matches a mud rock such as shale, not the pink rock. It contains no glass and no gas holes. The highest temperature it ever reached is estimated at about 550 °C, which is below the roughly 700 °C at which a rock of this makeup begins to melt.

7 Card 7 (Set C): The cap rock on top

The mesa's flat cap is a dark gray rock with crystals about 0.2 mm across, too small to see without a lens. Near its top surface it is full of small holes left by gas bubbles. The cap lies flat (horizontal) and is about 15 m thick.

8 Card 8 (Set C): The sandstone and limestone under a lens

The sandstone's grains are rounded sand, glued together by a mineral cement, with small gaps between grains. The limestone is built mostly of broken shells of sea animals, pressed together in layers.

9 Card 9 (Set C): Crystal sizes measured in the lab

Pink rock: 4 to 8 mm, interlocking, random directions.
Banded rock: 1 to 2 mm, flattened and lined up.
Cap rock: about 0.2 mm, interlocking, random directions.
Sandstone: grains about 0.5 mm, rounded, not interlocking.

10 Card 10 (Set D): The surface under the cap

The tilted layers do not continue up into the cap. Their tops are cut off along an uneven surface, and a thin layer of old soil with plant roots lies on that surface, directly under the flat cap rock.

11 Card 11 (Set D): Drill-hole temperature log

A drill hole near the mesa measured rock temperatures: 15 °C at the surface, 40 °C at a depth of 1 km, and 65 °C at 2 km. The deeper the hole went, the hotter the rock.

12 Card 12 (Set D): Weather and the canyon edge

The mesa receives about 300 mm of rain a year, mostly in storms. In winter, water freezes in cracks along the cap rock's edge, and blocks of cap rock break off and fall to the canyon floor, where the river gradually rounds and moves them.

Part A: Expert round (one set per person)

1. Your expert set: _____. For each of your three cards, write one sentence: what the card is evidence **for** (which rock-cycle process or event), and whether the energy behind it is the Sun (with gravity) or Earth's interior.

Answer: Set A: card 1, weathering and erosion of the pink rock into sand carried by the river today (Sun and gravity); card 2, the pink rock was exposed, weathered into pebbles, and the pebbles were deposited and cemented (Sun and gravity); card 3, deposition of sand, mud and shells in layers, later tilted (Sun and gravity for deposition; Earth's interior for tilting). Set B: card 4, slow cooling of magma underground into coarse igneous rock (Earth's interior); card 5, deformation of an older rock into banded metamorphic rock, later cut and heated by the intrusion (Earth's interior); card 6, the banded rock's parent was shale and it changed below its melting point, so it never melted (Earth's interior). Set C: card 7, fast cooling of lava at the surface into fine-grained igneous rock with gas holes (Earth's interior supplied the lava; it cooled in the air); card 8, compaction and cementation of sand and of shells (Sun and gravity); card 9, crystal size matches cooling speed and metamorphic alignment (both sources, by rock). Set D: card 10, uplift, tilting and erosion before the lava flow (Earth's interior for tilting; Sun and gravity for erosion); card 11, Earth's interior supplies heat that increases with depth; card 12, weathering and erosion of the cap today (Sun and gravity).

Why: Each expert set mixes surface and deep evidence on purpose, so every student handles both energy sources.

Also acceptable: Accept 'Sun' alone without gravity, and 'tectonic forces' for Earth's interior.

- Identifies the set
- Each of the three cards tied to a process or event
- Energy source named for each

Part B: Home group task

1. Lay all twelve cards on the desk. Each expert teaches their three cards in two minutes or less.
2. Decide which rock is the oldest. Use the rules: a rock that cuts across another is younger than it; a layer on top of another is younger than it; pebbles of a rock are younger than the rock they came from.
3. Arrange the events in order from oldest to today. There are eight events. Write them in the timeline table, with the card numbers that are your evidence for each.
4. For each event, write the rock-cycle process (melting, cooling and crystallization, weathering, erosion, deposition, compaction and cementation, deformation, recrystallization, uplift, tilting) and the energy source.
5. Prepare a one-minute defense of the two placements your group found hardest. Every member must be able to give it.

2. Group timeline: complete all eight rows.

Answer: 1 (oldest): mud deposited and buried, becoming shale (card 6); deposition, compaction and cementation; Sun and gravity. 2: the shale squeezed and heated into banded metamorphic rock (cards 5, 9); deformation; Earth's interior. 3: magma intrudes into the banded rock and cools slowly into the pink rock, heating the banded rock within 30 m so its crystals regrow (cards 4, 5, 6, 9, 11); melting elsewhere, then cooling and crystallization, plus recrystallization of the neighbor; Earth's interior. 4: uplift and erosion expose the pink rock; weathering breaks it into pebbles and sand (cards 2, 12); uplift (Earth's interior), weathering and erosion (Sun and gravity). 5: pebbles, then sand, mud and shells are deposited in layers and compacted and cemented into the pebbly rock, sandstone, shale and limestone (cards 2, 3, 8); deposition, compaction and cementation; Sun and gravity. 6: the layers are tilted 20 degrees and their tops eroded to an uneven surface where soil forms (card 10); tilting (Earth's interior), weathering and erosion (Sun and gravity). 7: lava flows over the surface and cools quickly into the cap rock (cards 7, 9); cooling and crystallization; lava supplied by Earth's interior. 8 (today): frost and the river weather and erode the cap and the pink rock, carrying sand downstream (cards 1, 12); weathering, erosion, deposition; Sun and gravity.

Why: The order is fixed by three relationships: the pink rock cuts the banded rock (so the banded rock is older); pebbles of pink rock lie in the lowest layer (so the pink rock was exposed before the layers formed); the tilted layers are cut off under the flat cap (so tilting and erosion came before the lava). Events 1 and 2 may be combined by some groups into 'an older rock was deformed'; accept that as long as card 6's shale parent is mentioned somewhere.

Also acceptable: Accept seven rows if events 1 and 2 are merged, or if event 8 is folded into event 4's description, provided the order is otherwise correct.

- Events in a defensible order with the three key relationships respected
- Each event cites at least one card
- Process named for each event
- Energy source correct for each event

3. Group answer: Which placement did the neighboring group challenge, and which card(s) did you use to answer the challenge?

Answer: Common challenges and good replies: 'Why isn't the pink rock the oldest, since it is at the bottom?' (card 5: it cuts across the banded rock, so the banded rock was there first). 'Why do you say the pink rock was at the surface before the layers?' (card 2: the lowest layer contains pebbles of it, and pebbles only form from rock exposed to weathering). 'Why put tilting before the cap?' (card 10: the tilted layers are cut off and soil-covered under a flat cap; if tilting came after, the cap would be tilted too). 'Did the banded rock melt?' (card 6: 550 °C is below the 700 °C melting point, and there is no glass).

Why: Credit any specific challenge answered with a card.

Also acceptable: Any reasonable challenge with an evidence-based reply earns credit.

- Records a real challenge
- Reply cites a card

Part C: Individual accountability (complete alone)

4. Explain how cards 2 and 4 together prove that the pink rock is older than the tilted layers, and what must have happened to the pink rock between its formation and the deposition of the pebbly layer.

Answer: Card 2 says the lowest layer contains pebbles of the pink rock and rests on top of it; card 4 describes the pink rock as a large body of coarse crystals formed underground. Pebbles can only be made from rock that has been broken by weathering at the surface, so the pink rock must already have existed, been uplifted and exposed, and been weathered and eroded before the pebbly layer was deposited on it. Between forming and the pebbly layer, the pink rock had to be lifted from depth and the rock above it removed.

Why: This is the 'pebble rule' plus the need for uplift and exposure of an intrusive rock.

Also acceptable: Accept 'the land rose and the rock on top wore away' for uplift and erosion.

- Uses the pebble evidence to establish the pink rock as older
- States that uplift and erosion exposed it first

5. Using card 9, explain why the cap rock and the pink rock have such different crystal sizes even though both have interlocking crystals in random directions. Where did each one cool?

Answer: Both are igneous rocks that crystallized from a melt, which is why both have interlocking crystals in random directions. The pink rock's crystals (4 to 8 mm) are large because its magma cooled very slowly deep underground, insulated by surrounding rock. The cap rock's crystals (about 0.2 mm) are tiny because it was lava that poured out onto the surface and cooled fast in the air; the gas holes near its top confirm it was at the surface.

Why: Crystal size tracks cooling time; the setting follows from the size.

Also acceptable: Naming granite and basalt is acceptable but not required.

- Both identified as igneous
- Large crystals linked to slow underground cooling
- Small crystals linked to fast surface cooling

6. Card 10 shows an uneven surface with old soil between the tilted layers and the flat cap. List the events that must have happened, in order, between the limestone forming and the cap forming. Name the energy source for each.

Answer: In order: (1) the layers were buried, compacted and cemented into rock (Sun and gravity for the deposition; gravity for the weight); (2) tectonic forces tilted the whole stack 20 degrees and lifted it (Earth's interior); (3) weathering and erosion wore the tilted tops down to an uneven surface (Sun and gravity); (4) soil and plants developed on that surface (Sun); then the lava arrived.

Why: The old soil proves the surface was exposed and stable for a while before the lava buried it.

Also acceptable: Accept three events if compaction and cementation is treated as part of the limestone forming.

- Tilting/uplift listed before erosion
- Erosion and soil formation listed before the cap
- Energy sources matched correctly

7. From card 11, calculate how many degrees Celsius the temperature rises for each kilometer of depth. Then estimate the rock temperature at 20 km depth. Using card 6's figures, decide whether a shale at 20 km would more likely be melting or changing while solid, and explain.

Answer: Rise per kilometer: $(40\text{ }^{\circ}\text{C} - 15\text{ }^{\circ}\text{C}) \div 1\text{ km} = 25\text{ }^{\circ}\text{C per km}$ (check: $65 - 40 = 25\text{ }^{\circ}\text{C}$ for the second kilometer). At 20 km: $15\text{ }^{\circ}\text{C} + 25\text{ }^{\circ}\text{C/km} \times 20\text{ km} = 15 + 500 = 515\text{ }^{\circ}\text{C}$. A shale at about $515\text{ }^{\circ}\text{C}$ is below the roughly $700\text{ }^{\circ}\text{C}$ at which it begins to melt (card 6), so it would more likely be changing while solid (metamorphism) than melting. Melting would need greater depth, extra heat from nearby magma, or added water.

Why: Linear extrapolation of the gradient; students then compare with the melting figure from card 6. Note that real gradients vary and flatten with depth, so the estimate is rough.

Also acceptable: Accept $500\text{ }^{\circ}\text{C}$ if the student multiplied 25×20 without adding the surface $15\text{ }^{\circ}\text{C}$, provided the conclusion (metamorphism, not melting) is the same.

8. Card 5 says the banded rock's crystals are larger within 30 m of the pink rock. Explain what caused this and why the effect stops at about 30 m. Does card 6 support or contradict your explanation?

Answer: When the magma intruded, heat flowed from it into the neighboring banded rock by conduction. The extra heat let the rock's crystals regrow larger while the rock stayed solid (recrystallization). Heat spreads out and weakens with distance, so beyond about 30 m the rock never got hot enough to change. Card 6 supports this: the rock reached about $550\text{ }^{\circ}\text{C}$ (hot enough to recrystallize) but stayed below its $700\text{ }^{\circ}\text{C}$ melting point, and it contains no glass, so it changed without melting.

Why: This is contact metamorphism explained through heat conduction and distance; students need not use the term.

Also acceptable: Accept 'baked' for heated if the rock is described as staying solid.

- Heat from the intrusion caused crystal growth
- Distance explains the 30 m limit
- Card 6 cited as support (below melting, no glass)

9. Trace the material in **one** of the pink-and-gray pebbles in card 2 from its earliest stage in the cards to where it is now, naming each rock type or material it was part of, the process that moved it to the next stage, and the energy source. Then say what could happen to it next, and why the rock cycle has no end point.

Answer: Model response: The pebble's material started as magma made by melting deep underground (Earth's interior). It cooled slowly into the pink intrusive igneous rock (cooling and crystallization, Earth's interior supplied the heat that was lost). Uplift raised the rock (Earth's interior), and weathering and erosion exposed it and broke off a chunk that a river rounded into a pebble (Sun and gravity). The pebble was deposited in a layer and cemented into the pebbly sedimentary rock (deposition, compaction and cementation; Sun and gravity). The layer was tilted and partly eroded (Earth's interior, then Sun and gravity) and is now exposed in the canyon wall. Next, it could be weathered out again and become river sand, be buried and heated into metamorphic rock, or be melted into magma; the cycle has no end point because every rock at the surface is exposed to weathering and every rock at depth is exposed to heat and pressure, so something is always able to change it.

Why: Full credit requires at least three stages with processes and energy sources, consistent with the group's timeline, and a reasoned 'no end point' statement.

Also acceptable: Starting at the pink rock rather than at magma is acceptable; starting earlier (what melted to make the magma) is speculative but not wrong.

- Traces magma → igneous rock → pebble (sediment) → sedimentary rock
- Process named for each change
- Energy source for each change
- Gives a possible next stage and explains why there is no end

Scoring rubric

Criterion	4 • Exemplary	3 • Proficient	2 • Developing	1 • Beginning
Expert teaching (Part A)	All three cards correctly tied to a process or event and an energy source; taught to the home group clearly enough that others can use them.	Two of three cards correctly interpreted; teaching mostly clear.	Cards read aloud but not interpreted, or energy sources missing.	Expert role not fulfilled.
Timeline order and evidence (Part B)	All eight events in a defensible order that respects the cut-across, layer-on-top and pebble relationships; every event cites cards.	One event out of order or one event lacking card evidence.	Two or more placements violate a relationship, or several events lack evidence.	Events listed without order or evidence.
Processes and energy (Part B)	Correct process and energy source for every event, including metamorphism without melting and the Sun for surface processes only.	One process or energy source wrong.	Several wrong, or energy sources assigned without reasons.	Processes and energy sources missing.
Individual accountability (Part C)	All six Part C answers accurate, cite cards, and show the student understands the group's reasoning; q7 calculation correct.	Four or five accurate with card evidence; one thin or partly incorrect.	Two or three accurate; others restate the group result without reasoning.	Part C mostly blank or inaccurate.

Teacher notes

Print and cut the twelve cards; shuffle before handing a full deck to each home group. The expert sets each mix surface and deep evidence on purpose. The site is fictional but every relationship is a real geologic principle: cross-cutting (the intrusion is younger than the banded rock), superposition (each layer younger than the one below), inclusions (pebbles older than the layer that holds them), and an unconformity with a buried soil under the lava. The drill-log gradient of 25 °C per km is a typical continental value, and 550 °C below a roughly 700 °C melting onset is realistic for shale next to a granite; both are teaching numbers. Do not require rock names beyond those on the cards; mineral identification is outside the PE's assessment boundary. The most common error is placing the pink rock first because it is at the bottom; let the neighboring group's challenge, not the teacher, surface card 5.

Scaffold offered to students: Three age rules and two energy rules

Age rules: (1) a rock that cuts across another rock is younger than the rock it cuts; (2) in an undisturbed stack, each layer is younger than the one below it; (3) a pebble inside a layer is older than the layer, and the rock the pebble came from must have been at the surface before the layer formed. Energy rules: anything done by rain, rivers, wind, ice or living things at the surface runs on the Sun (with gravity pulling material downhill); anything that needs heat or squeezing underground, or that lifts or tilts whole regions, runs on Earth's interior. Start by finding the oldest rock with rule 1 (what does the pink rock cut?).

Extension: Thirteenth card

Write a thirteenth evidence card that would **change** your group's timeline if it were true: for example, a fossil found inside the banded rock, or a pebble of cap rock found inside the pebbly layer. Explain which placement it would force you to move and why. Then explain why a geologist would treat a single surprising card with caution and what further evidence they would look for before rewriting the history.