

Case File: Pinecrest Valley. Which Processes Shaped It, and How Fast?

Investigation question: Using only twelve pieces of field evidence, which geoscience processes shaped Pinecrest Valley, at what space and time scales did each one work, and in what order did they happen?

Evidence-based mystery

Groups of 4

1 session

Setup 5 · Activity 42 · Cleanup 3 min

MS-ESS2-2 · assesses

MS-ESS2-1 · supports

Scientific purpose

Students act as a survey team handed a case file of twelve evidence cards from a fictional valley: scratched bedrock, out-of-place boulders, a fresh rock scar, tilted layers with an ash bed, a cave, a gravel fan with a mud coat, an offset stream, a hoodoo and its fallen cap, GPS data and tilted fence posts. They must match each card to a process and an agent, place it on a space-time grid, use the numbers on the cards to compute rates and ages, order the events from oldest to youngest, and write an evidence-based explanation of how the valley formed. The valley is invented so that the answers cannot be looked up and every claim must trace to a card.

Why this helps students with this chapter

Geologists never watch a valley form; they infer its history from clues and from rates they can measure today. A mystery with invented evidence forces students to do the same reasoning instead of recalling a textbook story, and the numbers on the cards (an offset, a GPS rate, a formation length, a fence that tilted in twenty years) let them compute ages and rates themselves. The cards mix slow processes with sudden events on purpose, so the explanation has to use both.

Standards connections

MS-ESS2-2 (assesses, constructing an explanation from evidence of surface change at varying time and spatial scales): The final written explanation requires students to name specific processes, cite evidence, assign each a space and time scale, distinguish gradual processes from sudden events, and order them, which is the performance expectation as written. The teacher can score it directly against the assessment criteria.

MS-ESS2-1 (supports, weathering, sedimentation and uplift as steps in the cycling of Earth's materials): The tilted sandstone, the ash bed and the cave are pieces of the rock cycle that Lesson 17 assembles; here students only have to recognize them as deposited, hardened and uplifted material.

Roles (rotate each session)

- **Lead investigator:** Reads each card aloud, keeps the group arguing from the card's words, and makes sure every claim in the final explanation names a card number.

- **Scale keeper:** Places each card number in one cell of the space-time grid and defends the placement with the card's numbers.
- **Timeline builder:** Arranges the events from oldest to youngest on the order table and writes the reason for each position.
- **Rate checker and reporter:** Does every calculation on the calculation table (rates, ages, how long), checks units, and leads the writing of the final explanation, which every member signs.

Materials

Item	Quantity	Per	Note
Evidence card set (12 cards printed from the recording sheet and cut apart)	1 set	group	Laminate or put in sheet protectors to reuse across periods.
Recording sheet with the process table, space-time grid, calculation table, order table and explanation page	1	student	
Calculator	1	group	
Large sheet of paper or whiteboard space for a group sketch of the valley	1	group	
Sticky notes for placing card numbers on the group's grid before committing	12	group	
Colored pencils (two colors: slow and sudden)	1 set	group	

Estimated cost: 2 to 5 per class (an estimate; Printing and cutting twelve cards per group on card stock; sheet protectors if reused. Everything else is classroom stock.)

Safety

- No hazards beyond ordinary classroom materials; no chemicals, heat or sharp tools are used.
- Keep walkways clear if groups spread out on the floor to arrange cards.

Teacher preparation and setup

1. Print one card set per group on card stock, cut apart, shuffle, and clip; number the backs so lost cards can be returned.
2. Print the recording sheet for each student and one enlarged space-time grid per group (optional) so the whole group can see sticky notes move.
3. Read the answer key once so you can ask pointed questions without giving placements away; decide in advance whether you will reveal the full history at the end or only the scoring criteria.
4. Write the two rate formulas on the board before class: $\text{rate} = \text{change} \div \text{time}$, and $\text{time} = \text{change} \div \text{rate}$.
5. If the class has not finished slides 11 to 16 (slow and fast changes, the two rulers), do the two-rulers diagram first; the grid depends on it.

Investigation design

Independent variable	The evidence card being interpreted (twelve different features and measurements)
Dependent variable	The process, agent, space scale, time scale and order the group assigns to each card, and the rates and ages computed from the cards' numbers
Controlled	Same twelve cards for every group; Same grid categories and the same rate formulas; No outside sources during the investigation; every claim must cite a card
Trials	Each group makes one full set of placements and one explanation; the class compares placements across groups in the debrief and resolves disagreements by returning to the cards.
Comparison	Group placements and orders versus the key, and group versus group where they disagree.

Student procedure

1. Read the case file introduction on the recording sheet. Shuffle the twelve cards and deal them around the group. Each person reads their cards aloud, one at a time, and the group paraphrases what each card actually says before anyone names a process.
2. First pass (process table): for each card, agree on the process (weathering, erosion, deposition, uplift, or 'other' with a name) and the agent (water, ice, wind, gravity, living things, chemical reaction, forces inside Earth). Write both in the table. Some cards show two processes; write both.
3. Second pass (space-time grid): for each card, decide how much space the change covers (millimeters to meters; tens to hundreds of meters; kilometers; regional or larger) and how long the change took (seconds to minutes; hours to days; years to decades; thousands of years; millions of years). Use sticky notes on the group grid first, argue, then copy card numbers into the grid on your own sheet. Color each number: one color for slow processes, the other for sudden events.
4. Third pass (calculation table): use the numbers on cards 5, 7, 9 and 10 to compute a rate or an age. Show every calculation with units. Decide what each number tells you about the time scale of that card.
5. Fourth pass (order table): arrange all the events from oldest to youngest. Some cards describe something still going on; mark those 'ongoing' and place them by when they started. For each position write one sentence of reasoning that names the card.
6. Draw the group's cross-section of the valley on the large sheet: the U-shaped floor, the tilted layers with the ash bed, the cave, the fan, the fault line, the hoodoo, the fresh scar. Label each feature with its card number.
7. Write the explanation individually: how Pinecrest Valley got its shape and features. Name at least three slow processes and two sudden events, give each a space scale and a time scale, cite card numbers for every claim, and state which sudden events had slow causes you can point to in the cards.
8. Compare your explanation with one other group's. Record one place where you disagree and what evidence would settle it.

Expected observations

- Groups readily identify the rockfall (Card 3), the ash bed (Card 11) and the toppled cap (Card 8) as sudden, and the cave, fan and tilted layers as slow; the offset stream (Card 7) and the fan with its mud (Card 6) produce the most argument because each contains both.
- Most groups connect Cards 1 and 2 to ice once someone notices the scratches all point the same way and the boulders are far from their source; a few groups first suggest a flood and must explain why a flood would not polish and scratch the walls in parallel lines.
- Calculations come out at 4,000 years (Card 5), 600 years (Cards 7 and 9), 2 cm/yr (Card 10) and 20 m per thousand years (Card 9); unit slips (centimeters versus millimeters) are the common error.
- Explanations that cite card numbers for each claim are noticeably stronger and shorter than ones that retell the story from memory.

Likely difficulties

- Students want to assign one process per card; Cards 4, 6, 7 and 8 each contain two or more (for example deposition, then compaction and cementation, then uplift). Allow multiple entries and reward them.
- The scale columns feel arbitrary at the edges (is a 600 m fan 'hundreds of meters' or 'kilometers'?). Tell students the argument matters more than the cell; any defensible placement with the card's number earns credit.
- Groups may place Card 11's eruption as 'millions of years' because the ash is old. The eruption took days; its age is a different question from its duration. The grid asks how long the change took.
- The order table has ten positions and some events overlap or are ongoing; students should use 'ongoing' and justify starts rather than forcing a single line.
- Unit conversions in q3 and q4 (40 cm to 400 mm; 12 m to 1,200 cm) are where most numerical errors happen.

Structured debrief

1. Project a blank grid and have each group place one card number with a reason until all twelve are placed. Stop on disagreements and return to the card's words. Card 6 (fan and mud) and Card 7 (offset) should appear twice, because each contains a slow process and a sudden event.
2. Walk the calculations: Card 5, $400 \text{ mm} \div 0.1 \text{ mm/yr} = 4,000 \text{ years}$; Cards 7 and 9, $1,200 \text{ cm} \div 2 \text{ cm/yr} = 600 \text{ years}$ of stored motion released in a few earthquakes; Card 10, $40 \text{ cm} \div 20 \text{ yr} = 2 \text{ cm/yr}$ of soil creep; Card 9, $2 \text{ cm/yr} \times 1,000 \text{ yr} = 20 \text{ m}$. Ask which of these the team could have watched happen in one visit (none) and which they could detect with instruments in one year (the GPS motion).
3. Build the agreed order on the board: sand and mud deposited in shallow water with the ash bed falling into it about 760,000 years ago (Cards 4, 11); layers hardened, uplifted and tilted (Card 4); ice filled the valley, scratched and polished the floor and walls, carried the pink boulders and dropped them when it melted (Cards 1, 2); after the ice, water dissolved the cave and formations began growing about 4,000 years ago (Card 5); the stream built the fan over thousands of years (Card 6); the hoodoo was carved and one cap toppled (Card 8); the fault accumulated 12 m of offset over about 600 years in sudden jumps (Cards 7, 9); the fence tilted over 20 years (Card 10); a flash flood coated the fan with mud within the last

few years (Card 6); the rockfall happened within the last three years after years of frost wedging (Cards 3, 12). Accept reasonable alternatives that the evidence allows and point out which positions the evidence does not pin down.

4. End on the two rulers: the fault motion (regional, years to centuries plus seconds), the cave formation (centimeters, thousands of years) and the rockfall (tens of meters, seconds) show that size and speed do not travel together. Ask students which card they would most want a real measurement for and what instrument they would use.

Recording sheet: what students fill in

Lab 2 recording sheet: Case file, Pinecrest Valley

About this case — Pinecrest Valley is invented for this investigation. Every feature and number on the cards is a teaching example designed to resemble real field evidence. Do not look anything up; the only evidence is the cards.

You are a survey team sent to a valley about 45 km long with a flat floor, steep walls and a stream. You have twelve observations. Your job is to explain, with evidence, how the valley got its shape and its features, which changes were slow and which were sudden, and in what order they happened.

Evidence cards (teacher prints and cuts apart; 12 cards)

Card 1

CARD 1. The valley has a flat, wide floor and steep walls; seen from the end, its shape is a U, not a V. The bare bedrock on the lower walls carries long, straight, parallel scratches, all pointing down-valley. The scratches are polished smooth in places.

Card 2

CARD 2. Boulders of pink granite, some as big as a car, sit scattered on the valley floor. The bedrock of the valley is gray. The nearest pink granite outcrop is 40 km up-valley, at the head of the valley.

Card 3

CARD 3. On the south wall there is a pale, fresh-looking scar about 30 m across and 20 m tall, surrounded by darker, lichen-covered rock. Below it lies a pile of sharp-edged blocks with no soil, moss or plants on them. A hiker's photograph taken three years ago shows the same wall with no scar.

Card 4

CARD 4. The north wall is made of layered rock: bands of sandstone alternating with softer gray mudstone. The layers are tilted about 20 degrees. The surfaces of some sandstone layers show ripple marks like those on a sandy stream bed today. Some layers hold the shells of sea creatures.

Card 5

CARD 5. Near the valley mouth a cave opens in a limestone layer. Formations hang from the ceiling; the longest is 40 cm. A dated sample from one formation shows it has grown at about 0.1 mm per year. The cave walls are dissolved into smooth, rounded shapes, and water drips from the ceiling.

Card 6

CARD 6. Where a side canyon meets the valley, a fan-shaped apron of gravel and sand spreads about 600 m across the floor. The fan is covered by a layer of cracked, dried mud 3 cm thick. In the mud the team found a plastic bottle cap and flattened grass still partly green.

Card 7

CARD 7. The stream crossing the valley bends sharply where it meets a straight line of crushed rock that runs across the valley. The stream channel on one side of the line is offset 12 m from the channel on the other side. Old maps from 300 years ago show a smaller offset.

Card 8

CARD 8. Beside the north wall stands a pillar of soft gray rock 8 m tall with a slab of hard sandstone on top like a cap. Twenty meters away a second slab of the same sandstone lies on the ground, with crumbled gray rock scattered around it and the stump of a pillar beside it.

Card 9

CARD 9. Two GPS stations, one on each side of the line of crushed rock in Card 7, show that the east side is moving north at about 2 cm per year compared with the west side. The motion is steady from year to year.

Card 10

CARD 10. On a gentle grassy hillside above the valley, a line of wooden fence posts is tilted downhill. The post tops have moved about 40 cm downhill from their bases. A survey made 20 years ago recorded the fence as straight and upright. There is no sign of a slide or a scar.

Card 11

CARD 11. Inside the layered rock of the north wall, between two sandstone layers, lies a bed of fine volcanic ash 2 m thick. Dating shows the ash is about 760,000 years old. The nearest volcano is 300 km away.

Card 12

CARD 12. Along the cliff top above the fresh scar (Card 3), cracks in the granite run parallel to the cliff face. Winter photographs show the cracks filled with ice. Each spring the team finds new chips and small slabs of granite at the cliff base.

Process table: what each card shows

Card	Process (weathering, erosion, deposition, uplift, other)	Agent (water, ice, wind, gravity, living things, chemical, forces inside Earth)	Slow process or sudden event?	One phrase from the card that proves it
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

Space-time grid: write each card number in one cell (a card with two events may appear twice)

How long it took	Millimeters to meters	Tens to hundreds of meters	Kilometers	Regional or larger
Seconds to minutes				
Hours to days				
Years to decades				
Thousands of years				
Millions of years				

Calculation table: rates and ages from the cards

Card	What you are finding	Numbers from the card	Calculation with units	Result	What it tells you about the time scale
5	Age of the 40 cm formation				
7 and 9	Years of motion stored in the 12 m offset				
10	Rate of soil movement				
9	Distance the east side moves in 1,000 years				

Order table: oldest to youngest (write 'ongoing' where a process is still happening)

Position	Event (card number)	Why it goes here (what evidence puts it before or after its neighbors)
1 (oldest)		
2		
3		
4		
5		
6		
7		
8		
9		
10 (youngest)		

-  Draw a cross-section of Pinecrest Valley as seen from its mouth: the U-shaped floor and steep walls, the tilted layers with the ash bed on the north side, the cave, the gravel fan, the fault line, the hoodoo and the fresh scar. Label each feature with its card number and mark each as slow (S) or sudden (X).

Answer: A cross-section with a flat U-shaped floor and steep walls; on the north side, tilted layered bands with an ash bed drawn between two sandstone layers, a cave in a limestone band near the mouth, and a capped pillar (hoodoo) at the base; on the south side a fresh scar near the top with a block pile below and cracks along the cliff top; a fan at the floor edge with a thin mud layer on it; a vertical fault line through the floor; pink boulders on the floor. Each feature labeled with its card number and marked S (slow: 1, 2, 4, 5, 6 fan, 8 pillar, 9, 10, 12) or X (sudden: 3, 6 mud, 7 jumps, 8 toppled cap, 11).

Why: The drawing checks that the student can turn text evidence into a spatial model and keep the slow/sudden distinction visible.

- U-shaped valley drawn
- At least six features placed sensibly and labeled with card numbers
- Slow and sudden marked and correct for the features drawn

1. Which card was hardest to place on the grid, and what made it hard?

Answer: Student-specific. Common choices: Card 7 (contains steady motion and sudden jumps), Card 6 (a slow fan and a fast mud layer), Card 11 (the eruption was fast but the ash is ancient), Card 4 (several processes over millions of years).

Why: Any card with a clear reason earns credit; the strongest answers notice that the hard cards contain two time scales.

- Names a card
- Gives a specific reason tied to scale or multiple processes

2. Name one sudden event in the cards and the slow process in the cards that led up to it.

Answer: Examples: the rockfall (Card 3) led up to by years of frost wedging (Card 12); the toppled cap (Card 8) led up to by slow weathering and erosion thinning the pillar; the stream's sharp offsets (Card 7) led up to by steady motion storing strain (Card 9).

Why: This is the slow-build-up, sudden-release pattern. Any of the three pairs is full credit.

- Names a sudden event from the cards
- Names a slow process from the cards that causes it

Analysis questions: answer key

3. Card 5: show the calculation for how long the 40 cm formation took to grow at 0.1 mm per year. What does the result say about the time scale of the cave?

Answer: 40 cm = 400 mm. $400 \text{ mm} \div 0.1 \text{ mm/yr} = 4,000 \text{ years}$. The formation has been growing for about four thousand years, so the cave is at least that old, and the cave itself (which had to be dissolved before anything could hang from its ceiling) is older still, probably by a lot.

Why: Checks unit conversion and the inference that the cave predates its formations. Accept 'thousands of years' as the time scale.

Also acceptable: Accept 4,000 years with the conversion shown; deduct for 400 years (forgot the cm-to-mm step).

4. Cards 7 and 9: if the ground moves 2 cm per year on average, how many years of motion are stored in the 12 m offset? Then explain how the stream can be offset in sharp jumps (Card 7's old maps) even though the GPS motion is steady.

Answer: $12\text{ m} = 1,200\text{ cm}$. $1,200\text{ cm} \div 2\text{ cm/yr} = 600\text{ years}$ of motion. The GPS shows the two sides moving steadily, but at the fault line itself the rock is locked and does not slip; the motion is stored as strain, like a bent stick, and is released in sudden jumps during earthquakes. The old maps show a smaller offset because fewer earthquakes had happened; each one moved the stream a few meters in seconds. The 2 cm/yr is an average of long stillness and short jumps.

Why: The key idea is the difference between the long-term average rate and the way the motion actually happens at the fault. Full credit needs both the calculation and the stored-strain explanation.

- Calculation with the m-to-cm conversion, result about 600 years
- Explains that motion is stored and released suddenly in earthquakes
- Connects the old maps' smaller offset to fewer earthquakes

5. Cards 1 and 2 together: what carved the valley, and what is the evidence? Explain how boulders of pink granite ended up 40 km from the nearest pink granite.

Answer: A glacier carved the valley. Evidence: the U-shaped cross-section (a river cuts a V; moving ice fills and widens the whole valley), the long parallel scratches pointing down-valley (rock fragments frozen into the bottom of the ice scraped the bedrock as the ice moved), and the polish. The pink granite boulders were plucked from the outcrop at the valley head, carried inside or on the ice for 40 km, and dropped where they lay when the ice melted; water could not carry car-sized boulders that far, and the boulders sit on the surface rather than in a river deposit.

Why: Students should link each clue to what ice does and rule out a river. Space scale: kilometers; time scale: thousands to tens of thousands of years.

- Identifies ice (a glacier) as the agent of erosion
- Uses at least two clues (U shape, scratches, polish)
- Explains the boulders as carried by ice and deposited when it melted

6. Card 4 and Card 11: these layers started as sand and mud with ripple marks and sea shells and now stand tilted on a valley wall far from any sea. List, in order, the processes that must have happened, and say roughly how long the whole sequence took using the ash date.

Answer: Sand and mud were deposited in shallow water (ripple marks, sea shells); the ash from a large eruption 300 km away fell into those layers about 760,000 years ago (Card 11) while deposition was still going on, since sandstone lies above the ash too; the layers were buried, compacted and cemented into sandstone and mudstone; uplift raised them above sea level and tilted them 20 degrees; then weathering and erosion (including the glacier) exposed them on the valley wall. The ash date shows that the layers below it are older than 760,000 years and the layers above it are younger, so the whole sequence, from deposition to today, took on the order of a million years or more.

Why: This is the rock-cycle sequence in miniature. Students should order deposition, hardening (both steps), uplift/tilting and exposure, and use the ash as a time marker rather than as the age of the valley.

- Deposition in water identified from ripples and shells
- Compaction and cementation named (or 'hardened into rock')
- Uplift and tilting placed after hardening
- Ash used to bracket the age: layers below older, above younger; total on the order of a million years

7. Card 6 shows one feature built by a slow process and one built by a sudden event. Identify both, give each a time scale, and say what evidence tells you the mud layer is recent.

Answer: The gravel-and-sand fan is the slow feature: the stream from the side canyon slows as it leaves the canyon and drops its load, building the 600 m fan grain by grain over thousands of years (deposition by water). The mud layer is the sudden feature: a flash flood spread muddy water across the fan and left a 3 cm coat in hours. The mud is recent because it holds a plastic bottle cap and grass that is still partly green, so the flood happened within the last few years, probably months.

Why: Students should name deposition for both and distinguish the time scales, using the bottle cap and green grass as the dating evidence.

- Fan identified as slow deposition over thousands of years
- Mud layer identified as a flash-flood deposit in hours
- Bottle cap and green grass cited as evidence of recency

8. Write your explanation of how Pinecrest Valley got its shape and features. Name at least three slow processes and two sudden events, give each a space scale and a time scale, cite the card number for every claim, and identify a slow cause for at least one sudden event.

Answer: A full-credit explanation, in outline: Long ago sand and mud were deposited in shallow water (Card 4, regional, millions of years); ash from an eruption 300 km away fell into them about 760,000 years ago (Card 11, sudden, days; regional); the layers hardened and were uplifted and tilted (Card 4, regional, millions of years). A glacier filled the valley, scraping it into a U shape, polishing and scratching the walls (Card 1, kilometers, thousands of years) and carrying pink granite boulders 40 km before dropping them (Card 2). After the ice melted, weakly acidic water dissolved a cave and formations began growing about 4,000 years ago (Card 5, centimeters, thousands of years). The side stream built a fan (Card 6, hundreds of meters, thousands of years). Weathering and erosion carved a hoodoo whose cap protected a pillar until one pillar thinned and its cap toppled (Card 8, meters, thousands of years then seconds). The fault across the valley stored about 600 years of 2 cm/yr motion and released it in earthquakes that offset the stream 12 m (Cards 7 and 9, regional, centuries plus seconds). Soil on the hillside crept 2 cm/yr for 20 years (Card 10, meters, decades). A flash flood coated the fan in mud within the last few years (Card 6, hundreds of meters, hours). Frost wedging along the cliff-top cracks (Card 12, slow, years to centuries) led to the rockfall within the last three years (Card 3, tens of meters, seconds). The valley is still changing: GPS motion, drips, creep and frost continue.

Why: Score with the rubric-style criteria: processes named, both kinds present, scales given, cards cited, order reasoned, slow cause for a sudden event. The exact wording and order of overlapping events may vary; what matters is that each claim traces to a card and the scales are right.

- At least three slow processes and two sudden events named with correct process words
- A space scale and a time scale for each
- A card number cited for every claim
- Events ordered with reasons, with ongoing processes marked
- At least one sudden event linked to a slow cause in the cards (3 to 12; 8's cap to thinning; 7 to 9)

9. Uniformitarianism says today's processes explain the past. Pick one card where you used a process you can watch today to explain something ancient, and one thing about the past that the cards cannot tell you.

Answer: Examples of present-to-past reasoning: ripple marks forming in a stream today explain the ripple marks in the ancient sandstone (Card 4); scratches under today's glaciers explain the scratched bedrock (Card 1); dripping water building a formation at a measured 0.1 mm/yr explains how the 40 cm formation got its length (Card 5). Things the cards cannot tell: exactly how thick the ice was or exactly when it melted; how fast the water flowed when the ripples formed; whether the growth rate of the formation was always 0.1 mm/yr; how many earthquakes made up the 12 m offset.

Why: Checks that students can use uniformitarianism and also see its limits (rates may have varied; some facts need more evidence).

- One correct present-process to past-feature link with a card number
- One honest limit: something the evidence does not determine

Individual evidence of learning

Each student completes their own process table, grid, calculation table, order table and cross-section, and writes the explanation (q8) individually. The explanation is scored against the assessment criteria as direct evidence toward MS-ESS2-2; the grid and calculations are evidence for the scale and rate targets.

Assessment criteria

Criterion	Proficient looks like
Evidence to process	At least ten of twelve cards matched to a correct process and agent, with a phrase from the card as proof; multi-process cards (4, 6, 7, 8) recognized.
Scales	Grid placements defensible for all cards, with slow and sudden events distinguished and Cards 6 and 7 placed twice; the student can state the two rulers for any card when asked.
Rates and ages	All four calculations shown with units and correct results (4,000 years; 600 years; 2 cm/yr; 20 m), and each result interpreted as a time scale.
Explanation (MS-ESS2-2)	Names at least three slow processes and two sudden events with space and time scales, cites a card for every claim, orders the events with reasons, and identifies a slow cause (frost wedging; stored fault motion; pillar thinning) for at least one sudden event.

Accessibility adaptations

- Provide large-print cards and a version of the card set with the key phrase on each card underlined for students who need reading support; read cards aloud in the group as the procedure already requires.
- Offer a reduced set of eight cards (1, 2, 3, 5, 6, 7, 9, 12) for groups who need fewer decisions; the explanation criteria stay the same.
- Allow the explanation (q8) to be delivered as a recorded two-minute 'survey team report' with the cross-section as the visual, scored with the same criteria.
- Provide a bilingual word bank for the process and agent columns and sentence frames for the explanation ('Card __ shows __, which happens over __ and covers __').

Low-cost alternative

Write the twelve cards on index cards by hand or display them on the board one at a time and have groups copy the key phrase; use any blank paper for the grid and order table. The investigation needs no purchased materials at all.

Model limitations

Pinecrest Valley is invented; its features and numbers are chosen to be realistic but are not measurements from a real place, and real valleys rarely show all these features in one spot. The grid's scale bands are coarse, so some placements are judgment calls. The ash date, growth rate and GPS rate are given as exact numbers to keep the arithmetic clean; real field numbers come with uncertainty. The activity has not been physically tested with students; timing is an estimate for a 50-minute period and the explanation may need to be finished as homework.

Teacher notes

Grade the explanation (q8) first; it is the MS-ESS2-2 evidence. Do not penalize a different but defensible order for overlapping events (for example the fan and the hoodoo), but do require the ash bed to be inside the layers (so before uplift) and the glacier before the cave formations and the fan. If a group argues a river carved the valley, ask them to explain the parallel scratches, the polish and the car-sized boulders; the point is to reason to ice from the evidence, not to be told. Reveal the intended history only after groups have compared explanations.