

The Calder Basin Treasure Mystery: Read the Clues, Place the Drills

Investigation question: Using only surface clues and geologic history, where in the Calder Basin should a survey team drill for copper ore, petroleum, geothermal heat and groundwater, and why are those resources there and not elsewhere?

Evidence-based mystery

Groups of 4

1 session

Setup 5 · Activity 40 · Cleanup 5 min

MS-ESS3-1 · assesses

MS-ESS2-1 · supports

Scientific purpose

Students act as an exploration team for a fictional region divided into sixteen map cells. Each cell has a clue card describing its rocks, landscape, rainfall and history. Groups must infer which geoscience processes operated in each cell, predict which resource (if any) is hidden there, and commit six drill sites with written evidence before the teacher reveals the hidden answer map. The lab turns the lesson's central explanation, 'a resource is here because a specific chain of processes happened here', into a decision students make and defend.

Why this helps students with this chapter

Students readily accept that resources are unevenly spread but rarely practice the reasoning geologists use to predict where they are. Working from clue cards to a prediction, then seeing the hidden map, makes the cause-and-effect chain explicit and rewards reasoning from the full recipe rather than from a single clue. The cells that look promising but hold nothing (fossils without a trap, rain without porous rock) are where the learning happens.

Standards connections

MS-ESS3-1 (assesses, the explanation of uneven distribution from past and current geoscience processes): Students construct an evidence-based explanation of where mineral, energy and groundwater resources are concentrated in a region, citing past processes (subduction and hydrothermal fluids, burial of marine mud under a trap, long-term recharge) and judging which aquifers could be pumped sustainably. Analysis question q7 then asks how pumping and drilling would redraw the map, the 'current processes' half of the PE.

MS-ESS2-1 (supports, rock-cycle processes as the mechanism behind ore and reservoir formation): Students use melting, crystallization, weathering and sedimentation to reason from a landscape to a hidden resource; they are never asked to identify or name minerals.

Roles (rotate each session)

- **Chief geologist:** Reads each clue card aloud, leads the discussion of which process the clues point to, and makes sure every drill site has a written reason.

- **Cartographer:** Colors the prediction map, places the sticky-dot drill markers, and keeps the map consistent with the team's table.
- **Recorder:** Fills in the clue table row by row, writing the process and the predicted resource in the team's own words.
- **Auditor:** Checks each prediction against the full recipe (not just one clue), challenges weak reasoning, and scores the team after the reveal.

Materials

Item	Quantity	Per	Note
Calder Basin grid map (4 columns A-D west to east, 4 rows 1-4 north to south), printed on letter or tabloid paper	1	group	A blank 4 x 4 grid with cell labels is enough; add a river running down column B and a coastline on the west edge if you like.
Set of 16 clue cards (printed from the recording sheet and cut apart)	1 set	group	Laminate or put in sleeves for reuse.
Sticky dots or small colored chips for drill markers	6	group	
Colored pencils (four colors for four resources)	1 set	group	
Sealed answer envelope with the hidden resource map (from the answer key)	1	group	Or reveal once on the projector after every group has committed.
Recording sheet	1	student	

Estimated cost: 3 to 6 per class (an estimate; Estimate. Printing and sticky dots only; colored pencils are classroom stock. Laminating the card sets adds about \$5 once.)

Safety

- No hazards beyond paper, scissors (if cutting cards in class) and sticky dots; pass scissors handle first and keep them closed on the desk.
- If the activity is run as a floor map, keep walkways clear and have students step, not jump, between cells.

Teacher preparation and setup

1. Print one grid map and one set of clue cards per group; cut the cards apart and shuffle so cell order gives nothing away.
2. Prepare the answer envelope (the hidden map in the answer key) or a projector slide; do not reveal it until every group's drill markers are placed and their reasons are written.
3. Run the slide 23 four-site task first; it uses the same reasoning on a smaller scale and warms up the process-to-resource links.

4. Decide the drill rule in advance: six markers, and at least one marker aimed at each of the four target resources.

Investigation design

Independent variable	The set of geologic clues in each map cell (rock type, landscape, history, rainfall)
Dependent variable	The team's predicted resource for each cell and the six drill-site choices
Controlled	Every group uses the same sixteen clue cards and the same grid; Six drill markers per group, at least one per target resource; Predictions and reasons are written before the reveal
Trials	One prediction round per group; the class compares scores and the cells that fooled the most teams.
Comparison	Each team's prediction map against the hidden answer map.

Student procedure

1. Lay the grid map flat and sort the sixteen clue cards by cell label. The chief geologist reads each card aloud while the recorder fills in the clue table: what the clues say, which process they point to, and which resource, if any, the team expects.
2. For every cell, check the full recipe before writing a prediction. Oil needs buried marine mud, deep burial, a porous layer and a sealed trap. Metal ore needs magma and hot fluids, or a stream that concentrated dense grains. Geothermal heat needs magma near the surface. Groundwater needs porous sediment or rock plus recharge, now or in a wetter past.
3. The cartographer colors each cell on the prediction map with the resource color the team expects, and leaves cells the team thinks are empty white. Mark cells where the team is unsure with a question mark.
4. Decide on six drill sites. You must aim at least one marker at each of the four target resources (ore, petroleum, geothermal, groundwater). Place the sticky dots and record each site in the drill table with the evidence for it.
5. The auditor reads every drill reason aloud and challenges any that rest on a single clue. Revise if needed. When the team agrees, sign the drill table; after this point no changes are allowed.
6. Open the answer envelope (or watch the reveal). Score each drill site with the points in the drill table and total the team's score. Record which predictions were wrong and why.
7. Answer the analysis questions individually. Then compare answers in the group and discuss which clue turned out to be the most reliable and which one fooled you.

Expected observations

- Most teams correctly place geothermal at A1, copper ore at A2, groundwater at B2 or B3, and oil at C1 or C2, because those cards carry the full recipe.
- Several teams drill C3 for oil because of the reef fossils and are surprised; a few drill A4 for water because of the rain; some miss D1 because 'desert' overrides the sandstone and the water-age clue.
- Teams that write the process chain in the drill table score higher on the bonus and are less often fooled, which the auditor role is designed to produce.

Likely difficulties

- Students match pictures instead of reasoning from processes ('fossils means oil'). The auditor's job is to demand the chain; the slide 23 task before the lab shows the pattern.
- The drill rule (one marker per resource type) can feel like a constraint that wastes a marker; explain that an exploration company also spreads its bets.
- Some students want to drill every cell; limit to six and point out that each real exploration well costs millions of dollars.
- D3 (salt and gypsum) is not one of the four target resources; accept it as a modest mineral resource worth 2 points and use it to note that not all minerals are metals.

Structured debrief

1. Pool scores on the board and tally which cells fooled the most teams. C3 (fossils but no trap or deep burial) and A4 (rain but no porous rock) are the usual culprits; use them to make the point that a single clue is a hint, not evidence, and that the full chain is what counts.
2. Walk the answer map cell by cell and say the process aloud for each: subduction and hydrothermal fluids (A2), weathering and stream sorting (A3), magma near the surface (A1), burial, heating and a sealed fold (C1, C2), river-filled valley with snowmelt recharge (B2, B3), ancient rain in a wetter climate (D1), evaporation of a sea (D3).
3. Ask where humans would change this map first. B2 and B3 would be pumped; C1 would be drilled; A2 would be mined. Connect to the Central Valley, Kern County and the Mother Lode on the phenomenon slide: Calder Basin is a sketch of California turned on its side.
4. Close on D1: a large aquifer that is not renewable on any human timescale. Ask whether a town there should drill it at all, and what information they would need (water age, recharge rate, how long the supply must last). This leads into Lab 3.

Recording sheet: what students fill in

Lab 1 recording sheet: The Calder Basin treasure mystery

The Calder Basin is a made-up region. Its west edge is a coast; a river runs down column B from the mountains in the north; the east side (column D) is desert. Use the clue cards to decide what each cell hides. Write the process first, then the resource. A clue is only evidence when the whole recipe is there.

Clue cards (cut apart, one per cell)

1 A1: coast, north

A young volcano with steaming vents and hot springs. Lava flows only a few thousand years old. Small earthquakes most months. A plate boundary lies just offshore. Rain: 100 cm a year.

2 A2: coast range

Old rounded mountains of granite. White quartz veins with green and blue stains cut through the rock. No volcano has erupted here for 40 million years, but the granite is the cooled root of ancient ones. Rain: 60 cm a year.

3 A3: foothills

Streams leave the granite mountains and slow down over gravel bars. A prospector's pan from one bar shows a few tiny, dense yellow flakes. Rain: 50 cm a year.

4 A4: coast, south

Steep mountains covered in thick forest. Thin rocky soil. The granite here has no veins and no stains. Rain: 150 cm a year.

5 B1: lava plateau

A flat plateau of cracked gray lava two million years old. The springs are cold. Soil is thin and stony. Rain: 30 cm a year.

6 B2: upper valley

A wide valley floor. A river fed by mountain snowmelt flows all year. Old well logs show 150 m of gravel and sand before bedrock. Rain: 70 cm a year.

7 B3: lower valley

The same valley farther south, lined with orchards. Well logs show 120 m of sand and gravel. The river still flows most of the year. Rain: 55 cm a year.

8 B4: old lake bed

The valley opens into a flat basin of gray clay laid down in a lake that dried up 10,000 years ago. Three wells drilled here produced only a trickle each. Rain: 40 cm a year.

9 C1: folded hills

Low hills of sandstone and shale with marine fossils. The layers arch upward like a bridge. Black, sticky tar oozes from a crack near the top of the arch. Rain: 25 cm a year.

10 C2: dry plain

A flat plain. A survey well found sandstone arched beneath a thick shale layer, with marine fossils. This was a sea 20 million years ago; the layers were later buried 3 km deep, then folded. Rain: 20 cm a year.

11 C3: reef limestone

Flat layers of limestone full of coral and shell fossils. The layers lie flat and were never buried deeper than 1 km. No shale or salt layer on top. Rain: 25 cm a year.

12 C4: stripped layers

Tilted sandstone layers exposed by erosion. The sand is stained brown and smells faintly of oil but is dry. The shale that once covered it has eroded away. Rain: 25 cm a year.

13 D1: dune desert

Sand dunes over thick sandstone. Ancient rock paintings show lakes, fish and hippos. The few wells give sweet water, and tests show that water fell as rain more than 10,000 years ago. Rain: 8 cm a year.

14 D2: granite desert

Bare granite bedrock at the surface with almost no sediment. No veins, no stains. Rain: 8 cm a year.

15 D3: salt flats

White crusted flats. Beneath them lie thick beds of salt and gypsum left when an arm of the sea dried up. Rain: 10 cm a year.

16 D4: flat shale

Flat-lying dark shale with marine fossils, buried 2 km at most and never folded or faulted. A survey well found no sandstone layer and no oil. Rain: 10 cm a year.

Clue table: process first, resource second

Cell	Key clues (your words)	Process the clues point to	Predicted resource (or none)	Confidence (low / medium / high)
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Cell	Key clues (your words)	Process the clues point to	Predicted resource (or none)	Confidence (low / medium / high)
A1				
A2				
A3				
A4				
B1				
B2				
B3				
B4				
C1				
C2				
C3				
C4				
D1				
D2				
D3				
D4				

- ✎ Draw the 4 x 4 grid (A-D across, 1-4 down). Color each cell with your predicted resource using a key: one color each for metal ore, petroleum, geothermal heat and groundwater; leave empty cells white. Mark your six drill sites with an X.

Answer: Hidden answer map. A1: geothermal heat (rich, 3). A2: copper (and some gold) ore in hydrothermal quartz veins (rich, 3). A3: placer gold in gravel bars (modest, 2). A4: nothing to drill; a renewable timber resource at the surface (0). B1: nothing (cracked old lava, dry, cold springs) (0). B2: groundwater, thick gravel with snowmelt recharge (rich, 3). B3: groundwater (rich, 3). B4: nothing worth drilling; clay stores water but will not release it (0). C1: petroleum in a folded sandstone under shale, leaking at the seep (rich, 3). C2: petroleum in a sealed fold (rich, 3). C3: nothing; shallow burial, no seal (0). C4: nothing; seal eroded, oil escaped (0). D1: groundwater, ancient water in sandstone with near-zero recharge today (modest, 2). D2: nothing (0). D3: salt and gypsum beds, a sedimentary mineral resource (modest, 2). D4: nothing; source rock without a reservoir or a trap (0).

Why: Score the drill table against this map. A perfect six-marker set is A1, A2, B2 or B3, C1 or C2 plus any two other rich cells (18 points) with six correct process bonuses (24). Give full credit for a prediction map that colors every rich cell correctly and leaves C3, C4, A4 and D2 white; accept D3 and A3 colored or white with a stated reason.

- Four resource colors with a key
- Rich cells (A1, A2, B2, B3, C1, C2) colored with the correct resource
- The four decoy cells (A4, C3, C4, D2) left white or marked with a reason
- Six drill sites marked

Drill table (sign before the reveal)

Drill site (cell)	Resource you expect	Evidence: the process chain in one sentence	Result after the reveal	Points
1				
2				
3				
4				
5				
6				
Total				

Scoring after the reveal — Rich target resource found: 3 points. Modest resource found (a placer, a slow-refilling desert aquifer, or the salt beds): 2 points. Nothing worth drilling: 0 points. Add 1 bonus point for each drill site whose written evidence names the correct process, even if the drill came up dry. Maximum: 24.

1. Which cell fooled your team the most, and which single clue led you astray?

Answer: Group-specific. Common answers: C3 (reef fossils suggested oil, but there was no deep burial and no seal), A4 (heavy rain suggested groundwater, but granite without sediment stores little), or D1 (desert suggested no water, but the sandstone holds ancient water).

Why: The question is a reflection on the single-clue trap; any honest identification of a misleading clue earns credit.

- Names a specific cell
- Names the single clue that misled the team and what was missing

2. Which drill site were you most confident about before the reveal? Write the full chain of evidence you used.

Answer: Group-specific. A full chain for A2 would be: subduction long ago → magma rose and cooled into granite → hot fluids from the magma carried copper through cracks → cooled and left copper minerals in quartz veins (the green and blue stains). For C2: sea 20 million years ago → plankton-rich mud buried 3 km → heated into oil → oil rose into the sandstone → shale seal over a fold trapped it.

Why: Credit requires a chain of at least three linked steps, not a label.

- Names the drill cell
- Writes a cause-and-effect chain with at least three steps that ends at the resource

Analysis questions: answer key

3. Cells C1, C2, C3 and C4 all had marine fossils, yet only two hold oil. Explain, using the full oil recipe, why C3 and C4 came up dry.

Answer: Oil needs four things together: organic-rich marine mud (source), deep burial so the rock is hot enough for long enough to turn the organic matter into oil, a porous reservoir rock for the oil to collect in, and a sealed trap (a fold or fault under shale or salt) to stop it rising. C1 and C2 have all four: marine layers buried 3 km, sandstone, a fold and a shale cap, and C1 even leaks tar. C3 was never buried deeper than 1 km, so the mud never reached the oil-forming temperature window, and it has no seal, so any oil would have escaped. C4 once had oil (the sand is stained) but erosion stripped away the shale seal and tilted the layers, so the oil leaked out long ago. Fossils only show there was a sea; they are the first ingredient, not the whole recipe.

Why: This is the core explanation for petroleum in the PE. Full credit requires naming the missing ingredients for each dry cell, not just 'no trap'.

- Lists the oil recipe (source, burial heat, reservoir, trap)
- Explains C3 by shallow burial and no seal
- Explains C4 by a seal that eroded, so the oil escaped
- States that fossils alone are not evidence of oil

4. Cell A4 has the most rain in the basin but no useful groundwater, while D1 is a desert with a large aquifer. Explain both facts, and then say which aquifer could be pumped sustainably and why.

Answer: Groundwater needs two things: porous, permeable rock or sediment to store and release water, and water to fill it. A4 has plenty of rain but its granite has almost no pores and no sediment cover, so the rain runs off in streams instead of being stored. D1 has almost no rain today, but its thick sandstone is porous, and it was filled during a wetter climate more than 10,000 years ago (the rock paintings of lakes and the water age both show this). Only an aquifer with recharge can be pumped sustainably, and D1's recharge today is close to zero, so pumping it is like mining: the water will not come back on a human timescale. B2 or B3, with thick gravel and snowmelt recharge, are the aquifers that could be pumped sustainably if pumping stays below recharge.

Why: Checks the two-ingredient idea (porous rock plus recharge) and the fossil-water case from the reviewed accuracy notes. Students must address sustainability, not just presence.

- Explains A4 by lack of porous rock or sediment
- Explains D1 by porous sandstone filled during a wetter past
- States that D1 cannot be pumped sustainably because recharge is near zero
- Names B2 or B3 as the sustainable option because recharge exists

5. Copper ore is in A2 but not in D2, even though both cells are granite. What is different about the history of A2, and what process concentrated the metal there?

Answer: A2 is granite that formed above a subduction zone, where a sinking plate produced magma. As that magma cooled, it released hot, metal-rich water (hydrothermal fluid) that flowed through cracks and dropped copper minerals as it cooled, leaving quartz veins with green and blue copper stains. D2 is bare granite with no veins and no stains: it never had the hot-fluid stage, so its copper stayed spread thinly through the rock at ordinary concentrations, far too low to be ore.

Why: Students must identify the hydrothermal step as the concentrating process; granite alone is not the clue.

- Names subduction or magma as the setting
- Names hydrothermal fluids as the concentrating process
- Explains D2 by the absence of veins, so no concentration happened

6. The gold flakes in A3 did not form in A3. Describe the two-step history that put them there, naming the process at each step.

Answer: Step 1: the gold formed in quartz veins in the granite mountains of A2 when hydrothermal fluids from cooling magma deposited it. Step 2: weathering broke the veins apart over a very long time, streams carried the grains downhill, and because gold is far denser than sand, the flakes dropped out first where the streams slowed on the gravel bars in A3. This is a placer deposit, concentrated by weathering and stream sorting.

Why: Mirrors the Mother Lode story: lode gold then placer gold. Both steps are required.

- Step 1: hydrothermal veins upstream
- Step 2: weathering, transport and sorting by density in a slowing stream

7. Suppose B2 is pumped for forty years at twice its recharge rate and C1 is drilled until its reservoir is empty. Redraw the resource map in words: what changes, what does not, and which change could reverse?

Answer: After forty years of pumping at twice the recharge, the water table under B2 has dropped (if recharge is 1 unit and pumping is 2, the aquifer loses 1 unit a year, 40 units in all), wells have to be drilled deeper, and the river may dry up in summer because it no longer receives groundwater; if clay layers are present the ground may also sink. C1's oil reservoir is empty, so C1 becomes a blank on the oil map, and any new oil would have to come from somewhere else. The clues at the surface (the fold, the fossils, the granite veins) do not change; the hidden resource does. The B2 change could partly reverse: if pumping dropped below recharge, the gravel aquifer would slowly refill over decades (though compacted clay would not re-expand). The C1 change cannot reverse on any human timescale, because oil takes millions of years to form.

Why: This is the 'current processes' half of MS-ESS3-1 plus the reversibility idea from the slide 22 discussion. The arithmetic is optional but welcome.

- Describes the falling water table and its effects
- Describes the drained reservoir as a blank on the map
- Identifies that the aquifer can recover if pumping drops below recharge
- Identifies that the oil cannot return on a human timescale

8. Write the one-sentence rule your team would give a new survey crew about when a single clue is enough and when it is not.

Answer: Sample: 'A single clue tells you one ingredient is present; drill only when every ingredient in the recipe is present.' Or: 'Fossils are not oil, rain is not water, granite is not ore; look for the whole chain.'

Why: Any rule that distinguishes one ingredient from the full recipe earns credit.

- Distinguishes one clue from the complete set of conditions
- Is stated as a usable rule

Individual evidence of learning

Each student submits their own clue table, prediction map, drill table with written evidence, and answers to q1 through q8. The drill-table evidence column and q3, q4 and q7 are the primary evidence for MS-ESS3-1: an explanation of uneven distribution that cites past processes and describes how human removal changes the pattern.

Assessment criteria

Criterion	Proficient looks like
Evidence-based prediction	Each drill site names at least two clues and the process they point to; no prediction rests on a single clue such as fossils or rain.
Process explanation	Correctly explains why fossils without a trap, rain without porous rock, and granite without veins yield nothing (q3, q4, q5).
Past and current processes	q7 describes how pumping and drilling would change the map, distinguishes a reversible change (a recharging aquifer) from an irreversible one (a drained reservoir), and ties the change to rates.

Use of vocabulary	Uses aquifer, recharge, trap, hydrothermal fluid and ore accurately in the drill table and analysis.
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Accessibility adaptations

- Provide a process-to-resource lookup strip (volcano and hot springs → geothermal; granite with quartz veins → metal ore; folded marine sandstone under shale → oil; thick river gravel plus rain → groundwater) for students who need more support.
- Offer the clue cards with a picture glossary for landscape words (vein, fold, gravel, hot spring, shale) and allow the clue table to be completed in a home language first.
- Run the activity as a floor map with students standing on cells to defend drill sites for groups who need movement; accept a spoken explanation recorded on a device for q3 and q7.
- Print the grid and cards in large type with high contrast; the cartographer role can be shared so that a student with limited fine-motor control directs placement while a partner marks.

Low-cost alternative

Draw the grid on the board and read the clue cards aloud to the whole class; groups record predictions on notebook paper and place drill sites with their initials on the board. No printing beyond one copy of the cards is needed.

Model limitations

Calder Basin is invented, and its clues are simplified: real exploration uses seismic surveys, drill cores and chemistry, and real cells are not uniform. The card for D1 compresses water dating into one sentence, and the salt beds in D3 are a modest resource rather than one of the lesson's four targets. The scoring system is a teaching device, not a model of exploration economics. This activity has not been physically tested by the authors; the 40-minute estimate assumes groups have done the slide 23 four-site task first.

Teacher notes

Keep the answer map sealed until every drill table is signed; the lab's value comes from committing before the reveal. When scoring, weight the evidence column more than the points: a dry hole with a correct chain (for example drilling C3 and writing 'fossils suggest a sea, but I am unsure about burial') shows better reasoning than a lucky hit with no chain. Save a few prediction maps to show the class which cells fooled the most teams; the pattern (C3 and A4) is reliable and leads straight into the misconception worksheet.