SCHOOL LAUNCH · EARTH SCIENCE K–8

Grade 7 Earth Science: Earth History and the Flood

A year of reading the rocks with real people and real places, from Nicolas Steno's three principles and the walls of the Grand Canyon to Guy Berthault's flume, the coelacanth hauled up in 1938, Louis Agassiz and his glaciers, a dice-roll half-life lab and the dacite of Mount St. Helens, each one taken apart to see what was observed, what was measured and what the Flood of Genesis 6–9 would have left behind, and then tested in miniature at the kitchen table.

First edition

> *"In the beginning God created the heaven and the earth." (Genesis 1:1, KJV)*

Course guide

This course follows one question through a school year: how do we read the history written in the earth? It is answered in eight units. First come **Steno's principles**, the rules a Danish anatomist worked out in 1669 for telling which layer came first. Then **layers**, read on the walls of the Grand Canyon and made in a kitchen flume. Then the **fossil record**, the **Flood year** of Genesis 6–9, the **Ice Age** that Louis Agassiz announced in 1837, **dinosaurs in depth**, the **dating methods** that put numbers on rocks, and a closing unit on **reading a museum** so that the student can walk into any natural history hall, read every sign, and say clearly what was observed and what was inferred.

Every lesson follows the same path. First comes **the story**: a real person at a real place on a real date, such as Steno dissecting a shark's head in Florence, Marjorie Courtenay-Latimer spotting a strange blue fish on a dock in 1938, or Steven Austin collecting dacite from the new lava dome at Mount St. Helens. Then **what they observed and measured**: the layers, the fossils, the rates, the counts. Then **the big idea**, explained for a seventh grader: superposition, cross-cutting, sorting, zonation, half-life, the difference between a measurement and an assumption. Then the student does it in miniature: a jar of sediment, a tray of sand under running water, a bag of dice, a graph in the field notebook. Three worked examples and ten practice problems with answers in each lesson build the habits of a scientist: measure, record, compute, compare.

The thread of the year is **what the sign says and what we observe**. Museum signs, textbooks and park guides use names such as "Jurassic," "Pleistocene" and "66 million years." The course teaches those names so the student can read any sign or book, and at every such point a ⏳ Thinking About Time box lays out three things side by side: what the sign says, what was actually observed and measured, and how Christians have read it. The student learns to argue carefully, to quote the other side fairly, and to speak kindly to a docent, a friend or a grandparent who sees it differently.

The course is written from a Christian view of creation: "In the beginning God created the heaven and the earth." (Genesis 1:1). The Flood of Genesis 6–9 is taught as history, with its worldwide memory in the flood legends of many peoples, and the rocks are read in that light. The student also learns that the earth is God's work and that honest observation of it is an act of worship, not a threat to faith. "For in six days the LORD made heaven and earth, the sea, and all that in them is" (Exodus 20:11) stands over the whole year, and the student is asked, again and again, simply to look closely and to tell the truth about what is there.

WHO IT IS FOR

Written for students in grade 7 (about ages 12–13) who read well on their own, can work with fractions, decimals, ratios and simple graphs, and are ready for middle-school science that builds toward high-school Earth Science. A parent or teacher reads along, supervises every experiment, and asks the three questions the course repeats all year: What did you observe? What did you measure? What are you assuming? Nothing needs to be bought

beyond ordinary household items: jars, sand, gravel, dice, a tape measure, graph paper and a notebook.

HOW TO USE THIS COURSE

The weekly rhythm. The year has 32 lessons, one a week, in eight units of four lessons, plus an optional ninth unit, the Field Lab, for families who can get to a road cut, a creek or a museum. Each lesson takes two sessions of about 45 minutes. Session 1 is the warm-up, the story, the core ideas, the key terms and the picture study. Session 2 is the experiment, the worked examples and the practice set, with the field notebook open the whole time. In the last week of each unit, add a third session for the unit test and the unit project.

The ★ quarter path. Ten lessons are marked with a star: Steno (1.1), reading the Grand Canyon (2.1), what museums say and the order of fossils (3.1 and 3.2), Genesis 6–9 as history (4.1), Agassiz and the mammoths (5.1 and 5.2), dinosaur kinds (6.1), half-life with dice (7.1) and the field trip guide (8.1). A family that wants a one-quarter course, or a student who is also taking another science, can do these ten lessons in order and still come away with the principles, the Flood, the time question and the museum skills.

The field notebook. Use one graph-paper composition book for the whole year. Every experiment ends with something drawn, measured and written down: a sketch of a layered jar with each layer labeled and its thickness in millimeters, a table of dice left after each roll, a graph of grain size against distance, a column of a road cut, a museum sign copied word for word with the student's observations beside it. Date every page, label every column and unit, and finish with one sentence beginning "I observed" and one beginning "I think this means." Keeping the two sentences apart is the main skill of the year.

Experiments and safety. Every project uses household things: jars, sand, gravel, flour, clay, dice, string, a bucket, a garden hose. An adult supervises all of them. Wear eye protection when pouring gravel or breaking rock, do not taste or breathe any powder, keep water experiments on a tray or outdoors, and never collect from a road cut without an adult standing watch for traffic. No experiment in this course uses heat, chemicals or anything radioactive; the half-life lab uses dice and the ice-core lab uses layered ice cubes.

Worked examples and practice. Each lesson has three worked examples that put numbers on the idea: a rate of deposition in millimeters per hour, a ratio of layer thicknesses, a graph to read, a half-life stepped through four times, a scale on a map or a model. Read them with the student and have him or her redo one without looking. Then the student does the ten practice problems, which include two data-reading items in the style of the ACT and SAT science sections, with a table or graph to read before answering, and one experiment-design item that asks what to change, what to measure and what to keep the same. Answers are given; a wrong answer is corrected in the notebook with the reason.

Unit reviews and unit projects. Each unit ends with a 60-point unit test of ten to twelve problems: multiple choice, short answer and one diagram to label or draw, such as a cross-cutting sketch or a fossil column. Each unit also ends with a unit project that pulls the unit together: a Steno's-principles poster from a real photograph, a model canyon in a clear

container, a fossil-order chart, an Ark scale drawing, a glacier map of North America, a dinosaur classification key, a half-life graph from the dice lab, and a written museum report. Keep the unit projects in one folder for the year.

A word about time. The course is written from a Christian view of creation (Genesis 1:1) and the Flood (Genesis 6–9). Deep-time names such as “Jurassic,” “Pleistocene” or “Ice Age,” and figures such as “66 million years,” are taught as museum words, so that the student can read any sign, park guide or textbook and know exactly what it is claiming. Wherever they come up, a ⏳ Thinking About Time box sets out three things in order: what the sign says, what we actually observe and measure, and how Christians read it. The student is never asked to pretend the sign is not there, and never asked to be unkind to the people who wrote it. The goal is a young scientist who can tell a measurement from an assumption, state both views fairly and hold his or her own with a clear conscience.

SCOPE AND SEQUENCE

Unit 1: Steno’s Principles (1–4)

Nicolas Steno, the Danish anatomist who dissected a shark in Florence, saw that “tongue stones” were shark teeth, wrote the first rules for reading rock layers in 1669 and later became a bishop; superposition, original horizontality, lateral continuity and cross-cutting relationships, each tested in a jar.

Unit 2: Layers (5–8)

Reading the walls of the Grand Canyon layer by layer; the flat, knife-edge contacts between layers and what the museum sign says about them; Guy Berthault’s 1986 flume experiments showing layers forming sideways and at once in moving water; and how coal seams form from buried plant mats.

Unit 3: The Fossil Record 🦕⏳ (9–12)

What the museum sign says about the fossil column and why; the order of fossils read as ecological zonation, sea floor first and highland last; the coelacanth, a “fossil fish” hauled up alive off South Africa in 1938; and the missing transitions, with each side’s explanation given fairly.

Unit 4: The Flood Year ⏳ (13–16)

Genesis 6–9 read as history, with its dates, depths and days laid out on a timeline; the Ark’s dimensions in cubits and the 1994 Korean ship-stability study of its proportions; flood memories from Mesopotamia, China, the Americas and the Pacific; and what a year-long global flood would leave behind in the rocks.

Unit 5: The Ice Age ⏳ (17–20)

Louis Agassiz reading scratched bedrock and erratic boulders and announcing an ice age at Neuchâtel in 1837; the woolly mammoths of Siberia and Alaska and what their remains

show; Michael Oard's model of one post-Flood ice age driven by warm oceans and volcanic dust; and how ice-core layers are actually counted.

Unit 6: Dinosaurs in Depth 🦕 (21–24)

Dinosaur kinds sorted by hip, skull and foot into a working classification key; eggs, nests and what they tell about how dinosaurs lived and how they were buried; dragon accounts from Job 40 to medieval chronicles weighed as evidence; and the feathers-and-birds question with the evidence laid out as it stands.

Unit 7: Dating Methods ⏳ (25–28)

Radioactive decay and half-life modeled with a bag of dice and graphed; the three assumptions behind every radiometric date (starting amount, no gain or loss, constant rate); carbon-14 found in diamonds and coal by the RATE project in 2005; and the 1996 Mount St. Helens dacite that gave ages of hundreds of thousands of years for rock formed in 1986.

Unit 8: Reading a Museum (29–32)

A field trip guide for any natural history museum, park visitor center or online gallery; the two-column habit of "what the sign says" and "what we observe"; how to talk about it kindly and accurately with docents, friends and family; and a written report that closes the year.

Unit 9: Field Lab (optional) (Optional; use alongside the year or in the summer)

Four outdoor lessons for families with a road cut, a creek bank or a museum within reach: measuring and sketching exposed layers, mapping local strata across two or three sites, reading the sorted deposits a flooding creek leaves behind, and keeping a journal of museum signs with observations beside each one.

MATERIALS

- **Field notebook (a graph-paper composition book)**: One for the whole year: sketches of layers, data tables, graphs, museum-sign copies and the "I observed / I think this means" sentences.
- **Clear jars and a clear plastic storage box or aquarium**: For settling columns, layered models and the kitchen flume. Any tall, clear container works.
- **Sand, fine gravel, potting soil, flour and modeling clay**: Sediments of different sizes for sorting, layering, cross-cutting and coal-seam models. A bag of each from a garden center lasts the year.
- **A metric ruler, a tape measure and a kitchen scale**: Every layer is measured in millimeters and every sample weighed in grams. A protractor is useful for dip angles.
- **About 100 dice (or 100 pennies)**: For the half-life lab in Unit 7. Dice are best; pennies work with heads-and-tails.
- **A garden hose or watering can, a shallow tray and a bucket**: For the flume and the creek-deposit models. Do these outdoors or over a tray.

- **Safety glasses and gloves**: For pouring gravel, breaking rock samples and any work at a road cut.
- **Graph paper, colored pencils, a calculator and an ice-cube tray**: For graphs of rates and half-lives, labeled columns, and the layered-ice model in Unit 5.
- **A Bible (King James Version)**: Genesis 6–9, Exodus 20:11, Job 40 and 2 Peter 3 are read in their place during the year.
- **Optional: one of the books or resources listed in a unit**: Never required. See the list in each unit.

GRADING

Grades come from unit tests, the field notebook, the experiments and the unit projects, in roughly equal measure, because earth science is learned both by solving problems and by observing and recording carefully. An experiment whose result did not match the prediction but is honestly measured and explained earns full credit.

- Unit tests (eight tests, 60 points each) and lesson practice sets: 35%
- Field notebook (dated pages, labeled sketches, units on every number, the two closing sentences): 20%
- Experiments (prediction, careful measurement, honest record and the improve-it step): 20%
- Unit projects: 25%

A 90–100, B 80–89, C 70–79, D 60–69. Below 60: redo the test or project with help.

- Each unit test is 60 points with ten to twelve problems: multiple choice, short answer and one diagram item to draw or label. Give partial credit for a correct method with an arithmetic slip.
- A notebook page earns full marks when it has a date, a title, a labeled sketch or table with metric units, and one sentence beginning “I observed” and one beginning “I think this means.”
- Grade the experiment on the process: Did the student predict, measure in metric units, record honestly, compare with the prediction and suggest one improvement?
- On the time question, grade the reasoning, not the conclusion. A student earns full credit for stating what the sign says, what was observed, and how Christians read it, clearly and fairly, in his or her own words.
- Unit tests may be done orally for a student who writes slowly; the parent writes down the answers. The diagram item is always drawn by the student.
- Keep each unit’s project in one folder. Together with the notebook they make the record of the year and the basis of the Unit 8 report.

A NOTE TO PARENTS

You do not need to be a geologist to teach this course. Read the story aloud together, work through the core ideas, and then stand beside the student at the jar or the tray and ask three

questions: “What do you observe?”, “What did you measure?” and “What are you assuming?” Those three questions are most of what a good science teacher does, and they are the questions a careful scientist asks all day long.

The course is written from a Christian view of creation and the Flood, and it is also written to be fair. Every museum claim is quoted as the museum makes it, every measurement is reported as it was made, and the other view is given its best case before the Christian reading is set beside it. Your child will come away able to read any sign in any museum, to say exactly what was observed and what was inferred, and to disagree with a docent or a textbook politely and with reasons. That is a better protection for faith than never hearing the other side.

Supervise every experiment and every field trip. Water goes on a tray or outdoors, gravel and rock call for safety glasses, and no one stands near a road cut without an adult watching the traffic. Above all, the course hopes to raise a young person who looks at the earth closely, tells the truth about what is there, and sees in it the hand of the One who made it: “The heavens declare the glory of God; and the firmament sheweth his handywork.” (Psalm 19:1)

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★ quarter path · ⏳ Thinking About Time box

UNIT 1

Steno's Principles

In 1666 a young Danish anatomist in Florence was handed the head of a great white shark. By the time he was done comparing its teeth with the "tongue stones" people dug out of the hills, Nicolas Steno had found a way to read the past from things that can be seen and measured today. Three years later he printed the rules that every geologist still learns first: in an undisturbed stack of layers the lowest is oldest; layers are laid down level and spread out sideways; and anything that cuts a layer came after it. This unit teaches those rules one at a time, each with a real person, a real place and a real date, and with a jar, a tray or a block of clay on your table.

You will meet Steno himself, who gave up science to serve as a bishop and died poor; William Smith, the blacksmith's son who drew the first geological map of a whole country; and James Hutton, who found red granite veins cutting through the dark rock of a Highland river. You will measure settling times, slopes and fault offsets, and you will build cross-sections that a family member must read without having watched you make them.

Through it all you will practice the habit that matters most in the rest of this course: separating what the rock shows (the order of events) from what a reader assumes (how long each event took). Steno believed the layers of Tuscany agreed with the history in Genesis, including the Flood. Whether you stand before a road cut or a museum sign, you will learn to say exactly which part is observed and which part is interpretation.

BEFORE YOU BEGIN

- Can measure length in millimeters and centimeters and convert between millimeters, centimeters and meters
- Can compute a rate (distance ÷ time) and a ratio, and read a simple data table
- Knows that rocks come in three families (igneous, sedimentary and metamorphic) and that sediment is loose material such as sand and mud
- Can read a protractor and name angles in degrees

MASTERY CHECKLIST

- I can tell the story of Steno and the shark's head and state his rule for a solid within a solid.
- I can state the principle of superposition with its condition and put the layers of a cross-section in order from oldest to youngest.
- I can explain original horizontality and lateral continuity, measure a layer's slope as rise over run, and match layers across a valley.
- I can use cross-cutting relationships and inclusions to place dikes, faults and erosion surfaces in a sequence of events.
- I can calculate how long a layer would take to form under two different assumed rates and explain why the rock gives order but not years.

- I can design a fair test of one of Steno’s rules with a clear question, variables, controls and measurements.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History, online collections and geology pages** (https://naturalhistory.si.edu/): Free. Search the collection pages for fossil shark teeth and for sedimentary rock samples to compare with your project pieces. Read any ages given on the pages as “what the sign says” and practice naming the assumptions behind them.
- **U.S. Geological Survey (USGS) education resources** (https://www.usgs.gov/): Free. Search the site for photographs of dikes, faults and layered road cuts, and for the schoolyard geology lessons that use building stones and sidewalks to practice reading rock.
- **Project Gutenberg: James Hutton, Theory of the Earth** (https://www.gutenberg.org/): Free. Search for Hutton’s Theory of the Earth. The prose is heavy, so a parent may choose a short passage about the granite veins or the layered rocks of Scotland to read aloud in Lesson 1.4.

1.1 Nicolas Steno, the Danish Anatomist Who Became a Bishop (1669) ★

OBJECTIVES

- Tell the story of Steno's dissection of a great white shark in Florence in 1666 and explain how he showed that "tongue stones" are fossil shark teeth.
- State Steno's rule for a solid within a solid and use it to decide which of two solids hardened first.
- Place the main events of Steno's life on a timeline and explain how his faith and his science grew from the same root.

Warm-up. Take a lump of modeling clay or play dough and press a seashell, a key or a coin firmly into it, then lift the object out. Look at the hollow it left. Which was hard first, the clay or the object? How do you know just by looking at the clay? Now imagine you found a rock with a perfect seashell shape pressed into it. What would you conclude about the rock on the day the shell arrived?

Video. Coming soon. Nicolas Steno (Niels Stensen), the shark's head of 1666, tongue stones and the beginnings of geology; how fossils form in sediment (search Smithsonian National Museum of Natural History, USGS, university geology departments, SciShow, Science Max and Moody Science classics).

KEY TERMS

anatomist
A scientist who studies the structure of living bodies, usually by careful dissection and drawing.

fossil
The remains or traces of a once-living thing preserved in rock: a bone, tooth, shell, leaf print, footprint or burrow.

tongue stone (glossopetra)
The old name for a triangular stone found in rock and once thought to have fallen from the sky. Steno showed tongue stones are fossil shark teeth.

sediment
Loose grains such as mud, sand, gravel or shell pieces that settle out of water or air and may later harden into rock.

stratum (plural strata)
A single layer of sedimentary rock, laid down as a sheet and separated from the layers above and below by a visible surface.

mold and cast

A mold is the hollow shape a hard object leaves in sediment; a cast is the copy made when the hollow is later filled.

CORE IDEAS

The story. In October 1666, fishermen off Livorno, the port of Tuscany in Italy, hauled in an enormous great white shark. Ferdinando II de' Medici, the Grand Duke of Tuscany, who collected curious things for his court, ordered the head cut off and carted to Florence for a young Danish doctor living there, Niels Stensen, known by his Latin name, Nicolaus Steno. Steno was twenty-eight and already famous as an **anatomist**: at twenty-two, as a student in Amsterdam, he had discovered the duct that carries saliva from the cheek gland into the mouth, and it still bears his name. In Florence he studied the shark's rows of triangular, saw-edged teeth. They looked exactly like the "tongue stones" (in Latin, *glossopetrae*) that farmers dug out of the rocks of Malta and the hills of Tuscany. The Roman writer Pliny the Elder had said tongue stones fell from the sky during eclipses of the moon. Steno measured, compared and concluded: tongue stones are shark teeth turned to stone, and the rock they lie in was once soft mud on the floor of the sea.

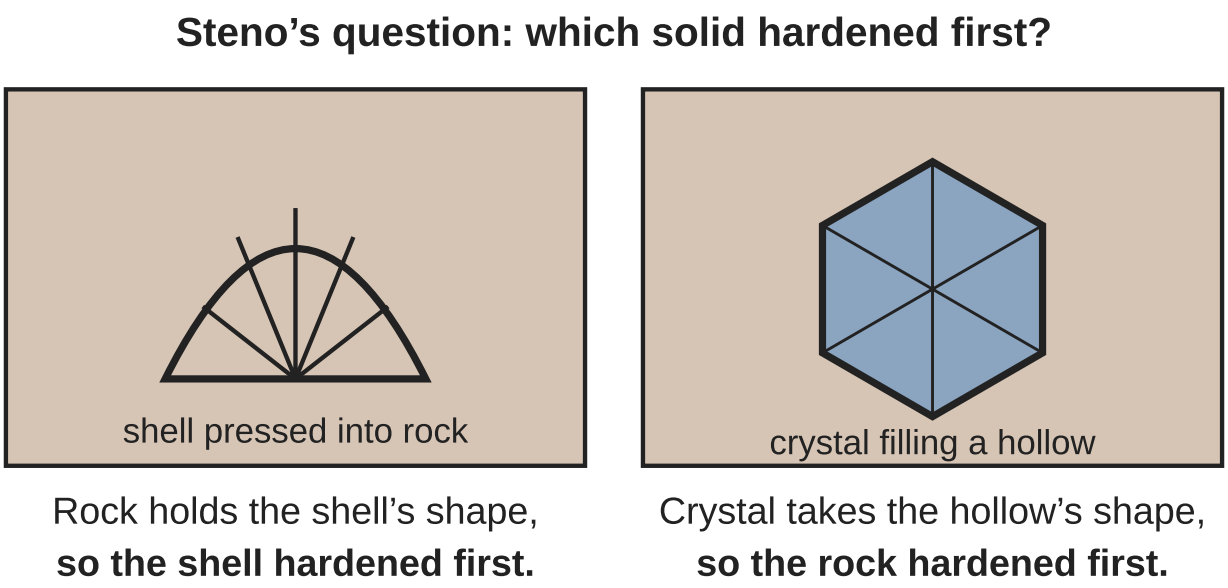
How he figured it out. An Italian naturalist, Fabio Colonna, had guessed this in 1616, but Steno was the first to give a clear rule for deciding such questions. He called it the problem of a solid within a solid. When one solid body lies inside another, ask: which one was hard first? The answer is written in their shapes. If the rock around a shell carries every ridge and groove of the shell's surface, then the shell was already hard while the rock was soft mud pressing around it. If a crystal fills a hollow in a rock and takes the shape of that hollow, then the rock was hard first and the crystal grew afterward. That is the whole trick: **the body that holds the other's shape hardened second**. Steno printed his shark report in 1667. Then he rode through the Tuscan countryside, studied hillsides cut open by streams, and in 1669 printed a little Latin book usually called the *Prodromus*, which means "forerunner." He meant it as the preface to a big book he never finished, and that preface holds the rules for reading rock layers that you will study in the next three lessons.

The big idea. Steno's way of working is the method of all earth history. You cannot watch the past; you can only examine what it left behind, compare it with processes you can watch today, and reason carefully. A shark tooth in stone records a chain of events: a shark lost a tooth, it sank into soft **sediment**, more sediment settled around it, and the sediment hardened into rock, every step something we can see happening today on a small scale. Steno also insisted on saying plainly what he was assuming. That habit matters most when someone tells you how long a process took, because the rock shows you what happened, not how many years it took. Steno himself believed that the layers of Tuscany fit the history recorded in Genesis, including the Flood, and he said so in the *Prodromus*. For him the Bible and the rocks were two true records of one real history.

God's handiwork. Steno treated study as a kind of worship. In 1667 he joined the Catholic Church. In 1673, opening a course of dissections in Copenhagen, he told his students that what we see is beautiful, what we understand is more beautiful, and what we do not yet understand is the most beautiful of all. Then he gave up science altogether. He was ordained

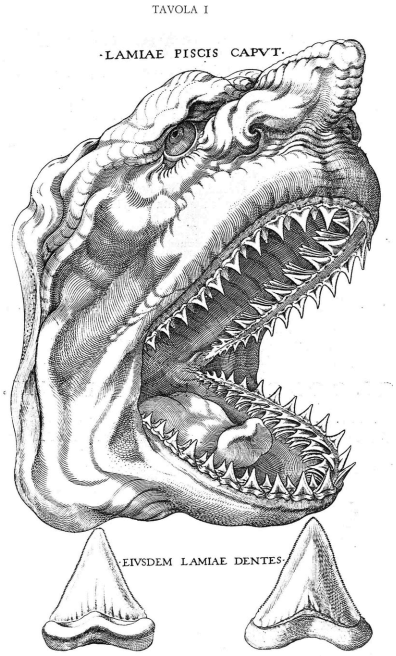
a priest in 1675, and in 1677 he was made a bishop and sent to northern Germany to care for scattered Catholics in Hanover, Münster, Hamburg and Schwerin. He gave away nearly everything he owned, traveled on foot, and died in Schwerin in 1686, aged forty-eight; his body rests in the church of San Lorenzo in Florence. Christians of every church honor him as a founder of geology and as a man whose faith and science grew from the same root: the conviction that the world is a made thing, and so it can be read.

In the world today. Every geology textbook still begins with Steno's rules, usually called Steno's principles. Doctors still speak of Stensen's duct. Mineralogists still use Steno's law: the angles between the faces of quartz crystals are always the same, whether the crystal is tiny or as long as your arm. And tongue stones still turn up: along the Calvert Cliffs of Maryland, collectors pick fossil shark teeth out of the sand every year, some from the giant shark called megalodon, whose teeth can be longer than your hand. Hold one, and you can do exactly what Steno did: compare it point by point with the tooth of a living shark, and reason from what you see to what must have happened.



Steno's question of a solid within a solid. The body that carries the other body's shape hardened second.

PICTURE STUDY



The Head of a Shark Dissected, with Two Tongue Stones, Engraving printed with Nicolas Steno's report Canis carchariae dissectum caput (the shark-head drawing was borrowed from an earlier work by the papal physician Michele Mercati), 1667 · Copperplate engraving in a printed book, Florence · Printed in Steno's Elementorum myologiae specimen; copies are held in many rare-book libraries

This is the picture Steno's readers saw in 1667. The shark's head gapes at the viewer so that every row of teeth shows. Below it, two tongue stones are drawn at large size, front and back, so that a reader could set the drawings side by side and judge for himself whether a tongue stone is really a shark tooth. The shark-head drawing itself was not new; it had been made years earlier for a book by Michele Mercati, a physician in Rome, and Steno's printer reused the plate.

Notice what kind of argument the picture makes. It does not ask the reader to trust Steno. It puts the evidence on the page and lets the eye do the comparing. That is still how good science writing works.

Look closely

- Count the rows of teeth you can see in the open mouth. Sharks grow new teeth behind the old ones and shed the old ones all their lives. Why would that make shark teeth common in sea-floor sediment?
- Compare the two large teeth below with the teeth in the jaw. What shape do they share? Where is the root, and where is the cutting edge?
- Look for the fine saw edge (serrations) on the drawn teeth. Why would tiny details like these matter more to Steno than the overall triangle shape?
- The engraver drew the two teeth larger than life. How does enlarging a thing help a scientist compare it?

Talk about it

1. Pliny said tongue stones fell from the sky. What observation could prove that idea wrong?
2. If tongue stones are shark teeth, what must the rock around them once have been? What must have covered the land where they are found?
3. Why is a careful drawing sometimes better evidence than a written description?

> **Safety first.** Plaster of Paris warms up as it sets and must never be used to make a mold of fingers or any body part. Mix it outdoors or near an open window, avoid breathing the dry powder, and never pour leftover plaster down a drain. Have an adult handle the mixing. Wash hands when finished.

EXPERIMENT: A SOLID WITHIN A SOLID: MOLDS, CASTS AND WHO HARDENED FIRST

Steno's rule says that when one solid sits inside another, the one that carries the other's shape hardened second. You will make both kinds of solid within a solid, measure them, and then test whether a family member can read the order of events from the finished pieces alone.

Question: Can a person who did not watch the molding tell which solid hardened first just by examining the pieces? Prediction: write yours before you begin.

You will need

- Modeling clay or play dough (about a fist-sized lump)
- Three hard objects with texture: a seashell, a large coin, a plastic toy animal or a key
- Plaster of Paris and a disposable cup for mixing (adult help)
- Water, a plastic spoon, a shallow disposable tray or paper bowl
- Metric ruler, pencil, lab notebook
- Petroleum jelly (a little, to keep plaster from sticking to the shell)

Steps

1. Flatten the clay into a slab about 2 cm thick. Press the shell firmly into it, then lift it out. You have made a **mold**. Measure the length and width of the shell and of the mold in millimeters and record both. The mold copies the shell, so the shell was hard first.
2. Rub a little petroleum jelly in the mold. With an adult, mix plaster to the thickness of pancake batter and pour it into the mold. Let it set at least 30 minutes, then peel the clay away. You now have a **cast**. Measure it. Which object does it copy, and what does that tell you about the order of hardening?
3. Now make the other kind of solid within a solid. Mix a second small batch of plaster in the tray and, while it is still soft, push the coin or toy halfway into it. Let it set fully. The plaster has taken the object's shape, so the plaster hardened second. Record what you see where the object meets the plaster.

4. What we change: which solid is soft when the two meet. What we keep the same: the same objects, the same ruler, the same careful notes. What we measure: lengths in millimeters, and how many order-of-events questions your tester gets right.
5. Hand your mold, your cast and your plaster-with-object to a parent or sibling who did not watch. Ask them to say, for each piece, which solid hardened first and what evidence they used. Record their answers in a table and mark each one right or wrong.
6. Compare your shell measurements with your mold and cast measurements. How close are they? A difference of 1 mm or less means the copy is very faithful, which is what Steno saw in tongue stones.
7. Write a conclusion of three or four sentences: was your prediction right, and what rule did your tester use (even without knowing Steno's name)?

Tips

- If you have no plaster, a cast can be made by pressing a second lump of a different-colored clay into the mold.
- Keep the plaster thin (about 1 cm) so it sets quickly and does not crack.
- Save your cast. It is a picture of Steno's argument you can hold, and you can use it again in Lesson 1.2.

Check your work

- I can state Steno's rule for a solid within a solid in my own words.
- I made a mold and a cast and measured both in millimeters.
- I tested whether someone else could read the order of hardening and recorded the results.

FIELD NOTEBOOK

1. Draw a modern great white shark tooth and a tongue stone side by side, each about 8 cm tall. Label the root, the cutting edge and the serrations on both. Write under them the one sentence Steno would say about them.
2. Make a timeline of Steno's life from 1638 to 1686 with at least six dated events. Mark the years when he was a scientist and the years when he was a bishop in two different colors.
3. Draw the two cases of a solid within a solid (shell in rock, crystal in a hollow). Under each, write which hardened first and what shape evidence proves it.

> **From history.** Steno made his first discovery in 1660, when he was a twenty-two-year-old student in Amsterdam dissecting a sheep's head in the house of his teacher Gerard Blasius. His probe slipped into a small tube running from the cheek gland to the mouth that no one had described: the parotid duct. Blasius later tried to claim the find as his own, and the young Steno had to defend it in print. Anatomists today still call it Stensen's duct, and you have one on each side of your face, opening inside your cheek near the upper back teeth.

WORKED EXAMPLES

Example 1. Steno was born in Copenhagen in 1638. He discovered the parotid duct in 1660, dissected the shark's head in 1666, published the *Prodromus* in 1669, was made a bishop in 1677 and died in 1686. How old was he at each event, and for how many years was he a bishop?

1. Age at an event = year of the event − year of birth.
2. 1660 − 1638 = 22 years old (parotid duct).
3. 1666 − 1638 = 28 years old (the shark's head).
4. 1669 − 1638 = 31 years old (the *Prodromus*).
5. 1677 − 1638 = 39 years old (made a bishop).
6. 1686 − 1638 = 48 years old (death).
7. Years as a bishop = 1686 − 1677 = 9 years.

Answer: Ages 22, 28, 31, 39 and 48. He was a bishop for about 9 years. All of his famous science was done before age 32.

Example 2. A student measures a modern great white shark tooth: 4.2 cm from tip to base and 3.0 cm wide at the base. A tongue stone from a rock measures 6.3 cm tall and 4.5 cm wide. Are the two the same shape? If a 4.2 cm tooth came from a shark 4.5 m long, how long would a shark with a 6.3 cm tooth be, if the proportions stay the same?

1. Same shape means the height-to-width ratio is the same. Modern tooth: 4.2 ÷ 3.0 = 1.4. Tongue stone: 6.3 ÷ 4.5 = 1.4. The ratios match, so the two outlines are the same shape at different sizes.
2. Find the scale factor between the teeth: 6.3 ÷ 4.2 = 1.5. The tongue stone is 1.5 times as large.
3. If body length scales with tooth height, the shark was 1.5 × 4.5 m = 6.75 m long.
4. State the assumption: we assumed the big shark had the same body proportions as the small one. That is reasonable for the same kind of shark but is still an assumption, and Steno would have said so.

Answer: Yes, both have a height-to-width ratio of 1.4, so they are the same shape. The tongue stone is 1.5 times larger, and under the proportion assumption its shark was about 6.8 m long.

Example 3. Steno traveled a great deal. Copenhagen and Florence are about 1,600 km apart by today's roads. If a seventeenth-century traveler by coach and horse averaged 40 km per day, how many days would the journey take? How does that compare with a jet flying at 800 km/h?

1. Time = distance ÷ rate.
2. By coach: 1,600 km ÷ 40 km per day = 40 days (and seventeenth-century roads were rougher and more winding, so even more).
3. By jet: 1,600 km ÷ 800 km/h = 2 hours.
4. Ratio: 40 days = 40 × 24 = 960 hours; 960 ÷ 2 = 480. The coach trip took about 480 times as long.

Answer: About 40 days by coach, about 2 hours by jet. Steno's travels cost him months of his short life.

PRACTICE

1. EASY What did Steno dissect in Florence in 1666, and what did he conclude about tongue stones?
2. EASY In your own words, what question does Steno's rule of a solid within a solid ask, and how do you answer it?
3. EASY What did Pliny the Elder say tongue stones were? Name one observation that contradicts his idea.
4. MEDIUM A limestone block contains a clam shell. Every ridge of the shell is pressed into the surrounding stone. Which hardened first, the shell or the limestone? Explain.
5. MEDIUM A geode is a hollow rock lined with quartz crystals that point inward and fit the shape of the hollow. Which hardened first, the rock or the crystals? Explain.
6. MEDIUM A student measured four teeth, two from living great white sharks (A and B) and two tongue stones from rock (C and D).

   Tooth | Height (cm) | Width at base (cm)
   A (modern) | 3.6 | 2.6
   B (modern) | 4.8 | 3.4
   C (tongue stone) | 5.6 | 4.0
   D (tongue stone) | 7.0 | 5.0

   Which statement is best supported by the data?
   (a) Tongue stones have a different outline from modern shark teeth.
   (b) All four teeth have about the same height-to-width ratio, which is consistent with their being the same kind of object at different sizes.
   (c) Tongue stones are smaller than modern shark teeth.
   (d) Modern shark teeth have a larger height-to-width ratio than tongue stones.

7. MEDIUM Steno dissected the shark in 1666 and was consecrated a bishop in 1677. How many years passed between the two events? What fraction of his 48-year life was that?
8. HARD A collector records where tongue stones were found and what else was in the same rock layer.

   Site | Tongue stones found? | Fossil sea shells in same layer? | Rock type
   Malta hillside | yes | yes | limestone
   Tuscan stream bank | yes | yes | sandy marl
   Maryland cliff | yes | yes | sandy clay
   Mountain granite outcrop | no | no | granite

   Which conclusion is most consistent with the table?
   (a) Tongue stones form only in granite.
   (b) Tongue stones occur in water-laid sedimentary rock together with sea shells, which supports a sea-floor origin.
   (c) Tongue stones and sea shells are never found together.
   (d) The rock type has no connection to where tongue stones occur.
9. HARD Experiment design. Suppose a friend still believes tongue stones fell from the sky. Design a fair test of the claim “tongue stones are fossil shark teeth.” Say what you would compare, what features you would measure, how many specimens you would use, and what result would count against the claim.
10. CHALLENGE In three or four sentences, explain Steno’s method for studying the past (observe the present, reason to what must have happened, state your assumptions). Then explain why that third step matters when you read a museum sign that gives a number of years.

COMMON MISTAKES

- Thinking fossils are stones that happened to grow into the shape of bones or teeth. A fossil is the remains or trace of a real once-living thing that was buried in sediment, which later hardened around it.
- Thinking the rule says the enclosed object is always older. It is the shape that decides: the body that carries the other body’s surface hardened second. A crystal inside a rock hollow is younger than the rock around it.
- Thinking Steno had to choose between faith and science. He did his best science as a believing Christian, and he believed the layers of Tuscany agreed with the history in Genesis. He later gave up science to serve as a bishop, but he never said the two were enemies.

> **Make it a game · Which Hardened First?.** A parent gathers five objects that are one solid inside another: a chocolate-chip cookie, an ice cube frozen around a berry, a candle with a shell pressed into it, a piece of concrete with pebbles in it, and a plaster cast from your project. For each one, you have fifteen seconds to say which solid hardened first and what shape evidence proves it. One point for the right order, a second point for naming

the evidence. Then switch roles: you find three new objects and quiz your parent. Play to twelve points.

Scripture. “The works of the LORD are great, sought out of all them that have pleasure therein.” (Psalm 111:2, KJV)

Steno took pleasure in seeking out God’s works, in a shark’s jaw, a tongue stone and a hillside of layers. The psalm says such seeking is a fitting response to a great Maker.

Practice answers

1. He dissected the head of a great white shark caught near Livorno. He concluded that tongue stones (glossopetrae) are fossil shark teeth, so the rock that holds them was once soft sea-floor sediment.
2. It asks which of two solids, one inside the other, was hard first. Look at the shapes: the body that carries the shape of the other’s surface was soft when they met, so it hardened second.
3. He said they fell from the sky during eclipses of the moon. Contradicting observations: they match shark teeth point for point (shape, root, serrations), they lie inside layered rock along with sea shells, and no one has ever seen one fall.
4. The shell. The limestone carries the shell’s shape, so the limestone was soft mud when it surrounded the already-hard shell, and it hardened second.
5. The rock. The crystals grew inward from the walls and take the shape of the hollow, so the hollow (and the rock around it) existed first and the crystals formed afterward.
6. (b). The ratios are A $3.6 \div 2.6 \approx 1.38$, B $4.8 \div 3.4 \approx 1.41$, C $5.6 \div 4.0 = 1.40$, D $7.0 \div 5.0 = 1.40$. They are nearly identical, so the outlines match. The tongue stones in this set are larger, not smaller, so (c) is wrong.
7. $1677 - 1666 = 11$ years. $11 \div 48 \approx 0.23$, about 23 percent, or a little under one quarter of his life.
8. (b). In every site with tongue stones, the rock is sedimentary and contains sea shells too; the one site without sea shells (granite, which is not water-laid) has no tongue stones. This matches Steno’s conclusion that the teeth were buried in sea-floor sediment.
9. Sample answer: Collect at least 10 tongue stones and at least 10 teeth from living sharks of several species. Measure height, base width, height-to-width ratio, the number of serrations per centimeter, root shape and the layered structure inside a cut tooth, using the same ruler and magnifier for all. Also record what rock the tongue stones were in and whether sea shells were in the same layer. If the tongue stones match some living shark species in every measured feature, the claim is supported. If the tongue stones differed from all shark teeth in internal structure or serration pattern, or if they occurred in rocks with no other sea fossils, that would count against the claim. Keep the measuring method the same for all specimens (the control).
10. Sample answer: Steno could not watch a tooth turn to stone, so he studied what he could see today (shark teeth, soft sediment, hardened rock) and reasoned step by step to the events that must have produced a tongue stone in rock. He wrote down what he assumed, such as that shapes are copied by soft material pressing on hard material. A museum sign that gives a number of years is also reasoning from the present to the past, but the number depends on assumptions about how fast things happened. Knowing Steno’s method lets you ask what the

sign assumed and whether the rock itself shows that or whether it only shows the order of events.

1.2 Superposition

OBJECTIVES

- State the principle of superposition and the one condition it requires (the layers must be undisturbed).
- Put the layers of a rock cross-section in order from oldest to youngest and explain what relative age means.
- Calculate how long a layer would take to form under different assumed rates and explain why the rock itself does not give the rate.

Warm-up. Find a stack of things that piled up over time: the newspapers or mail on a counter, the laundry in a basket, or the dishes in the sink. Without asking anyone, decide which item was put down first and which last. Now shake a clear jar that is half full of water with a spoonful each of gravel, sand and garden soil. Set it down and watch for two minutes. What settles first? What is still cloudy?

Video. Coming soon. Law of superposition and reading rock layers; how sediment settles into layers in a jar; Steno's principles explained for middle school (search USGS, Smithsonian National Museum of Natural History, SciShow, Science Max, Homeschool Pop (Alternate) and university geology departments).

KEY TERMS

superposition
Steno's rule that in an undisturbed stack of sedimentary layers, each layer is younger than the one below it and older than the one above it.

deposition
The settling and laying down of sediment by water, wind or ice.

bedding plane
The flat surface that separates one layer (bed) from the next; it marks the top of one layer and the bottom of the one above.

relative age
Whether one thing is older or younger than another, with no number of years attached.

undisturbed
Layers that have not been folded over, pushed on top of one another by faulting, or had molten rock squeezed between them since they formed.

graded bed
A single layer in which grains are coarse at the bottom and finer toward the top, because large grains settle first.

CORE IDEAS

The story. In Florence in 1669, Steno drew six small pictures. Engraved on one page of the *Prodromus*, they tell the history of the hills of Tuscany as he had worked it out on horseback. The first picture shows flat layers of sediment lying under water. Later pictures show hollows eaten out beneath the layers, the roof collapsing so that the layers tilt, new flat layers filling the valleys, and the whole process happening a second time, until the last picture looks like the Tuscan countryside Steno rode through: some layers flat, some tilted, hills between stream valleys. To draw such a history he first needed a rule for telling which layer came first, and he wrote it down plainly. When any layer was being formed, everything above it was still water or loose sediment, so none of the upper layers existed yet. Therefore, in a stack of layers, the lowest was laid down first. That is the principle of **superposition**, and it is the first thing every geology student still learns.

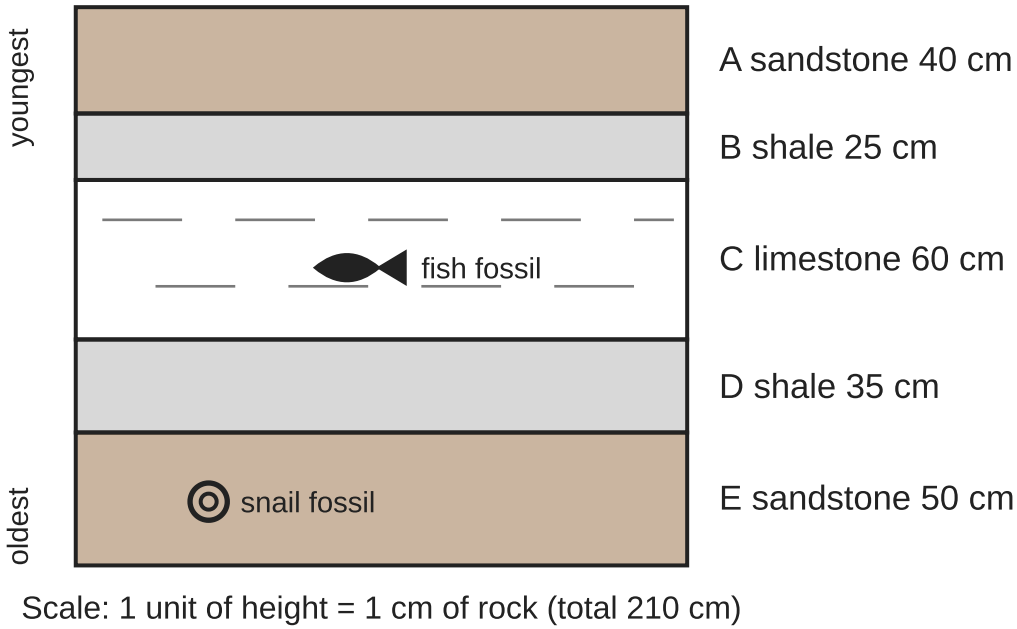
How they figured it out. Steno's reasoning starts with something you can watch. Sediment settles out of water. A grain of sand cannot float in midwater forever; it drops until it lands on something solid, and the next grain lands on top of it. A layer needs a floor to rest on. So the floor is older than the layer, and the layer is older than whatever lands on it next. In your warm-up jar, the gravel hit bottom in a second, the sand in a few seconds, and the fine soil took minutes, so a single stir made one **graded bed**, coarse at the bottom and fine on top. Stir the jar again and a second graded bed forms on top of the first. Each flat surface between beds is a **bedding plane**. Steno looked at hillsides where streams had cut through the Tuscan layers and saw the same thing on a huge scale: beds stacked on beds, each resting on the one below. (In moving water, layers can also grow sideways; you will test that in Unit 2.)

The big idea. Superposition gives **relative age**. It answers the question "older or younger?" and never the question "how many years?" Lower is older; higher is younger; that is all. The rule also has one condition built in: the layers must be **undisturbed**. Mountain-building can fold a stack of layers completely over, so that the oldest beds end up on top. A fault can shove one slab of rock up and over another. Molten rock can squeeze between two layers and harden into a sheet (called a sill) that looks like a layer but is younger than the beds on either side of it. So a careful geologist checks for signs that the layers are still right side up: graded beds coarse at the bottom, ripple marks with their sharp crests pointing up, mud cracks that open upward, footprints pressed down into the surface, shells lying the way shells come to rest. If those signs all point the same way, the stack is undisturbed and superposition can be trusted.

Thinking about time. A layer carries no clock. Suppose a sandstone bed is 3 m thick. Textbooks often assume that sand collected slowly, a few millimeters a year, as it does in some quiet bays today, and then they divide: 3 m at 1 mm per year is 3,000 years, and a whole cliff of such beds becomes millions of years. But the same bed could form in hours if the water was moving fast and carrying a great load of sand. On May 18, 1980, Mount St. Helens in Washington buried the valley below it under deposits that averaged about 45 m thick in a matter of minutes, and later eruptions that summer laid down finely layered ash and pumice beds several meters thick in a few hours. Rivers in flood drop meters of layered

sand in a day. So when a sign gives a number of years for a stack of layers, the number came from an assumed rate, not from the rock. Superposition tells you the order with confidence; the years are a separate question.

In the world today. Superposition is used far beyond cliffs. When a well is drilled, the driller records every layer passed through in order, and the record reads like a history book from newest at the top to oldest at the bottom. Archaeologists dig downward and know that the pottery in a lower level was dropped before the pottery above it; at Hisarlik in Turkey, the site of ancient Troy, excavators found nine cities stacked one above another. Even a snowbank shows it: yesterday's snow lies under today's. Whenever you see a layered road cut, read it as Steno did: start at the bottom and read upward toward the present.



Five undisturbed layers. By superposition, E is the oldest and A the youngest. The snail in E was buried before the fish in C.

⏳ Thinking About Time

What the sign says. What the sign says: textbooks and museum signs often state that a thick stack of sedimentary layers took millions of years to form. The reasoning is that sediment collects slowly today in quiet water, about a millimeter or a few millimeters a year, so a cliff hundreds of meters thick is divided by that rate.

What we observe. What we observe: in an undisturbed stack, lower layers are older than upper ones; that is superposition, and everyone agrees on it. We also observe that floods, volcanic eruptions and laboratory flumes lay down layered sediment meters thick in hours, and that no layer carries a record of how many years it took.

How Christians read it. How Christians read it: many Christians take Genesis 6–9 as history and understand much of the layered rock record as deposited rapidly during the

Flood year and its aftermath, when water covered and then drained off the land. Superposition gives the same order of layers under either reading; the number of years comes from the assumed rate, not from the rock.

Try it. Shake a jar of mixed gravel, sand and soil in water and time with a watch how long it takes to form a clearly layered bed. Write the time next to the thickness.

Genesis 7:19

PICTURE STUDY



Portrait of Niels Stensen (Nicolas Steno), Attributed to Justus Sustermans, court painter to the Medici, between 1666 and 1677 · Oil on canvas · Uffizi Gallery, Florence

This is the only well-known portrait of Steno from his Florence years, painted at the court of the Grand Duke of Tuscany, where Justus Sustermans had been the official painter for decades. The sitter is the same man who dissected the shark's head in 1666 and who, in 1669, drew the six little diagrams of the Tuscan hills that begin this lesson. He was about thirty.

Look at how plainly he is dressed. Steno had every chance of a comfortable career among the princes and scholars of Europe, and within a few years of this portrait he gave it up. The face is calm and the eyes are steady: the face of a man who liked to look carefully at things, whether a duct in a sheep's head or the layers of a hillside.

Look closely

- Study the face. About how old does the sitter look? Steno published the Prodromus at thirty-one.

- Notice what is missing from the picture: no shells, no instruments, no books. Compare this with the portrait of James Hutton in Lesson 1.4, which is crowded with specimens. Which portrait tells you more about the man's work, and which about the man?
- Find where the light falls strongest. Why do painters so often light the face and leave the rest in shadow?
- The collar is plain white and the coat is dark. What might that simple dress say about the sitter's character?

Talk about it

1. Steno drew layers of rock as neat stacked lines in his Prodromus. Looking at this quiet, careful face, why do you think he insisted on stating exactly what he had seen and exactly what he assumed?
2. This portrait was made for a court. Steno's diagrams were made for other scholars. How do the purposes of a picture change the way it is drawn?
3. If you could ask the man in this portrait one question about the hills of Tuscany, what would it be?

> **Safety first.** Work over a tray or outdoors, wipe up spills so no one slips, and do not pour sand or soil down the drain. Use only water in this experiment.

EXPERIMENT: LAYERS IN A JAR: DOES THE ORDER OF LAYERS RECORD THE ORDER OF EVENTS?

You will build a stack of sediment layers one pour at a time, bury a "fossil" in a known layer, and then see whether a reader can recover the order of events from the finished jar. You will also time how fast each kind of grain settles.

Question: Does the order of the layers in a jar record the order in which the sediment was added, and how long does each layer take to settle out? Prediction: write what you expect to see and roughly how long you think the fine soil will take to clear.

You will need

- Two tall clear jars or bottles with lids (1 liter or larger)
- Aquarium gravel, play sand and dry garden soil or potting soil (about 100 mL of each per jar)
- Water, a measuring cup, a funnel
- A small bead or button (the "fossil")
- Metric ruler, a watch or timer, lab notebook, pencil
- Masking tape and a marker to label the jars

Steps

1. Fill Jar 1 about three-quarters full of water. Pour 1 (bottom layer): add 50 mL of sand through the funnel. Start the timer the moment it enters the water and record how

many seconds until the water above it is clear. Measure the thickness of the layer in millimeters with the ruler against the glass.

2. Pour 2: add 50 mL of soil. Drop the bead in with it. Record the settling time (fine soil may take many minutes; note the time when you can see the layer boundary even if the water is still a little cloudy) and the thickness.
3. Pour 3: add 50 mL of gravel. Record time and thickness. Wait until everything has settled, then draw the jar to scale in your notebook and label each layer with its pour number, thickness and settling time.
4. Jar 2 (the comparison): add all three sediments at once, cap the jar, shake it hard for 10 seconds, set it down and start the timer. Record what settles first, second and third, and the total time until the water clears. Draw this jar too. What you have made is a single graded bed.
5. What we change: whether the sediment is added in separate pours or all at once. What we keep the same: the amounts of each sediment, the water volume, the same jars and ruler. What we measure: settling time in seconds or minutes and thickness in millimeters.
6. Cover the labels and hand both jars to a family member. Ask: Which layer was added first? Which last? In which pour did the bead go in? Record their answers and mark them right or wrong. Then ask: Can you tell from the jar how many minutes each layer took? (They cannot; only your timer knows.)
7. Conclusion: write three or four sentences. Did the layers record the order of events? Did they record the time each took? Which jar shows superposition, and which shows a graded bed?

Tips

- If the soil stays cloudy for hours, add a pinch of table salt to the water; clay particles clump together in salty water and settle faster, which is also one reason sea water clears more quickly than muddy fresh water.
- Sand settles so fast that you may need a helper to run the timer while you pour.
- Keep Jar 1 for Lesson 1.3; you will tilt it.

Check your work

- I built a stack of layers and recorded the thickness and settling time of each.
- I can explain why the bottom layer is the oldest and why a reader cannot tell the settling time from the jar alone.
- I can tell the difference between a stack of separate beds and one graded bed.

FIELD NOTEBOOK

1. Draw the five-layer cross-section from this lesson to scale (1 cm on paper for every 10 cm of rock) and number the layers 1 to 5 from oldest to youngest.
2. Draw your settling jar after it cleared. Label the layers, the bedding planes and the position of your bead “fossil.”

3. Make a two-column list titled “Right side up?” with five signs that show which way was up when a layer formed (graded bedding, ripple crests, mud cracks, footprints, resting shells), with a tiny sketch of each.

From history. Steno never finished the big book that the *Prodromus* was meant to introduce. He wrote to friends that he hoped to return to it, but within two years he had left science for the priesthood. Even so, the short book he did print was translated into English in London in 1671, only two years after it appeared in Florence, and geologists have been building on it ever since. The six engraved diagrams of Tuscany are often called the first geological cross-sections in history.

WORKED EXAMPLES

Example 1. Use the five-layer cross-section (figure e7-1-2-layers). The layers from top to bottom are A sandstone 40 cm, B shale 25 cm, C limestone 60 cm, D shale 35 cm and E sandstone 50 cm. List the layers from oldest to youngest, find the total thickness of the stack in meters, find what fraction of the stack the limestone makes up, and say whether the snail in E or the fish in C was buried first.

(Use the map or drawing “Read the stack from the bottom up: E is oldest, A is youngest.” shown earlier in this lesson.)

1. By superposition, the lowest undisturbed layer is oldest. Oldest to youngest: E, D, C, B, A.
2. Total thickness = 40 + 25 + 60 + 35 + 50 = 210 cm = 2.1 m.
3. Limestone fraction = 60 ÷ 210 = 0.286, about 29 percent of the stack.
4. The snail lies in E, below the fish in C. The snail was buried first. Superposition says nothing about how many years separated them.

Answer: Order E, D, C, B, A; total 2.1 m; limestone about 29 percent of the stack; the snail in E was buried before the fish in C.

Example 2. A sandstone bed is 3 m thick. (a) If the sand collected at 1 mm per year, how long did the bed take to form? (b) If a flood dropped sand at 1 cm per minute, how long did it take? (c) What does the rock itself tell you about which rate is right?

1. Convert the thickness to the units of each rate. 3 m = 3,000 mm = 300 cm.
2. (a) Time = thickness ÷ rate = 3,000 mm ÷ 1 mm per year = 3,000 years.
3. (b) Time = 300 cm ÷ 1 cm per minute = 300 minutes = 5 hours.
4. (c) The two answers differ by a factor of 3,000 years ÷ 5 hours. 3,000 years × 365 × 24 ≈ 26,000,000 hours; 26,000,000 ÷ 5 ≈ 5,000,000. The same bed gives answers about five million times apart, depending only on the assumed rate. The bed's thickness cannot settle the question; you would need evidence about how the sand was moving (grain sorting, current structures, how sharp the boundaries are).

Answer: (a) 3,000 years. (b) 5 hours. (c) Nothing in the thickness alone; the rate is an assumption that must be supported by other evidence.

Example 3. Rough settling speeds in still water are about 2 cm per second for sand, 0.03 cm per second for silt and 0.0003 cm per second for clay. How long would each take to fall 30 cm, the depth of water in a settling jar?

1. Time = distance ÷ speed.
2. Sand: 30 cm ÷ 2 cm/s = 15 seconds.
3. Silt: 30 cm ÷ 0.03 cm/s = 1,000 seconds ≈ 17 minutes.
4. Clay: 30 cm ÷ 0.0003 cm/s = 100,000 seconds. 100,000 ÷ 3,600 ≈ 28 hours, a little over a day.
5. So one stir of mixed sediment makes a graded bed: sand on the bottom within seconds, silt over it within the hour, clay on top by the next day (faster in salty water, where clay particles clump).

Answer: Sand about 15 s, silt about 17 min, clay about 28 h. Coarse grains land first, which is why a single pour forms a graded bed.

PRACTICE

1. EASY State the principle of superposition in one sentence, including its condition.
2. EASY A road cut shows six layers. Which layer is the youngest, and which is the oldest, if the layers are undisturbed?
3. EASY What is the difference between relative age and a number of years?
4. MEDIUM A cliff has 12 layers, each 25 cm thick. What is the total height of the cliff in meters? If a textbook assumes 2 mm of sediment per year, how many years would it assign to the whole cliff? If instead each layer were a one-day flood deposit, how many days?

5. MEDIUM A student built a jar of layers in three timed pours and recorded the results.

   Pour | Sediment | Settling time | Layer thickness
   1 | sand | 12 s | 18 mm
   2 | soil | 9 min | 15 mm
   3 | gravel | 3 s | 22 mm

   Which statement is supported by the data?
   (a) The thickest layer took the longest to settle.
   (b) The bottom layer in the jar is the gravel.
   (c) Settling time depended on grain size, not on layer thickness.
   (d) The soil layer is the oldest layer in the jar.
6. MEDIUM A fossil snail is found in a layer 4 m below a layer that holds a fossil clam. The layers are flat and undisturbed. Which animal was buried first? Can you say how many years apart they were buried? Explain.
7. HARD During a flume test, a student measured the total thickness of sand deposited over time.

   Time (min) | 0 | 10 | 20 | 30 | 40
   Thickness (cm) | 0 | 4 | 9 | 13 | 18

   (a) What is the average deposition rate in cm per minute? (b) At that rate, how long would it take to build a 2 m bed? (c) Which assumption are you making in part (b)?
8. HARD A dark sheet of rock lies between two sandstone layers in a cliff. The sandstone directly above the sheet and directly below it is baked hard and discolored for about 20 cm. Does superposition tell you the dark sheet is younger than the sandstone below and older than the sandstone above? Explain.
9. HARD Experiment design. You want to find out whether moving water or still water makes thicker, better-sorted layers. Describe the setup, the independent variable, the dependent variable, two things you would keep the same, and how you would record results.
10. CHALLENGE In four or five sentences, explain why superposition gives the order of layers but not their age in years, what extra information a geologist would need to turn order into years, and why two scientists who agree on the order can still disagree about the years.

COMMON MISTAKES

- Thinking the thickest layer must have taken the longest to form. Thickness depends on how much sediment arrived and how fast, not on time alone; a flood can drop a thick bed in a day while a thin clay layer may represent slow settling.
- Applying superposition to layers that have been folded over or faulted. Always check for right-side-up signs (graded bedding, ripple crests, mud cracks) before trusting the order.

- Thinking that a number of years on a sign was measured in the rock. The order is observed; the years come from an assumed rate of deposition and must be judged separately.

Make it a game · Oldest to Youngest Relay. Cut ten strips of colored paper and number the backs 1 to 10. A parent stacks them face up in a scrambled pile while you look away, then turns the stack on its side so you can see the edges. You have thirty seconds to list the colors from oldest (bottom) to youngest (top). Check the numbers on the backs. Then the parent adds a twist: flips the whole stack upside down or slides a "sill" card in from the side, and tells you one clue. Can you still get the order? One point per correct position; play three rounds.

Scripture. "Or speak to the earth, and it shall teach thee: and the fishes of the sea shall declare unto thee." (Job 12:8, KJV)

Job says the earth itself can teach those who ask it. Steno asked the hills of Tuscany, and the layers answered with their order. We can read that order today, and the fish buried in those layers still declare that the sea once covered the land.

Practice answers

1. In an undisturbed stack of sedimentary layers, each layer is younger than the layer below it and older than the layer above it.
2. The top layer is youngest and the bottom layer is oldest.
3. Relative age says only whether one thing is older or younger than another. A number of years is a separate claim that needs a known rate or a dated record; superposition by itself never gives years.
4. 12 × 25 cm = 300 cm = 3 m. At 2 mm per year: 3,000 mm ÷ 2 mm per year = 1,500 years. As twelve one-day flood deposits: 12 days. The cliff looks the same either way; the difference is the assumed rate.
5. (c). The gravel layer is thickest (22 mm) but settled fastest (3 s), and the thinnest layer (soil, 15 mm) took longest (9 min), so settling time followed grain size rather than thickness. The bottom (oldest) layer is the sand from pour 1, so (b) and (d) are wrong.
6. The snail was buried first, because its layer is lower. No, superposition gives only order. The 4 m between them could represent anything from hours in a fast-moving flood to a long span at slow rates; the thickness alone does not tell.
7. (a) 18 cm ÷ 40 min = 0.45 cm per minute. (b) 200 cm ÷ 0.45 cm per minute ≈ 444 minutes ≈ 7.4 hours. (c) That the rate stays constant at the same water speed and sediment supply for the whole time; if conditions changed, the time would change.
8. No. The baked zones both above and below show the dark sheet was molten when it arrived and heated both neighbors, so it was squeezed in between existing layers (a sill). It is younger than both sandstones. Superposition applies only to layers deposited one on another, not to molten rock pushed in later.
9. Sample answer: Use two identical clear containers with the same volume of water and the same 100 mL mixture of sand and soil. In one, pour the sediment into still water; in the other, keep the water moving with a steady stirring or a small pump at a set speed. Independent variable: whether the water is still or moving (and its speed). Dependent variables: layer

thickness in millimeters and how sharply the sand and soil separate (sorting), judged by measuring the thickness of the mixed zone. Keep the same: amount and kind of sediment, water volume and temperature, container shape, settling time before measuring. Record thickness and settling times in a table and draw both containers to scale.

10. Sample answer: Superposition rests on the fact that sediment needs a floor to land on, so a lower layer must already have existed when the upper one formed; that gives order only. To turn order into years you would need a known rate of deposition for each layer, or a record laid down at a known date, and you would need to know the rate did not change. The rock does not carry its rate; the same 3 m of sand could form in hours in a flood or in centuries in a quiet bay. Two geologists can therefore read the same cliff in the same order and still assign very different ages, because they bring different assumptions about rates and about events like the Flood. Reading a sign well means noticing which part is observed order and which part is assumed rate.

1.3 Original Horizontality and Lateral Continuity

OBJECTIVES

- State the principles of original horizontality and lateral continuity and explain the observation about settling water that each rests on.
- Explain what tilted layers and layers that end abruptly at a valley or cliff tell us about events that happened after deposition.
- Measure the slope of a tilted layer as rise over run and use lateral continuity to estimate how much rock a valley has removed.

Warm-up. Hold a glass of water level, then tilt it. The glass tilts but the water surface stays flat. Now take the layered jar from Lesson 1.2 (or make a quick one with sand and soil in water) and tilt the whole jar to about 30 degrees. Look at the old layers: do they stay level or tilt with the jar? Hold the jar tilted and sprinkle in a spoonful of fresh sand. Does the new layer settle level or tilted? What does this tell you about any rock layer you see standing at a steep angle?

Video. Coming soon. Original horizontality and lateral continuity explained; William Smith’s 1815 geological map of England; tilted and folded rock layers in road cuts (search USGS, Smithsonian, Geological Society of London, SciShow, Science Max and university geology departments).

KEY TERMS

original horizontality
Steno’s rule that sediment settling from water forms layers that are flat (level) or nearly so; layers that are now tilted or folded were moved after they formed.

lateral continuity
Steno’s rule that a layer of sediment spreads out in all directions until it thins to nothing or meets a barrier; so layers now separated by a valley were once connected.

dip
The angle at which a tilted layer slopes down from level, measured in degrees.

outcrop
A place where bedrock shows at the surface, such as a cliff, road cut or stream bank.

correlation
Matching a layer seen in one outcrop with the same layer in another outcrop, using its position, rock type and fossils.

cross-bedding
Small sloping layers inside a single bed, formed on the face of a moving dune or sandbar; these slopes are original, not later tilting.

CORE IDEAS

The story. In 1815 a map went on sale in London that was about 2.6 m tall, printed on fifteen sheets and colored by hand. Its title began *A Delineation of the Strata of England and Wales*, and its maker was William Smith, a village blacksmith's son from Churchill in Oxfordshire with no university training, who learned the rocks by surveying coal mines and digging canals, above all the Somerset Coal Canal in the 1790s. As the diggers cut their trench, Smith noticed that the same layers appeared in the same order mile after mile, each with its own fossils, and that the whole stack sloped gently toward the southeast like a pile of slices of bread and butter tipped on one side. He began following each layer across the land on horseback, marking where it reached the surface. Twenty years later he had drawn the first geological map of an entire country. Every band of color on it is a statement of Steno's third rule: a layer seen here and the same layer seen miles away were once one continuous sheet.

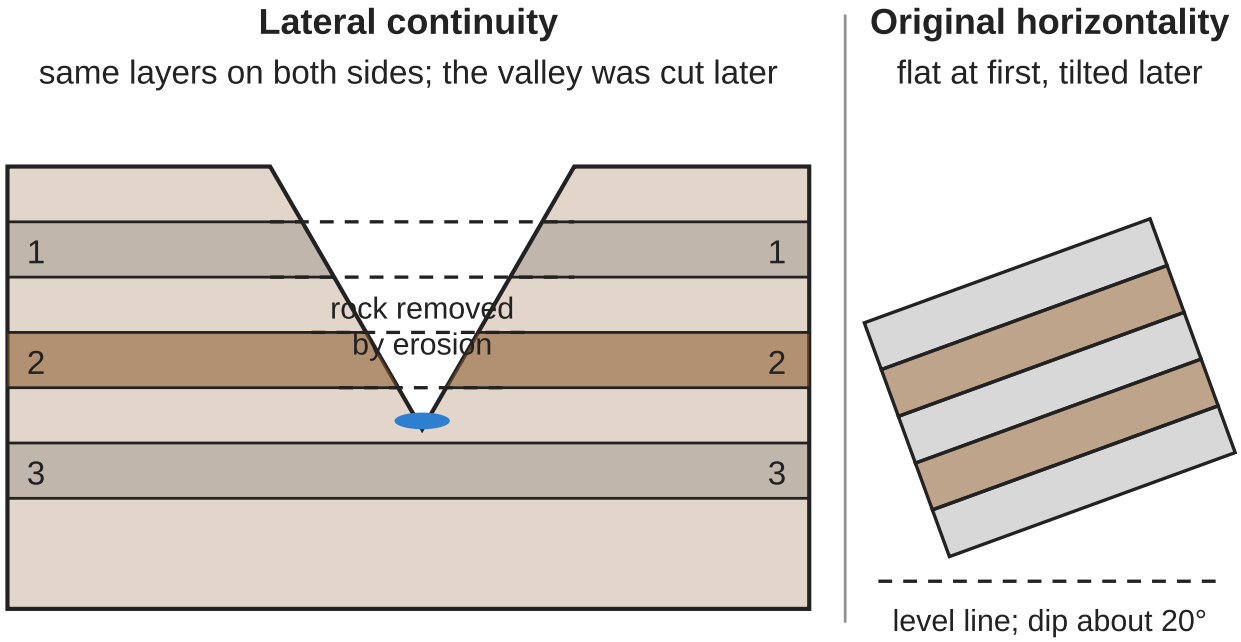
How they figured it out. Steno had written down two more rules in 1669, and both come from watching water. First, sediment settling out of still water comes to rest in level sheets, because water finds its own level and grains roll downhill into every low place until the surface is flat. Steno concluded that layers were originally level, or very nearly so, and that any layer now standing at a steep angle was tilted afterward. This is **original horizontality**. Second, settling sediment spreads out sideways as far as the water carries it, until the layer thins to nothing at its edge or runs up against something solid, such as the wall of a basin. So wherever a layer ends suddenly at a cliff face or a valley wall, something has happened since: either the missing part was carried away, or the layer was broken and moved. This is **lateral continuity**. Smith added a tool of his own: fossils. When two **outcrops** showed the same rock with the same fossils in the same position in the stack, he matched them as one layer, a step called **correlation**.

The big idea. With these two rules you can read events that are no longer happening. Stand in a valley and see the same three layers in the cliff on your left and the cliff on your right at the same heights. Lateral continuity says they were one sheet; superposition says they are in order; therefore the valley was cut through them after they were laid down, and the amount of rock missing can be estimated from the valley's shape. Find layers standing at 40 degrees in a road cut. Original horizontality says they were level once; therefore something lifted and tilted them later. The tilt is measured as the **dip**, and you can estimate it as rise over run: how far the layer drops for each meter you walk along it. One caution: sand sliding down the face of a dune or sandbar rests at its angle of repose, about 30 to 34 degrees, so a single bed can contain small sloping layers called **cross-bedding** that were never level. The rule applies to the big sheets, not to the little slopes inside them.

In the world today. Lateral continuity is the reason a geologist can predict what a drill will hit before it is drilled, and the reason coal miners could follow a seam underground from one shaft to the next. The white chalk cliffs at Dover in England reappear across the English Channel at Cap Blanc-Nez in France: one sheet of chalk, with the sea now running through the gap. Some sandstone and limestone sheets can be traced across whole regions, flat and thin, for hundreds of kilometers. Everyone agrees such sheets were laid down by water

spread over an enormous area. Geologists who take the Flood of Genesis as history see in these vast, even sheets just what a year of water covering the continents would leave; others picture seas that spread slowly over the land. Both readings begin from the same measured fact: the layer is continuous, and it was level when it formed.

God's handiwork. The flatness of a settled layer is not an accident. It is gravity and water doing exactly what they were made to do, the same today as on the day the layer formed. That reliability is what makes Steno's rules work at all. The psalmist describes the God who set the earth in order and then covered it with the deep: "the waters stood above the mountains" (Psalm 104:6). Chalk at Dover or sand in a jar, it is one lawful world, and because the laws hold in every place and time, even someone who was not there can read what the water did.



Left: lateral continuity. The layers on both sides match, so they were one sheet before the valley was cut. Right: original horizontality. These layers were level when deposited and tilted later.

PICTURE STUDY



A Delineation of the Strata of England and Wales, with Part of Scotland, William Smith (engraved and published by John Cary, London), 1815 · Engraved map in fifteen sheets, hand-colored with watercolor · Original copies at the Geological Society of London and other libraries

This is the first geological map of a whole country. William Smith colored each rock layer where it reaches the surface, and he shaded the color darker along the lower edge of each band to show that the layer slopes down underneath the next one. Follow any band with your finger and you will see it run for hundreds of kilometers across the country. Smith could draw it that way only because he trusted lateral continuity: the chalk he saw in one hillside and the chalk he saw forty kilometers away were the same sheet.

The map nearly ruined him. Others copied it and sold cheaper versions, and in 1819 Smith spent time in a debtors' prison. Years later the Geological Society of London gave him its first Wollaston Medal, in 1831, and called him the father of English geology.

Look closely

- Find the long curved bands of color running from the northeast coast toward the south coast. Do they look like separate patches or like continuous ribbons?
- Look at how the color is darker along one edge of each band. Smith used that shading to show the direction the layer slopes down. Which way do most of the layers slope?
- Find London, in the southeast. What color surrounds it, and what does that tell you about the rock under the city?
- The map has no numbers of years on it. What does it record instead?

Talk about it

1. How could a man with no university training make a discovery like this? What did his work as a canal surveyor let him see?
2. Smith matched layers partly by their fossils. Why would the same fossils in two distant outcrops support the idea that the two outcrops are one layer?
3. What would it take to make a map like this of the county where you live?

> **Safety first.** Use only water in these experiments. Work over a tray or outdoors, wipe spills right away, and keep sand and soil out of sinks and drains.

EXPERIMENT: TILTED TANK AND CUT VALLEY: TESTING STENO'S TWO RULES

Two small experiments. In the first you will test whether sediment settles level even in a tilted container. In the second you will build a layered block, cut a valley through it, and check whether the layers can be matched across the gap.

Question 1: If the container is tilted, do the layers settle tilted or level? Question 2: Can a reader match layers across a cut valley and estimate how much was removed? Write your predictions first.

You will need

- A clear rectangular plastic container (a food storage box about 15 to 20 cm long)
- Play sand, dry garden soil or flour, and (optional) a dark sand or crushed cereal for a third color
- Water, a measuring cup, a spoon
- A protractor and a metric ruler
- Books to prop the container at an angle
- A shallow baking pan or tray, a butter knife, lab notebook

Steps

1. Experiment 1, level trial: fill the container with about 6 cm of water. Sprinkle in 3 spoonfuls of sand and let it settle, then 3 spoonfuls of soil. Measure the angle the settled layer's top surface makes with the container's bottom (it should be 0 degrees). Record.
2. Tilted trial: pour out the water carefully, dry the container, and prop it on books so its bottom tilts 20 degrees (check with the protractor). Refill with water and repeat the same two pours. When settled, hold the protractor against the side and measure the angle of the layer's top surface compared with a level line (use the water surface as your level). Record.
3. What we change: the tilt of the container (0 degrees, then 20 degrees). What we keep the same: the amount of water, the amount and kind of sediment, the settling time. What we measure: the angle of the settled layer in degrees. Does the new layer follow the container or the water surface?
4. Experiment 2: in the dry tray, build a layered block about 4 cm thick using three different-colored dry materials in flat layers (sand, soil, dark sand), 1 to 1.5 cm each.

Measure and record each layer's thickness.

5. With the butter knife and spoon, carefully dig a V-shaped valley across the middle of the block, scooping the material out into a cup. Measure the valley's width at the top and its depth.
6. Ask a family member who did not watch to look at the two sides of the valley and match the layers across it. Record how many layers they matched correctly. Then estimate the volume removed: for a V-shaped valley, volume ≈ ½ × width × depth × length. Compare your estimate with the amount of material actually in the cup (measure it in the measuring cup).
7. Conclusion: write four sentences. Did the layers settle level in the tilted tank? Could your reader match layers across the valley? How close was your volume estimate? Which of Steno's rules did each experiment test?

Tips

- In the tilted trial the first grains will slide to the low corner and build the layer thicker there, but the top surface still comes out level. That thick-to-thin wedge is exactly what geologists see when sediment fills a tilted basin.
- If the dry layers mix when you dig, dampen each material slightly with a spray bottle before building the block.
- A metric measuring cup gives volume in milliliters; 1 mL = 1 cubic centimeter, so you can compare directly with your ½ × width × depth × length estimate.

Check your work

- I measured the angle of a settled layer in a level and a tilted container and recorded both.
- I built a layered block, cut a valley and had someone match the layers across it.
- I estimated the volume removed and compared it with the amount actually removed.

FIELD NOTEBOOK

1. Draw a valley cross-section with three layers showing in both walls. Connect the matching layers with dashed lines and shade the part that erosion removed.
2. Draw a tilted set of layers from a road cut or a photograph. Draw a level line through them, measure the angle with your protractor, and label the dip in degrees.
3. Copy the outline of your state or county and invent a simple Smith-style map with three colored bands, including a small key that tells what each color means.

> **From history.** William Smith kept his first list of the layers of England in a small notebook. In 1799, at a house in Bath, he dictated a table of twenty-three layers in order, from the chalk at the top down to the coal, to two friends, the Reverend Benjamin Richardson and the Reverend Joseph Townsend, who wrote it down. That single sheet, often called the Order of the Strata, was passed from hand to hand among English

naturalists for years before the great map appeared. Smith also noticed that each layer had its own fossils, which let him match beds that looked alike in different places.

WORKED EXAMPLES

Example 1. Along a road cut, the top of a sandstone layer is 3.0 m lower at one end than at the other, and the two ends are 20 m apart horizontally. What is the slope of the layer as a decimal and a percent, and roughly what is its dip in degrees? Use this table: a slope of 0.09 is about 5°, 0.18 is about 10°, 0.27 is about 15°, 0.36 is about 20°, 0.58 is about 30°, and 1.00 is 45°.

1. Slope = rise ÷ run (here the drop is the rise). Slope = 3.0 m ÷ 20 m = 0.15.
2. As a percent: 0.15 × 100 = 15 percent. The layer drops 15 cm for every meter you walk along it.
3. From the table, 0.15 lies between 0.09 (5°) and 0.18 (10°), a bit closer to 0.18. The dip is about 8 degrees.
4. Interpretation: by original horizontality the layer was level when it formed, so it has been tilted about 8 degrees since.

Answer: Slope 0.15, or 15 percent; dip about 8°. The layer was tilted after it was deposited.

Example 2. A limestone bed shows on both walls of a valley at an elevation of 412 m. The valley is V-shaped, 600 m wide at the top and 90 m deep, and this stretch of valley is 1 km long. (a) About how much rock was removed from this stretch? (b) If a river carried away 15,000 cubic meters a year on average, how many years would that take? (c) What does the rock tell you about the rate?

1. Lateral continuity: the bed was once continuous across the gap, so the valley’s volume is rock that was removed.
2. (a) The cross-section is a triangle. Area = ½ × base × height = ½ × 600 m × 90 m = 27,000 square meters. Volume = area × length = 27,000 × 1,000 m = 27,000,000 cubic meters.
3. (b) Time = volume ÷ rate = 27,000,000 ÷ 15,000 = 1,800 years.
4. (c) The rock shows how much is missing, not how fast it went. A slow river gives 1,800 years at that rate; a single great draining flood could move it in days. The volume is measured; the years are assumed.

Answer: (a) About 27 million cubic meters. (b) 1,800 years at the assumed rate. (c) The valley’s shape tells what is missing, not how long it took.

Example 3. On William Smith’s 1815 map, one inch stood for five miles. In metric units, 2.54 cm on the map stands for about 8.0 km on the ground. (a) How many kilometers does 1 cm on the map represent? (b) A band of chalk measures 14 cm wide on the map; how wide is it on the ground? (c) Write the scale as a ratio.

1. (a) 8.0 km ÷ 2.54 cm ≈ 3.15 km per cm.
2. (b) 14 cm × 3.15 km per cm ≈ 44 km.
3. (c) A ratio compares map distance to ground distance in the same units. 8.0 km = 800,000 cm. 2.54 cm : 800,000 cm = 1 : 315,000 (about 1 to 317,000 using the exact 8.047 km in five miles).

Answer: (a) About 3.2 km per cm. (b) About 44 km. (c) Roughly 1 : 316,000.

PRACTICE

1. EASY State the principle of original horizontality and the observation about water that it rests on.
2. EASY State the principle of lateral continuity. Name two ways a layer can legitimately end.
3. EASY In a road cut you see layers standing at 40 degrees from level. What does original horizontality tell you happened?
4. MEDIUM Inside a single thick sandstone bed you see thin layers sloping at 25 degrees, while the top and bottom of the whole bed are level. Were these thin layers tilted after they formed? Explain.
5. MEDIUM The top of a shale layer drops 5 m over a horizontal distance of 50 m. Give the slope as a decimal and a percent, and estimate the dip using the table in the worked example (0.09 ≈ 5°, 0.18 ≈ 10°).
6. MEDIUM A geologist measured three layers at three outcrops along a valley, 2 km apart.

   Layer | West outcrop | Middle outcrop | East outcrop
   Sandstone (top) | 2.0 m | 2.1 m | 1.9 m
   Shale | 3.5 m | 3.4 m | 3.6 m
   Limestone (bottom) | 1.2 m | 1.2 m | 1.1 m

   Which statement is best supported by the data?
   (a) The layers are different rocks at each outcrop and cannot be matched.
   (b) The same three layers appear in the same order with nearly the same thickness at all three outcrops, consistent with one continuous set of layers cut by the valley.
   (c) The shale thickens sharply toward the east.
   (d) The limestone is the youngest layer.
7. HARD The top of a limestone bed was measured at four points in a straight line, each 500 m farther east than the last.

Point | Distance east (m) | Elevation of bed top (m)
1 | 0 | 300
2 | 500 | 295
3 | 1,000 | 290
4 | 1,500 | 285

(a) What is the slope of the bed? (b) In which direction does it dip? (c) Predict the elevation of the bed top at 2,500 m east, assuming the slope continues.

8. HARD In a cliff, a 1 m sandstone bed runs across the face and then stops at a narrow crack. On the far side of the crack the same bed appears 2 m lower and continues. Was this bed eroded away or broken and moved? What rule did you use, and what else could you check?
9. HARD Experiment design. A classmate claims that sediment settling in a tilted tank will form tilted layers. Design a test. State the hypothesis, the independent variable and at least three values you would test, the dependent variable and how you would measure it, and two controls.
10. CHALLENGE In four or five sentences, explain how William Smith could draw a layer across a whole county when he could see it only in scattered outcrops. Name the two rules of Steno he relied on and the extra tool he added, and explain why the direction of dip helped him predict where a layer would appear next.

COMMON MISTAKES

- Thinking tilted layers were deposited on a slope. Large sheets of sediment settle level; steep tilt came later. The exception is small-scale cross-bedding inside a bed, which forms at the angle of repose on dunes and bars.
- Thinking a layer that ends at a valley wall simply stopped there. Lateral continuity says the sheet continued and was later removed by erosion or shifted by a fault; look for its match on the other side.
- Thinking lateral continuity means every layer stretches forever. Layers do thin and end naturally at their edges; the rule says they do not end abruptly at a sheer face unless something cut or broke them.

Make it a game · Match the Layers. A parent draws two cliff faces on a sheet of paper with a wide valley between them, each cliff showing six colored layers in the same order and thickness, but one cliff drawn 3 cm lower than the other and with one layer hidden behind a drawn bush. Timed for one minute, you must draw dashed lines matching every layer across the valley, name the hidden layer, and say whether the two cliffs were tilted or faulted (the whole stack sits lower on one side). One point for each correct match, two for the hidden layer, three for the right explanation. Then you draw a puzzle for the parent.

Scripture. “Thou coveredst it with the deep as with a garment: the waters stood above the mountains.” (Psalm 104:6, KJV)

The psalm remembers a time when water stood over the whole land. Steno and Smith read, in the flat, far-reaching sheets of water-laid rock, the signs of a world once covered by the deep and then uncovered again.

Practice answers

1. Sediment settling from water forms level (horizontal) layers because water finds its own level and grains roll into low spots until the surface is flat; so layers now tilted or folded were moved after they formed.
2. A layer spreads sideways as far as the water carries it, so it is continuous unless it thins to nothing at its edge or runs against a barrier such as a basin wall. A layer that instead ends abruptly at a cliff or valley has been eroded or broken since it formed.
3. They were deposited level and have since been tilted (lifted on one side or dropped on the other) by movement of the earth's crust.
4. No. They are cross-bedding, formed on the sloping face of a moving dune or sandbar at about the angle of repose of sand (around 30 to 34 degrees or less). The slopes are original. Original horizontality applies to the big bed, whose top and bottom are level.
5. Slope = 5 ÷ 50 = 0.10, or 10 percent. 0.10 is just above 0.09, so the dip is about 6 degrees.
6. (b). The order (sandstone over shale over limestone) is the same everywhere and the thicknesses vary by only 0.1 to 0.2 m, so correlation across the valley is well supported. The shale changes by only 0.1 m, so (c) is wrong; the limestone is at the bottom, so it is the oldest, not youngest.
7. (a) It drops 5 m every 500 m: slope = 5 ÷ 500 = 0.01, or 1 percent (a dip of about half a degree). (b) It dips toward the east, since elevation falls as you go east. (c) At 2,500 m east, 1,000 m beyond point 4, it drops another 10 m: 285 − 10 = 275 m.
8. Broken and moved: the bed continues beyond the crack but at a different height, so it was offset along a break (a fault). Lateral continuity says the bed was once one sheet at one level, so the 2 m difference is movement after deposition. To check, see whether the layers above and below are offset by the same 2 m and look for scraped or crushed rock along the crack.
9. Sample answer: Hypothesis: the settled layer's surface stays level no matter how the tank is tilted. Independent variable: the tilt of the tank, tested at 0, 10, 20 and 30 degrees (set with a protractor). Dependent variable: the angle between the settled layer's top surface and a true level line (the water surface), measured with a protractor against the tank wall. Controls: the same tank, the same amount and kind of sand, the same water depth and the same settling time for every trial. Repeat each tilt twice and average. If the layer angle stays near 0 degrees at every tilt, the classmate's claim is wrong and original horizontality is supported.
10. Sample answer: Smith saw a layer only where it reached the surface in quarries, canal cuts and hillsides, but lateral continuity told him that outcrops of the same rock in the same position in the stack were parts of one sheet. Superposition told him the order of the sheets, so he knew which layer should appear next as he walked up or down the stack. He added fossils: each layer carried its own kinds, so he could confirm a match between distant outcrops. Because the layers dipped gently southeast, each one disappeared under the next in that direction and reappeared from beneath the one above as he walked northwest, so the dip told him where to look. His map is therefore a prediction as much as a record, and later quarries and wells confirmed it.

1.4 Cross-Cutting Relationships

OBJECTIVES

- State the principle of cross-cutting relationships and the related principle of inclusions, and give examples of features that cut layers (dikes, faults, veins, erosion surfaces).
- Work out the order of events in a rock cross-section that includes deposition, intrusion, erosion and faulting.
- Use measurements of fault offset and dike width to reason about events, and explain why cross-cutting gives order but not years.

Warm-up. Spread peanut butter or frosting on a slice of bread, add a second slice, then a third. Now push a drinking straw straight down through the stack and pull it out, leaving a hole through all three layers. Which came first, the layers or the hole? How do you know? Then cut the stack in half with a knife and slide one half up by a centimeter. Which came first, the hole or the cut? What would someone who did not watch you need to look at to find out?

Video. Coming soon. Cross-cutting relationships, dikes, faults and inclusions in relative dating; James Hutton at Glen Tilt and the granite veins; Shiprock volcanic dikes (search USGS, Smithsonian, National Park Service geology, SciShow, Science Max and university geology departments).

KEY TERMS

cross-cutting relationships
The rule that a feature which cuts across a rock (a crack, fault, dike or erosion surface) is younger than the rock it cuts.

dike
A sheet of once-molten rock that filled a crack cutting across layers and hardened there; a sill is the same kind of sheet pushed in between layers.

fault
A break in rock along which the two sides have moved past each other.

offset
The distance a layer has been shifted across a fault, measured from its position on one side to its position on the other.

inclusion
A piece of one rock enclosed inside another; the enclosed piece is older than the rock around it.

baked zone
A band of rock next to a dike or sill that was heated and hardened by the molten rock; it proves the intrusion was hot and came later.

CORE IDEAS

The story. In the summer of 1785 a Scottish doctor and farmer named James Hutton rode up Glen Tilt, a long valley in the Highlands north of Blair Atholl, with his friend John Clerk of Eldin, who had come to draw. In the river bed, where the water had scrubbed the rock clean, Hutton found what he had come to see. Veins of red granite ran through the dark layered rock, branching like the roots of a tree, forcing their way between the layers and across them. His friend John Playfair later wrote that Hutton was so delighted that the guides were sure he must have found gold or silver. What he had found was an argument. Granite had always been thought the oldest rock of all, the floor beneath everything else. But a vein that cuts across layers cannot be older than those layers; it had to come later, pushed in while hot and liquid, and then it hardened in place. Clerk of Eldin drew the veins carefully, and Hutton went home to write. Steno had stated the same rule briefly in 1669: whatever cuts a layer formed after the layer. Glen Tilt made it unforgettable.

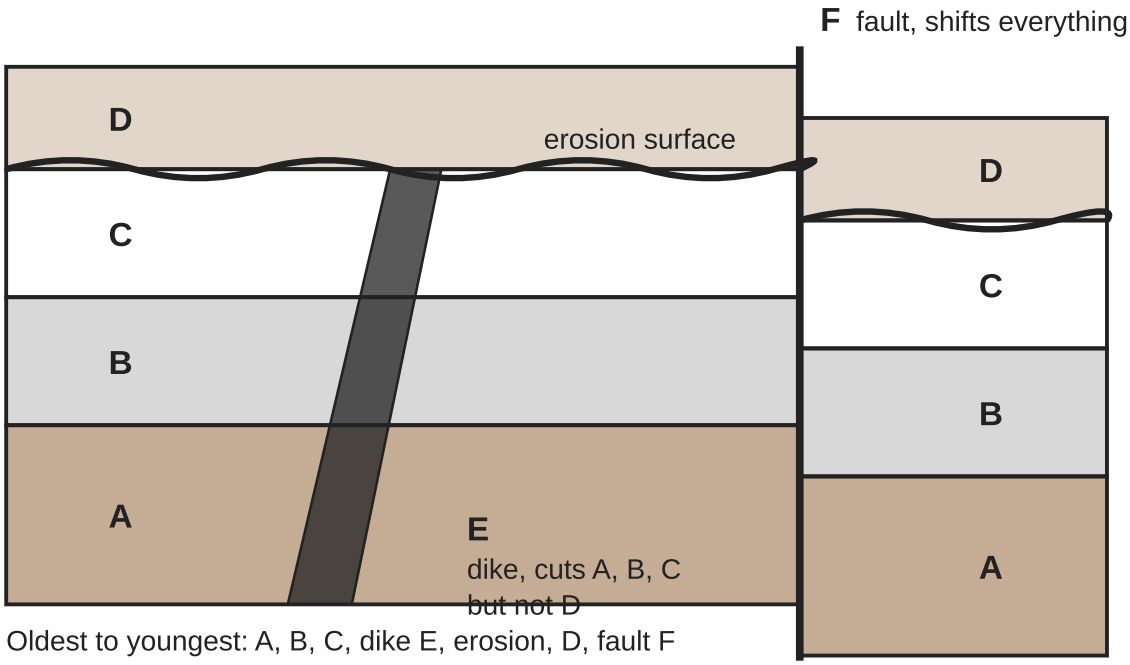
How they figured it out. The reasoning is the one you used with the straw and the sandwich. A thing cannot be cut before it exists. So a crack, a **fault**, a vein of mineral, a **dike** of hardened molten rock, or a channel carved by a river is younger than every layer it cuts across. This is the principle of **cross-cutting relationships**. It comes with helpful clues. Beside a dike, the rock on both sides is often discolored and hardened for a few centimeters to a few meters: a **baked zone**, which shows the dike arrived hot after the layers were already there. Along a fault, layers are shifted, and you can measure the **offset**, how far a layer on one side has moved from its match on the other. A related rule is the principle of **inclusions**, which is Steno's solid-within-a-solid again: pebbles of granite inside a sandstone mean the granite was already hard and broken up before the sand was laid down, so the granite is older. But granite that holds chunks of sandstone inside it was molten after the sandstone existed, so there the granite is younger.

The big idea. Put Steno's rules together and you can write a history. Superposition orders the layers. Original horizontality tells you whether they have been tilted since. Lateral continuity lets you match them across gaps and recognize where something has been removed. Cross-cutting relationships then slot in the events that interrupted the stack: first the layers, then the dike that cuts them, then the erosion surface that planed off the top of the dike, then the new layers deposited on that surface, then the fault that shifts everything, including the new layers. Notice also what the rules cannot do. They give order only. A fault that offsets a layer by 4 m might have moved in one earthquake or in many; the 1964 Alaska earthquake lifted parts of Montague Island about 11 m in a few minutes, so a single event can do a great deal. A dike tells you it came after the layers, not how long after. Order is observed; years are a separate claim.

In the world today. Dikes stand out across the desert of New Mexico at Shiprock, where dark walls of volcanic rock run for kilometers in straight lines radiating from the old volcanic neck, still standing after the softer rock around them wore away. In Hawaii, molten rock rises through cracks to feed the fissure eruptions of Kilauea; when such a crack cools, it is a new dike cutting older lava flows. After big earthquakes, geologists measure offsets on fences, roads and stream beds. Miners following a coal seam use cross-cutting every day:

when the seam ends against a fault, they measure the offset on nearby layers to know where to dig to pick it up again.

God's handiwork. Genesis 7:11 records that on one day "all the fountains of the great deep" were "broken up." Many Christian geologists who take the Flood as history see the earth's great faults and the enormous bodies of once-molten rock as marks of that breaking and of the year that followed, when the crust was torn and shifted on a scale we do not see today; other geologists picture the same features forming in many separate events. Cross-cutting relationships give the same order of events to both. A crack through the layers is still younger than the layers. What the rule cannot do is set a clock, and an honest reader of rocks, whatever his view, says so.



Order of events: A, B and C deposited; dike E cut them; erosion planed off the top; D deposited; fault F shifted everything, so F is youngest.

PICTURE STUDY



James Hutton, Sir Henry Raeburn, about 1776 · Oil on canvas · Scottish National Portrait Gallery, Edinburgh

Henry Raeburn, the great Scottish portrait painter, shows James Hutton not as a doctor or a farmer but as a man of rocks. Shells and fossils lie on the table beside him, and the papers under his hand carry drawings. Hutton was a quiet, plain-dressed man who never married and spent most of his money on books and travel. Nine years after this portrait he would ride up Glen Tilt and see the granite veins.

Raeburn painted hundreds of Edinburgh’s leading figures. Here the objects on the table do the talking: they tell us what the sitter cared about and how he spent his days.

Look closely

- Find the specimens on the table. Which look like sea shells? Why would a man who studied rocks keep sea shells at his elbow?
- Look at the papers and the quill. Hutton wrote one of the longest books in the history of geology. What might be drawn on the sheets?
- Look at Hutton’s face and the way he sits. Does he look like someone eager to argue, or someone who prefers to look and think?
- Raeburn uses plain brown and white for the clothes. Where does he put the strongest light, and what does that make you look at?

Talk about it

1. Hutton overturned the idea that granite is always the oldest rock. What single observation at Glen Tilt made that possible?
2. Why do scientists often keep collections of specimens, as Hutton did, instead of only reading about them?

3. Hutton and Steno disagreed about how much time earth history took, but both used the same rule for a vein that cuts a layer. Why can people with different views still agree on the order of events?

> **Safety first.** Use a butter knife or plastic knife for cutting the sandwich and the clay, never a sharp kitchen knife. Cut on a board, keep fingers behind the blade, and have an adult nearby.

EXPERIMENT: CLAY CROSS-SECTION: CAN A READER RECOVER THE ORDER OF EVENTS?

You will build a layered block of modeling clay, then act out a geological history on it (an intrusion, an erosion surface, a new layer and a fault), keeping a secret log of what you did in order. Then you will slice the block to make a cross-section and find out whether a reader can reconstruct your history using Steno's rules alone.

Question: Can someone who did not watch recover the full order of events from a cross-section? Prediction: how many of your events do you think a reader will place correctly?

You will need

- Modeling clay or play dough in at least four colors (one color reserved for the dike)
- A butter knife or plastic knife, a rolling pin or round jar, a ruler with millimeters
- A sheet of waxed paper or a cutting board
- Lab notebook and pencil; a sealed envelope for your secret log

Steps

1. Roll three colors of clay into flat sheets about 1 cm thick and stack them to make layers A (bottom), B and C. Record them in your log as events 1 to 3.
2. Intrusion: roll the reserved color into a thin rope about 5 mm thick. With the knife, cut a slanted slit from the bottom of the block up through layer C and press the rope into it so that it reaches the top. This is dike E. Record event 4. Measure and record the dike's width in millimeters.
3. Erosion: with the knife, slice off the top of the block so the surface is slightly uneven, cutting off the top of the dike as well. Record event 5.
4. New deposition: roll a fourth color into a 1 cm sheet and lay it on the eroded surface as layer D. Record event 6.
5. Faulting: cut straight down through the whole block with the knife, then slide one side down (or up) by exactly 15 mm and press it gently so it holds. This is fault F. Record event 7 and the offset in millimeters. Seal your log in the envelope.
6. Cut the block in half along a line that crosses the dike and the fault, and set one half with the cut face up. Hand it to a family member with a blank numbered list and ask them to write the events in order and to measure the fault offset and the dike width with the ruler.

7. What we change: nothing, this time; the test is of the reader. What we keep the same: the reader sees only the cut face and the ruler. What we measure: the number of events placed in the correct order, and how close the reader's offset and width measurements are to yours in millimeters.
8. Open the envelope and compare. Score the reader's order (how many of 7 events are in the right place) and the measurement differences. Write a conclusion of four sentences: which events were easy to place, which were hard, and which of Steno's rules the reader used for each.

Tips

- Make the dike a color very different from the layers so the baked-zone idea can be discussed: in real rock, the layers right beside the dike would be darker and harder.
- Chill the clay block in the refrigerator for 20 minutes before slicing; a cold block cuts cleanly and the layers do not smear.
- For a second round, swap the order of the dike and the fault and see whether your reader notices the difference. (If the fault cuts the dike, the fault is younger; if the dike cuts the fault, the dike is younger.)

Check your work

- I built a cross-section with at least seven events and kept a sealed log of their order.
- I had a reader reconstruct the order and scored how many events were correct.
- I can explain which rule (superposition, cross-cutting, inclusions) places each event.

FIELD NOTEBOOK

1. Draw the cross-section from this lesson and number the events 1 to 7 directly on the drawing, with one sentence for each saying which rule placed it.
2. Draw a dike cutting layers, and shade the baked zones on both sides. Beside it draw a sill between layers with its baked zones. Label how the baked zones differ from those under a lava flow (which bakes only the rock below it).
3. Draw a pebble of granite inside sandstone and a chunk of sandstone inside granite. Under each, write which rock is older and why (the principle of inclusions).

> **From history.** John Clerk of Eldin, the friend who rode up Glen Tilt with Hutton, was a skilled artist, and his drawings of the granite veins and other sites were meant to illustrate Hutton's great book. Most of them were never printed. The drawings were lost for nearly two centuries and were found again in 1968 among family papers at Penicuik House near Edinburgh. They were finally published in 1978 under the title *James Hutton's Theory of the Earth: The Lost Drawings*, so that readers today can see what Hutton saw in 1785.

WORKED EXAMPLES

Example 1. Use the cross-section (figure e7-1-4-crosscut). Layers A, B and C lie flat, oldest at the bottom. A slanting dike E cuts A, B and C and stops at a wavy surface. Layer D lies on top of that surface and on top of the dike. A fault F shifts A, B, C, D and the erosion surface downward on the right. List every event in order and name the rule that places each one.

(Use the map or drawing "Read the history: layers, then dike, then erosion, then new layer, then fault." shown earlier in this lesson.)

1. Events 1 to 3: A, then B, then C were deposited. Rule: superposition (lower is older).
2. Event 4: dike E was intruded. Rule: cross-cutting; E cuts A, B and C so it is younger than all three.
3. Event 5: erosion planed off the top of C and the top of the dike. Rule: cross-cutting; the erosion surface cuts the dike, so it is younger than the dike.
4. Event 6: D was deposited on the erosion surface. Rule: superposition; D lies on top of everything beneath it, including the cut-off dike.
5. Event 7: fault F moved. Rule: cross-cutting; F offsets D and all the older layers, so it is the youngest event shown.
6. Check: could the dike be younger than D? No, because D is not cut by it and covers its top. Could the fault be older than D? No, because D is offset.

Answer: Order: A, B, C deposited; dike E intruded; erosion; D deposited; fault F. Seven events, all placed by superposition and cross-cutting relationships.

Example 2. A fault has offset a sandstone bed by 4.5 m vertically. (a) If each earthquake on this fault moved the rock 30 cm, how many earthquakes would be needed, at minimum? (b) The 1964 Alaska earthquake lifted parts of Montague Island about 11 m in one event. What does that tell you about the number of earthquakes needed? (c) What does the fault itself record?

1. (a) Convert to the same units: 4.5 m = 450 cm. Number of events = total offset ÷ offset per event = 450 cm ÷ 30 cm = 15 earthquakes.
2. (b) Since one earthquake has been observed to move rock 11 m, which is more than 4.5 m, the whole offset could have happened in a single large earthquake. The minimum number of events is 1.
3. (c) The fault records the total offset (4.5 m) and that the movement happened after the sandstone was deposited. It does not record how many events made up the offset or how much time passed between them. Fifteen small events or one large one leave the same offset.

Answer: (a) 15 earthquakes at 30 cm each. (b) It could have been one large earthquake, since single events of 11 m have been measured. (c) The fault records the amount and the order, not the number of events or the years.

Example 3. A field sketch of a dike is drawn at a scale of 1 cm = 2 m. On the sketch the dike is 1.5 cm wide and the baked zone on each side is 0.4 cm wide. (a) How wide are the dike and each baked zone in real life? (b) What is the ratio of baked-zone width to dike width? (c) If another dike nearby is 6 m wide and the same ratio holds, how wide would its baked zones be?

1. (a) Real width = sketch width × scale. Dike: 1.5 cm × 2 m per cm = 3 m. Baked zone: 0.4 cm × 2 m per cm = 0.8 m on each side.
2. (b) Ratio = 0.8 m ÷ 3 m ≈ 0.27, or about 1 to 4 (each baked zone is roughly a quarter of the dike width).
3. (c) Wider dikes carry more heat, so if the ratio holds, baked zone = 0.27 × 6 m ≈ 1.6 m on each side.
4. Interpretation: the baked zones on both sides show the dike was hot when it arrived, so it is younger than the rock it cut.

Answer: (a) Dike 3 m wide, baked zones 0.8 m each. (b) About 0.27, or roughly 1 to 4. (c) About 1.6 m on each side.

PRACTICE

1. EASY State the principle of cross-cutting relationships and give three examples of features that cut across rock layers.

2. EASY A dike cuts through layers 1, 2, 3 and 4 but stops at the base of layer 5, which lies across its top. Put the dike in order with the layers.
3. EASY What did James Hutton see at Glen Tilt in 1785, and what did it prove about the granite there?
4. MEDIUM A sandstone layer contains rounded pebbles of granite. Nearby, a body of granite contains angular chunks of sandstone. In each case, which rock is older? Which of Steno’s ideas is this?
5. MEDIUM A dark sheet of volcanic rock lies between two sandstone layers. In case 1 the sandstone is baked both above and below the sheet. In case 2 only the sandstone below is baked and the sandstone above contains pebbles of the dark rock. Which case is a sill and which is a lava flow, and what is the order of events in each?
6. MEDIUM A geologist measured the vertical offset of several layers across one fault.

   Layer | Position | Offset across fault
   A | bottom | 2.4 m
   B | above A | 2.4 m
   C | above B | 2.4 m
   D | top, lies across the fault | 0 m

   Which conclusion is best supported?
   (a) The fault moved a little during the deposition of each layer.
   (b) The fault moved 2.4 m after C was deposited and before D was deposited, and has not moved since.
   (c) Layer D is older than the fault.
   (d) Layer A was offset more than layer C.
7. HARD Four dikes were measured in a canyon wall along with the width of the baked zone on one side of each.

   Dike | Dike width (m) | Baked zone width (m)
   1 | 0.5 | 0.1
   2 | 1.0 | 0.2
   3 | 2.0 | 0.4
   4 | 4.0 | 0.8

   (a) Describe the relationship between dike width and baked-zone width. (b) Predict the baked-zone width for a 3.0 m dike. (c) Which of the following would the data NOT tell you: the relative age of each dike and the layers it cuts, the heat each dike carried, or the year each dike formed?
8. HARD Put these events in order from oldest to youngest and name the rule for each placement: a limestone layer; a fault that offsets the limestone and the shale above it but not the sandstone on top; a shale layer above the limestone; a dike that cuts the limestone, the shale and the fault; a sandstone layer that lies across the fault and the dike.

9. HARD Experiment design. You want to test whether readers can tell a dike that is older than a fault from a dike that is younger than a fault. Describe two clay blocks you would build, what differs between them, what you would keep the same, what you would measure, and how many readers you would use.
10. CHALLENGE In four or five sentences, explain what cross-cutting relationships can and cannot tell about the faults and intrusions a Christian geologist might connect with Genesis 7:11, when “the fountains of the great deep” were “broken up.” What is observed, what is interpreted, and why can geologists who disagree about time still agree about order?

COMMON MISTAKES

- Thinking the rock that is cut must be younger because the dike or fault is inside it. The cutting feature is always younger; a rock cannot be cut before it exists.
- Mistaking a sill for a layer. A sill looks like a bed, but it has baked zones both above and below and may send small fingers into the neighboring rock; it is younger than the layers on both sides.
- Thinking a large fault offset proves a long history of many small movements. A single earthquake has been measured to shift rock more than 10 m, so the offset gives the total movement, not the number of events or the years.

Make it a game · Cut and Order. A parent draws a secret cross-section with five to seven events (layers, a dike, a fault, an erosion surface, a sill), then shows it to you for one minute. You write the events in order from oldest to youngest and name the rule for each. One point per event in the correct place, one bonus point for each correct rule, and two bonus points if you spot an event that could be placed in more than one position and say why. Then draw one for your parent. Play three rounds and keep a running score.

Scripture. “In the six hundredth year of Noah’s life, in the second month, the seventeenth day of the month, the same day were all the fountains of the great deep broken up, and the windows of heaven were opened.” (Genesis 7:11, KJV)

Scripture records a day when the deep was broken up. Faults and dikes are the marks of breaking in the rocks, and cross-cutting relationships let us place each break in order after the layers it cuts, even though the rock itself does not tell us the date.

Practice answers

1. A feature that cuts across a rock is younger than the rock it cuts. Examples: a fault, a dike (or vein), an erosion surface or stream channel, a crack, a burrow or root hole.
2. Layers 1, 2, 3 and 4 were deposited first (oldest to youngest); then the dike cut them; then (after erosion planed the top) layer 5 was deposited on top. The dike is younger than 1 to 4 and older than 5.
3. Veins of granite branching through and across dark layered rock. Because the granite cut the layers, it had to be younger than them and had been pushed in molten, not laid down first as the oldest rock.

4. Pebbles of granite in sandstone: the granite is older (it was already hard and broken before the sand was laid down). Chunks of sandstone in granite: the sandstone is older (the granite was molten around it). This is the principle of inclusions, the same reasoning as Steno’s solid within a solid: the enclosed piece came first.
5. Case 1 is a sill: it was pushed in molten between two existing layers, baking both, so it is younger than both sandstones. Case 2 is a lava flow: it flowed out onto the lower sandstone (baking it), cooled, was eroded (pebbles), and then the upper sandstone was deposited on top; so it is younger than the lower sandstone and older than the upper one.
6. (b). A, B and C are all offset by the same 2.4 m, so they were all in place before the fault moved and moved together; D is not offset and lies across the fault, so it was deposited after the movement. If the fault had moved during deposition, the lower layers would be offset more than the upper ones, which is not what the data show.
7. (a) The baked zone is one fifth of the dike width in every case (ratio 0.2); doubling the dike width doubles the baked zone. (b) 0.2 × 3.0 m = 0.6 m. (c) The year each dike formed. The baked zones show the dikes were hot and younger than the layers they cut, and wider dikes carried more heat, but nothing in the table gives a date.
8. 1. Limestone deposited (superposition: lowest). 2. Shale deposited (superposition). 3. Fault moved (cross-cutting: it offsets limestone and shale, so it is younger than both). 4. Dike intruded (cross-cutting: it cuts the fault, so it is younger than the fault). 5. Erosion, then sandstone deposited across both (superposition and cross-cutting: it is not cut by either, so it is youngest).
9. Sample answer: Build two identical three-layer clay blocks. In Block 1, insert the dike first and then cut and offset the fault so the fault shifts the dike. In Block 2, cut and offset the fault first and then insert the dike so it runs unbroken across the fault. Independent variable: the order of dike and fault. Keep the same: the colors, layer thicknesses, dike width, fault offset (say 15 mm) and the way the blocks are sliced. Dependent variable: whether each reader states the correct order (dike then fault, or fault then dike). Use at least five readers who see both blocks in random order, and record the fraction correct for each block. If readers do much better than chance, the cross-cutting evidence is readable.
10. Sample answer: Cross-cutting relationships tell us that a fault or dike is younger than the layers it cuts and older than any layer that lies across it uncut; that order is observed in the rock. They do not tell how many years passed between events or how many separate movements made an offset, since one large earthquake can shift rock many meters. A geologist who takes the Flood as history may read widespread faulting and great bodies of intruded rock as marks of the breaking up of the fountains of the deep and the year that followed; another geologist may read the same features as many separate events spread over long ages. Both are interpretations about time laid on top of the same observed order. That is why two people can agree completely about which event came first and still disagree about the clock.

Unit 1 review

Answer each question. Show your work for calculations, use complete sentences for explanations, and draw the diagram in question 9 neatly with labels. The test is worth 60 points.

1. (5 pts) Multiple choice. In 1666 Nicolas Steno dissected the head of a great white shark in Florence. What did he conclude about “tongue stones”?
   (a) They fell from the sky during eclipses of the moon.
   (b) They were stones that grew into tooth shapes inside the rock.
   (c) They were fossil shark teeth, so the rock holding them was once sea-floor sediment.
   (d) They were carved by ancient people as charms.
2. (5 pts) A block of limestone contains a sea urchin shell, and the limestone carries the pattern of every bump on the shell’s surface. Using Steno’s rule for a solid within a solid, which hardened first? Explain in one or two sentences.
3. (5 pts) Steno was born in 1638, published the Prodromus in 1669 and died in 1686. How old was he when the Prodromus appeared, and how many years did he live after it?
4. (5 pts) Multiple choice. Which statement correctly gives the principle of superposition?
   (a) In any stack of rock layers, the top layer is always the oldest.
   (b) In an undisturbed stack of sedimentary layers, each layer is younger than the one below it.
   (c) Thicker layers are always older than thinner layers.
   (d) Layers that contain fossils are older than layers without them.
5. (6 pts) A sandstone bed is 2.4 m thick. (a) If the sand collected at 1 mm per year, how long did the bed take to form? (b) If a flood deposited it at 2 cm per minute, how long did it take? (c) In one sentence, what does the bed’s thickness alone tell you about which rate is right?
6. (5 pts) Multiple choice. A thick sandstone bed has a level top and bottom, but inside it thin layers slope at about 25 degrees. What is the best explanation?
   (a) The whole bed was tilted 25 degrees after it formed.
   (b) The thin layers are cross-bedding, formed on the sloping face of a dune or sandbar, and the slopes are original.
   (c) Sediment always settles at 25 degrees in water.
   (d) A fault inside the bed tilted the thin layers.
7. (6 pts) The top of a limestone bed drops 4 m over a horizontal distance of 40 m. (a) What is the slope as a decimal and as a percent? (b) Using the table (a slope of 0.09 is about 5°, 0.18 is about 10°), estimate the dip in degrees. (c) By which of Steno’s principles do you know the bed was not deposited at this angle?
8. (5 pts) The same three layers appear in the same order at the same heights in both walls of a valley 500 m wide. In two or three sentences, explain what lateral continuity tells you about the layers and about the valley.
9. (8 pts) Diagram. Draw a cross-section showing the following, then number the events from oldest to youngest on your drawing: three flat layers A (bottom), B and C; a dike that cuts A, B and C and stops at an erosion surface on top of C; a layer D lying on the

erosion surface and across the top of the dike; a fault that offsets A, B, C, D and the dike. Under the drawing, write the order of events and the rule that places the dike and the fault.

10. (5 pts) Multiple choice. A dark sheet of rock lies between two sandstone layers, and both sandstones are baked and hardened where they touch the sheet. The best conclusion is:
    (a) The sheet is a lava flow that is older than the sandstone above it.
    (b) The sheet is a sill that was intruded molten between existing layers, so it is younger than both sandstones.
    (c) The sheet is a normal layer, older than the sandstone above and younger than the one below.
    (d) The baked zones show the sandstones were hot when they were deposited.
11. (5 pts) Written response. In four or five sentences, explain what Steno's four principles can tell us about a cliff of layered rock and what they cannot. Use the words relative age and assumed rate, and give one example of a sign or textbook claim you could now read more carefully.

UNIT PROJECT: MY STENO CROSS-SECTION AND FIELD NOTEBOOK

Build a finished clay or layered-sand cross-section at least 15 cm wide that shows every one of Steno's principles at work: at least four flat layers, one set of layers tilted after deposition, a valley or gap that interrupts the layers, a dike and a fault. Keep a sealed log of the order in which you built the events, then have two different family members read the block and record their answers.

Present the block with a labeled scale drawing of its cut face, a numbered list of events with the rule that places each one, your readers' results, your settling-jar data table from Lesson 1.2 with settling times and thicknesses, and a one-page life of Nicolas Steno with a dated timeline. End with a paragraph that explains, using one layer from your block, the difference between the order the rock shows and the years a reader might assume.

- **Accuracy**: The block and drawing show all four principles correctly; the event order is right and each event is matched to the rule that places it.
- **Measurement and data**: Layer thicknesses, dike width, fault offset and the settling-jar times are measured in metric units, recorded in tables and used in the write-up.
- **Reasoning about time**: The closing paragraph clearly separates observed order from assumed rate, with a worked example of two rates for one layer, and treats both readings fairly.
- **Care and presentation**: The drawing is to scale and labeled, the Steno timeline is accurate and dated, and the whole portfolio is neat and easy to follow.

Answer key

1. (c).
2. The shell hardened first. The limestone carries the shell's shape, so it was soft mud pressing around an already-hard shell, and it hardened second.

3. 1669 − 1638 = 31 years old. 1686 − 1669 = 17 more years.
4. (b).
5. (a) 2.4 m = 2,400 mm; 2,400 ÷ 1 = 2,400 years. (b) 2.4 m = 240 cm; 240 ÷ 2 = 120 minutes = 2 hours. (c) Nothing; the thickness is the same under either assumption, so the rate must be supported by other evidence.
6. (b).
7. (a) 4 ÷ 40 = 0.10, or 10 percent. (b) Just above 0.09, so about 6 degrees. (c) Original horizontality: sediment settles level, so the tilt came later.
8. The layers were once one continuous sheet that stretched across the whole width; layers spread out as far as the water carries them and do not end at a sheer face on their own. Therefore the valley was cut through the layers after they were deposited, and the rock that once filled the valley has been removed.
9. Drawing shows A, B, C stacked; a slanting dike through all three ending at a wavy surface; D on top; a fault line shifting everything including D. Order: 1 A, 2 B, 3 C deposited (superposition); 4 dike intruded (cross-cutting: it cuts A, B, C); 5 erosion surface (cuts the top of the dike); 6 D deposited (superposition, on top of the surface and the dike); 7 fault (cross-cutting: it offsets everything, including D, so it is youngest). Full credit requires correct labels, the dike stopping at the erosion surface, D not cut by the dike, and the fault cutting D.
10. (b).
11. Sample answer: Steno’s principles give the relative age of everything in the cliff: superposition orders the layers, original horizontality shows whether they were tilted later, lateral continuity lets us match them across gaps and see what was removed, and cross-cutting relationships place dikes, faults and erosion surfaces after the rocks they cut. What they cannot give is a number of years; the same 3 m layer forms in hours at a flood rate or in centuries at a quiet-bay rate, and the rock does not carry its rate. Any years on a sign therefore come from an assumed rate added to the observed order. For example, a sign that says a canyon’s layers took millions of years to form is reporting order plus an assumption, and I can ask what rate was assumed and whether other evidence supports it. Christians who take the Flood as history and geologists who do not can agree on the order and discuss the rate.

UNIT 2

Layers

In Unit 1 you learned Nicolas Steno's rules for reading rock layers: the bottom layer came first, water lays sediment flat, and a layer once stretched farther than the piece you can see. In this unit you take those rules to the greatest wall of layers on earth, the Grand Canyon, and learn to read it the way John Wesley Powell did on his 1869 river trip. You will name the formations from the Kaibab Limestone at the rim to the Tapeats Sandstone at the river, draw them to scale in meters, and learn to separate what is **observed** in the rock from what a museum sign **interprets** about its age.

Then you will look hard at the lines between layers. Some contacts show plain evidence of a break, like the tilted layers James Hutton found at Siccar Point in 1788. Others are flat and sharp with nothing missing that the eye can see, yet a sign may say 165 million years passed there. You will calculate what ordinary erosion would do in that time and weigh both readings fairly. In the lab you will build a flume and repeat the experiments Guy Berthault reported to the French Academy of Sciences in 1986, watching mixed sand sort itself into many thin layers at once. Finally you will study coal seams, the buried forests Charles Lyell saw standing upright in the cliffs at Joggins, Nova Scotia, and compare two models of how they formed.

Throughout, the course holds that God created the heaven and the earth (Genesis 1:1) and that the Flood of Genesis 6 through 9 is history. You will learn the mainstream reading accurately enough to understand any textbook or museum, name the assumptions behind it, and state the creation reading beside it with respect for people who read the rocks differently.

BEFORE YOU BEGIN

- Can state Steno's principles of superposition, original horizontality and lateral continuity (Unit 1)
- Can multiply and divide decimals and convert between millimeters, centimeters, meters and kilometers
- Can read a simple data table and a bar graph and compute an average
- Can tell a sandstone, a shale and a limestone apart by grain size and by the fizz test with vinegar

MASTERY CHECKLIST

- I can name the main Grand Canyon layers from rim to river and draw them to scale in meters.
- I can explain the difference between an observation about a rock layer and an interpretation of its age.
- I can define the four kinds of unconformity and describe what is seen at a flat gap such as the Muav and Redwall contact.

- I can use an erosion or deposition rate in millimeters per year to compute a thickness over a stated time, and say what assumptions the calculation rests on.
- I can describe Berthault's flume experiments and run my own controlled flume test, changing one variable at a time.
- I can name the four ranks of coal, use the 10 to 1 compaction ratio, and compare the swamp and floating-mat models with evidence for each.

OPTIONAL BOOKS AND RESOURCES

- **Grand Canyon National Park (National Park Service)** (https://www.nps.gov/grca/index.htm): Free. The park's geology pages list every formation with rock type, thickness and fossils. Read the park's stated ages as the "What the sign says" column of your notes and the rock descriptions as observations.
- **John Wesley Powell, *Canyons of the Colorado* (free at Project Gutenberg)** (https://www.gutenberg.org/ebooks/search/?query=Powell+Canyons+of+the+Colorado): Free. Powell's own account of the 1869 expedition. A parent may choose passages to read aloud; the chapters describing the Grand Canyon itself are vivid and short.
- **U.S. Geological Survey** (https://www.usgs.gov/): Free. Search the site for Grand Canyon geologic maps, coal resource maps and the 1980 Mount St. Helens eruption record. Good for checking thicknesses, areas and dates of eruptions and floods.

2.1 Reading the Grand Canyon ★

OBJECTIVES

- Name the main rock layers of the Grand Canyon from the rim to the river and describe what each is made of.
- Use Steno's principles to read the canyon wall as a sequence of events, telling what came first and what came later.
- Draw the canyon's layers to scale in metric units and explain the difference between what is observed in the rock and what a sign says about its age.

Warm-up. Stack five or six different books flat on the table, big ones and thin ones, in any order. Now tell a partner the "history" of the stack: which book was put down first, which last, and how you know. Then set one book on a slant under the others. What changed about your story?

Video. Coming soon. Grand Canyon rock layers tour and John Wesley Powell's 1869 river expedition; look for National Park Service, USGS, Smithsonian, and PBS American Experience clips, plus river-level footage of the Redwall and Tapeats cliffs.

KEY TERMS

strata
Layers of sedimentary rock, one on top of another. One layer is a stratum.

formation
A body of rock thick and distinct enough to be mapped and given a name, such as the Coconino Sandstone.

sandstone
Rock made of sand grains cemented together, usually laid down by moving water or wind.

shale
Fine-grained rock made of mud and clay that settled out of quiet or slowing water and then hardened; it splits into thin sheets.

limestone
Rock made mostly of calcium carbonate, often full of shells and other sea fossils.

Great Unconformity
The surface in the Grand Canyon where flat Tapeats Sandstone rests on tilted or crystalline rocks below; named by John Wesley Powell.

CORE IDEAS

The story. On May 24, 1869, a one-armed Civil War veteran named John Wesley Powell pushed off from Green River, Wyoming, with nine men and four wooden boats. Powell had lost his right forearm at the Battle of Shiloh, but he was a geology professor with a hunger to

see the last blank spot on the map of the United States: the deep canyons of the Colorado River. For three months the men ran rapids, lost a boat and much of their food, and measured the cliffs as they went. In August they entered the Grand Canyon itself. Powell wrote that the walls rose like a great book whose pages were layers of rock, and he spent his evenings reading them by firelight, noting the color and thickness of each one. On August 30 Powell and the five men who stayed with him floated out of the canyon's lower end, hungry and sunburned, having made the first recorded trip through it. Powell later became the second director of the United States Geological Survey.

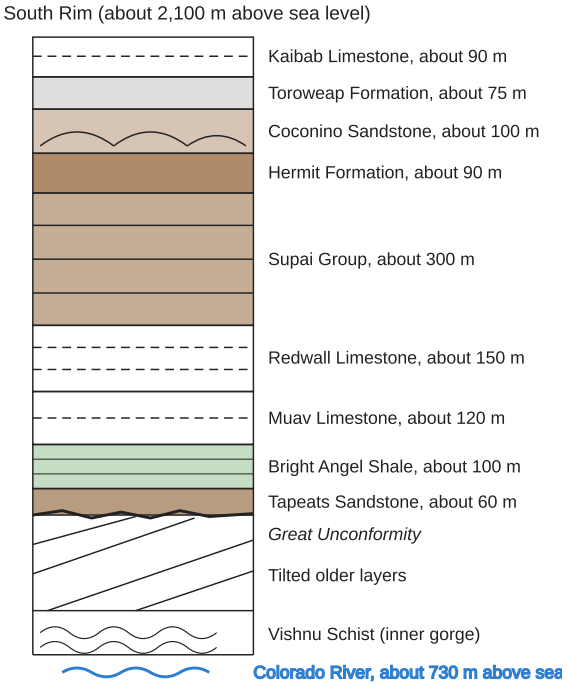
How they figured it out. Powell and the geologists who followed him, especially Clarence Dutton in 1882, did what Steno had taught two centuries before. They used **superposition** (lower layers were laid first), **original horizontality** (water lays sediment in flat sheets) and **lateral continuity** (a layer once stretched across the whole area) to put the layers in order. Then they gave each distinct body of rock a name, called a **formation**, usually from the place where it is easy to see. Reading from the rim down, the main layers are the Kaibab Limestone, Toroweap Formation, Coconino Sandstone, Hermit Formation, Supai Group, Redwall Limestone, Muav Limestone, Bright Angel Shale and Tapeats Sandstone. Below the Tapeats lies the **Great Unconformity**, a surface Powell named, and under that are tilted layers and dark crystalline rock, the Vishnu Schist, at the bottom of the inner gorge. The whole stack of flat layers is roughly 1,100 m thick, and the canyon is about 1,800 m deep, 446 km long and up to 29 km wide.

The big idea. Each layer tells you what it is made of and how it was laid down, even before anyone says a word about age. The Kaibab Limestone on the rim is packed with sea creatures: brachiopods, crinoid stems and sponges, 2,100 m above today's sea level. The Coconino Sandstone is a pale cliff of clean, fine sand with sweeping cross-beds, and the same sandstone sheet spreads far beyond the canyon across northern Arizona and into neighboring states. The Redwall Limestone is really gray; its red face is iron staining that washed down from the Supai layers above. The Bright Angel Shale is soft green-gray mud that weathers into a broad bench, the Tonto Platform, that hikers cross on the way to the river. The Tapeats Sandstone is coarse and rests on a flat-cut surface with nothing but hard, older rock beneath. These are observations. Anyone standing at the rim with a hand lens can check them.

Reading the sign. A visitor center sign gives each layer an age in millions of years and says the river carved the canyon slowly over about five or six million years. That is an interpretation built on assumptions, mainly that sediment piled up at about the slow rates we see in quiet places today. Many creation geologists read the same wall differently: the flat, continent-wide sheets of sand, mud and lime were laid rapidly by the moving waters of the Flood described in Genesis 7 and 8, and the canyon was cut quickly as that water, or great lakes left behind by it, drained off the rising land. In this course you will learn to do what Powell did first: observe carefully, record exactly, and then listen to both readings with the assumptions of each one named out loud.

God's handiwork. Standing at the South Rim, you can see a wall more than a kilometer high laid out in bands of cream, red, gray and green, each one running straight to the

horizon. Powell’s men, hungry and worn out, still wrote about the beauty of it. Order on this scale is not an accident. The psalmist says the waters “go up by the mountains; they go down by the valleys unto the place which thou hast founded for them” (Psalm 104:8). The canyon is a place where water and rock have written large, and where a patient young scientist can learn to read.



The Grand Canyon’s main layers, from the rim down, drawn to scale. Thicknesses are rounded averages; each layer varies from place to place.

⏳ Thinking About Time

What the sign says. What the sign says: the park signs give the Kaibab Limestone at the rim as about 270 million years old, the Tapeats Sandstone as about 525 million years, and the Vishnu Schist in the inner gorge as about 1.7 billion years. The Colorado River, the sign says, has been cutting the canyon for about 5 to 6 million years.

What we observe. What we observe: flat, parallel layers that can be traced for hundreds of kilometers; sharp, even contacts between layers; marine fossils in the rim rock 2,100 m above sea level; a river that today carries sand and silt but whose side canyons are dry most of the year.

How Christians read it. How Christians read it: most creation geologists hold that these layers were laid down rapidly by the waters of the Flood (Genesis 7:11, 7:19–20) as they rose over the continent, and that the canyon was carved quickly as the water drained, perhaps when large lakes left behind by the Flood broke through their rims. The ages on the sign depend on assuming slow, steady rates; the observations do not depend on that assumption.

> **Try it.** Pick one layer from the figure and write two sentences: one thing you could see or measure in it, and one thing the sign claims about it that you could not measure directly.
>
> *Genesis 7:19*

PICTURE STUDY



The Chasm of the Colorado, Thomas Moran, 1873–1874 · Oil on canvas · Smithsonian American Art Museum, Washington, D.C. (lent by the U.S. Department of the Interior)

Thomas Moran traveled to the Grand Canyon in 1873 with John Wesley Powell’s survey, four years after Powell’s first river trip. Back in his studio he painted this enormous canvas, more than three and a half meters wide, and the United States Congress bought it to hang in the Capitol beside his painting of Yellowstone.

Moran was not a geologist, but he looked hard. He showed the flat banding of the layers, the way cliffs of hard rock stand above slopes of soft rock, and a thunderstorm pouring rain onto the canyon, the very force that cuts the side canyons today.

Look closely

- Find the horizontal bands in the far cliffs. How many distinct layers can you count? Which look like steep cliffs and which like gentle slopes?
- Find the rainstorm. Where is the water going? What will it carry with it?
- Look for the river. Why do you think Moran made it so small?
- Notice the colors: creams, reds, grays, purples. Which real layers from the lesson might those colors match?

Talk about it

1. Moran painted cliffs above slopes above cliffs. Using the key terms, which kinds of rock make cliffs and which make slopes, and why?
2. A painting can show a whole canyon at once, which a photograph from one spot cannot. What did Moran gain by painting it this way, and what might he have lost?
3. If you were Powell looking at this scene, what would you want to measure first?

EXPERIMENT: SCALE MODEL OF THE CANYON WALL

You will build a scale model of the Grand Canyon's layers out of colored paper or cardboard strips, with every thickness measured to the same scale, and then test whether a drop of "rain" runs off hard layers and soaks into soft ones.

Question: Which layers would stand as cliffs and which would wear back into slopes? Prediction: write yours before you build.

You will need

- Metric ruler and pencil
- Colored construction paper or thin cardboard (cream, tan, red, gray, green)
- Scissors and glue stick
- A sheet of poster board at least 50 cm tall
- A sponge and a sheet of smooth plastic or a flat stone (for the "soft rock, hard rock" test)
- Dropper or spoon and a cup of water

Steps

1. Choose a scale of 1 cm = 25 m. Make a table with three columns: layer name, real thickness in meters, model thickness in centimeters. Fill it in using the figure (for example, Kaibab 90 m becomes 3.6 cm).
2. Cut one strip per layer at its model thickness and 20 cm wide. Color code: cream for limestone, tan or red for sandstone, green or gray for shale. The Supai Group will be your tallest strip, 12 cm.
3. Glue the strips onto the poster board in the correct order, Tapeats at the bottom and Kaibab at the top. Below the Tapeats, draw a wavy line and label it "Great Unconformity," then sketch tilted lines and dark crystalline rock beneath.
4. Label each layer with its name, its rock type and one fossil or feature you learned (for example, "Coconino: cross-bedded sand; animal tracks").
5. Measure the finished stack. Does it come to about 44 cm? Record the real total it represents.
6. Now the test: lay the sponge (soft shale) and the smooth plastic or stone (hard limestone) side by side on a slight slope. Drop 10 drops of water on each. Record what happens: run-off or soak-in. Repeat three times and record every trial.
7. Write a paragraph: which real layers behave like the sponge and which like the stone, and what that means for cliff-and-slope shapes in the canyon.

Tips

- Keep the scale the same for every layer; a model with a mixed scale cannot be read.
- If you do not have five colors, use pencil patterns: dots for sandstone, dashes for shale, brick lines for limestone. That is how geologists draw them.

Check your work

- Every strip is cut to the chosen scale and labeled with name and rock type.
- The layers are in the correct order from Tapeats to Kaibab.
- My sponge-and-stone trials are recorded in a table with all three trials.
- My paragraph connects soft rock to slopes and hard rock to cliffs using evidence from the test.

FIELD NOTEBOOK

1. Draw the canyon wall in profile as a staircase of cliffs and slopes, and label which layers make each step.
2. Sketch three fossils found in the Kaibab Limestone (a brachiopod shell, a crinoid stem, a sponge) and write one sentence about what each tells us about the water that laid the layer.
3. Copy Powell’s route in a small map of the Colorado River from Green River, Wyoming, to the lower end of the Grand Canyon, and mark the dates May 24 and August 30, 1869.

> **From history.** Powell’s 1869 trip nearly ended in disaster. On August 28, three men, convinced the rapids ahead could not be survived, climbed out of the canyon at a place now called Separation Canyon and were never seen again. Two days later Powell and the five who stayed floated out of the Grand Canyon safely. Powell went back in 1871 with better boats and a photographer, and in 1875 he published his report, which made the canyon famous.

WORKED EXAMPLES

Example 1. You are drawing the Grand Canyon layers to scale on a sheet of paper 25 cm tall. The canyon is about 1,800 m deep. What scale should you use, and how tall will the Kaibab Limestone (90 m) and the Supai Group (300 m) be on your drawing?

(Use the map or drawing "Use the thicknesses on the column for scale drawings." shown earlier in this lesson.)

1. Choose a scale that fits 1,800 m onto less than 25 cm. If 1 cm = 100 m, then 1,800 m becomes 1,800 ÷ 100 = 18 cm. That fits.
2. Kaibab: 90 m ÷ 100 m per cm = 0.9 cm, so just under 1 cm.
3. Supai Group: 300 m ÷ 100 m per cm = 3 cm.

Answer: Scale 1 cm = 100 m. The whole canyon is 18 cm tall; the Kaibab is 0.9 cm and the Supai Group is 3 cm.

Example 2. The flat sedimentary layers in the canyon wall total about 1,100 m. The Supai Group is about 300 m of that. What fraction and what percent of the flat layers does the Supai Group make up?

1. Write the fraction: 300 ÷ 1,100.
2. Simplify: 300/1,100 = 3/11.
3. Convert to percent: 3 ÷ 11 = 0.2727…, which is about 27%.

Answer: About 3/11, or roughly 27%, of the flat layers.

Example 3. The Bright Angel Trail runs about 15.3 km from the South Rim to the Colorado River and drops about 1,335 m. What is the average grade (drop per 100 m of trail), and how long would the hike down take at a steady 3 km per hour?

1. Grade = drop ÷ distance = 1,335 m ÷ 15,300 m = 0.087, or about 8.7 m of drop per 100 m of trail (an 8.7% grade).
2. Time = distance ÷ speed = 15.3 km ÷ 3 km/h = 5.1 hours.
3. Check: 3 km/h × 5.1 h = 15.3 km.

Answer: About an 8.7% grade and about 5 hours of walking down (and much longer coming back up).

PRACTICE

1. EASY Name the layer at the rim of the Grand Canyon and the flat layer just above the Great Unconformity.

2. EASY Which of Steno's principles tells us the Redwall Limestone was laid down before the Supai Group?
3. EASY What kind of rock is full of sea shells, and which Grand Canyon layer at the rim is an example?
4. MEDIUM Why is the Redwall Limestone red on the outside even though it is gray inside?
5. MEDIUM Data reading. A student measures layer thicknesses at one point on a trail: Kaibab 95 m, Toroweap 70 m, Coconino 105 m, Hermit 85 m. (a) What is the total thickness of these four layers? (b) Which layer is thickest, and by how much does it exceed the thinnest?
6. MEDIUM Data reading. The table below gives the number of cliff-forming and slope-forming layers a hiker recorded in two sections of the trail. Section A: 3 cliffs, 1 slope, made of limestone and sandstone. Section B: 1 cliff, 3 slopes, made mostly of shale. Which statement is best supported? (A) Shale tends to form cliffs. (B) Limestone and sandstone tend to form cliffs, and shale tends to form slopes. (C) The number of layers depends on the hiker. (D) Cliffs only form near the rim.
7. MEDIUM Using a scale of 1 cm = 50 m, how tall would you draw the Redwall Limestone (150 m) and the Tapeats Sandstone (60 m)?
8. HARD Suppose a sandstone sheet like the Coconino covers 260,000 km². If it averages 100 m thick, what is its approximate volume in cubic kilometers? (Hint: 100 m = 0.1 km.)
9. HARD Experiment design. You want to test whether sand settling in moving water forms flat layers like those in the canyon. Describe an experiment at home: what you would change, what you would keep the same, and what you would measure.
10. CHALLENGE Write a short paragraph explaining the difference between an observation and an interpretation at the Grand Canyon. Give one example of each from this lesson.

COMMON MISTAKES

- Thinking the Colorado River laid down the layers. The river only cuts through them; the layers were laid down by water that covered the whole region, long before the river existed in its present course.
- Thinking the Redwall is red rock. It is gray limestone stained red on the surface by iron from the layers above.
- Treating the ages on a museum sign as measurements. They are interpretations that depend on assumed rates; the thicknesses, fossils and rock types are the measurements.

> **Make it a game · Layer Stack Relay.** Write the nine flat Grand Canyon layers on nine index cards and shuffle them. On "go," race to stack them in the correct order from Tapeats on the bottom to Kaibab on top. For a harder round, add three cards: Great Unconformity, tilted layers, and Vishnu Schist. Time yourself; beat your own record, then challenge a parent.

> **Scripture.** “They go up by the mountains; they go down by the valleys unto the place which thou hast founded for them.” (Psalm 104:8, KJV)

Psalm 104 praises God for the order of the waters and the land. Many Christians read verses 6 through 9 as describing the waters of the Flood draining off the rising continents into the sea basins God prepared for them. The canyon shows water and rock working on a grand scale, under His command.

Practice answers

1. The Kaibab Limestone is at the rim; the Tapeats Sandstone sits just above the Great Unconformity.
2. Superposition: in undisturbed layers, the lower layer (Redwall) was laid down first.
3. Limestone; the Kaibab Limestone contains brachiopods, crinoids and sponges.
4. Iron-rich sediment from the Supai layers above has washed down the cliff and stained its surface red.
5. (a) 95 + 70 + 105 + 85 = 355 m. (b) The Coconino is thickest at 105 m; it exceeds the Toroweap (70 m) by 35 m.
6. (B). Section A, with hard limestone and sandstone, had mostly cliffs; Section B, mostly shale, had mostly slopes.
7. Redwall: 150 ÷ 50 = 3 cm. Tapeats: 60 ÷ 50 = 1.2 cm.
8. 260,000 km^2 × 0.1 km = 26,000 km^3 of sand.
9. Example: Fill a clear container with water and pour in a measured mix of sand and fine soil while tilting the container to make a gentle current (change: current on or off, or current speed). Keep the same: amount and type of sediment, water depth, container. Measure: whether layers form, how many, their thickness in millimeters with a ruler, and whether their tops are flat or sloped. Repeat three times.
10. An observation is something you can see or measure directly, such as “the Kaibab Limestone on the rim contains brachiopod shells” or “the layers are flat and parallel.” An interpretation is an explanation that depends on assumptions, such as “the Kaibab is 270 million years old,” which assumes slow, steady rates of deposition, or “these layers were laid rapidly in the Flood,” which rests on the history in Genesis. Good scientists record observations first and label interpretations as interpretations.

2.2 Flat Gaps Between Layers

OBJECTIVES

- Define an unconformity and tell apart the four kinds: angular unconformity, nonconformity, disconformity and paraconformity.
- Describe what geologists observe at a flat contact in the Grand Canyon and what a museum sign claims about the time it represents.
- Use an erosion rate in millimeters per year to calculate how much rock would be removed over a stated span of time, and compare that with what the contact shows.

Warm-up. Spread a thin, smooth layer of flour on a plate and leave it on the counter for the whole lesson while people walk past, doors open and a fan runs. At the end, look closely. Is the surface still perfectly smooth and flat? What marked it? Now imagine leaving that surface out for a year, or a thousand years, under rain and wind.

Video. Coming soon. Unconformities explained: Siccar Point, Hutton’s unconformity, and the Great Unconformity of the Grand Canyon; look for USGS, National Park Service, British Geological Survey and university geology department channels.

KEY TERMS

contact
The surface where one rock layer meets the next.

unconformity
A contact that is read as a break in the record: a surface where erosion happened or no sediment was laid down for a time before the next layer came.

angular unconformity
An unconformity where the layers below are tilted and the layers above lie flat across their cut-off ends, as at Siccar Point, Scotland.

nonconformity
An unconformity where sedimentary layers rest on crystalline rock such as granite or schist, as at the Great Unconformity.

disconformity
A gap between parallel layers that shows signs of erosion, such as channels, soil or pebbles of the lower rock.

paraconformity
A flat, sharp contact between parallel layers with no visible sign of erosion; it is called a gap only because of fossils or assigned ages, not because of anything seen at the contact.

CORE IDEAS

The story. In June 1788 three Scottish gentlemen took a small boat along the rocky coast of Berwickshire, east of Edinburgh. James Hutton, a farmer turned geologist, had a theory that the earth was shaped by slow processes repeated over immense ages, and he wanted to show his friends John Playfair and Sir James Hall the proof. At a headland called Siccar Point they landed and saw it: gray layers of rock standing nearly on end, and lying flat across their broken tops a second set of red sandstone layers, with pebbles of the gray rock caught in the red. Hutton explained that the gray layers had been laid flat, hardened, tilted upright, worn down to a level, and then buried under new sand. Playfair later wrote, “The mind seemed to grow giddy by looking so far into the abyss of time.” Siccar Point became the most famous rock outcrop in the world, and the surface between the gray and red layers was given a name: an **unconformity**.

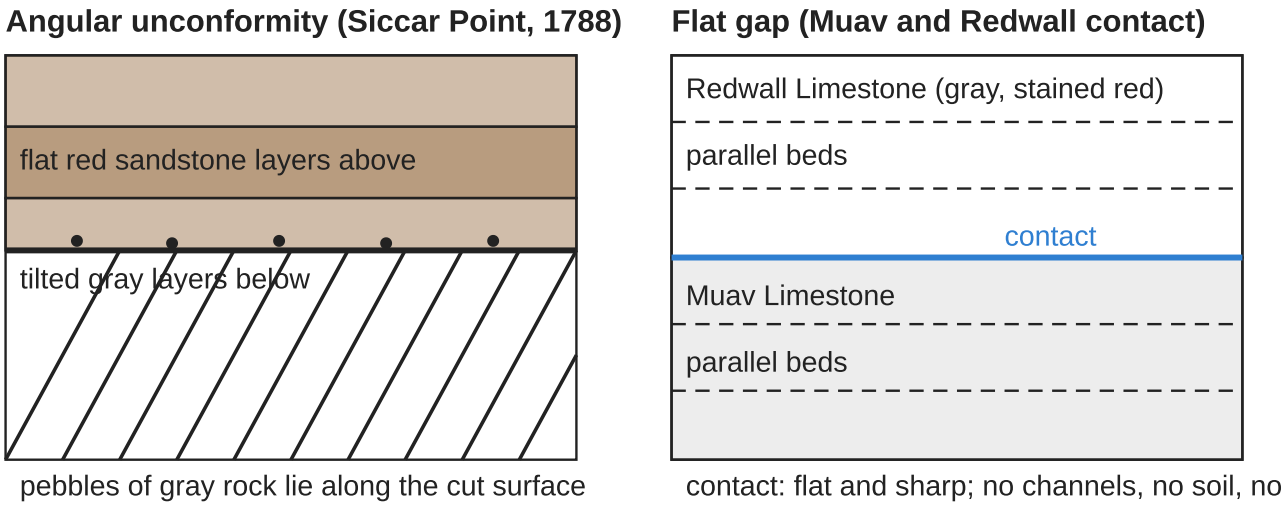
How they figured it out. Geologists after Hutton found that gaps between layers come in several kinds. If the lower layers are tilted and the upper ones flat, as at Siccar Point, it is an **angular unconformity**. If sediment rests directly on crystalline rock such as granite or schist, it is a **nonconformity**; the Great Unconformity in the Grand Canyon, where the Tapeats Sandstone sits on the Vishnu Schist, is the classic example. If the layers above and below are parallel but the contact shows channels, old soil, roots or pebbles of the lower rock, it is a **disconformity**. And if the layers are parallel and the contact is flat and sharp with no visible erosion at all, geologists call it a **paraconformity**. Notice what makes the last kind different: nothing at the contact itself says “gap.” It is called a gap only because the fossils above and below are assigned to different ages on a chart.

The big idea. The Grand Canyon has several of these flat gaps. The best known lies at the base of the Redwall Limestone, where it rests on the Muav Limestone. In the eastern canyon, patches of a third layer, the Temple Butte Limestone, fill channels cut into the top of the Muav, but over long stretches the Redwall sits straight on the Muav along a contact you could lay a ruler across. The park sign gives the Muav as about 505 million years old and the Redwall as about 340 million, so the sign is claiming that around 165 million years passed at that flat line. Now think about the warm-up. The land surface today wears down at an average rate of roughly 6 cm per 1,000 years, or 0.06 mm per year. At that rate, 165 million years would remove about 10 km of rock, far more than the whole canyon wall. Yet the contact is flat, unweathered, with no deep valleys, no soil, no roots. Geologists who hold the long ages reply that the region may have lain under a shallow sea or at a flat, low elevation where erosion was nearly nil, or that layers were deposited and stripped off again cleanly. Those are possible. But they are explanations added to protect the dates; they are not things seen at the contact.

How Christians read it. Many creation geologists point to flat gaps as some of the strongest field evidence for rapid deposition. If the Redwall was laid down soon after the Muav, within the Flood year described in Genesis 7 and 8, there was no time for a landscape to form on top of the Muav, and that is exactly what we see: a sharp, even surface, sometimes with shallow channels cut by moving water, then the next sheet of sediment. A flat gap, on this reading, is not a gap at all. The same observation fits both frameworks only

if you add unseen assumptions to one of them. Learning to spot where an assumption has been added is one of the most important skills in all of science.

In the world today. The lesson of unconformities reaches far beyond the canyon. Every time you read that a layer “records 20 million years,” ask two questions. First, what is actually there: how thick is it, what is it made of, what does its top surface look like? Second, what rate was assumed to turn that thickness into years? Steno taught us to read order from the layers. Order is observation. Duration is interpretation. Hutton was a careful observer, and his angular unconformity at Siccar Point truly shows a sequence of events: deposit, tilt, erode, deposit again. How long each step took is a separate question, and it was never written on the rock.



Two kinds of contact. At Siccar Point the gap is visible: tilted layers, a worn surface, pebbles. At the Muav and Redwall contact the layers are parallel and the surface is flat and sharp; the “gap” comes from the chart, not from the rock.

⏳ Thinking About Time

What the sign says. What the sign says: the Grand Canyon park sign dates the Muav Limestone at about 505 million years and the Redwall Limestone above it at about 340 million years, so about 165 million years are said to be missing at the flat contact between them.

What we observe. What we observe: a sharp, nearly level contact that can be followed for kilometers along the canyon walls, with the layers above and below lying parallel. In places shallow channels are filled by the Temple Butte Limestone; elsewhere there are no channels, no soil horizon, no roots and no deep weathering.

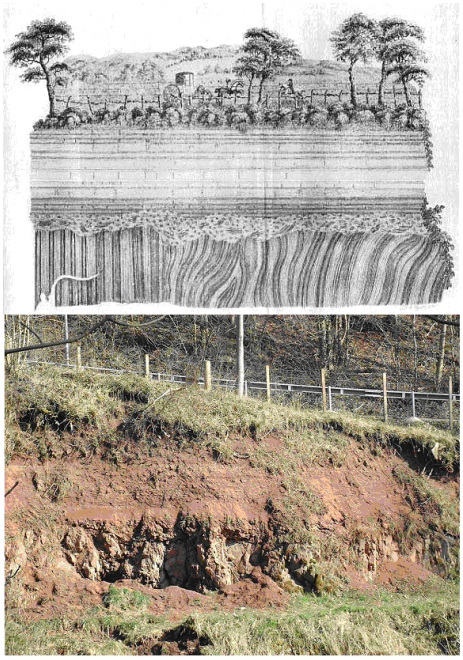
How Christians read it. How Christians read it: creation geologists read the flat contact as showing that the Redwall was laid down soon after the Muav, within the Flood year, with no long exposure to rain and wind in between. Geologists who hold the long ages

answer that the surface may have stayed flat under a shallow sea; students should know both explanations and notice which parts are observed and which are assumed.

Try it. Lay a ruler across the picture of any flat contact you can find online or in a book, and list every feature you can actually see at the line. Then list what you would expect to see after 165 million years of weather.

Genesis 7:11

PICTURE STUDY



Hutton's Unconformity at Jedburgh, John Clerk of Eldin (engraving after his drawing), Drawn 1787; published in Hutton's Theory of the Earth, 1795 · Engraving · Plate in James Hutton, Theory of the Earth, volume 1 (Edinburgh, 1795)

A year before Siccar Point, Hutton found a similar outcrop beside the Jed Water at Jedburgh, in the Scottish Borders. His friend John Clerk of Eldin, a skilled amateur artist, drew it so clearly that the picture is still used in textbooks today. The engraving was printed in Hutton's book in 1795.

Look at it as a geologist would. Clerk shows three things stacked up: the standing layers, the flat layers across their tops, and the living world of soil, road and cart above everything. Steno's rules let you put them in order without a single date.

Look closely

- Find the nearly vertical layers at the bottom. Which way do they lean?
- Find the flat layers above them. What is the shape of the line where the two sets meet?
- Look for broken pieces of the lower rock caught in the base of the upper layers. What do pebbles at a contact tell you?

- Notice the horse and cart. Why did the artist include people and animals in a geology picture?

Talk about it

1. List the events at Jedburgh in order using Steno's principles. Which steps are observations and which are inferences?
2. How is this contact different from a flat gap like the Muav and Redwall contact in the Grand Canyon?
3. Hutton believed the steps here took vast ages. Which parts of that belief can be tested by looking at the rock, and which cannot?

EXPERIMENT: WHAT DOES A SURFACE LOOK LIKE AFTER TIME PASSES?

You will make two smooth "rock surfaces" from damp sand and leave one exposed to the weather for a week while the other stays protected, then measure what time and weather do to a flat surface.

Question: Does a flat surface stay flat and sharp when it is exposed to rain and wind? Prediction: write what you expect to see after seven days on each tray.

You will need

- Two shallow trays or baking pans the same size
- Damp sand or sandy soil, enough to fill both trays 3 cm deep
- A straight edge (ruler) to level the surface
- A clear plastic cover or upside-down bin to protect one tray
- Metric ruler, notebook, camera or pencil for sketching

Steps

1. Fill both trays with damp sand and level the surfaces with the ruler so they are smooth and flat. Measure the depth at the center and at each corner and record all five numbers for each tray. This is Day 0.
2. Put both trays outdoors in the same spot. Cover one tightly so no rain or wind reaches it; leave the other open. The covered tray is your control.
3. Each day for seven days, record the weather (rain, wind, sun), then measure the depth at the same five points on each tray and sketch any channels, cracks, pits or debris you see.
4. On Day 7, gently pour a thin layer of dry sand of a different color over both trays to represent the next layer being deposited. Let it dry.
5. Carefully cut each tray in half with a knife or stiff card and look at the contact between the old sand and the new sand from the side. Sketch both cross-sections.
6. Compare: which tray's contact is flat and sharp? Which has an irregular surface, channels or mixed material at the line?

7. Write a conclusion that answers the question and connects it to the Muav and Redwall contact.

Tips

- If it does not rain, water the open tray with a watering can from a height of 50 cm for one minute each day to represent a rain shower. Record that you did.
- Measure at exactly the same five spots each day; mark them on the tray rim.

Check your work

- Both trays were level at Day 0 and the depths were recorded.
- The control tray was protected and measured the same way as the open tray.
- My cross-section sketches show the contact in each tray.
- My conclusion states what a flat, sharp contact suggests about the time a surface was exposed.

FIELD NOTEBOOK

1. Draw the four kinds of unconformity side by side, each in a small box, and label the one feature that identifies each.
2. Sketch the Muav and Redwall contact as a cross-section, with one place where a channel is filled by Temple Butte Limestone and one place where the contact is flat.
3. Write Playfair's sentence about Siccar Point at the top of a page; beneath it, write two sentences of your own: one observation Hutton made, and one assumption he added.

> **From history.** John Playfair, the friend who stood with Hutton at Siccar Point, was a mathematician. In 1802 he published Illustrations of the Huttonian Theory of the Earth, which explained Hutton's hard-to-read book in clear prose, and his 1805 biographical account of Hutton, which describes the 1788 boat trip, is where the famous line about "the abyss of time" comes from. Siccar Point is still visited by geology students from around the world, and the gray and red rocks look just as Clerk drew them.

WORKED EXAMPLES

Example 1. A sign says the Muav Limestone is about 505 million years old and the Redwall Limestone resting on it is about 340 million years old. According to the sign, how much time is "missing" at the contact?

1. Subtract the younger age from the older age: 505 − 340.
2. 505 − 340 = 165.

Answer: The sign is claiming about 165 million years passed at the flat contact. (That is the sign's interpretation, not a measurement of the rock.)

Example 2. The land surface today erodes at an average of about 0.06 mm per year. If that rate continued for 165 million years, how much rock would be removed? Compare with the canyon's flat layers, which total about 1,100 m.

(Use the map or drawing "The right-hand panel shows the flat Muav and Redwall contact." shown earlier in this lesson.)

1. Multiply rate by time: 0.06 mm/yr × 165,000,000 yr = 9,900,000 mm.
2. Convert to meters: 9,900,000 mm ÷ 1,000 = 9,900 m, which is about 9.9 km.
3. Compare: 9,900 m ÷ 1,100 m = 9. The amount removed would be about nine times the thickness of the whole stack of flat layers.

Answer: About 9,900 m (nearly 10 km) of erosion, about nine times the whole canyon stack. The flat, unweathered contact shows nothing like that, so either the rate was nearly zero for all that time (the long-age explanation) or the time was not there (the creation reading).

Example 3. Suppose a textbook says a 120 m limestone layer took 10 million years to form. What average deposition rate does that imply, in millimeters per year? A sheet of paper is about 0.1 mm thick; how many years would it take to add one paper thickness?

1. Convert thickness to millimeters: 120 m × 1,000 = 120,000 mm.
2. Divide by time: 120,000 mm ÷ 10,000,000 yr = 0.012 mm/yr.
3. Years per paper thickness: 0.1 mm ÷ 0.012 mm/yr = about 8.3 years.

Answer: About 0.012 mm per year, or one sheet of paper every 8 years. Compare: a single storm can lay down several centimeters of lime mud in a day. The textbook rate is an average that assumes the time; it is not an observed speed.

PRACTICE

1. EASY What is an unconformity?
2. EASY At Siccar Point, the lower layers stand nearly on end and the upper layers lie flat. What kind of unconformity is this?
3. EASY The Tapeats Sandstone rests on the Vishnu Schist, a crystalline rock. What kind of unconformity is the Great Unconformity?
4. MEDIUM What is the difference between a disconformity and a paraconformity?
5. MEDIUM Data reading. A field team recorded four contacts. Contact W: layers parallel, surface flat, no channels, no soil. Contact X: layers below tilted 40°, layers above flat, pebbles of lower rock in the upper layer. Contact Y: layers parallel, channels 2 m deep filled with pebbles, old root traces. Contact Z: sandstone resting on granite. Match each contact to its type.

6. MEDIUM Data reading. A class compiled average erosion rates measured in four landscapes: steep mountain slopes 1.0 mm/yr; rolling hills 0.3 mm/yr; plains 0.05 mm/yr; flat coastal lowland 0.01 mm/yr. (a) How many times faster is erosion on mountain slopes than on the coastal lowland? (b) Using the lowland rate, how much rock would be removed in 1 million years? (c) Which statement do the data best support? (A) Erosion rate does not depend on slope. (B) Steeper land erodes faster. (C) Erosion is fastest on flat land. (D) Erosion cannot be measured.
7. MEDIUM Using an erosion rate of 0.06 mm per year, how much rock would be removed in 50 million years? Give your answer in meters.
8. HARD A geologist who holds the long ages says the Muav surface stayed flat for 165 million years because it lay under a shallow sea. Name one thing you would expect to find at the contact if that were true, and explain why finding it or not finding it matters.
9. HARD Experiment design. Design a test of this claim: “A flat sand surface left exposed to weather for one month will no longer be flat.” State the independent variable, the dependent variable, two things you would keep the same, and how you would measure the result.
10. CHALLENGE Write a paragraph for a younger student explaining why a flat gap in the Grand Canyon is read in two different ways. Include one observation, one assumption from each side, and a respectful closing sentence.

COMMON MISTAKES

- Thinking a flat line between two layers shows that time passed. A flat, sharp contact shows a change in sediment; the amount of time is an interpretation.
- Confusing an angular unconformity with a fault. At an angular unconformity the tilted layers were worn flat before the upper layers were laid; a fault breaks layers that already exist.
- Assuming erosion rates measured today can be applied for millions of years. Rates vary with slope, climate and sea cover, and any long-term average is an assumption, not a measurement.

> **Make it a game · Gap Detective.** A parent or sibling describes a contact between two rock layers in a few words, such as “parallel layers, flat line, nothing else,” or “sandstone on granite,” or “tilted layers under flat ones with pebbles.” You have five seconds to name the type of unconformity and one point for saying what evidence would be needed to claim time passed there. Switch roles after five rounds. Ten points wins.

> **Scripture.** “In the six hundredth year of Noah’s life, in the second month, the seventeenth day of the month, the same day were all the fountains of the great deep broken up, and the windows of heaven were opened.” (Genesis 7:11, KJV)

Genesis gives the Flood an exact starting date in Noah’s life and describes water coming from below the earth as well as from the sky. Creation geologists read the great sheets of sediment and their flat contacts as the work of that single year of rising and draining waters.

Practice answers

1. A contact between rock layers that is read as a break in the record, where erosion happened or no sediment was deposited before the next layer was laid down.
2. An angular unconformity.
3. A nonconformity.
4. Both have parallel layers above and below. A disconformity shows visible signs of erosion at the contact (channels, soil, pebbles). A paraconformity shows no visible erosion; the contact is flat and sharp and is called a gap only because of the fossils or ages assigned to the layers.
5. W: paraconformity. X: angular unconformity. Y: disconformity. Z: nonconformity.
6. (a) 1.0 ÷ 0.01 = 100 times faster. (b) 0.01 mm/yr × 1,000,000 yr = 10,000 mm = 10 m. (c) (B).
7. 0.06 mm × 50,000,000 = 3,000,000 mm = 3,000 m (3 km).
8. Examples: burrows of sea animals boring deep into the hard top of the Muav, a thick crust of sea-floor minerals, or shells cemented to the surface. A hard sea floor exposed for millions of years should be heavily bored and encrusted. Finding such features would support the long exposure; a clean, sharp contact without them is what rapid burial predicts. The point is that each explanation makes a prediction that can be checked against the rock.
9. Independent variable: exposure to weather (one tray covered as a control, one open). Dependent variable: the roughness of the surface, measured as the difference in millimeters between the highest and lowest points at five fixed spots, plus the count of channels or pits. Keep the same: tray size, sand type and depth, location, starting flatness, measurement spots and schedule. Measure with a ruler at marked points each week and sketch or photograph.
10. Example: At the base of the Redwall Limestone there is a flat, sharp line where it meets the Muav Limestone. That line is an observation anyone can see. Geologists who hold the long ages assume that fossils above and below mark very different ages, so they believe about 165 million years passed there and that the surface somehow stayed flat, perhaps under a shallow sea. Creation geologists assume the Flood described in Genesis laid these layers quickly, so they read the flat line as showing almost no time passed. Both sides see the same line; they differ about the time, which is not written on the rock. We can hold our view firmly and still speak kindly of people who read it differently.

2.3 Lab: Rapid Layering in a Flume (Guy Berthault, 1986)

OBJECTIVES

- Describe Guy Berthault's sedimentation experiments and explain what they showed about how thin layers form in moving water.
- Build a simple flume, run a controlled experiment, and record how a mixed sediment sorts itself into laminae.
- Calculate flow speed, settling time and deposition rate from measurements, and compare a measured rate with a textbook rate.

Warm-up. Put a handful of mixed material (coarse sand, fine sand and a spoon of flour) into a clear jar, fill it with water, cap it, shake hard and set it down. Watch for two minutes without touching it. How many layers formed? Which grains landed first? You just watched sorting by grain size in still water. Today you will see what a current does instead.

Video. Coming soon. Flume tank sediment sorting and lamination experiments, stratification of mixed sand in flowing water, turbidity currents and the 1980 Mount St. Helens pyroclastic deposits; look for USGS, university civil engineering and geology lab channels, Little River Research and Design stream tables, and Science Max.

KEY TERMS

flume
A long channel through which water flows at a controlled speed, used to study how currents move and lay down sediment.

lamina (plural laminae)
A very thin layer of sediment, less than 1 cm thick; a stack of laminae makes up a bed.

sorting
The separating of sediment grains by size, shape or density as water or air moves them.

grain size
The diameter of sediment particles: clay is finer than 0.004 mm, silt runs from 0.004 to 0.0625 mm, sand from 0.0625 to 2 mm, and gravel is coarser than 2 mm.

graded bedding
A layer in which grain size changes from bottom to top, usually coarse at the base and fine at the top, formed as a current slows.

controlled experiment
A test in which one factor (the independent variable) is changed on purpose while everything else is held the same, so that any change in the result can be traced to that one factor.

CORE IDEAS

The story. In 1986 the French Academy of Sciences in Paris published a short report by Guy Berthault, an engineer trained at the École Polytechnique who had turned to the study of sediments. Berthault had done something simple that no one had looked at closely. He took sediments of different grain sizes, mixed them together, and poured them continuously into a container, first in air and then into still water. Everyone expected a single mixed heap. Instead, as the pile grew, it sorted itself into many thin, distinct layers, or **laminae**, all forming at the same time, not one after another. In 1988 he published a second report showing that the laminae looked the same whether the pouring was fast or slow. Thin layers that geologists had often read as the slow work of many seasons had appeared in his laboratory in minutes.

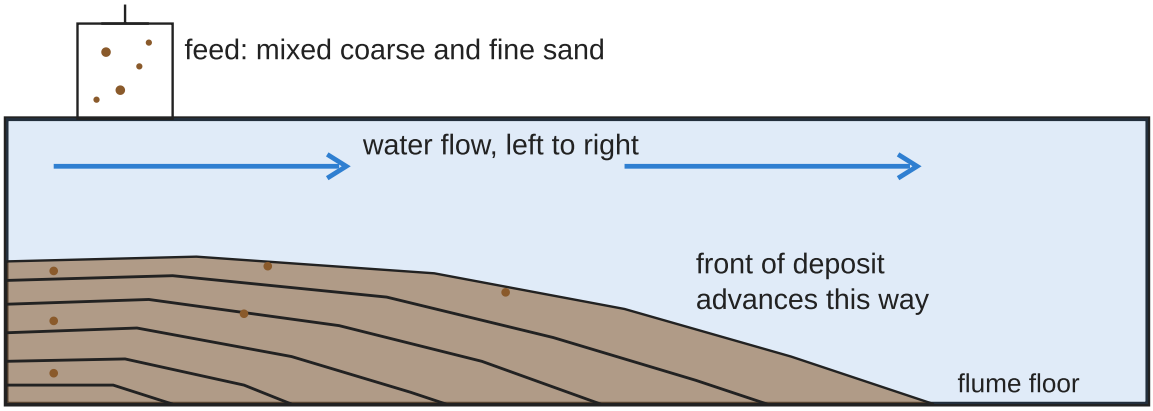
How they figured it out. Pouring into still water is not how most rock layers form, so Berthault went to a place with real currents: the hydraulics laboratory of Colorado State University in Fort Collins, where he worked with Professor Pierre Julien. There they used a **flume**, a long glass-sided channel through which water flows at a speed the operator controls. They fed mixtures of sand of two or three grain sizes into the moving water and watched. The sediment did not settle straight down in a sheet across the floor. Instead a deposit grew sideways, in the direction of the current, like a ramp being built forward from the inlet. Inside that ramp, laminae of coarse and fine grains formed side by side and at the same moment, and the finished deposit, sliced in cross-section, looked exactly like layered sandstone. Their results were published in 1993 in the Bulletin of the Geological Society of France. The key finding was this: in a current, the lower lamina and the upper lamina at a given spot can be laid down together, so a thin layer is not a clock.

The big idea. Steno's superposition still holds: at any one spot, the grain on the bottom landed before the grain on top. But Berthault showed that the *time between* two laminae can be almost nothing. Sediment moving in water sorts itself by **grain size**. Coarse grains need a strong current to move and drop out first when the water slows; fine grains stay suspended longer and travel farther. A current that pulses or wanders even slightly will leave alternating coarse and fine laminae in a single afternoon. Geologists who hold the long ages agree that an individual bed often forms fast; storm beds and undersea avalanche deposits called turbidites are well-known examples. The disagreement is about how much time hides between beds and in the whole stack. Berthault's work matters because it removes one assumption: you cannot count laminae and call them years unless you have first shown, in that rock, that each lamina took a year.

In the world today. Nature runs flume experiments on a huge scale. On November 18, 1929, an earthquake off the Grand Banks of Newfoundland set off an undersea slide of mud and sand. Telegraph cables on the sea floor snapped one after another, farther and farther from the slide, and the breaks were timed by the telegraph companies. The sediment current had raced downslope at tens of kilometers per hour and spread a layer of graded sand across the deep sea floor in a single day. At Mount St. Helens on June 12, 1980, hot flows of volcanic ash laid down several meters of finely layered deposits in a few hours; when the deposits were later cut open by erosion, the laminae looked like the work of long ages. Every flash

flood in a desert canyon leaves laminae too. The lesson is not that all rock formed fast. It is that layered rock does not, by itself, tell you how long it took.

Try it and see. In today's lab you will build a flume from a rain gutter or a long plastic box, and you will do what Berthault did: change one thing at a time and record what happens. You will measure the flow speed with a float, feed a mixed sediment, and then slice your deposit to count the laminae. A real scientist writes down the numbers before deciding what they mean. God made water to obey laws that are the same in a kitchen flume and in the Grand Canyon, and that is why a careful experiment on a table can teach you to read a cliff.

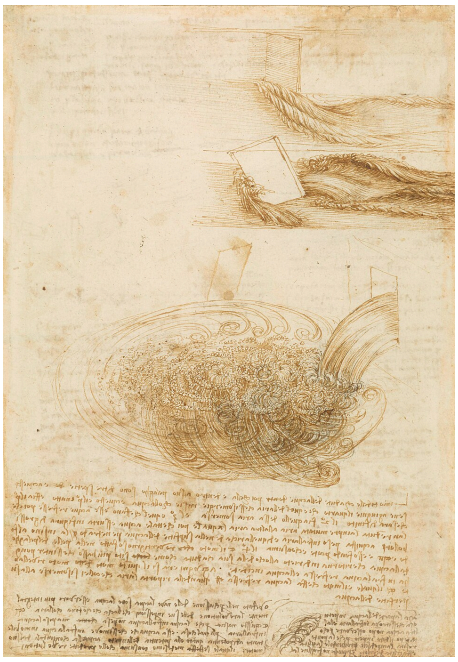


deposit grows forward as a ramp; coarse and fine laminae form side by side

After Berthault (1986, 1988) and Julien, Lan and Berthault (1993). Not to scale.

In Berthault and Julien's flume the deposit grew forward in the direction of the current, and its coarse and fine laminae formed at the same time rather than one after another.

PICTURE STUDY



Studies of Water Passing Obstacles and Falling, Leonardo da Vinci, about 1508–1509 · Pen and ink on paper · Royal Collection, Windsor Castle

Leonardo filled notebooks with drawings of moving water. In this sheet he studied what happens when a stream pours into a pool and when it flows past an obstacle: the water curls into spirals and braids that he drew with hundreds of tiny strokes. He wrote that water is the driver of nature and spent years watching rivers, canals and floods.

Leonardo was doing by eye what a flume lets us do slowly and on purpose. The swirls he drew are the eddies that sort sand grains by size, and his careful looking is exactly the habit a young scientist needs.

Look closely

- Find where the water enters the pool. How does Leonardo show that the water is moving?
- Trace one curl of water with your finger from where it starts to where it fades. Does it stay together or split?
- Look at the flat plate in the second study. What does the water do just behind it?
- Count how many separate currents you can see in the main pool. Where would heavy sand grains be dropped?

Talk about it

1. Why would eddies and swirls like these cause a flowing current to drop coarse and fine grains in different places?
2. Leonardo drew what he saw rather than what a textbook said water should do. How is that like a flume experiment?

3. If you were to add colored sand to Leonardo’s pool, what pattern would you predict on the bottom after one minute?

> **Safety first.** Do this lab outdoors or over a sink or tub; water and sand on a floor are slippery. An adult should supervise cutting the deposit and any use of a utility knife on the gutter. Do not pour sand down household drains.

EXPERIMENT: BUILD A TABLETOP FLUME

You will build a small flume, feed it a mixture of sediments of different sizes and colors, and test how the slope (and therefore the current speed) changes the deposit that forms.

Question: Does a faster current make more laminae, fewer laminae, or the same number? Prediction: write yours and your reason before you start.

You will need

- A plastic rain gutter about 1.5 m long, or a long clear storage box, or a half-pipe made from a 2-liter bottle cut lengthwise
- Two or three sediments of different grain size and color: coarse aquarium gravel (2–3 mm), play sand (about 0.5 mm) and fine dark sand or sifted dry soil
- A 4-liter jug or watering can, a bucket to catch the outflow, and a towel
- Books or bricks to prop up one end; a metric ruler and protractor
- A small floating object (a bottle cap) and a stopwatch
- A stiff card or spatula to slice the deposit, a hand lens, notebook and pencil

Steps

1. Set up the flume with the outlet end over the bucket. Prop the inlet end so the slope is gentle, about 2 cm of rise for every 100 cm of length. Record the rise and length.
2. Mix 300 g of sediment: equal parts by volume of each grain size. Keep the same recipe for every trial and record it.
3. Start a steady flow of water from the jug at the inlet end. Drop the bottle cap in and time how long it takes to travel 1 m. Record the time; you will compute the speed later.
4. While the water flows, feed the sediment mixture steadily at the inlet over exactly 2 minutes. Watch how the deposit grows. Does it build upward in a sheet or forward in a ramp? Sketch what you see every 30 seconds.
5. Stop the water and let the flume drain gently. Measure the length and the greatest thickness of the deposit in centimeters.
6. Slice the deposit lengthwise with the card and look at the cut face with the hand lens. Count the laminae and note the order of coarse and fine grains. Sketch the cross-section with a scale bar.
7. Repeat with a steeper slope (about 6 cm of rise per 100 cm). Change only the slope: same sediment recipe, same amount, same 2-minute feed, same water flow. Record everything again.

8. Compare your two trials in a table: slope, float time, flow speed, deposit length, thickness, number of laminae. Write a conclusion that answers the question and says whether your prediction held.

Tips

- If the water simply washes all the sediment out, slow the pour or lower the slope. If nothing moves, raise the slope. Record every adjustment.
- Dry sand of a different color for each grain size makes the laminae easy to see when you slice the deposit.
- Photograph the cut face beside a ruler so you can count laminae later.

Check your work

- I measured and recorded the slope, float time, deposit size and lamina count for both trials.
- I changed only one variable (slope) between trials.
- My cross-section sketches have a scale bar and show coarse and fine laminae.
- My conclusion compares the trials and states whether the number of laminae depended on the current speed.

FIELD NOTEBOOK

1. Draw your flume from the side with the deposit inside, labeling inlet, outlet, direction of flow and the shape of the deposit.
2. Draw the cut face of your deposit at twice its real size, with a 1 cm scale bar, and label coarse and fine laminae.
3. Copy the grain-size scale (clay, silt, sand, gravel) as a number line in millimeters and glue a few grains of each of your sediments at the right place.

> **From history.** A century before Berthault, the English geologist Henry Clifton Sorby of Sheffield (1826–1908) was already arguing that the small structures in sandstone, such as ripple marks and cross-beds, record the speed and direction of the currents that laid them. Sorby was the first to slice rocks thin enough to study under a microscope, and he liked to say that he studied small things to learn about large ones. Berthault and Julien’s flume work stands in that same tradition of letting a careful experiment on a bench speak to a cliff.

WORKED EXAMPLES

Example 1. A bottle cap floating in your flume travels 1.2 m in 4.0 seconds. What is the surface flow speed in meters per second and in centimeters per second?

1. Speed = distance ÷ time = 1.2 m ÷ 4.0 s = 0.30 m/s.
2. Convert to centimeters: 0.30 m/s × 100 cm/m = 30 cm/s.

Answer: 0.30 m/s, or 30 cm/s. (The surface moves a little faster than the water near the bed, so this is an upper estimate.)

Example 2. In still water a 0.5 mm sand grain settles at roughly 6 cm/s, and a 0.05 mm silt grain settles at roughly 0.2 cm/s. How long does each take to fall 30 cm to the bottom of a jar, and what is the ratio of the two times?

1. Sand: time = distance ÷ speed = 30 cm ÷ 6 cm/s = 5 s.
2. Silt: time = 30 cm ÷ 0.2 cm/s = 150 s, which is 2.5 minutes.
3. Ratio: 150 s ÷ 5 s = 30.

Answer: Sand reaches the bottom in about 5 seconds, silt in about 150 seconds; the silt takes 30 times longer. This is why a shaken jar sorts coarse grains to the bottom and fine ones to the top, and why a current carries fine grains farther.

Example 3. In your flume, a deposit 1.5 cm thick formed in 2 minutes. What is the deposition rate in centimeters per hour and in meters per day? A textbook gives the rate for deep-sea mud as about 1 cm per 1,000 years. How many times faster was your flume?

(Use the map or drawing "Measure the deposit's thickness and the feed time to find a deposition rate." shown earlier in this lesson.)

1. Rate = 1.5 cm ÷ 2 min = 0.75 cm/min. Per hour: 0.75 × 60 = 45 cm/h.
2. Per day: 45 cm/h × 24 h = 1,080 cm = 10.8 m per day.
3. Textbook rate per year: 1 cm ÷ 1,000 yr = 0.001 cm/yr. Flume rate per year: 45 cm/h × 8,760 h/yr = 394,200 cm/yr.
4. Ratio: 394,200 ÷ 0.001 = 394,200,000, about 400 million times faster.

Answer: About 45 cm per hour, or about 10.8 m per day; roughly 400 million times the textbook deep-sea rate. The two rates describe very different settings, which is exactly the point: a rate must be measured for the setting that laid the rock, not assumed.

PRACTICE

1. EASY What is a flume, and why do scientists use one?

2. EASY In Berthault's experiments, did the laminae form one at a time, from bottom to top, or at the same time? What did this mean for counting laminae as years?
3. EASY Using the grain-size scale, classify these particles: 0.03 mm, 1 mm, 5 mm, 0.002 mm.
4. MEDIUM Why do coarse grains usually end up at the bottom of a graded bed and fine grains at the top?
5. MEDIUM A float travels 2.0 m in 5.0 s in one trial and 2.0 m in 2.5 s in another. What were the two flow speeds, and which trial had the steeper slope?
6. MEDIUM Data reading. A student's flume results: Slope 2 cm/m: flow 25 cm/s, deposit length 40 cm, laminae 9. Slope 4 cm/m: flow 38 cm/s, deposit length 65 cm, laminae 10. Slope 6 cm/m: flow 52 cm/s, deposit length 95 cm, laminae 9. Which conclusion do the data best support? (A) Faster flow makes many more laminae. (B) Faster flow spreads the deposit farther but barely changes the number of laminae. (C) Slope has no effect on the deposit. (D) Laminae form only at slow speeds.
7. MEDIUM Data reading. In a jar test, a student recorded the time for the water to clear after shaking: pure coarse sand 8 s; pure fine sand 40 s; pure silt 20 min; mixture of all three 20 min. (a) Which single sediment took longest to settle? (b) Why did the mixture take as long as the silt alone? (c) Predict which grains were on top in the mixture.
8. HARD Experiment design. You want to find out whether the number of laminae depends on how long you feed sediment into the flume. Describe the independent variable, the dependent variable, three things to keep constant, and how many trials you would run.
9. HARD A deposit in a flume grew 60 cm long in 3 minutes. (a) What was its forward growth rate in centimeters per minute? (b) If it kept growing at that rate, how long would it take to reach 10 m?
10. CHALLENGE A friend says, "Berthault proved every rock layer formed quickly." Write three or four sentences correcting this fairly: what did the experiments show, what did they not show, and why do the results still matter for reading the Grand Canyon?

COMMON MISTAKES

- Thinking each thin layer must equal one year or one season. Laminae form by sorting, and many can form in minutes.
- Thinking sediment in a current settles straight down in a flat sheet. In a flume the deposit builds forward in the direction of flow, and laminae form side by side.
- Changing two things at once in an experiment, such as slope and amount of sediment, and then not knowing which one caused the change.

> **Make it a game · Settle Down.** Each player gets a jar of water and the same spoonfuls of coarse sand, fine sand and silt. On "go," shake and set your jar down. First player to correctly predict the order of the layers from bottom to top, before they finish settling, scores a point. Bonus point for the player who names the grain-size class of each layer using the millimeter scale. Play three rounds, then try a round where you tilt the jar gently to make a current and see what changes.

> **Scripture.** “And the waters returned from off the earth continually: and after the end of the hundred and fifty days the waters were abated.” (Genesis 8:3, KJV)

Genesis describes the Flood waters not as a still pond but as moving: rising for 150 days, then returning “continually” off the land. Moving water sorts and layers sediment, as the flume shows, and creation geologists read the great laminated sheets of sandstone as the record of those currents.

Practice answers

1. A long channel of flowing water whose speed can be controlled; it lets scientists watch how currents move and deposit sediment under known conditions.
2. At the same time, side by side as the deposit grew forward. So a lamina cannot be assumed to represent a year or any fixed amount of time.
3. 0.03 mm: silt. 1 mm: sand. 5 mm: gravel. 0.002 mm: clay.
4. Coarse grains settle faster and drop out as soon as the current slows; fine grains stay suspended longer and settle last, on top.
5. Trial 1: 2.0 ÷ 5.0 = 0.40 m/s. Trial 2: 2.0 ÷ 2.5 = 0.80 m/s. Trial 2 was faster, so it most likely had the steeper slope.
6. (B). Deposit length rose from 40 to 95 cm as flow increased, while the lamina count stayed at 9 or 10.
7. (a) Silt. (b) The water does not clear until the slowest grains, the silt, have settled, so the mixture is limited by the silt. (c) The silt was on top, fine sand in the middle, coarse sand on the bottom.
8. Independent variable: feed time (for example 1, 2 and 4 minutes). Dependent variable: number of laminae counted in the cut face. Keep constant: slope, water flow rate, sediment recipe and total amount per minute, flume, measuring method. Run each feed time at least three times and average the counts.
9. (a) 60 ÷ 3 = 20 cm/min. (b) 10 m = 1,000 cm; 1,000 ÷ 20 = 50 minutes.
10. Example: Berthault’s experiments showed that mixed sediment in moving water sorts itself into many laminae at the same time, so thin layers do not have to represent long periods. They did not prove that every rock layer formed quickly; each formation must be studied on its own. The results matter because they remove the assumption that layers are clocks, which means the ages on a canyon sign rest on other assumptions that must be stated and tested. Both creation geologists and geologists who hold the long ages agree that single beds can form fast; the real question is how much time lies between them.

2.4 Coal Seams

OBJECTIVES

- Describe what coal is made of, name its four ranks, and read a table of carbon content.
- Compare the swamp model and the floating-mat model of coal formation and list the field observations each one uses.
- Use the compaction ratio of peat to coal and a deposition rate to calculate thicknesses, masses and the time each model implies.

Warm-up. Take a stack of ten paper towels or a sponge and measure its height. Now press it as flat as you can with a heavy book and measure again. What fraction of its height is left? Plant matter squeezed into coal shrinks something like this. Keep your numbers for the worked examples.

Video. Coming soon. How coal forms, coal ranks from peat to anthracite, Joggins Fossil Cliffs upright trees, and the Spirit Lake log mat after the 1980 Mount St. Helens eruption; look for USGS, U.S. Energy Information Administration, Smithsonian, Nova Scotia Museum and university geology channels.

KEY TERMS

coal
A black or brown sedimentary rock made mostly of carbon from buried plant material; it burns.

peat
Partly decayed plant material that gathers in wet, oxygen-poor places; the starting material for coal.

coal rank
The stage of coal: lignite, subbituminous, bituminous or anthracite, in order of increasing carbon content and hardness.

seam
A single layer of coal between layers of other rock; also called a coal bed.

underclay
The fine clay layer often found directly beneath a coal seam.

polystrate fossil
A fossil, usually a tree trunk, that stands upright through several rock layers at once.

CORE IDEAS

The story. In July 1842 the English geologist Charles Lyell stood on the shore of the Bay of Fundy at Joggins, Nova Scotia, where the highest tides in the world scour a cliff of gray sandstone, shale and coal clean twice a day. In the cliff face he saw something he had read

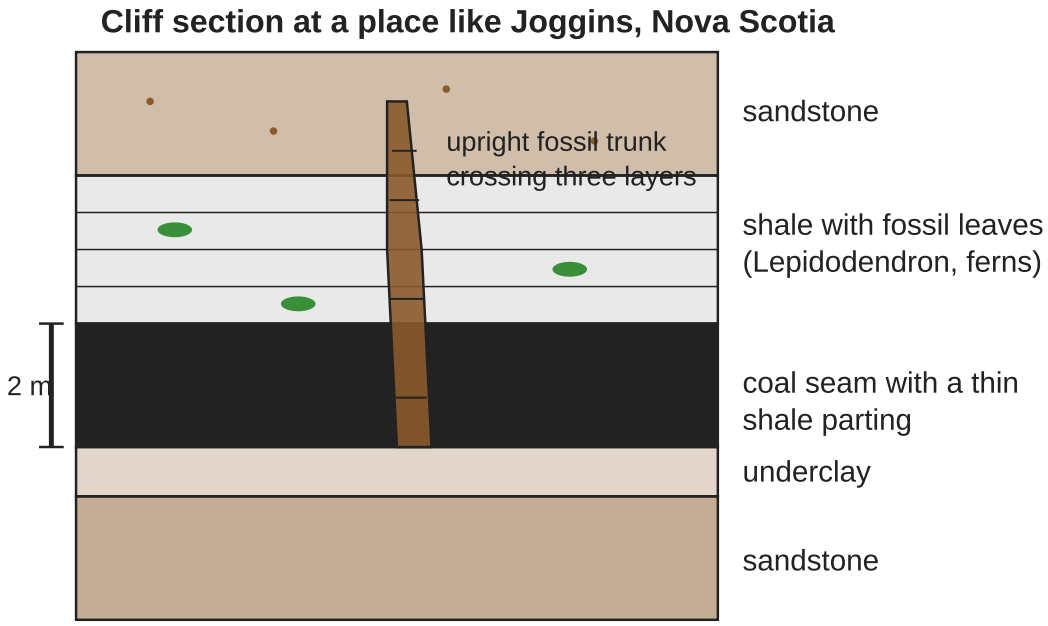
about but never seen: fossil tree trunks standing upright, their bases in one layer and their tops in another, passing straight through several beds of rock. Lyell counted many of them at different heights and wrote about them in his *Travels in North America*. Ten years later he returned with a young Nova Scotian geologist, John William Dawson, and inside one hollow upright trunk they found the bones of a small reptile, later named *Hylonomus lyelli*. Joggins is still the best place in the world to see coal seams and the fossil forests buried with them, and it became a World Heritage Site in 2008.

How they figured it out. Coal is a sedimentary rock made of plants. Under a microscope it shows cell walls, spores, bark and wood, and the shales above and below coal seams are full of fossil leaves and stems: giant scale-trees called *Lepidodendron* and *Sigillaria*, jointed reeds called *Calamites*, and tree ferns. Plant matter first collects as **peat**, then is buried, squeezed and heated until water and gases are driven off and carbon is left behind. Geologists rank coal by how far this has gone. Lignite is brown and soft with about 25 to 35 percent carbon; subbituminous has 35 to 45 percent; bituminous, the common black coal, has 45 to 86 percent; and anthracite, hard and glossy, has 86 to 97 percent. Measurements of modern peat and ancient coal give a **compaction ratio** of roughly 10 to 1: about 10 m of loose peat makes about 1 m of coal.

The big idea. How did the plants get there? The textbook model says coal seams formed in place, in vast swamps like today's Great Dismal Swamp or the Okefenokee, where trees grew, died, and piled up as peat for thousands of years before the sea rose and buried them; then the land rose, a new swamp grew, and the cycle repeated. Many creation geologists hold a second model: the plants did not grow where the coal lies but were ripped up by the Flood, floated in enormous mats of logs and bark, dropped their waterlogged debris onto the sea floor, and were buried by the next sheet of sand or mud. Each model makes predictions you can check in a cliff. A swamp should leave a soil with roots under the seam, uneven, local seams that thin and thicken like a swamp's edges, and freshwater fossils. A floating mat should leave flat seams with sharp tops and bottoms spread over enormous areas, clay beneath that is often not a true soil, and sea fossils in the thin shale partings between coal layers. The Pittsburgh seam, for example, averages about 2 m thick and is mined across roughly 28,000 square kilometers of Pennsylvania, West Virginia and Ohio, a sheet far flatter and wider than any swamp living today. Geologists who hold the swamp model answer that some underclays do hold in-place root systems, and the debate continues in the journals. Your job is to know both sets of evidence and to see which observations each model handles well.

In the world today. Nature gave a demonstration of the floating-mat idea on May 18, 1980, when Mount St. Helens blew down a forest and the blast hurled a vast raft of about a million logs onto Spirit Lake. Scientists watched the logs float for years, slowly soak, lose their bark, and sink, many of them upright, while a layer of bark and wood fragments gathered on the lake bottom as a peat. The upright trees at Joggins look like the sunken trunks in Spirit Lake, and they are the reason Lyell's cliff matters so much. A trunk standing through several layers cannot have stood upright for the long ages those layers are usually assigned; it would have rotted. The layers had to bury it faster than wood decays. Both models accept that; they differ on how often and how fast it happened.

God’s handiwork. Coal lit the lamps and drove the engines that built the modern world, and it is still a gift of buried forests from the past. Genesis says God made “the herb yielding seed, and the fruit tree yielding fruit after his kind” on the third day. The fossil plants in the coal measures are real plants of real kinds, many of them larger than their living relatives, and they were buried quickly enough to keep their leaves. Whether you picture a swamp or a floating forest, the coal in a stove is sunlight stored by plants God made, and reading its story is part of the dominion He gave us over the earth.



A coal seam and its neighbors as seen at a place like Joggins. The upright trunk passes through several layers, so those layers were laid before the wood could rot.

⏳ Thinking About Time

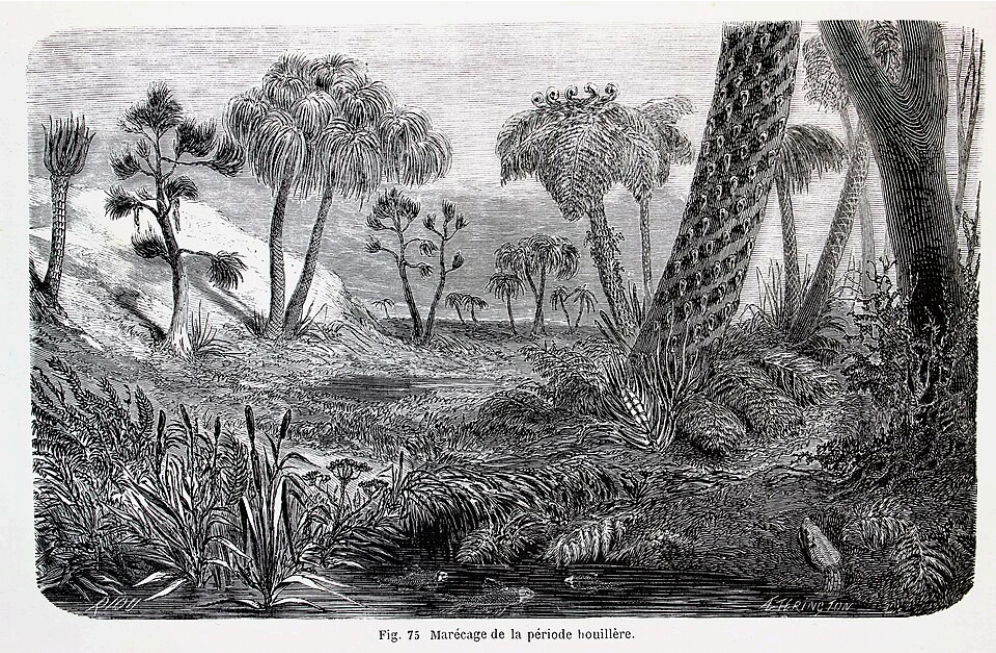
What the sign says. What the sign says: textbooks call the coal-bearing layers of North America and Europe the Carboniferous, the “coal age,” dated at about 360 to 300 million years ago, and say each seam formed as peat in a swamp over thousands of years before being buried.

What we observe. What we observe: flat coal seams with sharp tops and bottoms spread over tens of thousands of square kilometers; fossil leaves, bark and spores still visible in the coal; sea shells in some thin partings within seams; upright tree trunks at Joggins passing through several layers of rock; and, at Spirit Lake since 1980, a floating log mat shedding bark and sinking trunks upright.

How Christians read it. How Christians read it: creation geologists read coal seams as the remains of forests torn up by the Flood (Genesis 7:17–20), floated as great mats, and buried quickly under successive sheets of sediment, with the Spirit Lake log mat as a small modern picture. The textbook’s long ages rest on assumed slow peat growth; the sharp, wide, flat seams and the buried upright trees are what both sides must explain.

> **Try it.** Drop a handful of leaves and twigs into a bowl of water and leave it overnight. In the morning, note what floated, what sank, and what settled on the bottom.
>
> *Genesis 7:17*

PICTURE STUDY



Marsh of the Coal Period (Marécage de la période houillère), Édouard Riou (engraving, for Louis Figuier), 1863 · Wood engraving, published in Louis Figuier, La Terre avant le déluge (The World Before the Deluge) · Illustration in a printed book; this scan is from a copy in the University of Seville library

Photo: Fondo Antiguo de la Biblioteca de la Universidad de Sevilla from Sevilla, España · CC BY 2.0 (https://creativecommons.org/licenses/by/2.0) · via Wikimedia Commons

Louis Figuier's The World Before the Deluge was one of the most popular science books of the 1800s, and Édouard Riou, who also illustrated Jules Verne, drew its famous scenes. Here he imagined the forests whose remains became coal: scale-trees with diamond-patterned bark, tree ferns and giant horsetails crowded around dark water.

Notice that the picture is a reconstruction, not a photograph. Riou drew the plants from real fossils found in coal measures, but the scene itself, a quiet swamp growing in place, is one model of how coal formed. A floating-mat artist would have drawn the same plants torn up and rafted on moving water.

Look closely

- Find the trunks with patterned bark. Those are the scale-trees Lepidodendron and Sigillaria whose fossils fill the shales above coal seams.
- Find the tree ferns and the jointed reeds (Calamites). Which living plants do they resemble?

- Look at the water. Is it moving or still? Why does that matter for the two models of coal?
- Notice the fallen logs. Where would they end up if a flood swept through this scene?

Talk about it

1. Which parts of this picture come from fossil evidence, and which parts come from the artist's model of how coal formed?
2. How would you redraw this scene to show the floating-mat model? What would stay the same?
3. Figuier's title mentions the Deluge. Why do you think the Flood was in the minds of geologists and artists in 1863?

> **Safety first.** If you handle real coal or charcoal, wash your hands afterward and do not breathe the dust. Any burning of a coal or charcoal sample must be done by an adult outdoors.

EXPERIMENT: FLOATING FOREST IN A TUB

You will test the floating-mat idea on a small scale: soak a mat of plant debris in water, watch what it sheds and when it sinks, and then bury it with sand to see what the buried layer looks like in cross-section.

Question: When a mat of twigs, bark and leaves floats on water, does it drop a layer of fine plant debris to the bottom, and do the pieces sink flat or upright? Prediction: write yours.

You will need

- A clear plastic tub or large jar (at least 4 liters)
- Dry twigs with bark, dry leaves, pine needles and a few short pieces of stick 5 to 8 cm long
- Play sand (about 500 g) and a cup
- Metric ruler, marker, notebook, and a camera if available
- A kitchen scale (optional)

Steps

1. Fill the tub with water to a marked line. Weigh or measure your plant debris and record it. Float the whole mat on the surface and photograph or sketch it. This is Day 0.
2. Each day for five days, record: how much of the mat still floats, what has sunk, whether any debris lies on the bottom, and whether the sunken sticks lie flat or stand on end. Do not stir.
3. On Day 5, slowly pour a cup of sand through the water so it settles over the bottom debris. Wait ten minutes and pour a second cup. Measure the thickness of the sand layer with the ruler held against the outside of the tub.

4. Look through the side. Is there a dark layer of plant debris under the sand? Is it flat and even? Do any sticks poke up through the sand? Sketch the cross-section with a scale bar.
5. Compare with a control: a second tub with the same amount of sand poured in but no plant mat. What does the bottom look like there?
6. Write a conclusion answering the question. Then write one sentence about what a real coal seam would need that your tub could not supply (burial, pressure, heat, time).

Tips

- Bark and needles shed a fine brown layer first; whole twigs take days to soak and sink. Patience is part of the experiment.
- If you have a piece of coal from a hobby shop or a hardware store, compare its weight and feel with a piece of charcoal and a piece of dry wood of the same size.

Check your work

- I recorded the mat every day for five days with the same observations each time.
- My cross-section sketch shows the plant layer and the sand layer with a scale bar.
- I ran a control tub without plant material.
- My conclusion says what the tub showed and what it could not show about real coal.

FIELD NOTEBOOK

1. Draw the four coal ranks as a row of blocks from lignite to anthracite, shading each darker, and write its carbon percentage range beneath.
2. Sketch a fossil Lepidodendron bark pattern (diamond-shaped leaf scars) and a Calamites stem (jointed with vertical ribs) from reference photographs.
3. Draw a cross-section of the Joggins cliff with one upright tree passing through several layers, and label every layer it crosses.

> **From history.** The little reptile Lyell and Dawson found inside a hollow upright trunk at Joggins in 1852 was described by Dawson and named Hylonomus lyelli in 1860. It is about 20 cm long and lizard-like, and because it was found inside a standing tree stump, scientists have debated ever since how it got there: did it fall into a hollow stump in a living forest, or was it washed in with the debris that buried the tree? Dawson went on to become the principal of McGill University in Montreal and one of the most respected geologists in Canada.

WORKED EXAMPLES

Example 1. A coal seam is 2.0 m thick. Using a compaction ratio of 10 to 1, how thick a layer of peat (or plant debris) was needed to make it?

1. Compaction 10 to 1 means 10 m of peat becomes 1 m of coal.
2. Multiply: 2.0 m × 10 = 20 m.

Answer: About 20 m of peat or plant debris, roughly the height of a six-story building.

Example 2. Coal has a density of about 1,300 kg per cubic meter. How much coal is in one square kilometer of a seam 2.0 m thick? Give the answer in metric tonnes (1 tonne = 1,000 kg).

(Use the map or drawing "Seam thickness times area gives volume; volume times density gives mass." shown earlier in this lesson.)

1. Area: 1 km^2 = 1,000 m × 1,000 m = 1,000,000 m^2.
2. Volume: 1,000,000 m^2 × 2.0 m = 2,000,000 m^3.
3. Mass: 2,000,000 m^3 × 1,300 kg/m^3 = 2,600,000,000 kg.
4. Convert: 2,600,000,000 kg ÷ 1,000 = 2,600,000 tonnes.

Answer: About 2.6 million tonnes of coal per square kilometer. The Pittsburgh seam covers roughly 28,000 km^2, so you can see why it was one of the most mined seams in the world.

Example 3. Modern peat in a healthy swamp builds up at about 1 mm per year. (a) Under the swamp model, how long would it take to grow the 20 m of peat needed for a 2 m seam? (b) Under the floating-mat model, a 20 m mat of debris could be dropped and buried within days. Compare the two times as a ratio.

1. (a) Convert 20 m to millimeters: 20 × 1,000 = 20,000 mm. Time = 20,000 mm ÷ 1 mm/yr = 20,000 years.
2. (b) Suppose burial takes 10 days. Convert 20,000 years to days: 20,000 × 365 = 7,300,000 days.
3. Ratio: 7,300,000 ÷ 10 = 730,000.

Answer: The swamp model implies about 20,000 years per seam; the floating-mat model implies days. The ratio is roughly 730,000 to 1. Only the peat growth rate was measured; the 20,000 years is what you get if you assume the swamp model and that rate.

PRACTICE

1. EASY What is coal made of, and what evidence shows it?
2. EASY List the four ranks of coal from lowest to highest carbon content.
3. EASY What is a polystrate fossil, and where did Charles Lyell see famous examples in 1842?
4. MEDIUM A seam of coal is 1.5 m thick. With a 10 to 1 compaction ratio, how much peat was needed?
5. MEDIUM Data reading. Carbon content by rank: lignite 25–35%; subbituminous 35–45%; bituminous 45–86%; anthracite 86–97%. (a) A sample has 60% carbon. What rank is it? (b) Which rank has the widest range of carbon content? (c) Which statement do the data support? (A) Carbon content falls as rank rises. (B) Carbon content rises as rank rises. (C) All coal has the same carbon content. (D) Lignite has more carbon than anthracite.
6. MEDIUM Data reading. A survey measured one coal seam at five mines spaced across 120 km: 1.9 m, 2.1 m, 2.0 m, 1.8 m, 2.0 m. (a) What is the average thickness? (b) What is the difference between the thickest and thinnest measurements? (c) Which model, swamp or floating mat, predicts a seam this even over 120 km, and why?
7. MEDIUM Why can an upright fossil tree trunk crossing several layers tell us those layers were laid down quickly?
8. HARD A seam 1.2 m thick covers 500 km². Using a density of 1,300 kg/m³, how many tonnes of coal does it hold? (Work in meters.)
9. HARD Experiment design. You want to test whether waterlogged sticks sink upright or flat. State your independent variable, dependent variable, three things to keep the same, and how you would record the result.
10. CHALLENGE Write a paragraph comparing the swamp model and the floating-mat model of coal formation. Give two observations each model explains well and one observation each model finds harder, and end with a sentence about how to speak of the disagreement fairly.

COMMON MISTAKES

- Thinking coal is a mineral or a kind of rock made from dinosaurs. Coal is a sedimentary rock made of plant material; the fossils in and around it are plants, with occasional animals.
- Thinking a thicker seam always means a longer time. Thickness depends on how much plant material was supplied and how it was compacted, not on time alone.
- Thinking anthracite and charcoal are the same. Charcoal is wood heated by people without air; anthracite is natural coal of the highest rank, formed by deep burial, pressure and heat.

Make it a game · Rank the Coal. A parent calls out a carbon percentage, such as 30, 55, 90 or 40. You have three seconds to name the rank: lignite, subbituminous, bituminous or anthracite. Then switch: you call out an observation, such as “upright tree

through five layers” or “sea shells in a shale parting” or “roots in the underclay,” and your partner must say which coal model explains it most easily and why. First to twelve points wins.

Scripture. “And God said, Let the earth bring forth grass, the herb yielding seed, and the fruit tree yielding fruit after his kind, whose seed is in itself, upon the earth: and it was so.” (Genesis 1:11, KJV)

The plants in the coal measures, scale-trees, tree ferns and giant horsetails, reproduced after their kinds like the plants we know, and their smaller relatives still grow today. Coal is the buried remains of forests that God made, stored up and now used to warm and light homes.

Practice answers

1. Buried plant material. Under a microscope coal shows cell walls, spores, bark and wood, and the rocks next to seams are full of fossil leaves and stems.
2. Lignite, subbituminous, bituminous, anthracite.
3. A fossil, usually a tree trunk, standing upright through several rock layers. Lyell saw them at Joggins, Nova Scotia, on the Bay of Fundy.
4. 1.5 m × 10 = 15 m of peat.
5. (a) Bituminous. (b) Bituminous, a range of 41 percentage points. (c) (B).
6. (a) (1.9 + 2.1 + 2.0 + 1.8 + 2.0) ÷ 5 = 9.8 ÷ 5 = 1.96 m, about 2.0 m. (b) 2.1 − 1.8 = 0.3 m. (c) The floating-mat model more naturally predicts a very even sheet over a wide area, since debris settles from a floating mat onto a flat floor; a swamp usually thins toward its edges and varies with the ground beneath. (Swamp-model geologists reply that some ancient swamps were far larger and flatter than any today.)
7. A dead tree standing in the open rots and falls within years or decades. For the trunk to be buried standing up through several layers, those layers had to be deposited faster than the wood could decay.
8. Area: 500 km² = 500,000,000 m². Volume: 500,000,000 × 1.2 = 600,000,000 m³. Mass: 600,000,000 × 1,300 = 780,000,000,000 kg = 780,000,000 tonnes (780 million tonnes).
9. Independent variable: whether one end of each stick is heavier (for example, a stick with its root end or a stick with a small knot) versus even sticks of the same length. Dependent variable: the angle at which each stick comes to rest on the bottom, measured with a protractor against the tub side, or simply counted as upright (more than 60°), tilted, or flat. Keep the same: water depth, stick length, soaking time, tub, no stirring. Record each stick in a table and photograph the bottom at the end.
10. Example: The swamp model explains the plant fossils in and around coal and the in-place root systems found under some seams. It finds it harder to explain seams that are flat and sharp over tens of thousands of square kilometers and the sea shells in partings within seams. The floating-mat model explains the wide, flat seams with sharp contacts and the upright buried trunks that match sunken logs at Spirit Lake. It finds it harder to explain underclays that do show rooted soils. Both sides are looking at the same cliffs, and a fair student states the other side’s best evidence accurately before giving his own reading.

Unit 2 review

Answer each question. Show your work for calculations with units, and use complete sentences for explanations. For the diagram item, draw neatly and label every part. The test is worth 60 points.

1. (5 pts) Multiple choice. Which layer forms the rim of the Grand Canyon? (A) Tapeats Sandstone (B) Redwall Limestone (C) Kaibab Limestone (D) Vishnu Schist
2. (5 pts) Give one observation and one interpretation about the Coconino Sandstone, and explain in one sentence how you can tell which is which.
3. (5 pts) You draw the canyon at a scale of 1 cm = 50 m. How tall are the Supai Group (300 m) and the Muav Limestone (120 m) on your drawing? How tall is the whole 1,800 m canyon?
4. (6 pts) Diagram. Draw two small cross-sections side by side. Left: an angular unconformity. Right: a flat gap (paraconformity). Label the layers, mark the contact in each, and write beneath each drawing one feature you would see at the contact.
5. (5 pts) Multiple choice. A paraconformity is best described as: (A) sandstone resting on granite (B) tilted layers under flat layers (C) parallel layers with channels and old soil at the contact (D) parallel layers with a flat, sharp contact and no visible sign of erosion
6. (6 pts) A sign dates the Muav Limestone at about 505 million years and the Redwall Limestone above it at about 340 million years. (a) How many years does the sign say are missing at the contact? (b) At an erosion rate of 0.06 mm per year, how many meters of rock would be removed in that time? (c) In one sentence, what does the flat contact look like, and why does that matter?
7. (5 pts) Multiple choice. In Berthault and Julien’s flume experiments, what happened when a mixture of sand sizes was fed into flowing water? (A) It settled as one mixed layer across the floor. (B) It formed a deposit that grew forward in the direction of flow, with coarse and fine laminae forming side by side at the same time. (C) Only the coarse grains were deposited. (D) Laminae formed one per day.
8. (6 pts) A float travels 1.5 m down a flume in 3.0 s, and a deposit 2.4 cm thick forms in 4 minutes. (a) What is the flow speed in cm/s? (b) What is the deposition rate in cm per hour? (c) In one sentence, why does a measured rate like this matter when reading a rock layer?
9. (5 pts) You test whether the slope of a flume changes the number of laminae. Name the independent variable, the dependent variable, and two things you must keep the same.
10. (6 pts) A coal seam is 1.8 m thick. (a) Using a 10 to 1 compaction ratio, how much peat or plant debris was needed? (b) If coal has a density of 1,300 kg/m³, what is the mass of coal under one square kilometer of this seam, in tonnes?
11. (6 pts) Compare the swamp model and the floating-mat model of coal formation. Name one observation that supports each model and one observation that is hard for each, then state in one sentence how a Christian student should speak about the disagreement.

UNIT PROJECT: MY CANYON WALL POSTER AND FLUME LOG

Make a poster at least 50 cm tall showing the Grand Canyon layers to scale in meters from the Tapeats Sandstone to the Kaibab Limestone, with each formation labeled by name, rock type and one fossil or feature. Mark the Great Unconformity and the Muav and Redwall contact, and beside each write a two-column note: “What the sign says” and “What we observe.”

Attach your flume lab log (both trials with slope, flow speed, deposit size, lamina count and cross-section sketches) and your floating-forest tub record. Finish with a one-page essay explaining, with at least two calculations from this unit, why the thickness of a layer does not by itself tell you how long it took to form, and how a Christian can hold the creation reading while describing the mainstream reading fairly.

- **Accuracy**: Layers are in the correct order, drawn to a single stated scale, and labeled with correct rock types and features.
- **Observation versus interpretation**: The two-column notes clearly separate measured features from claims about age, for both marked contacts.
- **Lab records**: Flume and tub logs are complete, with one variable changed at a time, measurements in metric units, and scaled sketches.
- **Explanation**: The essay uses two correct calculations and states both readings fairly, with Scripture and observation supporting the creation reading.

Answer key

1. (C) Kaibab Limestone.
2. Observation: it is a pale, cross-bedded sandstone about 100 m thick in the canyon walls, with animal trackways on its bedding surfaces. Interpretation: it is about 275 million years old, or it was laid down rapidly by Flood waters. An observation can be measured or seen directly at the rock; an interpretation depends on assumptions such as rates of deposition or a historical framework.
3. Supai: 300 ÷ 50 = 6 cm. Muav: 120 ÷ 50 = 2.4 cm. Whole canyon: 1,800 ÷ 50 = 36 cm.
4. Left drawing: tilted layers below cut off by a flat surface, flat layers above; contact labeled; feature such as pebbles of the lower rock or the angle between the two sets of layers. Right drawing: parallel flat layers above and below with a straight contact; feature: flat, sharp line with no channels, soil or tilt. Full credit requires correct geometry, labels and one correct feature for each.
5. (D).
6. (a) 505 − 340 = 165 million years. (b) 0.06 mm × 165,000,000 = 9,900,000 mm = 9,900 m (about 10 km). (c) The contact is flat and sharp with no deep valleys, soil or weathering, so either erosion was nearly zero for all that time (the long-age explanation) or the time was not there (the creation reading).
7. (B).
8. (a) 1.5 m ÷ 3.0 s = 0.5 m/s = 50 cm/s. (b) 2.4 cm ÷ 4 min = 0.6 cm/min; × 60 = 36 cm/h. (c) It shows that laminated sediment can form very quickly, so the time a layer took must be measured or argued for, not assumed from its thickness or lamina count.

9. Independent variable: slope of the flume. Dependent variable: number of laminae in the deposit. Keep the same (any two): sediment recipe and amount, water flow, feed time, flume, measuring method.
10. (a) 1.8 × 10 = 18 m. (b) Volume: 1,000,000 m^2 × 1.8 m = 1,800,000 m^3. Mass: 1,800,000 × 1,300 = 2,340,000,000 kg = 2,340,000 tonnes (about 2.3 million tonnes).
11. Swamp model: supported by plant fossils and by rooted soils under some seams; hard to explain flat seams with sharp contacts over tens of thousands of square kilometers and sea shells in partings. Floating-mat model: supported by wide flat seams, upright buried trunks at Joggins and the sinking log mat at Spirit Lake; hard to explain underclays with in-place roots. A fair student states the other side’s best evidence accurately and kindly before giving his own reading.

UNIT 3

Fossil Record

Fossils are where the rocks speak most plainly, and museums are where most people hear them. In this unit you will learn to read a museum sign the way a careful scientist reads anything: sorting what was seen and measured (a skeleton 12 m long, dug from mudstone in Montana) from what was inferred (it ate meat) and from what was interpreted (it lived 66 million years ago). You will meet the Nation's *T. rex*, William Smith's great map of 1815, the blue fish that a young curator pulled from a trawler's catch in 1938, and the chapter in which Charles Darwin admitted the strongest objection to his own theory.

Along the way you will do what scientists do: make molds and casts, sort sediment in a jar, build and test fin shapes, and sample a jar of beads to see how much of any record a sample can show. You will learn the museum words (Cambrian, Jurassic, Cretaceous, Cambrian explosion) so you can read any sign accurately, and in every lesson you will set two readings side by side: the mainstream timeline, stated fairly, and the creation reading in which the Flood of Genesis buried living things zone by zone a few thousand years ago.

The unit ends with a poster in which you draw the fossil column, mark where the living fossils and the famous "transitional" fossils sit, and write both readings in your own words, kindly and accurately. That is the skill you will carry into the museum in Unit 8.

BEFORE YOU BEGIN

- Can state Steno's principle of superposition and read a simple cross-section of rock layers (Unit 1)
- Knows that sedimentary layers can form rapidly, from the flume lab and the Grand Canyon lessons (Unit 2)
- Can compute percents, averages and scale drawings, and read a data table and a line graph
- Can identify the independent variable, dependent variable and controls in a simple experiment

MASTERY CHECKLIST

- I can define a fossil, name four kinds, and explain why most fossils required rapid burial.
- I can sort the sentences on a museum sign into observations, inferences and interpretations.
- I can describe the general order of fossils in the geologic column and give both the museum reading and the ecological-zonation reading of it.
- I can tell the story of the 1938 coelacanth and explain what living fossils show about stasis and gaps in the record.
- I can state what Darwin admitted about missing transitions and explain fairly how each side accounts for gaps, mosaics and the Cambrian explosion.

- I can read a museum word such as Cretaceous or Cambrian as a label for a set of layers and treat the date beside it as an interpretation.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History: Hall of Fossils, Deep Time** (https://naturalhistory.si.edu/exhibits/david-h-koch-hall-fossils-deep-time): Free. The museum's own page for its fossil hall, with photographs of the Nation's T. rex and other mounts. Use it for Lesson 3.1 to practice sorting a real label into observations, inferences and interpretations. The dates on the page are the museum's reading; read them with the Thinking About Time box beside you.
- **Smithsonian Ocean** (https://ocean.si.edu/): Free. Search the site for the coelacanth to find photographs, a short account of the 1938 discovery and facts about where the fish lives. Good for Lesson 3.3 and the sketchbook drawing.
- ***On the Origin of Species* by Charles Darwin, first edition (free at Project Gutenberg)** (https://www.gutenberg.org/ebooks/1228): Free. For Lesson 3.4, a parent may read aloud the opening pages of Chapter IX, "On the Imperfection of the Geological Record," where Darwin states the objection in his own words. Older readers can read the chapter themselves.

3.1 What Museums Say: Reading a Fossil Sign ★

OBJECTIVES

- Define a fossil, name four kinds of fossils, and explain why rapid burial is needed for most fossils to form.
- Sort the statements on a museum sign into observations, inferences and interpretations.
- Explain what the museum number “66 million years” rests on and state the creation reading beside it.

Warm-up. Put a chicken bone, a seashell, a leaf and a pebble on the table. For each, write one sentence you can check by looking or measuring (“the shell is 4 cm across”) and one sentence that is a guess about the past (“the shell came from a warm sea”). Keep the two lists apart. That habit is the whole lesson.

Video. Coming soon. Search for a tour of the Smithsonian National Museum of Natural History fossil hall and the Nation’s T. rex, and for a short explainer on how fossils form (rapid burial, molds and casts). Good sources: Smithsonian channels, USGS, SciShow Kids, Homeschool Pop (Alternate), Moody Science classics, museum footage.

KEY TERMS

fossil
The preserved remains or traces of a once-living thing kept in rock: bone, shell, wood, a leaf print, a footprint, a burrow.

observation
A statement you could check with your own eyes or an instrument, such as a length, a count or a color.

inference
A careful conclusion drawn from observations and comparisons, such as “these pointed teeth belonged to a meat-eater.”

interpretation
A reading of the evidence that depends on a framework and its assumptions, such as a date in millions of years.

rapid burial
Being covered by sediment quickly, before scavengers, bacteria and weather destroy the remains. Most fossils required it.

Cretaceous
A museum word: the name geologists give to a certain set of rock layers worldwide, from the Latin creta, chalk. On signs it comes with a date; the name itself is only a label for the layers.

CORE IDEAS

The story. On June 8, 2019, the Smithsonian's National Museum of Natural History in Washington, D.C., opened a new fossil hall. In the middle of it stands a *Tyrannosaurus rex* skeleton that visitors call "the Nation's T. rex." It was found in 1988 by Kathy Wankel, a rancher from Montana, who noticed a bone sticking out of the ground near Fort Peck Reservoir while her family was out for the day. The Museum of the Rockies dug the skeleton out over the next two summers. Because the land belongs to the United States Army Corps of Engineers, the Corps lent the bones to the Smithsonian for fifty years. The sign beside the mount gives the animal's name, the rock layer it came from, the state where it was found, and an age: about 66 million years. Thousands of children read that sign every week. This lesson teaches you to read it the way a careful scientist reads anything, by sorting what was seen and measured from what was concluded.

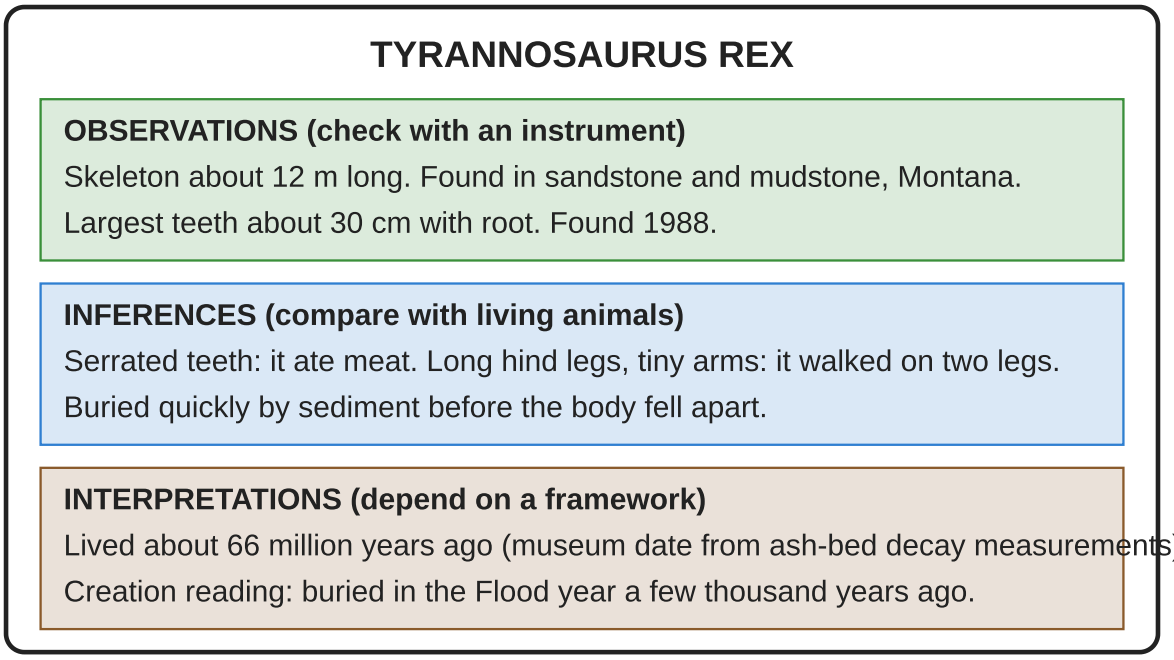
How they figured it out. A museum sign mixes three kinds of sentences. The first kind is **observation**. The skeleton is about 12 m long. The bones came out of sandstone and mudstone. The largest teeth are about 30 cm long with their roots. Anyone with a tape measure could check these. The second kind is **inference**. The teeth are pointed and edged like steak knives, so the animal ate meat. The hind legs are long and the arms are tiny, so it walked on two legs. These are good conclusions drawn by comparing the bones with living animals, and most people on either side of the age question agree with them. The third kind is **interpretation**. "It lived 66 million years ago." "It was a cousin of birds." These do not come from the bones alone. They come from a framework of assumptions about how fast rock forms and how living things came to be. A good reader asks of every sentence on a sign: could I check this with an instrument, with a comparison, or only by accepting a chain of assumptions?

The big idea. A **fossil** is any trace of a once-living thing kept in rock. Bones and shells may be filled or replaced by minerals until they are stone. A leaf pressed into mud leaves a thin carbon film. A shell that dissolves away leaves a hollow *mold*; if the hollow fills with mineral, the result is a *cast*. Footprints, burrows and droppings are *trace fossils*. Insects in amber and frozen mammoths are rarer still. Every standard textbook agrees on one point that matters greatly for this course: most fossils needed **rapid burial**. A dead animal left on a plain is torn apart by scavengers, softened by bacteria and scattered by wind and rain within months. Only when sediment covers the body quickly, before it falls apart, can minerals seep in and harden it. A fossil-rich layer is therefore a record of a burial event, not a snapshot of quiet, everyday life. Think about what kind of event buries whole fish schools, dinosaur herds and beds of shells meters deep.

In the world today. Where does the number on the sign come from? Not from the bone itself. The Hell Creek layers in Montana contain beds of volcanic ash, and geologists measure radioactive elements in crystals from that ash. Using the measured decay rate and three assumptions (a known starting amount, a constant rate, and no gain or loss of atoms since the crystal formed), they calculate an age for the ash and apply it to the bones between the ash beds. You will test those assumptions yourself in Unit 7. For now, learn the habit: when a sign says "Cretaceous, 66 million years ago," read **Cretaceous** as a **museum word**,

a label geologists give to a certain set of layers found around the world, and read the number as an interpretation that depends on assumptions. Then state the other reading beside it. Creation geologists read the same ash and mudstone layers as deposits of the Flood year and the years that followed, laid down rapidly a few thousand years ago, which is why the bones were buried fast enough to be preserved at all.

God's handiwork. Whichever reading of the date you hold, the skeleton itself is a wonder. The skull of a large *T. rex* is more than a meter long, yet it is pierced by large openings that save weight without losing strength, the same trick engineers use in bridge girders. The teeth are thick and ridged with fine serrations, built to grip, cut and crush bone. The leg bones are massive columns. None of this was accidental. The psalmist looked at living creatures and said, "in wisdom hast thou made them all." A museum is a fine place to say it again, quietly, with your sketchbook open.



Three kinds of sentences on one museum sign. Observations can be checked with instruments, inferences by comparison with living animals, and interpretations only by accepting a framework.

⏳ Thinking About Time

What the sign says. What the sign says: the label under the Nation's T. rex says the animal lived about 66 million years ago, at the end of the Cretaceous Period, and that its layer, the Hell Creek Formation, was dated by measuring radioactive decay in volcanic ash.

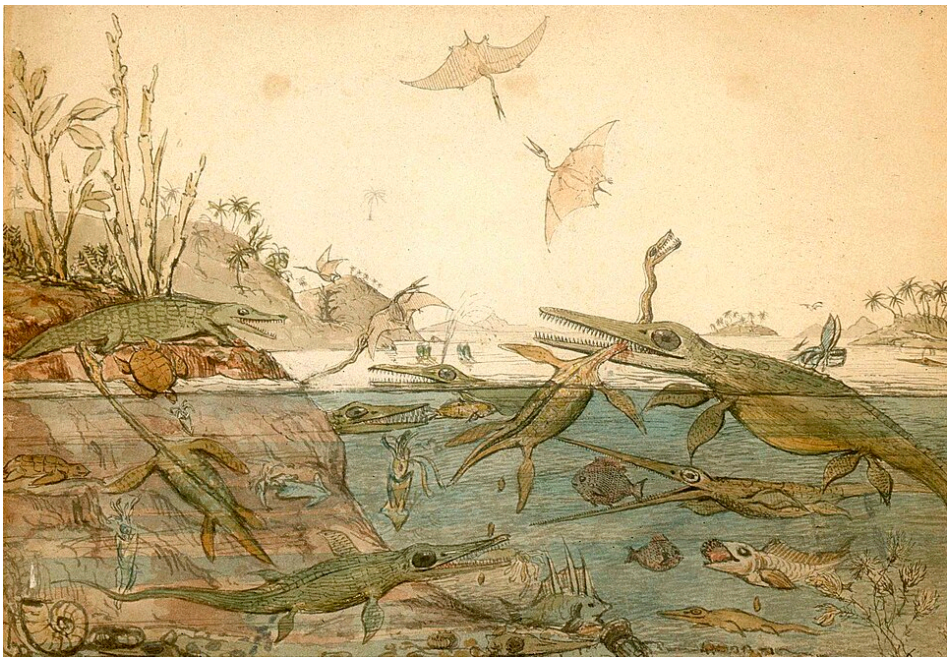
What we observe. What we observe: a skeleton about 12 m long with bones turned to stone, dug out of sandstone and mudstone in Montana; teeth, leg bones and a skull we can measure; and, in 2005, a report from a North Carolina State University team of soft, stretchy structures found inside a T. rex thigh bone from the same Montana layers.

How Christians read it. How Christians read it: the Flood of Genesis 7 and its aftermath buried these animals quickly under thick sediment a few thousand years ago. Rapid burial explains why the skeletons were preserved, and soft structures surviving in bone fit a young age better than a very old one. The decay measurements are real; the date is an interpretation built on assumptions we will test in Unit 7.

Try it. Copy one real museum label from a museum website and underline observations in one color and interpretations in another.

Genesis 7:21

PICTURE STUDY



Duria Antiquior (A More Ancient Dorset), Henry De la Beche, 1830 · Watercolor on paper · National Museum Cardiff, Wales

Henry De la Beche was an English geologist and a friend of the fossil collector Mary Anning of Lyme Regis, who had dug the first complete ichthyosaur and plesiosaur skeletons out of the sea cliffs of Dorset. In 1830 De la Beche painted this crowded scene of those animals alive, the first picture of its kind. Prints were sold to raise money for Anning, who was often poor.

This painting is a museum sign in pictures. The bones were real; Anning had dug them up and measured them. The water, the sunlight, the biting and the palms were De la Beche's inferences and imagination. Learning to see where the bones stop and the artist begins is exactly the skill of this lesson.

Look closely

- Find the ichthyosaur with the huge round eye biting a plesiosaur’s neck. Which parts of that scene could come from a skeleton, and which could not?
- Count the different kinds of animals you can find. Anning had found bones of ichthyosaurs, plesiosaurs and a pterosaur. Where did the other creatures come from?
- Look at the coiled shells on the sea floor. These are ammonites, which Anning sold by the basket. Why would an artist put them in a living scene?
- Notice how much of the picture is water. What does the artist assume about the land that is now Dorset?

Talk about it

1. Which statements about this scene are observations, which are inferences, and which are interpretations?
2. Why do you think the first picture of ancient life showed animals fighting and eating one another?
3. If you were painting the same bones from a Flood reading, what would you change and what would stay the same?

> **Safety first.** Plaster of Paris warms up as it sets and must never be poured down a sink or applied to skin. Mix it in a disposable container with adult help, work in a ventilated space, and wash hands after handling.

EXPERIMENT: MOLDS, CASTS AND GRAIN SIZE

Museum fossils are often molds and casts: the shell dissolved, and rock kept its shape. In this experiment you will make molds of a shell in two sediments and test which grain size records finer detail.

Question: does fine sediment or coarse sediment preserve more detail of a shell? Prediction: write yours before you start. What we change: the grain size of the sediment. What we keep the same: the shell, how hard we press, how long we wait. What we measure: the number of shell ridges you can count in each mold and cast.

You will need

- One ribbed seashell (a scallop or cockle works well), or a bumpy plastic toy if no shell is available
- Two small disposable containers (yogurt cups)
- Modeling clay or play dough (fine sediment)
- Damp coarse sand mixed with a little flour so it holds together (coarse sediment)
- Plaster of Paris and water, a stirring stick
- Petroleum jelly, a ruler, a hand lens, your lab notebook

Steps

1. Count the ridges on the real shell with the hand lens and record the number. Measure the shell's width in millimeters.
2. Fill one cup with clay and one with damp sand. Smooth the tops.
3. Rub a little petroleum jelly on the shell. Press it ridge side down into the clay with steady pressure for ten seconds, then lift it straight up. Do exactly the same in the sand. You now have two molds.
4. Look at each mold with the hand lens. Count how many ridges you can see clearly. Record the count in a table with columns: Sediment, Ridges on shell, Ridges in mold, Ridges in cast.
5. With adult help, mix plaster of Paris according to the package. Pour it gently into both molds. Wait 30 minutes or until hard.
6. Peel or dig away the sediment. You now have two casts. Count the visible ridges on each and complete the table.
7. Write two sentences: which sediment preserved more detail, and by how many ridges? Then write one sentence about what this suggests regarding the mud a museum fossil was buried in.

Tips

- If the sand mold crumbles, add a little more flour and water and try again. A crumbling mold is itself a result worth recording.
- Real fossil casts are made of minerals that seeped in over time. Plaster just does the same job fast.

Check your work

- I can explain the difference between a mold and a cast.
- I recorded a prediction, a table of counts and a conclusion.
- I can say which grain size preserves detail and why that matters for reading fossils.

FIELD NOTEBOOK

1. Draw the Nation's T. rex from a museum photograph. Beside it, write three observations, two inferences and one interpretation from the sign.
2. Draw your shell, your clay mold and your plaster cast side by side at the same scale, with the ridge counts written under each.
3. Make a labeled chart of five kinds of fossils: mineralized bone, carbon film, mold, cast and trace fossil, with a small drawing of each.

> **From history.** The first great fossil museum sign was a book. In 1812 the French anatomist Georges Cuvier published his studies of fossil bones from the quarries near Paris and showed that the mammoth and the mastodon were different from any living elephant. Cuvier was a careful comparer of bones who rebuilt whole animals from a few pieces, and he argued from the rocks that the earth had suffered sudden catastrophes

that buried creatures in a hurry. Museums still practice his method of comparing fossil bones with living skeletons.

WORKED EXAMPLES

Example 1. The Nation’s T. rex is about 12 m long and stands about 4 m tall at the hip. You want to draw it on a sheet of paper at a scale of 1 : 50. How long and how tall will your drawing be?

1. At 1 : 50, every 50 cm of real animal becomes 1 cm on paper. Convert the real lengths to centimeters: 12 m = 1,200 cm and 4 m = 400 cm.
2. Divide by 50. Length: 1,200 ÷ 50 = 24 cm. Hip height: 400 ÷ 50 = 8 cm.
3. Check: a 24 cm drawing fits sideways on a standard sheet of paper, which is about 28 cm wide.

Answer: The drawing will be 24 cm long and 8 cm tall at the hip.

Example 2. A sign says a mounted skeleton has 300 bones, of which 90 are real fossil bone and the rest are casts made from other specimens. What percent of the mount is real fossil? What percent is cast?

1. Percent real = (real bones ÷ total bones) × 100 = (90 ÷ 300) × 100.
2. 90 ÷ 300 = 0.30, so 0.30 × 100 = 30%.
3. The rest is cast: 100% − 30% = 70%, or 210 bones.

Answer: 30% of the mount is real fossil bone; 70% (210 bones) is cast.

Example 3. A dead animal on a riverbank is scattered by scavengers and weather within about 6 months. Its carcass needs about 1 m of sediment on top to be sealed away. (a) A textbook gives a quiet-river deposition rate of 2 mm per year. How long would it take to bury the carcass at that rate? (b) In a flood surge, sediment can pile up at 10 cm per hour. How long then?

1. Convert the burial depth to the same unit as each rate. 1 m = 1,000 mm = 100 cm.
2. (a) Time = depth ÷ rate = 1,000 mm ÷ 2 mm per year = 500 years. The carcass would be gone in 6 months, long before 500 years.
3. (b) Time = 100 cm ÷ 10 cm per hour = 10 hours. The carcass is sealed the same day.
4. Compare: only the fast rate buries the animal before it decays. This is why textbooks and creation geologists both say most fossils required rapid burial.

Answer: (a) 500 years, far too slow to make a fossil. (b) 10 hours, fast enough to preserve it.

PRACTICE

1. EASY Define a fossil and name four different kinds.
2. EASY Sort each sentence as observation (O), inference (I) or interpretation (P): (a) “The femur is 1.3 m long.” (b) “The animal lived 66 million years ago.” (c) “The serrated teeth show it ate meat.” (d) “The bones were found in mudstone.”
3. EASY Why do most fossils require rapid burial?
4. MEDIUM Who found the Nation’s T. rex, in what year and in what state? Who lent it to the Smithsonian?
5. MEDIUM A hadrosaur skeleton is 9 m long. At a scale of 1 : 30, how long is the drawing in centimeters?
6. MEDIUM Data reading. A museum lists four mounted skeletons. Mount A: 410 bones, 123 real. Mount B: 250 bones, 200 real. Mount C: 300 bones, 60 real. Mount D: 180 bones, 180 real. Which mount has the highest percent of real fossil bone, and what is that percent? Which has the lowest, and what is it?
7. MEDIUM Data reading. A table gives burial rates: quiet lake 1 mm/year; river delta 5 mm/year; storm layer 3 cm/hour; flood surge 20 cm/hour. A fish carcass must be covered by 30 cm within 2 days to be preserved. Which of the four settings can do it? Show your reasoning.
8. HARD Experiment design. You want to test whether burying a dead plant quickly preserves its shape better than leaving it exposed. Describe the question, what you change, what you keep the same, what you measure, and how long you run it.
9. HARD Explain in three or four sentences what the number “66 million years” on a sign rests on, and give the creation reading beside it.
10. CHALLENGE Henry De la Beche painted Duria Antiquior from Mary Anning’s fossils. Write a short paragraph explaining what parts of that painting a modern museum could defend

from the bones alone and what parts are interpretation. Then say what a sign for the painting should admit.

COMMON MISTAKES

- Thinking a fossil is the actual soft animal preserved. Most fossils are bone or shell replaced by minerals, or hollow molds and filled casts, with the original creature long gone.
- Thinking the date on a sign was measured from the bone itself. It comes from radioactive measurements of nearby ash layers plus a set of assumptions.
- Thinking fossils form slowly in quiet settings. A body left out decays in months; textbooks on both sides agree that most fossils needed rapid burial by sediment.

Make it a game · Sign or Science?. A parent reads sentences from real museum labels (find them on museum websites) one at a time. You call out “observation,” “inference” or “interpretation” within five seconds and give a one-line reason. Score a point for each correct call and a bonus point if you can say what instrument or comparison would check it. Switch roles after ten sentences. Play to fifteen points.

Scripture. “O LORD, how manifold are thy works! in wisdom hast thou made them all: the earth is full of thy riches.” (Psalm 104:24, KJV)

A museum hall full of skeletons is a hall full of design. Whatever the sign says about dates, the bones themselves speak of wisdom in their making.

Practice answers

1. A fossil is the preserved remains or trace of a once-living thing kept in rock. Kinds: mineralized bone or shell, a carbon film of a leaf, a mold, a cast, a trace fossil such as a footprint or burrow, or an insect in amber.
2. (a) O, (b) P, (c) I, (d) O.
3. Because scavengers, bacteria and weather destroy a dead body within months. Only quick covering by sediment protects the remains long enough for minerals to harden them.
4. Kathy Wankel, a rancher, found it in 1988 in Montana near Fort Peck Reservoir. The United States Army Corps of Engineers, which owns the land, lent it to the Smithsonian.
5. 9 m = 900 cm; 900 ÷ 30 = 30 cm.
6. D is 100% real (180 ÷ 180). C is lowest at 20% (60 ÷ 300). For reference, A is 30% and B is 80%.
7. Convert 2 days to hours: 48 hours. Storm layer: 3 cm/h × 48 h = 144 cm, enough. Flood surge: 20 × 48 = 960 cm, enough. Lake: 1 mm/year is 0.1 cm/year, nowhere near 30 cm in 2 days. Delta: 5 mm/year, also far too slow. Only the storm layer and flood surge can preserve the fish.
8. Question: does rapid burial preserve a leaf’s shape? Change: one leaf is pressed between layers of wet clay in a sealed container at once; a matching leaf is left on a tray outdoors (or in open air). Keep the same: leaf type and size, temperature, length of time. Measure: after 3 weeks, score each leaf for shape, veins visible and edges intact (for example 0 to 5 points each), and photograph both. Run two or three pairs so one odd result does not mislead.

9. The date is not measured from the bone. Geologists measure radioactive elements in crystals from volcanic ash beds above and below the bones and calculate an age by assuming a known starting amount, a constant decay rate and no atoms gained or lost. The result is an interpretation that depends on those assumptions. Creation geologists read the same layers as Flood-year deposits laid down rapidly a few thousand years ago, which also explains why the bones were buried fast enough to fossilize.
10. The animals’ bone shapes, sizes, long necks, paddles and big eye sockets come from real skeletons and can be defended. Their colors, the scene of biting, the sunlight, the palms and the idea that all lived together at one moment are inferences and imagination. A sign should say that the skeletons are real finds from Lyme Regis, that behavior and setting are the artist’s reconstruction, and that any date given is an interpretation.

3.2 Order of Fossils and Ecological Zonation ★

OBJECTIVES

- Tell how William Smith discovered that layers can be recognized by their fossils and explain the principle of faunal succession.
- Describe the general order of fossils from the lowest fossil-bearing layers to the highest, using the museum words for the main divisions.
- Compare the two readings of that order: evolution over long ages, and burial by habitat zone during the Flood.

Warm-up. Fill a tall clear jar two-thirds with water. Drop in a handful of mixed things at once: a few pebbles, some coarse sand, a crushed eggshell, a pinch of soil, a torn leaf and a small feather or bit of fluff. Watch for one minute. Draw the order in which they settled, bottom to top. Did the order come from what the things were, or from where they were in the jar?

Video. Coming soon. Search for William Smith and the first geological map of England (1815), the principle of faunal succession and index fossils, and a sediment-sorting demonstration in a jar or flume. Good sources: Geological Society of London, USGS, Smithsonian, SciShow, Homeschool Pop (Alternate), Moody Science classics.

KEY TERMS

faunal succession
William Smith’s rule: fossils occur in a definite order through the layers, so a layer can be recognized by the fossils it holds.

index fossil
A fossil found in only a narrow set of layers over a wide area, used to match layers from place to place.

correlation
Matching a rock layer in one place to the same layer in another place by its fossils or its rock type.

geologic column
A museum word: the ordered stack of all named layer sets (Cambrian, Devonian, Jurassic and so on) pieced together from many places. No single place contains the whole column.

ecological zonation
The creation reading of fossil order: creatures were buried roughly in the order of where they lived, from the sea floor upward, as the Flood waters rose.

trilobite
A three-lobed sea animal with a hard shell and jointed legs, common in the lowest fossil-bearing layers and found nowhere alive today.

CORE IDEAS

The story. In the 1790s a young surveyor named William Smith, the son of a blacksmith from Oxfordshire, was hired to lay out the Somerset Coal Canal near Bath, in the west of England. He walked every cutting and went down the coal pits, and he began to notice something that no one had put to use before. The layers always came in the same order, and each layer held its own fossils. A bed of limestone that looked just like another could be told apart by the shells inside it. He tested the idea over and over on journeys across the country, riding thousands of kilometers to check that the same layers held the same fossils in the same order. In 1815 he published a hand-colored map of the rock layers of England and Wales, nearly 2.6 m tall, the first geological map of a whole nation. People called him “Strata Smith.” The map ruined him financially, and in 1819 he spent weeks in a debtors’ prison. But in 1831 the Geological Society of London gave him its first Wollaston Medal, and its president, Adam Sedgwick, named him the Father of English Geology.

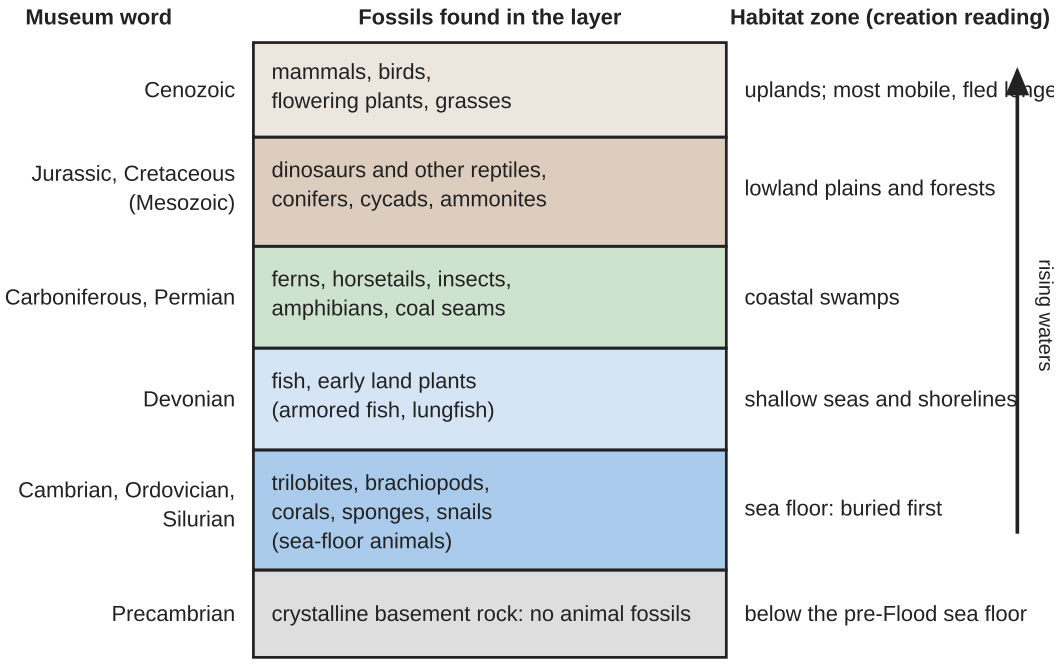
How they figured it out. Smith’s rule is called **faunal succession**: fossils appear in a definite order through the layers, so a layer can be recognized by its fossils. A fossil that occurs in only a narrow set of layers but across a wide region is an **index fossil**, and using it to match layers from one cliff to another is called **correlation**. Through the 1800s geologists stitched the local sequences of many countries into one ordered stack, the **geologic column**, naming its parts after the places where the layers were first studied. These are **museum words** you will meet on every sign: *Cambrian* from Cambria, the old name for Wales; *Devonian* from Devon; *Carboniferous*, meaning coal-bearing; *Permian* from Perm in Russia; *Jurassic* from the Jura Mountains; *Cretaceous* from the Latin for chalk. Notice two things. The names were given from order and fossils, decades before anyone measured radioactive decay. And no single place on earth contains the whole column. It is a composite, assembled by correlation, a fact that standard textbooks state openly.

The big idea. What is the order? Everyone who has dug into the layers agrees on the broad pattern. The lowest fossil-bearing layers are crowded with sea-floor animals: trilobites, brachiopods, corals, sponges and snails, often in beds many meters thick. Fish appear higher. Above them come layers with ferns, giant horsetails, insects, amphibians and seams of coal. Higher still come reptiles, including the dinosaurs, with conifers and cycads. Mammals, birds and flowering plants are found mostly in the highest layers. Two more facts matter. The great majority of all fossils, by count, are marine shellfish and other sea animals, not land vertebrates. And many creatures run through enormous thicknesses of rock looking the same from bottom to top. The order is an observation. The question is what it means.

Two readings. The museum sign reads the column as a timeline: sea creatures are at the bottom because they evolved first, and the column records about 540 million years from the Cambrian to today. Creation geologists read the same column through **ecological zonation**, an idea developed by the biologist Harold W. Clark in 1946. Before the Flood, living things were arranged in zones: bottom-dwelling shellfish on the sea floor, fish in the water above, amphibians and ferns in low coastal swamps, reptiles on the lowland plains, mammals and birds on higher ground, and the most mobile creatures able to flee longest. As the Flood waters rose over about five months (Genesis 7:11, 24), each zone was torn up and buried in

turn, lowest first. Moving water also sorts what it carries, as your jar showed. On this reading the column records *where creatures lived and how they were buried*, not the order in which they came to be. Zonation explains the broad trend well; like the museum reading, it has puzzles to work on, and Lesson 3.4 shows how each side handles the hard cases.

In the world today. Smith's method still earns its keep. Oil and gas geologists identify layers deep underground by tiny shells called foraminifera brought up in drill cuttings. You can practice correlation without a drill rig: two road cuts a kilometer apart, each with a layer full of the same oyster shells, are almost certainly the same layer. That is observation, and it works whatever you believe about dates. When you read a sign that says "Ordovician limestone," you now know what it means: a limestone whose fossils match the layer set first named in Wales. The age attached to the name is a separate claim, and you are learning to read the two apart.



The general order of fossils, bottom to top, with the museum words on the left and the creation reading (burial by habitat zone) on the right. The order is observed; the two columns of labels are two readings of it.

⏳ Thinking About Time

What the sign says. What the sign says: the geologic column records about 540 million years of life, from the Cambrian Period to today. Simple sea animals lie at the bottom because they evolved first; fish, amphibians, reptiles and mammals follow in the order in which they appeared.

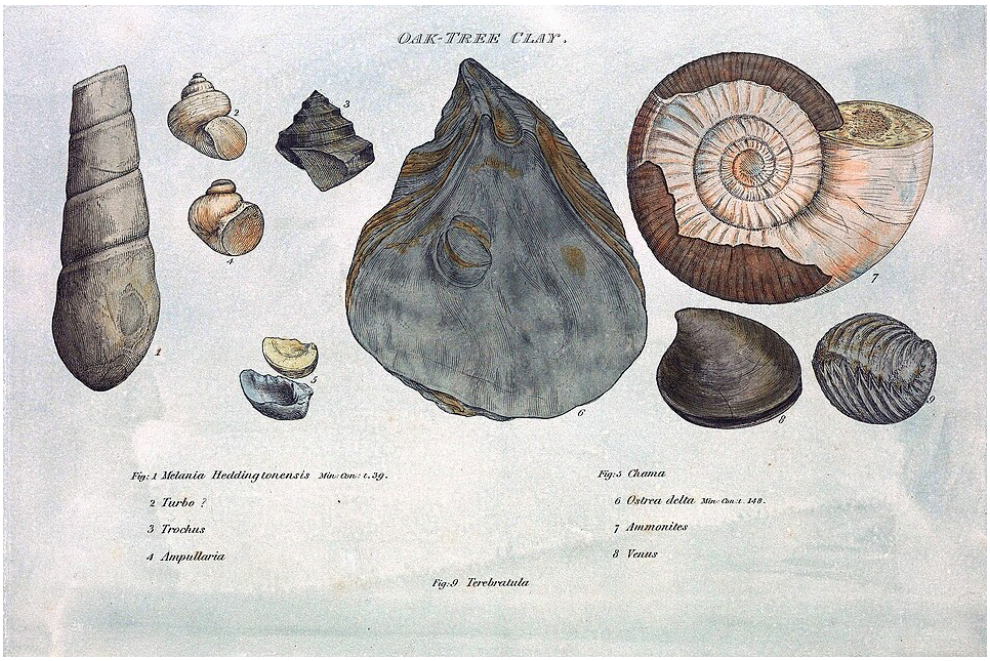
What we observe. What we observe: layers that come in a consistent order over wide regions; sea-floor animals in the lowest fossil layers, fish above them, then coal swamps with amphibians, then reptiles, then mammals and birds; most fossils are marine; many creatures look the same through great thicknesses of rock; and fossil beds, such as whole schools of fish, show rapid burial.

How Christians read it. How Christians read it: the Flood of Genesis 7 rose over months and buried living things zone by zone, sea floor first and uplands last, with flowing water sorting what it carried. The order records habitat and burial, not a long sequence of evolution, and the whole column was laid down within about a year and its aftermath, a few thousand years ago.

Try it. Repeat the warm-up jar with a stopwatch and record the settling time of each kind of object.

Genesis 7:19

PICTURE STUDY



Fossils of the Oak Tree Clay, plate from Strata Identified by Organized Fossils, William Smith (plate engraved by James Sowerby), 1817 · Hand-colored engraving, printed on paper tinted to match the color of the stratum on Smith's map · Published in London; copies at the Geological Society of London and in natural-history libraries

After his great map, William Smith set out to prove the rule it rested on. Between 1816 and 1819 he published Strata Identified by Organized Fossils in four parts, one plate for each layer, showing the shells that belong to that layer and no other. He had each plate printed on paper tinted the same color he had used for that layer on the map, so a reader could match fossil, color and stratum at a glance. This plate shows the fossils of the layer Smith called the Oak Tree Clay, which geologists today call the Kimmeridge Clay.

Nothing on this page is imagined. Every shell was drawn from a specimen in Smith's own collection, which he later sold to the British Museum to pay his debts. The plate says, in pictures, exactly what faunal succession says in words: if you find these shells together, you are standing on this layer.

Look closely

- Find the coiled shells. These are ammonites, sea creatures related to the living nautilus. Count how many different ammonites the plate shows.
- Find the rough, layered shells. These are oysters. Why would an oyster be a good fossil for recognizing a layer?
- Notice the tint of the paper. On Smith’s map this layer wore the same color. Why would matching the colors help a surveyor in the field?
- Each fossil is numbered. What would a numbered list let Smith do that a plain picture could not?

Talk about it

1. Smith chose fossils found in one layer and not in the layers above or below. Why are those the useful ones for correlation, and what would a fossil found in every layer tell you?
2. The plate records where these shells are found, not how old they are. Where does the age on a modern museum sign for the Kimmeridge Clay come from?
3. Smith sold his fossil collection to pay his debts and still kept working. What does that tell you about why he did science?

> **Safety first.** Use only clean, blunt shells and pebbles in the sorting jars. Wipe up spills at once so the floor is not slippery.

EXPERIMENT: SORTING JAR: DOES MOVING WATER ARRANGE WHAT IT BURIES?

Fossils lie in a general order through the layers. One part of the creation reading is that water sorts what it carries by size, shape and density, and that creatures were picked up in the order of their habitats. You will test the first part with a jar.

Question: does the order in which mixed objects settle depend on what they are, or on how they were dropped in? Prediction: write it down. What we change: the mix of objects, then the way they are added (all at once versus one by one). What we keep the same: the jar, the amount of water, the person dropping. What we measure: the position of each object from the bottom, in millimeters, and the settling time.

You will need

- Two tall clear jars or bottles with lids
- Water
- Coarse sand, fine sand or flour, small pebbles, crushed eggshell, dry leaves, small twigs, a few whole small shells
- Stopwatch, ruler, masking tape and a marker
- Lab notebook

Steps

1. Fill both jars three-quarters full of water. Put a strip of masking tape up the side of each so you can mark levels.
2. Trial 1, all at once: pour the full mixture into jar A, cap it, shake it for ten seconds, set it down and start the stopwatch. Record what settles first, second and third, and when the water clears.
3. After five minutes, mark the boundaries of each layer on the tape and measure each layer’s thickness in millimeters. Sketch the jar.
4. Trial 2, one kind at a time: into jar B add pebbles, wait a minute, then coarse sand, then fine sand, then shells, then leaves. Mark and measure as before.
5. Trial 3: shake jar B again so everything mixes, and let it settle. Compare its final order with the order you added things in and with jar A.
6. Write a conclusion in two or three sentences: what controlled the final order, the objects or the order of adding? Which objects always ended on top, and why?
7. Extension: tip a jar slightly so the sediment slides and settles on a slope. Do the layers still form? Record what you see.

Tips

- Flour clouds the water for a long time. That is a real observation about fine sediment, so note the time it takes to clear.
- If leaves float forever, that is also a result: buoyant things end up high or not at all, which matters for why some creatures are rare as fossils.

Check your work

- I measured and sketched layers from at least two trials.
- I can state whether settling order depended on the objects or on how they were added.
- I can connect the result to one part of the creation reading of fossil order and say what it does not explain.

FIELD NOTEBOOK

1. Copy the fossil column figure into your notebook, bottom to top, and draw one small fossil for each layer: a trilobite, a fish, a fern, a dinosaur bone, a mammal tooth.
2. Draw your sorting jar after Trial 1 at full size, with each layer labeled and measured in millimeters.
3. Make a two-column page headed “What the column shows” and “Two readings,” and fill in three observations and both explanations.

> **From history.** Many of the geologists who named the layer sets were devout Christians. Adam Sedgwick, who named the Cambrian in 1835, was an Anglican clergyman and professor at Cambridge, and he later publicly criticized Darwin’s theory. Roderick Murchison, who named the Silurian and the Permian, worked closely with Sedgwick until they quarreled over the boundary between their two systems. The names they chose are still on museum signs today, long after the men and their arguments are forgotten.

WORKED EXAMPLES

Example 1. In a region, index fossil A is found only in layers 2 to 5 (counting from the bottom), fossil B only in layers 4 to 7, and fossil C only in layers 6 to 9. A rock sample from a new cliff contains fossils A and B together. Which layer or layers could it be from? A second sample contains B and C. Which layers?

(Use the map or drawing “Index fossils with overlapping ranges let geologists narrow a sample to a few la” shown earlier in this lesson.)

1. Write the range of each fossil: A = {2, 3, 4, 5}, B = {4, 5, 6, 7}, C = {6, 7, 8, 9}.
2. A sample with A and B must be in a layer where both ranges overlap: {4, 5}.
3. A sample with B and C must be where B and C overlap: {6, 7}.
4. Check: a sample with A and C together would be impossible, since their ranges do not overlap. That is how geologists spot a mistake in identification.

Answer: A with B: layer 4 or 5. B with C: layer 6 or 7.

Example 2. A fossil collection of 1,000 specimens contains 950 marine shells and corals, 30 plant fossils, 15 fish, 4 reptiles and 1 mammal. What percent of the collection is marine invertebrates? What percent is land vertebrates (reptiles and mammals together)?

1. Percent marine invertebrates = (950 ÷ 1,000) × 100 = 95%.
2. Land vertebrates = 4 + 1 = 5 specimens. Percent = (5 ÷ 1,000) × 100 = 0.5%.
3. Check the total: 950 + 30 + 15 + 4 + 1 = 1,000. The proportions match the real fossil record, where sea creatures overwhelmingly outnumber land animals.

Answer: 95% marine invertebrates; 0.5% land vertebrates.

Example 3. A measured section has four layers: A (bottom) 40 m of limestone with trilobites, B 25 m of shale with fish, C 10 m of coal and sandstone with ferns, D (top) 5 m of mudstone with reptile bones. Draw the column at a scale of 1 cm = 5 m. How tall is each layer on paper, and how tall is the whole column? What fraction of the total thickness is layer A?

1. Divide each thickness by 5 m per cm. A: 40 ÷ 5 = 8 cm. B: 25 ÷ 5 = 5 cm. C: 10 ÷ 5 = 2 cm. D: 5 ÷ 5 = 1 cm.
2. Total real thickness: 40 + 25 + 10 + 5 = 80 m. On paper: 8 + 5 + 2 + 1 = 16 cm. Check: 80 ÷ 5 = 16 cm.
3. Fraction that is layer A: 40 ÷ 80 = 1/2, or 50%.

Answer: A = 8 cm, B = 5 cm, C = 2 cm, D = 1 cm; the column is 16 cm tall; layer A is half the total thickness.

PRACTICE

1. EASY State William Smith’s principle of faunal succession in your own words.
2. EASY Give the place or meaning behind three of these museum words: Cambrian, Devonian, Carboniferous, Jurassic, Cretaceous.
3. EASY List the general order of fossils from the lowest fossil-bearing layers to the highest.
4. MEDIUM Fossil X occurs in layers 3 to 6 and fossil Y in layers 5 to 8. A sample contains both. Which layers are possible?
5. MEDIUM In a collection of 400 fossils, 372 are marine invertebrates. What percent is that? How many fossils are not marine invertebrates?
6. MEDIUM Data reading. A table lists four cliffs and the fossils in their layers, bottom to top. Cliff 1: trilobites, fish, ferns. Cliff 2: fish, ferns, reptiles. Cliff 3: trilobites, fish. Cliff 4: ferns, reptiles, mammals. Using correlation, write the single combined order of all five fossil groups, and name which cliff shows the most groups.
7. MEDIUM Data reading. In a settling jar, a student recorded the time each material took to reach the bottom: pebbles 1 s, coarse sand 4 s, shells 6 s, fine sand 40 s, leaves did not sink in 10 min. Which material settled fastest, and what two properties of the pebbles explain it? Which layer would lie on top after the water cleared, and why?
8. HARD Experiment design. Design a test of whether the shape of a shell (flat versus rounded) changes how fast it settles in water. Name the independent variable, the dependent variable, two controls, and how many trials you would run.
9. HARD In a paragraph, explain how ecological zonation accounts for sea-floor animals lying below reptiles and mammals in the column. Then name one observation that zonation alone does not settle and that each side must still work on.
10. CHALLENGE William Smith named and ordered his layers before radioactive dating existed. Explain why the names of the layer sets (Cambrian, Jurassic) and the dates attached to them on a sign are two separate claims, and how you would say so kindly to a friend at a museum.

COMMON MISTAKES

- Thinking the whole geologic column can be seen in one place. It is a composite assembled from many regions by matching fossils; textbooks say so.
- Thinking the period names prove the ages. Names such as Cambrian and Jurassic were given from places and fossil order before radioactive dating existed.
- Thinking water sorts only by weight. Shape, size and density all matter, and living creatures also move, flee and float, which is why zonation and sorting together are used in the creation reading.

Make it a game · Strata Smith. Make twelve index cards, each with a fossil name and the layers it occurs in (for example, “Trilobite: layers 1 to 4”). Shuffle and deal. The dealer calls out a mystery sample, such as “a rock with fossils P and Q.” Players race to say which layer numbers are possible by finding the overlap. First correct answer takes

the cards used. A player who names an impossible pair (ranges that do not overlap) loses a card. Most cards after ten rounds wins.

Scripture. “And all flesh died that moved upon the earth, both of fowl, and of cattle, and of beast, and of every creeping thing that creepeth upon the earth, and every man: All in whose nostrils was the breath of life, of all that was in the dry land, died.” (Genesis 7:21–22, KJV)

Genesis describes a burial of land creatures by water on a scale that would leave exactly the kind of record the layers hold: zone after zone of living things swept up and covered. The order in the rocks is the order of that burial, on this reading.

Practice answers

1. Fossils occur in a definite order through the layers, so a layer can be recognized by the fossils it contains, and the same layer can be matched from place to place.
2. Cambrian: Cambria, the old name for Wales. Devonian: Devon, England. Carboniferous: coal-bearing. Jurassic: the Jura Mountains. Cretaceous: Latin creta, chalk.
3. Sea-floor animals such as trilobites, brachiopods and corals; then fish; then ferns, insects and amphibians with coal; then reptiles including dinosaurs; then mammals, birds and flowering plants mostly at the top.
4. Layers 5 and 6, where the ranges overlap.
5. 372 ÷ 400 = 0.93, so 93%. The remaining 28 fossils are not marine invertebrates.
6. Combined order: trilobites, fish, ferns, reptiles, mammals. Cliffs 1, 2 and 4 each show three groups, the most; cliff 3 shows two. No single cliff shows all five, which is how the real column is assembled.
7. Pebbles settled fastest because they are the densest and largest, so water drag slows them least. Fine sand would lie on top of the settled layers because it sank last; leaves never settled, so they would float or be left out of the deposit entirely.
8. Independent variable: shell shape (flat clam shell versus rounded snail shell of similar mass). Dependent variable: time to settle in a tall jar, measured with a stopwatch. Controls: same water depth and temperature, same release point at the surface, shells of nearly the same mass. Run at least five trials per shape and compare the average times.
9. Zonation says living things were arranged by habitat before the Flood: shellfish on the sea floor, fish above, amphibians in coastal swamps, reptiles on lowlands, mammals and birds on higher ground and more able to flee. As the waters rose, each zone was torn up and buried in turn, lowest first, so sea-floor animals lie lowest. One open question is why certain groups are found so consistently in their layers across continents and rarely mixed; both sides offer explanations, and the evidence is still studied.
10. The names come from order and fossils observed in the rocks, which anyone can check by digging; they are labels for layer sets. The dates were added later from radioactive measurements that depend on assumptions about starting amounts, constant rates and closed systems. One can accept the names and the order while reading the dates differently. To a friend: “The sign is right that this is Jurassic limestone, meaning it matches those layers. The age is a separate calculation, and I read the layers as laid down fast in the Flood. Want to see the fossils that tell them apart?”

3.3 Living Fossils: The Coelacanth of 1938

OBJECTIVES

- Tell the story of the 1938 coelacanth, naming Marjorie Courtenay-Latimer, J. L. B. Smith and the place and date of the find.
- Describe the coelacanth's body and habits and define a living fossil, with three other examples.
- Explain what the coelacanth shows about stasis and about gaps in the fossil record, and give both readings.

Warm-up. Look at a photograph of a horseshoe crab and a drawing of a fossil horseshoe crab (search the Smithsonian website). List three features that match and any that differ. Then write one sentence: if an animal's fossils stop appearing in the rocks, does that prove the animal died out? Keep your answer for the end of the lesson.

Video. Coming soon. Search for underwater footage of living coelacanths (submersible or diver film from the Comoros or South Africa), the 1938 discovery story of Marjorie Courtenay-Latimer, and short pieces on living fossils such as the horseshoe crab and ginkgo. Good sources: Smithsonian Ocean, Smithsonian channels, Deep Look, nature documentaries, Moody Science classics.

KEY TERMS

coelacanth
A large, deep-water fish with fleshy, limb-like fins and a three-lobed tail, known from fossils long before a living one was caught in 1938. The name means "hollow spine."

living fossil
Darwin's phrase for a living creature that closely matches its fossils and has few close living relatives: the coelacanth, the horseshoe crab, the ginkgo.

lobe fin
A fin carried on a muscular, bony stalk instead of spreading straight from the body. Coelacanths and lungfish have them.

stasis
Staying the same. A fossil group shows stasis when its form does not change from the lowest layers it appears in to the highest.

Lazarus taxon
A kind of creature that disappears from the fossil layers and then turns up again higher, or alive today, as if raised from the dead.

Devonian
A museum word: the layer set first studied in Devon, England, in which the lowest fossil coelacanths and many fish are found. On a sign it comes with a date of about 400 million years.

CORE IDEAS

The story. On December 22, 1938, Marjorie Courtenay-Latimer, the young curator of the small museum in East London, South Africa, got a telephone call from the docks. Captain Hendrik Goosen of the trawler *Nerine* had come in from fishing off the mouth of the Chalumna River and had set aside some odd fish for her. Under a pile of sharks and rays she saw a blue fin. She pulled out a fish about 1.5 m long and about 57 kg, steel blue with pale flecks, with hard, heavy scales and fins on fleshy stalks that looked almost like legs. The museum had no freezer, so she took it by taxi to a taxidermist, who saved the skin while the insides were lost. She made a careful sketch and mailed it to James Leonard Brierley Smith, a chemistry lecturer at Rhodes University College in Grahamstown who was also the best fish expert in the country. When Smith finally read the letter he could hardly believe the drawing. It showed a coelacanth, a fish known only from fossils, which every textbook said had died out with the dinosaurs. In 1939 he named it *Latimeria chalumnae*, after the curator and the river.

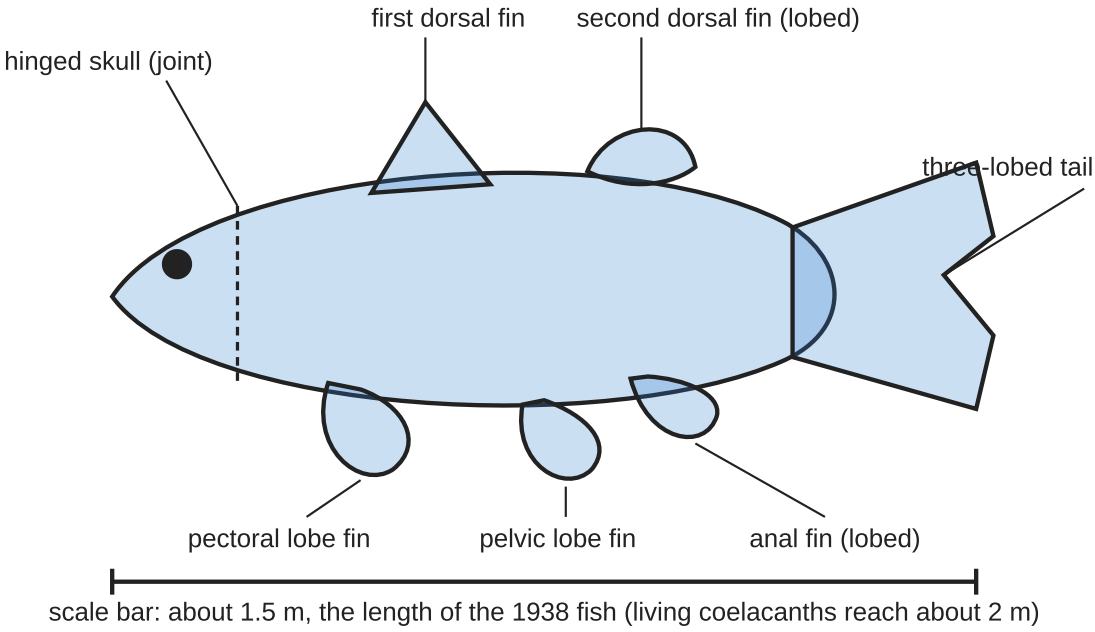
How they figured it out. The Swiss naturalist Louis Agassiz had named the fossil genus *Coelacanthus*, "hollow spine," in 1839, from fish with hollow fin rays found in the copper-bearing slates of Germany. Fossil coelacanths turned up in layer after layer, from the rocks museums call Devonian up through the Cretaceous, and then in none of the layers above. Smith wanted the fish's insides, so he printed reward leaflets in English, French and Portuguese offering 100 pounds for the next one. He waited fourteen years. On December 20, 1952, a fisherman at Anjouan in the Comoro Islands landed one, and Smith borrowed a military airplane from the South African prime minister and flew to fetch it. The islanders, it turned out, had been catching the fish for years and called it *gombessa*. Since then scientists have learned that coelacanths live 150 to 250 m down along steep volcanic slopes, rest in caves by day, grow to about 2 m and 90 kg, and give birth to live young. In 1987 they were filmed alive from a small submersible, and in 1997 a second species was found at a fish market in Sulawesi, Indonesia.

The big idea. Charles Darwin coined the phrase **living fossil** in 1859 for creatures that closely match their fossils and have few close living relatives. The coelacanth is the most famous, but there are many: the horseshoe crab, the nautilus, the ginkgo tree, the tuatara of New Zealand, the dawn redwood found growing in China in the 1940s, and the Wollemi pine found alive in an Australian canyon in 1994. The coelacanth teaches two lessons that both sides of the age question accept. First, **stasis**: fossil coelacanths and living ones share the same body plan, the lobed fins, the three-lobed tail, the hinged skull, through every layer in which they appear, though fossil kinds differ in size and some lived in fresh water. Second, absence from the rocks is not absence from the world. No coelacanth fossil has been found in any layer above the Cretaceous, yet the fish was alive the whole time those layers were forming. Geologists call such a creature a **Lazarus taxon**. The fossil record is a record of burial, not a diary of life.

Two readings. The museum sign explains the gap by saying that coelacanths retreated to deep water, and that deep-sea sediments are rarely lifted onto land where we can dig in them, so their fossils are missing for the last 66 million years of the textbook timeline. It

explains stasis by saying that a stable home gives little reason for a body plan to change. Creation geologists read the same facts differently. God made sea creatures “after their kind,” and the coelacanth has stayed a coelacanth. The fossil coelacanths were buried in the Flood year, when the sea floors were torn up and dumped in layers; the living ones descend from fish that survived in the sea, since the Ark carried only the air-breathing land animals. The upper layers were laid down in the months and years after the Flood, when deep-water fish were simply not being buried on land, so the gap is no mystery. Notice what both readings agree on: a creature can live through enormous stretches of the column and leave no fossil.

God’s handiwork. The living coelacanth is a marvel of design. Its skull has a hinge across the middle, found in no other living backboned animal, that lets the front of the head tilt up as the jaws open wide. A fat-filled organ in place of the usual swim bladder helps it hover at depth. A jelly-filled cavity in the snout senses the faint electric fields of prey in the dark. Its paired fins move in the alternating pattern of a walking animal, right front with left rear, as it drifts over the sea floor. The fish is now protected, and divers found a second population at Sodwana Bay, South Africa, in 2000. A fish that the textbooks had buried was living quietly in the dark the whole time, exactly as it was made.



The 1938 coelacanth, drawn to scale. The labeled features are the ones that matched the fossils in Smith’s books.

⏳ Thinking About Time

What the sign says. What the sign says: coelacanths first appear in rocks the textbook dates at about 400 million years (the Devonian) and vanish from the record in layers dated about 66 million years, so they were believed extinct until 1938. Their survival is explained by a stable deep-water home where few fossils form.

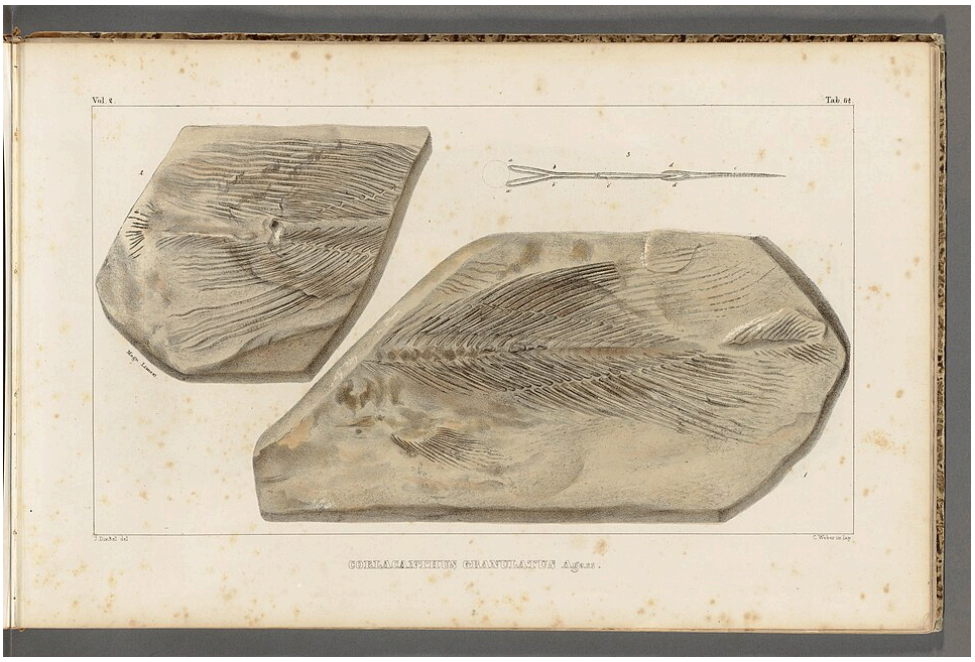
What we observe. What we observe: a living fish, caught and filmed, with the same body plan as its fossils: lobed fins on stalks, a three-lobed tail, a hinged skull. Fossil coelacanths occur through many layer sets and are absent from all the layers above the Cretaceous, although the animal was alive.

How Christians read it. How Christians read it: the coelacanth was made after its kind and has stayed that kind. Its fossils were buried when the Flood tore up the sea floors; its living descendants survived in the sea. The gap in the record is not a gap in time but a gap in burial, and the whole column was laid down a few thousand years ago.

Try it. On a strip of paper, mark where coelacanth fossils occur in the column and where they are absent, then mark 1938 at the top.

Genesis 1:21

PICTURE STUDY



Fossil Fishes, Plate 62 from the Atlas to Recherches sur les poissons fossiles, Louis Agassiz (plates drawn largely by his illustrator Joseph Dinkel), 1833–1843 · Lithograph · Published in Neuchâtel, Switzerland; this scan is from the copy at Harvard's Museum of Comparative Zoology library

Louis Agassiz was a Swiss naturalist who, before he studied glaciers, spent ten years describing every fossil fish he could borrow from the museums of Europe. The result was five volumes of text and an atlas of hundreds of lithographed plates, drawn mostly by the artist Joseph Dinkel, who traveled with Agassiz and drew each fossil exactly as it lay in the stone. It was in this work that Agassiz named *Coelacanthus*, the hollow-spined fish, in 1839.

A plate like this is the opposite of a crowded scene such as *Duria Antiquior*. Nothing is imagined. Every scale and fin ray is drawn from the specimen, so that another scientist, a

thousand kilometers away, could check Agassiz's descriptions against the picture. This is what a museum sign would look like if it contained only observations.

Look closely

- Find the fin rays, the fine lines that stiffen each fin. Can you tell which fins are paired (one on each side) and which are single?
- Look at the scales. Count how many rows you can trace along the body of one fish.
- Notice how the artist handled broken or missing parts. Did he fill them in or leave them blank?
- Compare the tail of a fossil fish on the plate with the three-lobed tail in this lesson's coelacanth figure. What is the same and what is different?

Talk about it

1. Why would a scientist insist that his artist draw only what is in the stone?
2. What could Agassiz learn from fossils alone, and what could he not learn until a living coelacanth was caught in 1938?
3. Agassiz never knew a coelacanth was alive. What would he have made of the 1938 fish?

> **Safety first.** Use a tub of water on a towel or outdoors, and wipe up splashes. Cut cardboard paddles with adult help.

EXPERIMENT: LOBE FIN OR RAY FIN: WHICH PADDLE PUSHES MORE WATER?

A coelacanth's fins sit on muscular stalks and move like short legs. Most fish spread thin, fan-like ray fins straight from the body. You will build two paddle shapes and test which one moves a floating object farther with one stroke.

Question: does a stalked, narrow lobe paddle or a wide, flat ray paddle move more water per stroke? Prediction: write it. What we change: the paddle shape. What we keep the same: paddle area, stroke length, stroke speed as best you can, water depth, starting position of the float. What we measure: how far a cork or bottle cap travels after one stroke, in centimeters.

You will need

- Stiff cardboard or a plastic lid, scissors, ruler
- Two wooden skewers or pencils for handles, tape
- A large tub or baking dish of water, at least 5 cm deep
- A cork or plastic bottle cap as the float
- Measuring tape, lab notebook

Steps

1. Cut two paddles with the same area: a lobe paddle 3 cm wide and 8 cm long on a 6 cm stalk, and a ray paddle 6 cm wide and 4 cm long attached directly to the handle. Check

the area of each: 3 × 8 = 24 square cm and 6 × 4 = 24 square cm.
2. Tape each paddle to its handle. Mark a start line and place the float 5 cm in front of the paddle.
3. Dip the lobe paddle to the same depth each time and make one stroke of 10 cm toward the float at a steady speed. Measure how far the float traveled. Record it.
4. Repeat five times with the lobe paddle and five with the ray paddle, letting the water settle between strokes.
5. Make a table with the ten results and compute the average distance for each paddle.
6. Draw a bar graph: two bars, one per paddle, showing the average distance.
7. Write a conclusion: which shape pushed more water, by how much, and what in the design might explain it? Then write one sentence on why a stalked fin might still be useful for a fish that hovers and turns in caves.

Tips

- A steady stroke speed is the hardest control. Count “one-and” for every stroke to keep the timing even.
- If results are close, that is a real finding too. Repeat with ten strokes each and see if the averages separate.

Check your work

- I kept paddle area and stroke length the same and changed only the shape.
- I recorded ten trials, averaged them and drew a bar graph.
- I can explain one advantage of a lobe fin for a slow, hovering fish.

FIELD NOTEBOOK

1. Draw a coelacanth from the lesson figure at a scale of 1 : 10 and label the hinged skull, the two dorsal fins, the paired lobe fins and the three-lobed tail.
2. Make a gallery page of four living fossils (horseshoe crab, ginkgo leaf, nautilus shell, tuatara) with a one-line caption for each saying where its fossils are found.
3. Draw a strip of the fossil column and shade the layers in which coelacanth fossils occur; leave the top blank and write “no fossils, but alive” beside it.

> **From history.** Marjorie Courtenay-Latimer had wanted to be a nurse, but at twenty-four she was offered the job of curator at the East London Museum, which then held little more than a few stuffed birds and a dodo egg. She built its collections by hand, and Captain Goosen was one of many fishermen she had befriended on the docks. Her quick sketch, mailed with a letter on museum paper, is one of the most famous drawings in the history of zoology, and the museum still displays the mounted 1938 fish today.

WORKED EXAMPLES

Example 1. The 1938 coelacanth was about 1.5 m long. The largest living coelacanths reach about 2 m. You draw both at a scale of 1 : 10. How long is each drawing, and how much longer is the second than the first?

(Use the map or drawing "Use the scale bar to check your drawing." shown earlier in this lesson.)

1. At 1 : 10, divide real lengths by 10. 1.5 m = 150 cm, so 150 ÷ 10 = 15 cm.
2. 2 m = 200 cm, so 200 ÷ 10 = 20 cm.
3. Difference on paper: 20 − 15 = 5 cm, which stands for 50 cm of real fish.

Answer: 15 cm and 20 cm; the larger drawing is 5 cm longer, representing 50 cm of real length.

Example 2. Water pressure rises by about 1 atmosphere for every 10 m of depth, on top of the 1 atmosphere of air pressure at the surface. Coelacanths rest in caves at about 200 m. What is the total pressure there? How many times greater is it than the pressure at the surface?

1. Pressure from the water: 200 m ÷ 10 m per atmosphere = 20 atmospheres.
2. Add the air pressure at the surface: 20 + 1 = 21 atmospheres total.
3. Compare with the surface: 21 ÷ 1 = 21 times greater. This is why coelacanths brought up quickly to the surface do not survive, and why a fat-filled organ serves them better at depth than a gas-filled swim bladder.

Answer: About 21 atmospheres, 21 times the surface pressure.

Example 3. A museum timeline says coelacanths first appear in rocks dated about 400 million years and last appear in rocks dated about 66 million years, yet the fish is alive today. On the museum's own numbers, for what fraction of the coelacanth's claimed history is there no fossil at all? Express it as a percent.

1. Claimed history on the museum timeline: from 400 million years ago to now = 400 million years.
2. Gap with no fossils: from 66 million years ago to now = 66 million years.
3. Fraction = 66 ÷ 400 = 0.165, or 16.5%.
4. Conclusion, which both sides accept: on the museum's own timeline, the fish lived for about one-sixth of its history without leaving a single known fossil. Absence from the rocks does not prove absence of the animal.

Answer: About 16.5% of the claimed history, roughly one-sixth, has no fossils even though the fish was alive.

PRACTICE

1. EASY Who found the first living coelacanth, where and on what date? Who named it, and what name did he give?
2. EASY What is a living fossil? Name three besides the coelacanth.
3. EASY Name three features of the coelacanth that match its fossils.
4. MEDIUM A coelacanth is 1.8 m long. At a scale of 1 : 20, how long is the drawing in centimeters?
5. MEDIUM At about 1 atmosphere per 10 m of water plus 1 atmosphere of air, what is the total pressure at 150 m? At 250 m?
6. MEDIUM Data reading. A table lists five coelacanth specimens: lengths 1.50, 1.65, 1.80, 1.40 and 1.75 m; masses 57, 65, 80, 48 and 75 kg; capture depths 70, 180, 210, 150 and 240 m. (a) What is the average length? (b) Does mass rise with length in this table? (c) Which specimen was taken from the shallowest water, and how does it compare with the usual resting depth of 150 to 250 m?
7. MEDIUM Data reading. A bar graph shows fossil coelacanth finds by museum layer set: Devonian 12 kinds, Carboniferous 20, Permian 15, Triassic 25, Jurassic 18, Cretaceous 6, all higher layers 0. Living kinds today: 2. Describe the pattern, and state what the final two bars together show about using fossils to decide whether a creature has died out.
8. HARD Experiment design. You want to test whether fin shape affects how quickly a model can turn in place. Describe your question, the variable you change, three things you keep the same, what you measure, and how you would make the result reliable.
9. HARD In a paragraph, explain the two things the coelacanth teaches about the fossil record (stasis and gaps), and give the museum reading and the creation reading of each.
10. CHALLENGE J. L. B. Smith waited fourteen years for a second coelacanth while the Comoro islanders had been catching them all along. Write a short paragraph on what this shows about scientific knowledge, local knowledge and humility, and connect it to how you should read a museum sign that says a creature is extinct.

COMMON MISTAKES

- Thinking the living coelacanth is identical to every fossil coelacanth. The body plan is the same, but fossil kinds differ in size and habitat, and the living fish is its own genus, Latimeria.
- Thinking a creature’s last fossil marks the time it died out. The coelacanth has no fossils above the Cretaceous layers and is alive today; the record is a record of burial.
- Thinking the coelacanth has lungs or walks on land. It has a fat-filled organ instead of a swim bladder and moves its fins in a walking rhythm, but it is a fully aquatic deep-water fish.

> **Make it a game · Extinct or Alive?.** A parent reads out creature names mixed from two lists: living fossils (coelacanth, horseshoe crab, nautilus, ginkgo, tuatara, dawn redwood,

Wollemi pine, lungfish) and creatures known only from fossils (trilobite, ammonite, ichthyosaur, pterosaur, Stegosaurus). You call “alive” or “fossils only” and, for a bonus point, say where the living one lives or where the fossil one is found in the column. A wrong call costs a point. Play to twelve.

Scripture. “And God created great whales, and every living creature that moveth, which the waters brought forth abundantly, after their kind, and every winged fowl after his kind: and God saw that it was good.” (Genesis 1:21, KJV)

The coelacanth in the rocks and the coelacanth in the sea are the same kind. Scripture told us to expect that creatures reproduce after their kind, and this fish has done so through every layer in which it appears.

Practice answers

1. Marjorie Courtenay-Latimer, curator of the East London Museum in South Africa, found it in Captain Goosen’s catch on December 22, 1938. J. L. B. Smith named it Latimeria chalumnae in 1939.
2. A living creature that closely matches its fossils and has few close living relatives. Examples: horseshoe crab, nautilus, ginkgo, tuatara, dawn redwood, Wollemi pine.
3. Lobed fins on fleshy stalks, a three-lobed tail with a small middle lobe, a hinged skull, and hollow fin rays.
4. 180 cm ÷ 20 = 9 cm.
5. 150 m: 15 + 1 = 16 atmospheres. 250 m: 25 + 1 = 26 atmospheres.
6. (a) Sum 8.10 m ÷ 5 = 1.62 m. (b) Yes: as length rises from 1.40 to 1.80 m, mass rises from 48 to 80 kg in the same order. (c) The 1.50 m specimen at 70 m is shallower than the usual resting range, like the 1938 fish, which was trawled from shallower water than the caves where the fish normally rest.
7. Fossil kinds rise from the Devonian to a peak in the Triassic, fall through the Jurassic and Cretaceous, and drop to zero in all higher layers. Yet two kinds live today. The zero bar followed by a living bar shows that absence from the fossil layers does not prove extinction; the record is incomplete.
8. Question: does a stalked lobe paddle or a flat ray paddle turn a floating model faster? Change: paddle shape, with equal area. Keep the same: the model, water depth, stroke length and speed, starting orientation. Measure: the angle turned by one stroke with a protractor drawn on paper under the clear tub, or the time to turn 90 degrees. Reliability: at least five trials per shape, averaged, with the order of trials alternated so the water is equally settled.
9. Stasis: fossil and living coelacanths share the same body plan through every layer they appear in. The museum reads this as a stable deep-water home giving little reason to change; Christians read it as a creature made after its kind and remaining that kind. Gaps: no coelacanth fossils occur above the Cretaceous although the fish lives today. The museum says deep-sea sediments are rarely preserved on land; the creation reading says the upper layers formed in the aftermath of the Flood when deep-water fish were not being buried on land. Both agree that a missing fossil does not prove a missing creature.
10. Smith’s science was sound, but it was limited by where he had looked; the islanders knew the fish as food and never thought it remarkable. Knowledge grows when scientists listen and look in new places. A sign that says a creature is extinct really means no living one has yet been found, which is a statement about our searching as much as about the animal. The

humble reading is to treat “extinct” and “missing from the record” as claims open to revision, as the coelacanth proved in 1938 and again in 1952 and 1997.

3.4 Missing Transitions and How Each Side Explains Them

OBJECTIVES

- State what Darwin admitted in 1859 about gaps in the fossil record and name the fossils later offered as transitional forms.
- Describe three patterns a fossil series can show (gradual change, sudden change, stasis) and read them from a graph.
- Explain fairly how the museum reading and the creation reading each account for gaps, mosaics and the sudden appearance of body plans.

Warm-up. Take a deck of cards and remove, without looking, about half of them at random. Spread the rest in order by suit and number. How many places have a gap? Could someone who had never seen a full deck tell from your spread whether the missing cards ever existed? Write two sentences. This is the question of the whole lesson.

Video. Coming soon. Search for the Burgess Shale and Charles Walcott's 1909 discovery, Archaeopteryx and the Solnhofen limestone, and a fair short explainer on transitional fossils and punctuated equilibrium. Good sources: Smithsonian, Royal Ontario Museum, Natural History Museum London, SciShow, Moody Science classics. Watch with a parent and sort claims as observation or interpretation.

KEY TERMS

transitional form
A fossil claimed to stand between two major groups, with some features of each. Whether such fossils are true links or complete creatures of their own kind is the point in dispute.

mosaic
A creature with a mix of features usually found in different groups, each feature fully formed: the platypus, a mammal with a bill that lays eggs, is a living example.

stasis
A fossil kind staying the same in form through all the layers in which it appears.

punctuated equilibrium
The 1972 proposal by Niles Eldredge and Stephen Jay Gould that most fossil kinds show stasis, with change happening in short bursts too brief to leave many fossils.

Cambrian explosion
A museum word for the sudden appearance of most major animal body plans in the lowest fossil-rich layers, with no chain of ancestors beneath them.

created kind
A group of living things made by God to reproduce after its kind (Genesis 1:24–25). Variation happens within a kind; the creation reading expects gaps between kinds.

CORE IDEAS

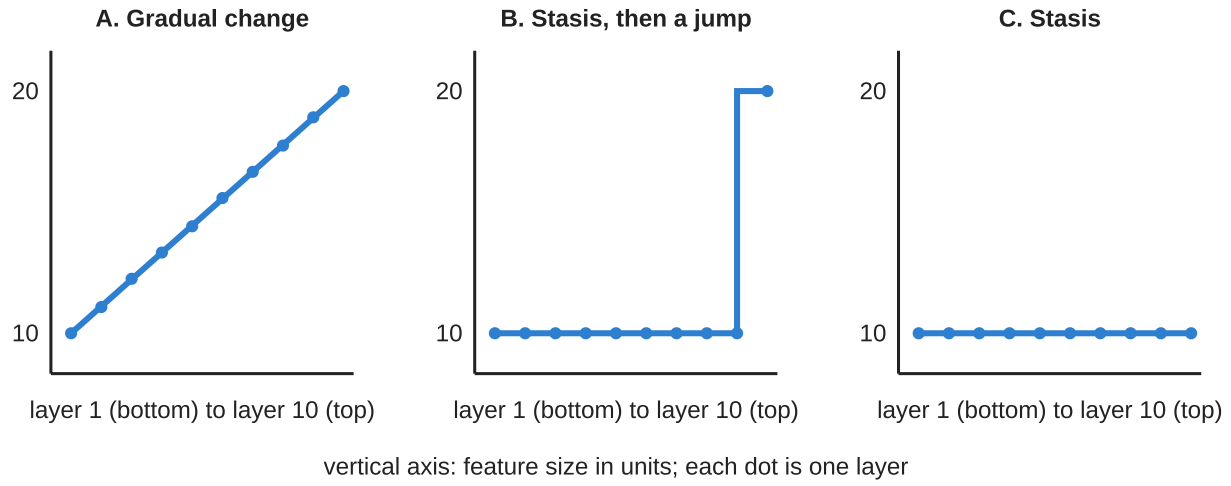
The story. In November 1859 Charles Darwin published *On the Origin of Species*, and he did something unusual for a man arguing a case: he wrote a whole chapter on the strongest evidence against himself. If living things had changed slowly from one form into another, the rocks should be full of in-between creatures. He wrote, “Why then is not every geological formation and every stratum full of such intermediate links? Geology assuredly does not reveal any such finely graduated organic chain; and this, perhaps, is the most obvious and gravest objection which can be urged against my theory.” His answer was that the record is extremely imperfect, like a book with most of its pages torn out. Two years later, in 1861, a quarry worker in the fine limestone of Solnhofen, Bavaria, turned up a crow-sized skeleton with the clear impression of feathers, together with teeth, clawed fingers and a long bony tail. Named *Archaeopteryx*, it was bought by the British Museum and described by Richard Owen in 1863, and it has been on museum signs as “the first bird” ever since.

How they figured it out. Over the next century and a half, museums gathered a short list of fossils presented as **transitional forms**. Besides *Archaeopteryx*, the best known are *Tiktaalik*, a flat-headed fish with sturdy fins found on Ellesmere Island in the Canadian Arctic in 2004 and announced in 2006, and a series of skeletons from Pakistan and Egypt, such as *Pakicetus* and *Basilosaurus*, that museums place between land mammals and whales. At the same time, two careful paleontologists, Niles Eldredge and Stephen Jay Gould, looked hard at the fossil series that had actually been dug up and reported in 1972 that most kinds show **stasis**: they appear suddenly, stay the same through all their layers, and disappear. They called their idea **punctuated equilibrium** and insisted that stasis was real data, not an absence of data. And the lowest fossil-rich layers posed their own puzzle. When Charles Walcott, the head of the Smithsonian, found the Burgess Shale in British Columbia in 1909, his quarry yielded about 65,000 specimens of complex animals with eyes, legs, gills and guts, all in layers museums call Cambrian, with nothing like a chain of simpler ancestors beneath them. Darwin had already admitted he had no satisfactory answer for that sudden appearance.

The big idea. Both sides agree on a surprising amount. The record is incomplete; the coelacanth proved that absence from the rocks is not absence from the world. Stasis is the common pattern. Major body plans appear abruptly in the Cambrian layers. The fossils offered as transitions are few compared with the gaps. Where the two sides part is in what these facts mean. The **museum reading** says gaps are expected because fossilization is rare and change happens quickly in small populations; the few transitional fossils show that the links were real; the Cambrian animals had soft-bodied ancestors that rarely fossilized; and stasis means a creature was well fitted to a stable home. The **creation reading** says gaps are expected because God made living things as separate **kinds** that reproduce after their kind; the famous transitional fossils are **mosaics**, complete creatures with a mix of fully formed features, as the living platypus is (the feathers of *Archaeopteryx* are flight feathers like a modern bird’s); the Cambrian layers are the first zones torn up by the Flood, full of creatures complete since creation; and stasis is exactly what “after their kind” predicts.

How to weigh it. A good reader does not pretend the other side has no answer. The museum reading explains the gaps by adding an idea, the imperfection of the record, that cannot be seen directly, and it reads each mosaic as a link. The creation reading explains the gaps as real boundaries, and it must then account for why mosaics exist at all, which it does by pointing out that a mix of features is a design pattern seen in living animals too. Each side predicts something. The museum reading predicts that more digging will keep turning up finely graded chains; the creation reading predicts that new finds will mostly be complete creatures of recognizable kinds, with variation inside the kind. Watch the news from museums with this in mind, asking which prediction each new fossil fits.

In the world today. When you stand in front of a sign that says “transitional fossil,” do what you did in Lesson 3.1. Find the observations: the bones, the feathers, the size, the layer. Find the inferences: it could fly a little, it lived in shallow water. Find the interpretation: it is the ancestor of birds or the cousin of whales. Then give the other reading beside it, plainly and kindly. The person who wrote the sign is usually a careful scientist who has handled the bones, and the right response to careful work is careful reading, not scorn. Unit 8 will give you practice in a real museum.



Three patterns a fossil series can show. Gradual change (left) is what Darwin expected. Stasis with a sudden jump (middle) and plain stasis (right) are what Eldredge and Gould reported as the common findings.

⏳ Thinking About Time

What the sign says. What the sign says: gaps between major groups come from an incomplete record, and fossils such as Archaeopteryx, Tiktaalik and the early whales are transitional forms that link the groups across tens of millions of years. The Cambrian layers, dated about 540 to 485 million years, record the rapid evolution of animal body plans.

What we observe. What we observe: distinct body plans in the rocks; most major groups fully formed in the lowest layers in which they appear; stasis as the usual pattern through a kind’s layers; a small number of mosaic fossils with fully formed features from more

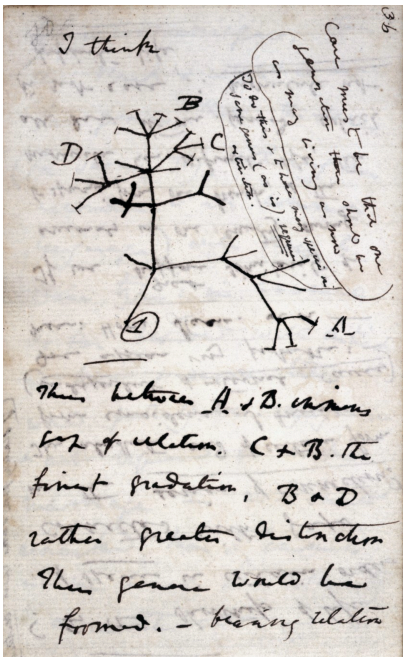
than one group; and complex Cambrian animals with no chain of simpler ancestors beneath them.

How Christians read it. How Christians read it: God made living things as separate kinds that reproduce after their kind, so gaps between kinds are expected and stasis within kinds is expected. Mosaic creatures are complete designs, like the living platypus. The Cambrian layers are the first sea-floor zones buried by the Flood, a few thousand years ago, not the record of a long unfolding.

Try it. Pick one fossil from a museum website and write its observations, inferences and both readings in a four-row table.

Genesis 1:24

PICTURE STUDY



The "Tree of Life" sketch from Notebook B, Charles Darwin, 1837 · Pen and ink on paper · Cambridge University Library, England

In the summer of 1837, a year after returning from his voyage on HMS *Beagle*, Charles Darwin opened a small notebook he labeled B and drew this branching diagram, writing "I think" above it. It is the first picture of his idea that all living things descend from common ancestors along branching lines. The letters at the tips mark living kinds; the forks below them are the links he expected the rocks to supply.

This page is worth studying because it shows what a scientific idea looks like before the evidence is in. Twenty-two years later Darwin would admit in print that geology had not revealed the finely graded chain the sketch implies. Looking at the sketch, you can ask the question he asked: where in the rocks are the forks?

Look closely

- Find the words “I think.” Why would a scientist write that above a drawing instead of “I know” or “I have shown”?
- Count the branch tips and the forks. Each fork is a place where the sketch expects a creature partway between two others. How many such creatures does the little tree require?
- Notice the line at the base marked with the number 1. What does the sketch claim about that single starting point?
- Look at the handwriting around the sketch. Does the page look like a finished argument or a private thought?

Talk about it

1. What would the fossil record have to contain to fill in every fork in this sketch?
2. A creation reading would draw living things as a grove of separate trees, one per kind, each with many branches. How would the two pictures differ, and how would they look alike?
3. Darwin wrote his doubts plainly in his book. What can you learn from that about how to argue your own view?

EXPERIMENT: THE SAMPLING JAR: HOW MUCH OF A RECORD DO WE SEE?

Both readings agree that the fossil record is a sample, not a complete list. This experiment shows how sample size controls how many kinds you discover, and how rare kinds can stay hidden.

Question: how does the number of items drawn from a mixed jar change the number of kinds found? Prediction: write it. What we change: the sample size (10, 20, 40, 80 items). What we keep the same: the jar and its contents, mixing before each draw, drawing without looking. What we measure: the number of different kinds found in each sample.

You will need

- About 200 small mixed items of 8 kinds: dried beans of different varieties, buttons, beads or colored paper squares
- A jar or bowl, a cloth to cover it
- A card listing the true contents, prepared by a parent: for example, 60 of kind A, 50 of B, 40 of C, 25 of D, 15 of E, 6 of F, 3 of G and 1 of H
- Lab notebook, graph paper

Steps

1. Have a parent fill the jar according to the card, with some kinds common and two or three kinds rare, without showing you the card.
2. Cover the jar, mix it, and draw 10 items without looking. Record how many different kinds you found. Return the items and mix again.

3. Repeat with 20 items, then 40, then 80. Record the number of kinds each time.
4. Do the whole set of four draws twice more, so you have three results for each sample size. Average them.
5. Plot a line graph: sample size on the horizontal axis, average kinds found on the vertical axis.
6. Now ask for the card. Which kinds did your samples miss, and how many of each were in the jar? Were the missed kinds the rare ones?
7. Write a conclusion of three sentences, then a fourth sentence applying it to fossils: what kind of creature is most likely to be missing from the rocks, and does its absence prove it never lived?

Tips

- The graph usually rises steeply at first and then levels off. The leveling point tells you when more sampling stops finding new kinds.
- If you found all eight kinds by the 80-item draw, make the rare kinds rarer and try again.

Check your work

- I recorded three trials at each of four sample sizes and averaged them.
- I drew a line graph of kinds found against sample size.
- I can explain why rare creatures are the ones most likely to be missing from any sample, including the rocks.

FIELD NOTEBOOK

1. Copy the three pattern graphs from the figure and label each with its name and the scientist who expected or reported it (Darwin; Eldredge and Gould).
2. Draw Archaeopteryx from a museum photograph, labeling feathers, teeth, clawed fingers and the long bony tail, and write the two readings beneath it in two columns.
3. Draw a Cambrian trilobite from the Burgess Shale and note its eyes, segments and legs. Write one sentence on what is beneath it in the rocks.

> **From history.** Charles Doolittle Walcott, the fourth Secretary of the Smithsonian Institution, found the Burgess Shale in late August 1909 while on a collecting trip in the Canadian Rockies with his family. He came back season after season, quarrying by hand high on a mountainside, and shipped his finds to Washington, where the roughly 65,000 specimens are still kept. Walcott was a trilobite specialist who had started work as a farm laborer and a hardware clerk, and he never earned a college degree.

WORKED EXAMPLES

Example 1. A 120 m cliff of layered rock has fossils in only three thin beds totaling 6 m of thickness. The rest of the layers are barren. What percent of the cliff's thickness holds any fossils at all? If creatures lived during the whole time the cliff's layers formed (on either reading), what does this say about how complete a record the cliff can give?

1. Percent fossil-bearing = (6 ÷ 120) × 100 = 5%.
2. Barren thickness = 120 − 6 = 114 m, which is 95% of the cliff.
3. A record can only hold what was buried in those 6 m. Anything alive while the other 114 m formed, but not buried in a fossil bed, left no trace here. Both readings accept that most of what lived was never recorded.

Answer: 5% of the thickness holds fossils; 95% is barren, so the cliff can record only a small sample of what lived.

Example 2. Use the three graphs in the figure. In graph A a feature measures 10 units in layer 1 and 20 units in layer 10, rising evenly. In graph B it measures 10 units in layers 1 through 9 and 20 units in layer 10. In graph C it measures 10 units in every layer. Find the average change per layer across all ten layers for each graph, and explain why averages can hide the difference between A and B.

(Use the map or drawing "Graph A: gradual. Graph B: stasis then a jump. Graph C: stasis." shown earlier in this lesson.)

1. Total change from layer 1 to layer 10 spans 9 steps. Graph A: (20 − 10) ÷ 9 ≈ 1.1 units per step, the same at every step.
2. Graph B: total change is also 20 − 10 = 10 units over 9 steps, so the average is also about 1.1 units per step. But the actual change is 0 for eight steps and 10 units in the final step.
3. Graph C: (10 − 10) ÷ 9 = 0 units per step. Pure stasis.
4. A and B have the same average but opposite patterns. Only looking layer by layer reveals that B is stasis plus a jump, which is why Eldredge and Gould studied the whole series instead of just the ends.

Answer: A ≈ 1.1 units per step, steady. B ≈ 1.1 units per step on average, but really 0 then 10. C = 0. The average alone cannot tell A from B.

Example 3. Charles Walcott’s quarry in the Burgess Shale yielded about 65,000 specimens between 1909 and 1924. (a) On average, how many specimens is that per year over the 15 years? (b) If one scientist can carefully examine and label 20 specimens per working day, how many working days would the whole collection take, and about how many years at 250 working days per year?

1. (a) 65,000 ÷ 15 = 4,333, about 4,300 specimens per year.
2. (b) 65,000 ÷ 20 = 3,250 working days.
3. 3,250 ÷ 250 = 13 years for one person. This is why the Burgess Shale was still being described decades after Walcott died, and why museum signs about it keep changing.

Answer: (a) About 4,300 specimens per year. (b) 3,250 working days, about 13 years of one scientist’s work.

PRACTICE

1. EASY What did Darwin call “the most obvious and gravest objection” to his theory, and what was his explanation?
2. EASY Name three fossils that museums present as transitional forms, and the group each is said to link.
3. EASY What is a mosaic creature? Give a living example.
4. MEDIUM A 90 m section has fossils in 4.5 m of its layers. What percent of the section is fossil-bearing?
5. MEDIUM In what year did Walcott find the Burgess Shale, where is it, and what museum word names its layers?
6. MEDIUM Data reading. A survey of animal body plans (phyla) with fossils reports where each body plan first appears: in layers below the Cambrian, 3 body plans; in Cambrian layers, 17 body plans; in all layers above the Cambrian combined, 2 body plans. (a) How many body plans are in the survey? (b) What percent of them first appear in the Cambrian layers? (c) Which reading does each side give of this pattern?
7. MEDIUM Data reading. A fossil snail species is measured in eight layers, bottom to top. Shell height in mm: 12, 12, 13, 12, 12, 13, 12, 12. Which pattern from the figure does this show, and what name did Eldredge and Gould give it? What is the total change from the lowest to the highest layer?
8. HARD Experiment design. Design an experiment, using a jar of mixed items, to test whether rare kinds are more likely to be missed by small samples than common kinds. State the variable you change, what you keep the same, what you measure, and how many repeats you would run.
9. HARD Write a paragraph giving the museum reading and the creation reading of Archaeopteryx, using at least three observations about the fossil.
10. CHALLENGE Each reading makes a prediction about future fossil finds. State both predictions, then describe one imaginary new fossil that would fit the museum

prediction better and one that would fit the creation prediction better.

COMMON MISTAKES

- Thinking Darwin claimed the fossil record proved his theory. He admitted in 1859 that the record lacked the intermediate chain he expected and blamed its imperfection.
- Thinking a mosaic creature must be half-made. Each feature of Archaeopteryx or the platypus is fully formed; the dispute is over what the mix of features means.
- Thinking the two readings disagree about everything. They agree on the bones, on stasis, on the sudden Cambrian appearance and on the incompleteness of the record; they disagree on what those facts mean.

Make it a game · Two Readings, One Fossil. Write the names of six fossils on cards: Archaeopteryx, Tiktaalik, Basilosaurus, a Burgess Shale trilobite, a fossil coelacanth, a fossil horseshoe crab. Draw a card. One player gives the museum reading in two sentences; the other gives the creation reading in two sentences. A parent awards a point for each reading that is accurate and fair and a bonus point to anyone who states an observation both sides share. Players switch sides every card. Six cards, highest score wins, and no scorn allowed.

Scripture. “And God said, Let the earth bring forth the living creature after his kind, cattle, and creeping thing, and beast of the earth after his kind: and it was so. And God made the beast of the earth after his kind, and cattle after their kind, and every thing that creepeth upon the earth after his kind: and God saw that it was good.” (Genesis 1:24–25, KJV)

Five times in two verses the phrase “after his kind” or “after their kind” is repeated. The creation reading of the fossil gaps rests on this: kinds were made as kinds, and the rocks show boundaries between them.

Practice answers

1. The absence of a finely graduated chain of intermediate fossils in the rocks. He explained it by the extreme imperfection of the geological record.
2. Archaeopteryx (reptiles to birds), Tiktaalik (fish to four-legged animals), and the early whale series such as Pakicetus and Basilosaurus (land mammals to whales).
3. A creature with a mix of fully formed features usually found in different groups. The platypus is a mammal with fur and milk that also lays eggs and has a bill.
4. 4.5 ÷ 90 = 0.05, so 5%.
5. 1909, in the mountains of British Columbia, Canada; the layers are called Cambrian.
6. (a) 3 + 17 + 2 = 22 body plans. (b) 17 ÷ 22 = 0.77, about 77%. (c) Museum reading: rapid evolution of body plans, with soft-bodied ancestors rarely preserved. Creation reading: complete created kinds of the sea floor, the first zone buried in the Flood.
7. Graph C, stasis. Total change: 12 − 12 = 0 mm; the small ups and downs are within normal variation.

8. Change: the sample size (for example 10, 30, 90 items). Keep the same: the jar contents (with known common and rare kinds), mixing, drawing without looking, returning items between draws. Measure: for each sample size, whether each rare kind and each common kind was found, recorded as a percent of trials in which it appeared. Repeat each sample size ten times and compare the discovery rate of rare kinds with that of common kinds.
9. Observations: it is crow-sized; it has flight feathers preserved in fine limestone; it has teeth, clawed fingers and a long bony tail. Museum reading: it is a transitional form between small reptiles and birds, showing feathers appearing on a reptile-like skeleton. Creation reading: it is a mosaic, a complete flying creature of its own kind with fully formed feathers, just as the platypus is a complete creature with a mix of features. Both agree on the observations; they differ on what the mix means.
10. Museum prediction: more digging will reveal finely graded series of forms between major groups. Creation prediction: new finds will mostly be complete creatures of recognizable kinds, with variation inside kinds and gaps between them. A fossil fitting the museum prediction better: a long series of skeletons in successive layers showing a smooth step-by-step change from fins to legs with every stage present. A fossil fitting the creation prediction better: another fully formed animal with a distinct body plan appearing in its lowest layer with nothing like it beneath, or a living fossil found alive after a long gap.

Unit 3 review

Answer each question. Show your work for calculations and use complete sentences for explanations. Questions 1 to 4 are multiple choice (3 points each). Questions 5 to 12 are short answer or drawing (6 points each). The test is worth 60 points.

1. (3 pts) Which sentence from a museum sign is an observation? (a) “It lived 66 million years ago.” (b) “The skeleton is about 12 m long.” (c) “It was a relative of birds.” (d) “It hunted in packs.”
2. (3 pts) William Smith’s principle of faunal succession says: (a) all layers are the same age; (b) fossils occur in a definite order through the layers, so a layer can be recognized by its fossils; (c) heavier fossils always sink to the bottom; (d) the geologic column can be seen complete in one place.
3. (3 pts) The first living coelacanth was found in: (a) Indonesia, 1997; (b) the Comoro Islands, 1952; (c) East London, South Africa, 1938; (d) Solnhofen, Bavaria, 1861.
4. (3 pts) Eldredge and Gould reported in 1972 that most fossil kinds show: (a) steady gradual change; (b) stasis, staying the same through their layers; (c) no variation of any kind; (d) a smooth chain of intermediate forms.
5. (6 pts) Explain why most fossils required rapid burial, and show the arithmetic: a carcass needs 1 m of sediment to be sealed and would be gone in 6 months. Compare burial at 2 mm per year with burial at 10 cm per hour.
6. (6 pts) Where does the number “66 million years” on the Nation’s T. rex sign come from, and what three assumptions does it depend on? State the creation reading in one sentence.
7. (6 pts) Diagram item. Draw the general fossil column as a stack of five layers above basement rock. In each layer write the typical fossils, bottom to top. On the left label the museum words for at least three layers, and on the right label the habitat zone of the creation reading for each layer.
8. (6 pts) Index fossil M occurs in layers 3 to 7 and fossil N in layers 6 to 10. A sample holds both. Which layers are possible? Then state in two sentences what ecological zonation says about why sea-floor animals lie below land animals.
9. (6 pts) The 1938 coelacanth was about 1.5 m long. At a scale of 1 : 10, how long is the drawing? Then name three features of the living fish that match its fossils.
10. (6 pts) No coelacanth fossils are found in any layer above the Cretaceous, yet the fish is alive. Explain what this shows about the fossil record, and give the museum reading and the creation reading of the gap.
11. (6 pts) Data reading. A fossil series is measured in ten layers. Series P: 8, 8, 8, 8, 8, 8, 8, 8, 8, 16 mm. Series Q: 8, 9, 10, 11, 12, 13, 14, 15, 16, 16 mm. For each, compute the total change from the first layer to the last and name the pattern (gradual, stasis then jump, or stasis). Which pattern did Darwin expect, and which did Eldredge and Gould report as common?
12. (6 pts) In a paragraph, give the museum reading and the creation reading of the gaps between major groups in the fossil record. Include at least two facts both sides agree

on, and end with one sentence on how to speak about the difference kindly.

UNIT PROJECT: TWO READINGS OF THE FOSSIL RECORD: A POSTER

Make a large poster with the general fossil column drawn to scale from your own measured-section exercise, with typical fossils drawn in each layer, the museum words on the left and the creation reading's habitat zones on the right. Mark where fossil coelacanths occur and where they are absent, mark the layers of Archaeopteryx and the Burgess Shale, and add your 1 : 10 coelacanth drawing.

Beside the column, mount your sorting-jar sketch, your sampling-jar graph and a copied museum label sorted into observations, inferences and interpretations. Finish with two short paragraphs in your own words: what the museum sign says, and how Christians read it, each stated accurately and without scorn.

- **Accuracy**: Fossil order, museum words, habitat zones and the marked positions of the coelacanth, Archaeopteryx and the Burgess Shale are correct.
- **Records**: The sorting-jar sketch, sampling graph and sorted museum label are complete, measured in metric units and clearly labeled.
- **Explanation**: The two paragraphs state each reading fairly, name the assumptions behind the museum date, and point to observations both sides share.
- **Care**: The poster is drawn to scale, neat, well labeled and easy to read from a meter away.

Answer key

1. (b)
2. (b)
3. (c)
4. (b)
5. Scavengers, bacteria and weather destroy a body within months, so only quick covering by sediment preserves it. At 2 mm per year, 1,000 mm takes 500 years, far longer than the carcass lasts. At 10 cm per hour, 100 cm takes 10 hours, fast enough to seal it. Most fossils therefore record rapid burial.
6. From measurements of radioactive decay in crystals from volcanic ash beds above and below the bones. It assumes a known starting amount, a constant decay rate, and no atoms gained or lost since the crystals formed. Creation reading: the layers were laid down rapidly in the Flood year and its aftermath a few thousand years ago, which also explains the rapid burial.
7. Bottom to top: sea-floor animals (trilobites, brachiopods, corals; museum: Cambrian, Ordovician, Silurian; zone: sea floor); fish (Devonian; shallow seas); ferns, insects, amphibians, coal (Carboniferous, Permian; coastal swamps); reptiles and dinosaurs (Jurassic, Cretaceous; lowland plains); mammals, birds, flowering plants (Cenozoic; uplands, most mobile). Basement rock below with no animal fossils. Award full marks for correct order, correct fossils, three museum words and the zones.
8. Layers 6 and 7. Ecological zonation says creatures lived in zones before the Flood, with shellfish on the sea floor and land animals on higher ground. As the waters rose, the lowest zones were torn up and buried first, so sea-floor animals lie lowest.

9. 150 cm ÷ 10 = 15 cm. Features: lobed fins on fleshy stalks, a three-lobed tail, a hinged skull, hollow fin rays (any three).
10. It shows that absence from the rocks does not prove absence of the animal; the record is incomplete and records burial, not all of life. Museum reading: the fish retreated to deep water where sediments are rarely preserved on land. Creation reading: the upper layers formed after the Flood when deep-water fish were not being buried on land; the fish was made after its kind and has stayed that kind.
11. P: 16 − 8 = 8 mm; stasis then a jump. Q: 16 − 8 = 8 mm; gradual change. Darwin expected gradual change; Eldredge and Gould reported stasis, often ending in sudden change, as the common pattern.
12. Both sides agree the record is incomplete, that stasis is common, that major body plans appear abruptly in the Cambrian layers, and that the famous transitional fossils are few. Museum reading: gaps come from rare fossilization and rapid change in small populations, and fossils such as Archaeopteryx and Tiktaalik are links. Creation reading: gaps are real boundaries between created kinds that reproduce after their kind; the mosaics are complete creatures, and the layers record Flood burial. A kind speaker states the observations first, gives the other reading accurately, and treats the scientist who wrote the sign as a careful worker rather than an enemy.

UNIT 4

The Flood Year

Genesis 7:11 begins the Flood with a date: the six hundredth year of Noah's life, the second month, the seventeenth day. In this unit you will read Genesis 6–9 the way the text asks to be read, as a dated record of a real year, and build its calendar from the verses themselves: forty days of rain, 150 days of prevailing water, the Ark grounding on the mountains of Ararat, the raven and the doves, and the earth dried on the twenty-seventh day of the second month of the following year.

Then you will test the record. You will convert the Ark's 300 by 50 by 30 cubits to meters, compute its volume and displacement, and learn how a team of Korean ship engineers in 1994 ran its proportions through the same stability calculations they use for tankers. You will meet George Smith, the London engraver who read the Babylonian flood tablet in 1872, and lay the world's flood legends in a data table beside Genesis. Finally you will ask what a flood of that size would leave behind, walk the Channeled Scablands with J Harlen Bretz, and run a dam burst in a tray of sand.

Every lesson in this unit carries a Thinking About Time box. You will learn what the textbooks and museum signs say, state it fairly, separate it from what can actually be measured, and set the young-earth reading beside it. The goal is a student who can read any sign accurately and still think for himself.

BEFORE YOU BEGIN

- Knows Steno's principles of superposition, original horizontality and lateral continuity (Unit 1)
- Can read a stratigraphic column and explain flat gaps and rapid layering in a flume (Unit 2)
- Can convert units (cm, m, km) and compute volume of a box and simple ratios and percents
- Has read Genesis 6–9 at least once with a parent

MASTERY CHECKLIST

- I can retell the Flood year in order with its dates from Genesis 7–8 and compute its length from 30-day months.
- I can convert the Ark's dimensions to meters, compute its volume and displacement, and explain why a long, wide, low box is a stable shape.
- I can describe what the 1994 Korean study tested and what its result does and does not show.
- I can compare at least four flood accounts with Genesis in a data table and state the three explanations scholars give for the sharing.
- I can list four things a worldwide flood would leave behind and name a place where each is observed.

- I can state what a museum sign says, what is observed, and how Christians read it, without mocking either side.

OPTIONAL BOOKS AND RESOURCES

- **Ice Age Floods National Geologic Trail (National Park Service)** (https://www.nps.gov/iafl/): Free. Maps, photographs and short explanations of the Missoula floods, Dry Falls, the giant ripples and the scablands for Lesson 4.4. Read the dates on the pages as the sign's claim and compare with the lesson's time note.
- **USGS Water Science School** (https://www.usgs.gov/special-topics/water-science-school): Free. Clear pages on river flow, sediment, floods and how discharge is measured in cubic meters per second, useful for the Lake Missoula calculation.
- **The King James Bible at Project Gutenberg** (https://www.gutenberg.org/ebooks/10): Free. A searchable KJV text for building the Flood timeline from Genesis 7–8 and for checking every verse quoted in the unit.

4.1 Genesis 6–9 as History ★

OBJECTIVES

- Retell the Flood account of Genesis 6–9 in order, using the dates the text gives, and explain why those dates mark it as a historical record rather than a poem or parable.
- Build a timeline of the Flood year from Genesis 7:11 to 8:14, calculate the length of a month and of the whole Flood year, and state what the waters did in each phase.
- State what mainstream textbooks say about the Flood, what is actually observed today, and how Christians who read Genesis as history respond.

Warm-up. Find two short passages in your Bible: Psalm 104:6–9 and Genesis 7:11–12. Read both aloud. One is a song and one is a report. Which one gives a date? Which one uses pictures like “the waters stood above the mountains”? Write one sentence on how you can tell a logbook from a hymn.

Video. Coming soon. Noah’s Flood timeline from Genesis 7 and 8 explained, and Leonard Woolley’s 1929 flood layer at Ur; look for Moody Science classics, Bible-history documentary channels, British Museum lectures on Ur, and homeschool Bible-overview channels.

KEY TERMS

fountains of the great deep
The underground and undersea sources of water that Genesis 7:11 says were “broken up” on the first day of the Flood; the text names them before it names rain.

windows of heaven
The Bible’s phrase for the opening of the sky that brought forty days and nights of rain (Genesis 7:11–12).

cubit
An ancient unit of length from the elbow to the fingertip, about 45 cm; the Ark’s measurements are given in cubits.

chronology
The ordering of events by date. Genesis 7–8 gives year, month and day for the main events of the Flood.

narrative prose
Plain reporting language with names, places, dates and measurements, as opposed to the parallel lines and word pictures of Hebrew poetry.

covenant
A solemn, binding promise. After the Flood God made a covenant never again to destroy the earth with a flood and set the rainbow as its sign (Genesis 9:11–17).

CORE IDEAS

The story. “In the six hundredth year of Noah’s life, in the second month, the seventeenth day of the month.” That is how Genesis 7:11 begins the Flood, like the first line of a ship’s log. A real man, Noah, had spent years building a wooden vessel 300 cubits long on dry land because God had told him a flood was coming (Genesis 6:13–22). Seven days before the water came, he, his wife, his three sons and their wives went aboard with the animals (Genesis 7:7–10). Then, on a day the text names exactly, two things happened at once: “all the fountains of the great deep” were broken up and “the windows of heaven were opened.” Rain fell forty days and forty nights. The waters rose until “all the high hills, that were under the whole heaven, were covered,” and they stood fifteen cubits above the mountains (Genesis 7:19–20). That is the plain report, told without a word of poetry.

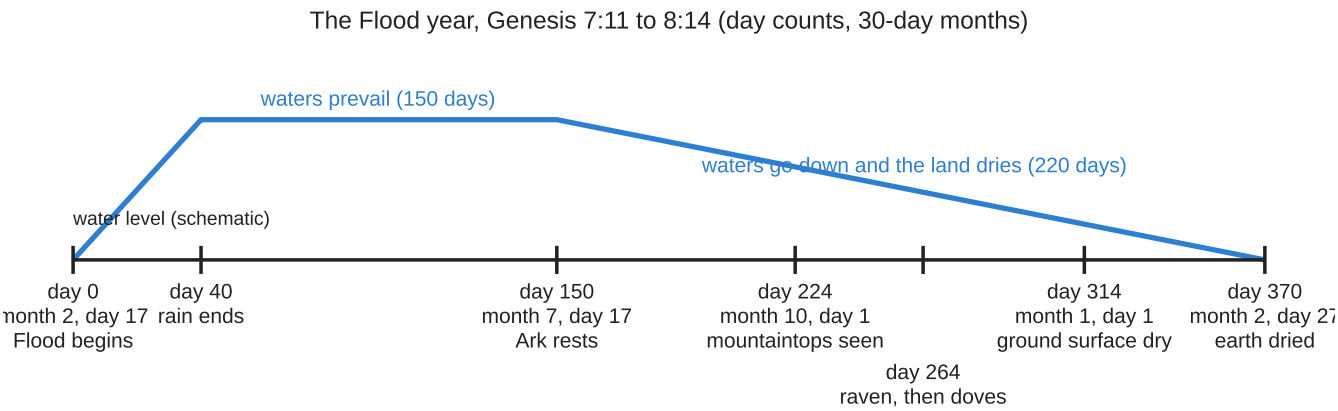
How they figured it out. From the dates in Genesis 7–8 a whole calendar of the Flood year can be built. The waters rose and “prevailed” for 150 days (Genesis 7:24). On the seventeenth day of the seventh month the Ark grounded “upon the mountains of Ararat” (Genesis 8:4). From the seventeenth of the second month to the seventeenth of the seventh month is exactly five months, and the text calls it 150 days, so each month in this calendar was 30 days long. On the first day of the tenth month the mountaintops showed. After forty more days Noah opened the window and sent out a raven, then a dove three times, a week apart; the second dove came back with a fresh olive leaf (Genesis 8:6–12). On the first day of the first month of Noah’s 601st year he removed the Ark’s covering and saw that the surface of the ground was dry. On the twenty-seventh day of the second month “was the earth dried,” and God told the family to come out (Genesis 8:13–16). Add it up: 360 days for twelve months, plus ten more days, is a Flood year of about 370 days.

The big idea. Genesis 6–9 is written as history, and the rest of the Bible treats it as history. It gives names (Noah, Shem, Ham, Japheth), a place (the mountains of Ararat), exact measurements (300 by 50 by 30 cubits, water 15 cubits over the hills) and exact dates. Genealogies run straight through it on both sides (Genesis 5 and 11), tying Noah to Adam before him and Abraham after him. Jesus spoke of “the days of Noe” as real days with real eating, drinking and marrying that ended “the day that Noe entered into the ark” (Luke 17:27). Peter wrote that the world that then was “being overflowed with water, perished” (2 Peter 3:6), and the writer of Hebrews lists Noah among people who really lived (Hebrews 11:7). Compare this with Psalm 104:6–9, which sings about the same waters in picture language: “at thy rebuke they fled.” The Bible has both kinds of writing, and a good reader knows which is which. Genesis 7 is the logbook; Psalm 104 is the hymn.

In the world today. Most earth-science textbooks say there never was a worldwide flood. They say the rock layers of the continents took hundreds of millions of years to form by the slow processes we watch today, and that Genesis is a retelling of older Mesopotamian flood stories, perhaps based on a large river flood in what is now Iraq. In 1929 the archaeologist Leonard Woolley, digging at Ur, found about three meters of clean, water-laid silt with no pottery in it, and he telegraphed home that he had found the Flood. Later digging showed the silt layer did not reach even the nearby cities, so it was a local river flood. A single local layer cannot prove a worldwide flood, and it cannot disprove one either. In this unit we will

take the Genesis record seriously as a historical claim and then ask, in Lesson 4.4, what a flood of that size would leave behind, and go and look.

God's handiwork. The Flood account ends not with wreckage but with a promise. God smelled the sweet savor of Noah's offering and said that "while the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease" (Genesis 8:22). Then He set His bow in the cloud as the token of a covenant with every living creature (Genesis 9:13). Every rain gauge, tide table and planting calendar depends on a world that keeps its rhythms; the regularity we measure in Earth Science is a kept promise. And every rainbow, red on the outside and violet on the inside, is sunlight bent and split by raindrops, the same rain that once fell for forty days, now turned into a sign of mercy.



The Flood year from the dates in Genesis 7–8, counted with 30-day months. The blue line shows the water rising for 40 days, prevailing to day 150, and then going down.

⏳ Thinking About Time

What the sign says. What the sign says: standard textbooks say there was no worldwide flood. The continents' rock layers formed slowly over hundreds of millions of years, and the Genesis story is a later version of Mesopotamian flood legends, perhaps remembering a large river flood in southern Iraq several thousand years ago.

What we observe. What we observe: Genesis 7–8 gives year, month and day for its events, exact measurements in cubits, and names tied to genealogies, which is how history is written, not how myths are written. Sedimentary rock, laid down by water, covers about three quarters of the land surface of the earth. Marine fossils such as shells and crinoids are found high on every continent, including the limestone near the summit of Mount Everest. A flood layer dug up at one city, like Woolley's at Ur, tells us only about that city.

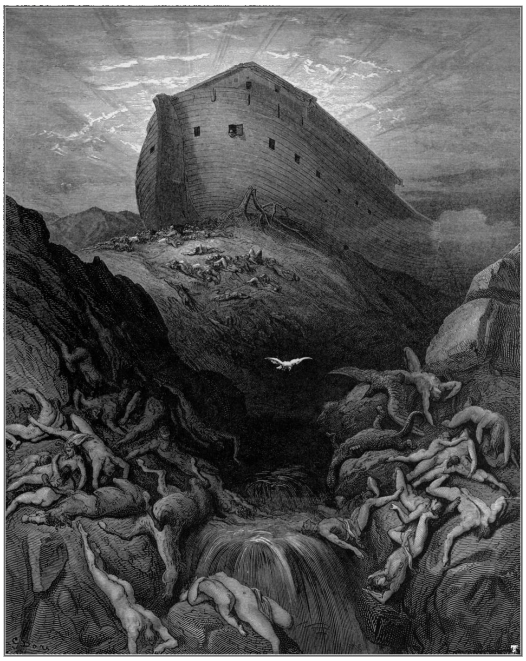
How Christians read it. How Christians read it: the Flood was a real, worldwide event, and Jesus, Peter and the writer of Hebrews spoke of it as one. Counting the Bible's own genealogies, Archbishop James Ussher in 1650 placed the Flood at 2348 BC, so the Flood year was roughly 4,400 years ago. Creation geologists expect much of the world's

sedimentary rock to be the Flood's own deposit, which is the question Lesson 4.4 takes up. The textbook reading rests on the assumption that the past worked only at today's slow rates; the observations themselves do not require that assumption.

Try it. Write the Genesis 7:11 date and the Ussher date side by side. One is a date inside the story's own calendar; the other is a date on our calendar worked out from genealogies. Which one did the writer of Genesis know?

Genesis 7:11

PICTURE STUDY



The Dove Sent Forth from the Ark, Gustave Doré, 1866 · Wood engraving, from Doré's illustrated Bible (La Sainte Bible, Tours) · Printed in many editions of Doré's illustrated Bible (Tours, 1866); impressions are held in print collections worldwide

Gustave Doré was a French artist who drew more than two hundred illustrations for a large Bible printed in 1866. Engravers cut his drawings into wood blocks, so the pictures are built entirely from fine lines of black and white. His Bible pictures became the way millions of people imagined these stories.

Here Doré shows the quiet moment of Genesis 8:8–12. The storm is over. The Ark has grounded, and Noah has opened the window to send out a dove to find whether the waters have gone down. Everything in the picture waits on that bird.

Look closely

- Find the dove. Where is it going, and what is Noah looking for when it comes back?
- Look at the water. How far does it stretch? What has Doré left showing above it?

- Study the Ark itself. Does it look like a boat with a pointed bow, or like a long box? Compare it with the measurements in Genesis 6:15.
- Notice the family. How many people does Genesis 7:13 say were aboard? Count what Doré shows.

Talk about it

1. Genesis gives the exact day the Ark rested and the exact day the ground was dry. Why might an artist choose the dove's flight, which has no date, instead?
2. Doré's engraving is made of lines only, with no color. How does he make the water look vast and the sky look heavy?
3. The olive leaf told Noah that plants were growing again somewhere below. What does that detail tell you about how long the waters had been going down?

EXPERIMENT: DRY ON TOP, DRIED ALL THROUGH: A SOIL-DRYING EXPERIMENT

Genesis 8:13 says the face of the ground was dry on the first day of the first month, and Genesis 8:14 says the earth was dried on the twenty-seventh day of the second month, 56 days later. The writer kept two separate records, because a surface can look dry long before the ground under it is. You will measure that difference.

Question: Does a deep tray of wet soil take longer to lose its water than a shallow tray of the same soil? Prediction: write yours before you start. What we change: the depth of the soil. What we keep the same: the kind of soil, the amount of water per cup of soil, the place and the air. What we measure: the mass of each tray each day.

You will need

- Two identical shallow containers (plastic food tubs or foil pans) of the same size
- Garden soil or potting mix, about 4 cups
- Measuring cup, water
- Kitchen scale that reads in grams
- Notebook, pencil, ruler, a fine skewer or toothpick

Steps

1. Label the trays A and B. Put 1 cup of dry soil in tray A and 3 cups in tray B. Measure the depth of each with the ruler and record it in centimeters.
2. Add water in the same proportion: 1/4 cup to tray A and 3/4 cup to tray B. Stir each until evenly wet. Weigh each tray and record the starting mass in grams.
3. Set both trays side by side in the same place indoors, away from a heater or a sunny window, so they share the same air.
4. Each day at the same time, weigh both trays and write the mass in a table with columns: day, mass A, mass B, water lost A, water lost B (starting mass minus today's mass). Also touch the surface and write "looks dry" or "looks wet."

5. Each day, push the skewer gently to the bottom of each tray and pull it out. Record whether soil sticks to the lower end. That is your test of “dried all through.”
6. Continue for at least seven days. Then plot both trays on one graph: day on the bottom axis, water lost in grams on the side axis.
7. Write a paragraph: Which tray looked dry on top first? Which was dried through first? How does this help you read Genesis 8:13 and 8:14 as two different observations?

Tips

- Weigh at the same hour each day; evaporation changes with temperature and the time of day.
- If the soil surface cracks as it dries, draw the crack pattern. Mud cracks are a real feature geologists look for in rock layers.

Check your work

- My table has at least seven days of masses for both trays.
- My graph has labeled axes with units (days, grams).
- I recorded both the “looks dry” day and the “dried through” day for each tray.
- My paragraph connects the two drying stages to Genesis 8:13 and 8:14.

FIELD NOTEBOOK

1. Rule a timeline 37 cm long (1 cm = 10 days) and mark every dated event of the Flood year from Genesis 7:11 to 8:14, with the month and day beside each mark.
2. Draw the three birds of Genesis 8 (raven, dove, dove with olive leaf) and under each write the verse and what Noah learned from it.
3. Copy Genesis 8:22 in your best hand and draw around it the four pairs it names: seedtime and harvest, cold and heat, summer and winter, day and night.

> **From history.** When Leonard Woolley’s team at Ur dug beneath the royal tombs in 1929 and found more than three meters of clean silt, Woolley sent a telegram saying that they had found the Flood. His wife Katharine is said to have suggested the idea while standing in the pit. It made headlines around the world. But other excavators soon found that the flood layers at Kish, Shuruppak and Ur were at different depths and from different times, so each was a local river flood. The episode taught archaeologists to check the extent of a layer before naming it.

WORKED EXAMPLES

Example 1. Genesis 7:11 says the Flood began on the seventeenth day of the second month. Genesis 8:4 says the Ark rested on the seventeenth day of the seventh month, and Genesis 7:24 and 8:3 say the waters prevailed 150 days. How long was a month in this calendar?

(Use the map or drawing "Use the day counts on the timeline to check each interval." shown earlier in this lesson.)

1. Count the months from the second month to the seventh month: 7 − 2 = 5 months, and both dates fall on the seventeenth, so the interval is exactly 5 whole months.
2. The text gives the same interval as 150 days.
3. Divide: 150 days ÷ 5 months = 30 days per month.

Answer: 30 days per month. The Flood calendar counts twelve 30-day months, a 360-day year.

Example 2. Using 30-day months, how many days passed from the start of the Flood (year 600, month 2, day 17) to the day the earth was dried (year 601, month 2, day 27)?

1. From month 2, day 17 of year 600 to month 2, day 17 of year 601 is twelve months: 12 × 30 = 360 days.
2. From day 17 to day 27 of that month is 27 − 17 = 10 more days.
3. Add: 360 + 10 = 370 days.

Answer: About 370 days, a year and ten days. (If you count both the first and the last day, you get 371.)

Example 3. The waters rose and prevailed for 150 days, and the rest of the 370-day Flood year was spent going down and drying. What percent of the Flood year was the rising-and-prevailing phase, and how many days was the going-down phase?

1. Rising phase as a fraction of the year: 150 ÷ 370 = 0.405.
2. Convert to percent: 0.405 × 100 = about 41%.
3. Going-down phase: 370 − 150 = 220 days. Check with the dates: from month 7, day 17 to month 2, day 27 of the next year is 7 months (210 days) plus 10 days = 220 days.

Answer: About 41% of the year the waters were rising or prevailing; the waters spent 220 days, about 59% of the year, going down and drying.

PRACTICE

1. EASY On what day of what month did the Flood begin, and what two things does Genesis 7:11 say happened on that day?
2. EASY How long did the rain fall, and how long did the waters prevail (stay high) on the earth?
3. EASY Where did the Ark come to rest, and in which month and day?
4. MEDIUM Give three features of Genesis 6–9 that mark it as narrative history rather than poetry.
5. MEDIUM Using 30-day months, how many days passed from the day the mountaintops were seen (month 10, day 1) to the day Noah removed the covering (month 1, day 1 of the next year)?
6. MEDIUM Data reading. The table gives the dated events of the Flood year and the day count from the start. Event: Flood begins, day 0; rain ends, day 40; Ark rests, day 150; mountaintops seen, day 224; raven sent, day 264; ground surface dry, day 314; earth dried, day 370. Which interval between neighboring events was the longest, and how many days was it?
7. MEDIUM Data reading. A student weighed two trays of wet soil for six days. Tray A (shallow) lost: day 1, 20 g; day 2, 35 g; day 3, 44 g; day 4, 48 g; day 5, 49 g; day 6, 49 g. Tray B (deep) lost: day 1, 22 g; day 2, 40 g; day 3, 55 g; day 4, 68 g; day 5, 79 g; day 6, 88 g. (a) Which tray had stopped losing water by day 6? (b) What is the best explanation for why tray B kept losing water?
8. HARD Leonard Woolley found a 3 m layer of clean silt at Ur in 1929 and announced he had found the Flood. Later digs found the layer did not reach the neighboring cities. Explain why this find neither proves nor disproves a worldwide flood.
9. HARD Experiment design. You want to test whether moving air makes a surface look dry sooner than still air does. Describe the setup: what you change, what you keep the same, what you measure, and how many trials you would run.
10. CHALLENGE Write a short paragraph answering: Why does it matter whether Genesis 6–9 is read as history or as a story with a moral? Give one reason from the New Testament and one from Earth Science.

COMMON MISTAKES

- Thinking the Flood lasted 40 days. The rain lasted 40 days, but Noah’s family was in the Ark for more than a year, and the waters stood high for 150 days.
- Thinking the Ark was a boat with a pointed bow and a little house on top, as in picture books. Genesis 6:15–16 describes a long box 300 by 50 by 30 cubits with three decks.
- Thinking that because Genesis 6–9 is history it must contain no miracles, or that because it contains a miracle it cannot be history. The text reports God’s acts and human acts side by side with the same plain dates.

Make it a game · Logbook Relay. Write each dated Flood event on its own card (Flood begins, rain ends, Ark rests, mountaintops seen, raven sent, dove with olive leaf, ground

surface dry, earth dried, family leaves the Ark). Shuffle. On “go,” lay the cards in order along a table and say the month and day for every card you can. Time it. A card in the wrong place costs ten seconds. Play again and try to beat your time; then play with the cards face down and recall the order from memory.

Scripture. “In the six hundredth year of Noah’s life, in the second month, the seventeenth day of the month, the same day were all the fountains of the great deep broken up, and the windows of heaven were opened.” (Genesis 7:11, KJV)

The Flood is dated to the year, month and day, and the first thing broken open is not the sky but the deep. History is written with dates like this, and a careful reader notices what comes first.

Practice answers

1. The seventeenth day of the second month of Noah’s 600th year. The fountains of the great deep were broken up and the windows of heaven were opened.
2. Rain fell 40 days and 40 nights (Genesis 7:12); the waters prevailed 150 days (Genesis 7:24).
3. Upon the mountains of Ararat, on the seventeenth day of the seventh month (Genesis 8:4).
4. Any three: exact dates (year, month, day); exact measurements in cubits; personal names tied to genealogies; a named place (mountains of Ararat); plain reporting sentences rather than the parallel lines and word pictures of Hebrew poetry such as Psalm 104.
5. Three months: $3 \times 30 = 90$ days.
6. From the end of the rain (day 40) to the Ark resting (day 150): $150 - 40 = 110$ days. The other intervals are 40, 74, 40, 50 and 56 days.
7. (a) Tray A; its loss stayed at 49 g on days 5 and 6, so it was dried through. (b) Tray B held three times the water in a deeper layer, and water deep in the soil must move up to the surface before it can evaporate, so it keeps losing mass for longer. The surface of B may have looked dry while the lower soil was still wet, just as Genesis 8:13 and 8:14 record two different drying stages.
8. A worldwide flood would be expected to leave vast, widespread deposits, not just one layer at one city, so one local layer cannot establish it. But the absence of that particular layer elsewhere only shows the Ur layer was a local river flood; it says nothing about whether a much larger event, which would be recorded in the deeper rock layers of the continents rather than in a town’s silt, happened earlier. The Ur silt is simply the wrong scale of evidence for the question.
9. Make two identical trays of wet soil (same soil, same depth, same water). Place one where a small fan blows across it and the other in still air in the same room at the same temperature. Change only the air movement. Keep the same soil, depth, water, room temperature and start time. Measure the mass of each tray every day and the day each surface first looks and feels dry. Repeat the whole test at least three times (three pairs of trays) and compare the average day of surface drying for fan versus still air.
10. Sample answer: If the Flood really happened, then Jesus and Peter were speaking of a real event when they compared it to the judgment to come (Luke 17:26–27; 2 Peter 3:5–7), and their warning carries its full weight. For Earth Science it matters because a real worldwide flood would have laid down enormous amounts of sediment quickly, so a geologist who believes it will read the rock layers differently from one who assumes only today’s slow rates.

The reading of the text changes the expectations we bring to the rocks, which is why the observations must be made carefully and separately from either reading.

4.2 The Ark's Size and Stability (Hong, 1994 Study)

OBJECTIVES

- Convert the Ark's dimensions from cubits to meters, compute its volume, deck area and the mass of water it would displace at a 15-cubit draft, and compare it with modern ships.
- Explain the three safety questions ship engineers ask (will it break, will it capsize, will it ride the waves) and describe how the 1994 Korean study tested the Ark's proportions against other hull shapes.
- Test boat shapes of equal volume in water, measure their tipping angles, and explain why a long, wide, low box is a stable shape.

Warm-up. Stand with your feet together and have someone push gently on your shoulder. Now stand with your feet wide apart and try again. Then crouch low with feet wide. Which stance is hardest to tip? Write one sentence about what "wide and low" does for stability. You have just tested the main idea of this lesson with your own body.

Video. Coming soon. Ship stability basics, center of gravity and buoyancy, how ships capsize, and Noah's Ark dimensions compared to modern ships; look for naval-architecture explainer channels, Science Max or Physics Girl style demonstrations, Moody Science classics, and maritime museum channels.

KEY TERMS

cubit
An ancient length unit, elbow to fingertip, about 45 cm (some reckonings use up to 52 cm). Genesis gives the Ark as 300 × 50 × 30 cubits.

buoyancy
The upward push of water on a floating object, equal to the weight of the water the object pushes aside (Archimedes' principle).

displacement
The volume or mass of water a floating vessel pushes aside; a floating ship displaces water equal to its own total weight.

draft
How deep a vessel sits in the water, measured from the waterline to the bottom of the hull.

overturning stability
A vessel's ability to right itself after being tilted by wind or waves instead of rolling over (capsizing).

seakeeping
How a vessel behaves in waves: how much it rolls, pitches and pounds, and whether the people and animals aboard can bear the motion.

CORE IDEAS

The story. In 1994 a team of nine ship engineers at the Korea Research Institute of Ships and Ocean Engineering in Daejeon, South Korea, led by Seon Won Hong, published a study with an unusual subject. They took the dimensions God gave Noah in Genesis 6:15, a vessel 300 cubits long, 50 cubits wide and 30 cubits high, and asked the same three questions their institute asks of every new cargo ship or tanker: Would the hull break in heavy seas? Would it capsize? Would its motion in the waves be bearable for what it carried? Using a cubit of 45 cm, the Ark becomes a box 135 m long, 22.5 m wide and 13.5 m high, with three decks. That is longer than a soccer field and about half the length of the *Titanic*. The engineers assumed it floated about half-sunk, with a draft of 15 cubits, the same figure Genesis 7:20 gives for the depth of water over the mountains. Then they ran the numbers the way they would for a real ship.

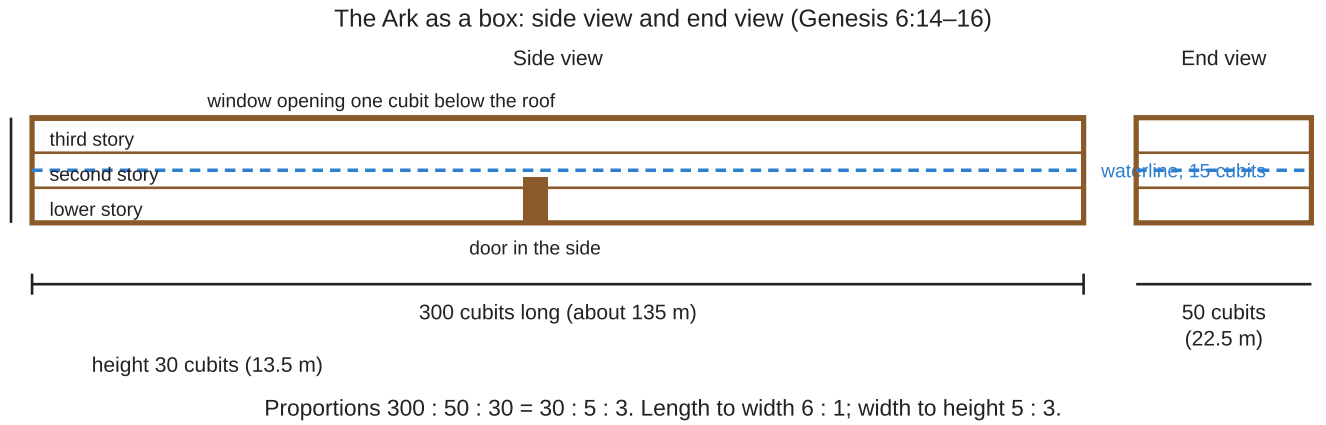
How they figured it out. Hong's team did not test the Ark alone. They designed twelve other hull shapes, each with the same total volume but different proportions: some taller and narrower, some shorter and wider, some longer and thinner. For every shape they calculated structural strength (the bending load on a long hull as a wave lifts its middle or its ends), overturning stability (how far it could heel before it would not come back) and seakeeping (how much it would roll and pitch in waves of various heights). Then they ranked all thirteen. No single shape was best in all three; a very wide box is hard to capsize but rolls violently, and a very long box rides smoothly but bends more. The Ark's proportions came out among the best overall, balancing all three, and the calculations showed it could survive waves higher than 30 m. The study used the standard methods of naval architecture that any shipyard would recognize.

The big idea. Why does the shape work? A floating object has two centers. Its **center of gravity** is where its weight acts; its center of buoyancy is the center of the water it displaces. When a wave tilts a wide, low hull, the submerged part shifts far toward the low side, so the upward push of buoyancy moves sideways and levers the hull back upright. A tall, narrow hull gets little of that help, like you standing with your feet together. The Ark's ratio of length to width is 6 to 1 and of width to height is 5 to 3, a long, broad, low barge. Its length lets it ride across several waves at once instead of pitching over each crest, and a heavy load on the bottom deck keeps the center of gravity low. A ratio of about 6 to 1 is still common in large cargo vessels today. The Ark did not need to sail anywhere; it needed only to float safely, and its shape fits that job.

In the world today. Some critics say no wooden vessel that long could hold together. The largest wooden sailing ship built in modern times, the six-masted schooner *Wyoming* launched in Maine in 1909, had a hull about 100 m long, and its long hull flexed and leaked in heavy seas until it was lost in a storm in 1924. But the Ark was not a sailing ship with tall masts and a narrow hull; it was a barge nearly a quarter as wide as it was long, and Genesis says it was built with "rooms" (6:14), internal compartments that stiffen a hull the way an egg carton stiffens cardboard. Ancient builders could work at this scale: two pleasure ships of the emperor Caligula raised from Lake Nemi in Italy in 1929 to 1932 were about 70 m long. A good student can state both sides: a 135 m wooden barge is a demanding structure,

and its proportions are exactly the kind a naval architect would choose for a vessel meant to survive, not to sail.

God's handiwork. Noah did not learn the ratio 30 to 5 to 3 from a shipyard; Genesis says God gave it to him. Yet when engineers put those proportions to the test with the same equations they use for supertankers, the numbers came out sound. That is a small example of something the Christian naturalists loved: the world is reasonable because it was made by a reasonable God, and His instructions fit the physics He built. Hebrews 11:7 says Noah, "warned of God of things not seen as yet, moved with fear, prepared an ark." He built for a year of water he had never seen, in a shape that would later pass an engineer's review. Faith and good engineering were not enemies on that building site.



The Ark as Genesis 6:14–16 describes it, drawn to scale: a long, wide, low box with three decks. The dashed line is the 15-cubit draft used in the 1994 study.

⏳ Thinking About Time

What the sign says. What the sign says: many textbooks and museum guides treat the Ark as a legend, saying a wooden vessel 135 m long could not have been built or survived, since even the largest wooden ships of the 1800s and 1900s, about 100 m long, leaked and broke up in storms.

What we observe. What we observe: Genesis gives exact proportions that can be tested, and ship engineers who tested them in 1994 found a shape that resists capsizing and rides waves well, with a strength that depends on how the hull was built inside. Ancient shipwrights did build hulls of 70 m and more, as the ships raised from Lake Nemi in 1929–1932 showed. Wooden sailing ships of the 1900s were long, narrow hulls carrying tall masts, a different and harder structural problem than a wide barge.

How Christians read it. How Christians read it: Noah built the Ark as God directed, about 4,400 years ago by the Bible's genealogies, and it floated through the Flood year as Genesis 7 and 8 report. The test of the proportions does not prove the Flood happened, but it shows that the record describes a vessel that works, which is what we expect of history and not of a fairy tale.

> **Try it.** Measure your own cubit from elbow to fingertip in centimeters. Multiply by 300. How long would the Ark be in "your" cubits, and how far is that from 135 m?
>
> *Genesis 6:15*

PICTURE STUDY



Noah's Ark, Edward Hicks, 1846 · Oil on canvas · Philadelphia Museum of Art, Philadelphia

Edward Hicks was a Quaker preacher and sign painter from Pennsylvania who painted the same few Bible subjects again and again, most famously the Peaceable Kingdom. He painted this Ark in 1846, three years before he died, working from a popular print of the day.

Hicks was not a shipbuilder, and his Ark is the picture-book kind. Compare his vessel with the proportions in Genesis 6:15 and with the figure in this lesson, and you will see how much the artist changed.

Look closely

- Find the Ark. Estimate its length compared with its height. Is it closer to 10 to 1, as Genesis gives, or to a shorter, taller shape?
- Look at the sky. What is the weather doing, and what time in the story does Hicks show?
- Count the kinds of animals you can name. Which walk in pairs? Genesis 7:2 says some kinds came by sevens.
- Where is the door? Genesis 6:16 says the door was in the side. Does Hicks agree?

Talk about it

1. Hicks painted the animals large and the Ark small so the viewer could see them. What does a painter gain by changing the true proportions, and what does a scientist lose?
2. If you redrew this scene with the Ark at its true size, 135 m long and 13.5 m high, how big would an elephant (about 3 m tall) be beside it?
3. The lightning tells us the storm is starting. According to Genesis 7:10, how long before the rain did the family go aboard?

> **Safety first.** This project uses a tub of water. Work outdoors or on a towel-covered floor, keep electrical devices away from the water, and have an adult handle any cutting of cardboard or foil.

EXPERIMENT: WHICH BOX FLOATS STEADIEST? A TIPPING TEST

You will build three floating boxes of the same volume but different proportions and find out which one resists tipping and waves best. One of them will have the Ark's proportions of 30 to 5 to 3.

Question: Which proportions give the largest tipping angle before the box capsizes? Prediction: rank your three boxes before you test. What we change: the proportions. What we keep the same: the volume, the material, the load and the water. What we measure: the heel angle when a coin is placed at the edge, and whether the box survives ten hand-made waves.

You will need

- Heavy-duty aluminum foil or thin cardboard with packing tape to waterproof
- Ruler, pencil, scissors
- A protractor and a straw or skewer to serve as a tilt pointer
- About 30 identical coins for cargo
- A large tub, sink or baking dish of water at least 8 cm deep
- Notebook for your data table

Steps

1. Build three open boxes with the same volume of 450 cm^3. Box A, the Ark shape: 30 cm × 5 cm × 3 cm high. Box B, the cube-like shape: 7.7 cm × 7.7 cm × 7.6 cm high. Box C, the tall narrow shape: 15 cm × 3 cm × 10 cm high. Check each volume by multiplying length × width × height.
2. Float each box empty and record whether it floats level. Then load each with 10 coins spread evenly on the bottom. Measure the draft (how deep it sits) with the ruler and record it.
3. Tape the straw upright at the center of each box as a pointer. Place one coin at the very edge of one side and read the tilt of the straw from vertical with the protractor. Record the heel angle. Repeat with two coins, then three, until the box takes water or capsizes. Record the number of edge coins each box carried before it failed.

4. Wave test: with all three boxes loaded with 10 coins and floating, make ten gentle waves by pushing a flat hand up and down at one end of the tub. Record for each box: stayed upright, took water, or capsized.
5. Make a table: box, proportions, draft (cm), heel angle with one edge coin (degrees), edge coins to failure, wave test result. Run the whole test three times and average the angles.
6. Graph edge coins to failure for A, B and C as a bar graph.
7. Write a paragraph ranking the three shapes and explaining the result with the idea of a wide, low hull and a low center of gravity. Then compare with the 1994 study's finding.

Tips

- Keep the walls of all three boxes about the same thickness so the material does not change the result.
- A cube-like box may float well but spin and roll; note that too. Rolling is a seakeeping problem, not a capsizing problem.

Check your work

- All three boxes have the same volume (show the multiplication).
- My table has three trials for each box and the averages.
- My bar graph has labeled axes.
- My paragraph uses the words draft, center of gravity and overturning stability correctly.

FIELD NOTEBOOK

1. Draw the Ark to scale on graph paper at 1 cm = 10 cubits (30 cm long, 5 cm wide, 3 cm high in the side view) and add the three decks, the side door and the waterline at 15 cubits.
2. Sketch a floating box tilted by a wave and mark its center of gravity and the shifted center of buoyancy with arrows showing the righting push.
3. Make a table comparing the Ark (135 × 22.5 × 13.5 m) with two real vessels you look up, such as a ferry and a container ship: length, width, and length-to-width ratio.

> **From history.** Between 1929 and 1932 the Italian government drained part of Lake Nemi, south of Rome, to recover two enormous wooden ships built for the emperor Caligula in the first century AD. They were about 70 m and 73 m long and 20 m or more wide, built with bronze fittings, lead sheathing and decks of marble and mosaic. They showed that ancient shipwrights could build hulls far larger than anyone had believed. Both ships were destroyed by fire in 1944 during the Second World War, and only models, photographs and some fittings survive in the Museo delle Navi Romane beside the lake.

WORKED EXAMPLES

Example 1. Using a cubit of 45 cm, convert the Ark's dimensions of 300 × 50 × 30 cubits to meters and find its volume. About how many 20-foot shipping containers (33 m³ of cargo space each) would that volume equal?

(Use the map or drawing "Dimensions used in the calculation." shown earlier in this lesson.)

1. Length: 300 × 0.45 m = 135 m. Width: 50 × 0.45 m = 22.5 m. Height: 30 × 0.45 m = 13.5 m.
2. Volume: 135 × 22.5 × 13.5 = 41,006 m³, about 41,000 m³.
3. Containers: 41,000 ÷ 33 = 1,242, so about 1,200 containers' worth of space.
4. Deck area, for interest: 135 × 22.5 = 3,037.5 m² per deck, and three decks give about 9,100 m².

Answer: 135 m × 22.5 m × 13.5 m, a volume of about 41,000 m³, roughly the space of 1,200 standard 20-foot containers.

Example 2. You want to build a model of the Ark at a scale of 1 : 300. What are the model's length, width, height and draft (15 cubits) in centimeters?

1. At 1 : 300, divide every real length by 300.
2. Length: 135 m ÷ 300 = 0.45 m = 45 cm. Width: 22.5 m ÷ 300 = 0.075 m = 7.5 cm. Height: 13.5 m ÷ 300 = 0.045 m = 4.5 cm.
3. Draft: 15 cubits × 0.45 m = 6.75 m, and 6.75 m ÷ 300 = 0.0225 m = 2.25 cm.
4. Notice the model is 45 cm long, exactly one cubit, because 300 cubits ÷ 300 = 1 cubit.

Answer: 45 cm long, 7.5 cm wide, 4.5 cm high, floating with 2.25 cm under water.

Example 3. At a draft of 6.75 m, what volume of water does the Ark displace, and what total mass could it have (hull, cargo and animals together) and still float at that depth? Use 1,000 kg/m³ for fresh water.

1. The submerged part is a box 135 m × 22.5 m × 6.75 m.
2. Displaced volume: 135 × 22.5 × 6.75 = 20,503 m³, about 20,500 m³.
3. Archimedes' principle: a floating object weighs the same as the water it displaces. Mass of water: 20,500 m³ × 1,000 kg/m³ = 20,500,000 kg.
4. Convert: 20,500,000 kg ÷ 1,000 = 20,500 metric tons (tonnes).

Answer: About 20,500 m³ of water displaced, so the loaded Ark could have a total mass of about 20,500 tonnes at that draft (about 21,000 tonnes in denser seawater).

PRACTICE

1. EASY Give the Ark’s length, width and height in cubits, and in meters using a 45 cm cubit.
2. EASY What is the ratio of the Ark’s length to its width? Of its width to its height?
3. EASY Name the three safety questions the 1994 study asked about the Ark.
4. MEDIUM The Titanic was about 269 m long and 28 m wide. Find its length-to-width ratio and compare it with the Ark’s. Which is the broader, barge-like shape?
5. MEDIUM If a cubit were 52 cm (a long royal cubit) instead of 45 cm, how long would the Ark be, and by how many meters would the estimate change?
6. MEDIUM Data reading. A student tested four foil boxes of equal volume and recorded the heel angle with one coin at the edge: width-to-height 1 : 1, 24°; 5 : 3, 15°; 3 : 1, 9°; 5 : 1, 5°. Describe the pattern, and predict the heel angle for a 2 : 1 box.
7. MEDIUM Data reading. In a wave test, each box was hit with waves of increasing height until it capsized. Results: box with length-to-width 1 : 1 capsized at wave height 3 cm; 3 : 1 at 5 cm; 6 : 1 at 8 cm; 12 : 1 at 7 cm (and its sides bent). Which proportions survived the highest waves, and what does the 12 : 1 result suggest?
8. HARD Explain, using the centers of gravity and buoyancy, why a wide, low box rights itself after a wave tilts it while a tall, narrow box of the same volume may capsize.
9. HARD Experiment design. Design a test to find whether placing the cargo low or high in a floating box changes the heel angle. State the variable you change, three things you keep the same, what you measure, and how you would make the test fair.
10. CHALLENGE The 1994 study found the Ark could survive waves over 30 m high. Write a short paragraph on what that result does and does not show about the Flood.

COMMON MISTAKES

- Thinking a heavier boat always sinks. A boat floats as long as the weight of the water it displaces equals its own weight; the Ark could carry about 20,000 tonnes at a 15-cubit draft.
- Thinking the Ark had to be fast or steer. It was a barge built to float and survive; it had no sails, rudder or keel in the text, and its wide, low shape suits exactly that job.
- Thinking the 1994 study proves the Flood. It tested only whether the Ark’s proportions are seaworthy; it found they are near the best of thirteen shapes tested, which answers one objection and no more.

Make it a game · Shipwright’s Challenge. Each player gets one sheet of foil of the same size and five minutes to fold a boat. Then load the boats with coins one at a time in the tub until each one takes water. The boat that holds the most coins wins the round. Before the next round, each player must say one change to the proportions they will make and why, using the words wide, low or draft. Play three rounds and see whether the winning shapes drift toward a long, wide, low box.

> **Scripture.** “And this is the fashion which thou shalt make it of: The length of the ark shall be three hundred cubits, the breadth of it fifty cubits, and the height of it thirty cubits.” (Genesis 6:15, KJV)

A legend says “a big boat.” A record says 300 by 50 by 30. Measurements can be tested, and these were tested with the equations that shipyards use.

Practice answers

1. 300 × 50 × 30 cubits; 135 m × 22.5 m × 13.5 m.
2. Length to width 300 : 50 = 6 : 1. Width to height 50 : 30 = 5 : 3.
3. Would the hull break (structural strength)? Would it capsize (overturning stability)? Would its motion in waves be bearable (seakeeping)?
4. 269 ÷ 28 = 9.6, so about 9.6 : 1. The Ark’s 6 : 1 is the broader, barge-like shape; the Titanic was long and narrow for speed.
5. 300 × 0.52 = 156 m, which is 156 − 135 = 21 m longer.
6. As the box gets wider for its height, the heel angle gets smaller; wider boxes tilt less under the same off-center load. A 2 : 1 box falls between 5 : 3 (15°) and 3 : 1 (9°), so a prediction of about 12° is reasonable.
7. The 6 : 1 box survived the highest waves (8 cm). The 12 : 1 box did slightly worse and bent, suggesting that a very long, thin hull gains nothing further in stability and starts to fail by bending (structural strength), which matches the 1994 study’s finding that the best shape balances all three safety questions.
8. When a wide box tilts, the submerged part shifts strongly toward the low side, moving the center of buoyancy far sideways while the center of gravity stays near the middle. The upward buoyant push and the downward weight then act as a pair that rotates the box back upright. A tall, narrow box shifts its center of buoyancy only a little, and its center of gravity is high, so the pair of forces is weak or even turns the box farther over.
9. Use one box (same proportions) loaded with the same 10 coins. Trial 1: coins flat on the bottom. Trial 2: coins taped to a cardboard shelf halfway up the walls. Change only the height of the cargo. Keep the same box, same coins, same water depth, and same position of the one extra edge coin that causes the tilt. Measure the heel angle with the protractor. Repeat each setup three times and average; test the same day in the same tub so the water and temperature are the same.
10. Sample answer: The result shows that the proportions in Genesis 6:15 describe a vessel that, by the standard methods of naval architecture, would resist capsizing and bending in very large waves, so the record is describing something that works. It does not show that the Flood happened, how high the Flood’s waves actually were, or exactly how Noah joined the timbers; those are separate questions. What it rules out is the claim that the Ark is an impossible shape. A careful student states the finding and its limits together.

4.3 Flood Legends Worldwide

OBJECTIVES

- Tell the story of George Smith’s 1872 reading of the Babylonian flood tablet and describe the main flood accounts of Mesopotamia, Greece, India and Hawaii.
- Compare several flood accounts in a data table, count the features they share with Genesis, and explain the three ways scholars account for the sharing.
- Explain why Christians read the worldwide spread of flood stories as evidence that the nations descended from Noah’s family, while treating Genesis as the accurate record.

Warm-up. Play one round of “telephone.” Whisper this sentence to one person, who whispers it to the next, and so on through everyone in the room: “On the seventeenth day the boat rested on a mountain, and after forty days a raven and a dove were sent out.” Have the last person say it aloud. Which details survived? Which changed? Keep the sentence; you will use it again in the project.

Video. Coming soon. George Smith and the Flood Tablet of Gilgamesh at the British Museum, and flood legends from around the world compared with Genesis; look for British Museum curator talks, university Assyriology lectures, Moody Science classics, and Bible-archaeology documentary channels.

KEY TERMS

cuneiform
Wedge-shaped writing pressed into wet clay with a reed, used in Mesopotamia for about three thousand years.

epic
A long poem telling the deeds of a hero. The Epic of Gilgamesh includes a flood story on its eleventh tablet.

Utnapishtim
The flood survivor in the Babylonian Epic of Gilgamesh; the Sumerian version calls him Ziusudra and the Babylonian Atrahasis poem calls him Atrahasis.

oral tradition
Stories, songs and genealogies passed down by speaking and memory rather than writing.

motif
A repeated element in stories, such as a divine warning, a vessel, a few survivors, birds sent out, or a landing on a mountain.

dispersion
The scattering of the nations from Babel described in Genesis 11, after which Noah’s descendants spread over the earth.

CORE IDEAS

The story. George Smith never went to university. He was a banknote engraver in London who spent his lunch hours in the British Museum staring at broken clay tablets from Nineveh, the Assyrian capital excavated by Austen Henry Layard and Hormuzd Rassam in the 1840s and 1850s. He taught himself to read cuneiform so well that the museum hired him. In 1872, sorting fragments from the library of King Ashurbanipal, he found a piece describing a ship that grounded on a mountain, after which its builder sent out a dove, a swallow and a raven. Smith realized he was reading a Babylonian account of the Flood. On December 3, 1872, he announced it to the Society of Biblical Archaeology in London, with the prime minister, William Gladstone, in the audience. The newspapers called it the Chaldean account of the Deluge.

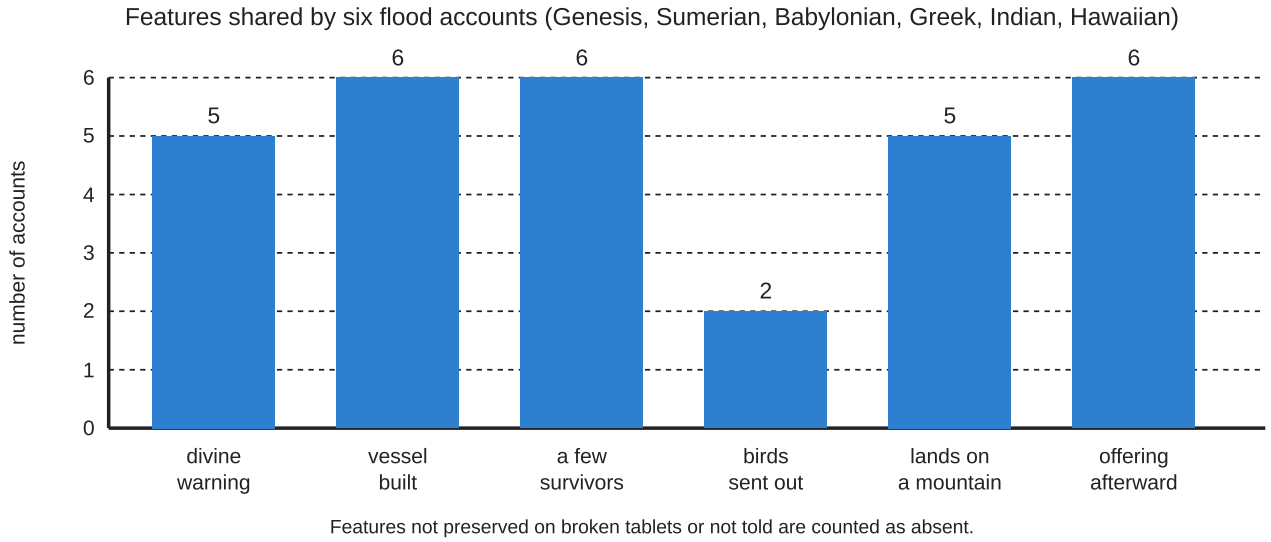
How they figured it out. What Smith had found was Tablet XI of the Epic of Gilgamesh, copied in the 600s BC from much older originals. In it the hero Gilgamesh visits Utnapishtim, the one man who survived the flood, and asks how he escaped death. Utnapishtim tells him that the god Ea warned him through the wall of a reed house to build a boat. The boat was a cube, 120 cubits on each side, with six decks. He loaded it with his family, craftsmen, silver, gold and the seed of every living thing. The storm lasted six days and seven nights, so terrible that the gods themselves cowered. The boat grounded on Mount Nimush. After seven days Utnapishtim released a dove, which came back, a swallow, which came back, and a raven, which did not. He offered a sacrifice, and the gods crowded around it. Older Mesopotamian versions were found later: the Atrahasis poem, copied around 1650 BC, and a Sumerian tablet whose hero is Ziusudra. Scholars have compared them line by line with Genesis 6–9 ever since.

The big idea. The flood story is not only Mesopotamian. The Greeks told how Zeus drowned the earth and Deucalion and his wife Pyrrha floated in a chest that came to rest on Mount Parnassus. In India, the Shatapatha Brahmana tells how a fish warned Manu to build a ship, then towed it to a northern mountain where Manu tied it to a tree. A Hawaiian tradition written down in the 1800s tells of Nuʻu, who survived a great sea in a large canoe with a house on it and landed on Mauna Kea, where he gave an offering. In 1918 the anthropologist James Frazer filled hundreds of pages with flood stories from the Americas, Australia, the Pacific islands, Asia and Europe. Not every story has every detail, and many are mixed with local lore, but the same motifs keep appearing: a warning, a vessel, a handful of survivors, a mountain, birds, a sacrifice. Lay them in a table and the pattern is hard to miss.

In the world today. Scholars give three kinds of explanation, and you should be able to state all three fairly. First, borrowing: most textbooks say Genesis was written down late, by Hebrews who knew the Babylonian story, and that the whole family of tales grew from a great river flood on the Tigris and Euphrates. Second, independent invention: floods happen everywhere, so every people made up its own story. Third, common memory: all these peoples descend from the survivors of one real flood and carried the memory with them as they scattered, each version drifting over the centuries like a sentence in a game of telephone. Christians who read Genesis as history hold the third view. They point out that the stories are found in places with no connection to Mesopotamia and no great rivers, that

the Babylonian cube would roll helplessly while the Genesis box is seaworthy (Lesson 4.2), and that only Genesis gives a dated, sober, year-long record. In their reading, Gilgamesh is not the parent of Genesis but a distorted cousin, and Genesis 9:19 with chapters 10 and 11 explain how the cousins spread: “of them was the whole earth overspread.”

God’s handiwork. There is something moving in the thought that a Hawaiian chief, a Greek poet and a Babylonian scribe were all, in their broken ways, remembering the same year. Scripture says God “hath made of one blood all nations of men for to dwell on all the face of the earth” (Acts 17:26). One family came out of the Ark, and from it came every people with its own language and its own half-remembered story of the water. A Christian student need not sneer at the legends or fear them, but can read them carefully, note what they keep and what they lose, and give thanks that one record was kept exactly, with its dates and its cubits.



Shared features in six flood accounts, counted from the data table in this lesson. A feature “not preserved” on a broken tablet is counted as absent.

⏳ Thinking About Time

What the sign says. What the sign says: many textbooks say that Genesis 6–9 was written down after 600 BC by Hebrews living in Babylon, who adapted the Gilgamesh flood story, itself descended from Sumerian tales, and that all of these remember a large but local river flood in Mesopotamia several thousand years ago.

What we observe. What we observe: the oldest surviving written flood accounts are on Mesopotamian clay, the Atrahasis copies from about 1650 BC being older than any surviving Bible manuscript. Flood traditions are also recorded among peoples on every inhabited continent and on islands far from any great river. The Babylonian vessel is a cube, which would roll in a seaway; the Genesis vessel is a long, low box whose proportions pass an engineer’s test. Only Genesis gives dates for the events.

How Christians read it. How Christians read it: Moses recorded the true account, handed down from Noah's family, and the worldwide spread of flood stories is just what Genesis 10–11 leads us to expect after the dispersion from Babel, roughly 4,200 to 4,400 years ago by the Bible's genealogies. The age of a surviving copy is not the age of the account; a tablet copied in 1650 BC can preserve a corrupted version of an older true story, while a later manuscript can preserve the accurate one.

Try it. Pick one legend from the table and underline every detail that matches Genesis in one color and every detail that differs in another. Which list is longer?

Genesis 9:19

PICTURE STUDY



The Flood Tablet (Tablet XI of the Epic of Gilgamesh), Assyrian scribe, Library of Ashurbanipal, Nineveh, 7th century BC · Clay tablet with cuneiform writing, about 15 cm tall · British Museum, London

This is the actual tablet George Smith read in 1872. It was written in the Akkadian language by a scribe working for King Ashurbanipal of Assyria, who collected thousands of tablets at Nineveh in the 600s BC. The library burned when Nineveh fell in 612 BC, and the fire baked the clay hard, which is why it survived.

Look at it as a document, not as a decoration. Every one of those wedge marks is a sign pressed with the cut end of a reed into wet clay, and Smith taught himself to read them in his lunch hours.

Look closely

- Find the rows of signs. Which way do they run, and how many lines can you count on the visible face?

- Find the broken edges. How much of the text is missing? This is why Smith went to Nineveh in 1873 to find more pieces.
- Compare the size of the tablet with your hand. The whole flood story fits on one object you could hold.
- Look at the color and texture. What does fire do to wet clay, and why did that help the tablet last?

Talk about it

1. Why is a text pressed into clay, then baked, so much more durable than one written in ink on papyrus or leather? What does that tell you about which ancient texts survive and which do not?
2. The tablet is a copy of an older text. Does the date of the copy tell you the date of the story it contains? Explain.
3. If you could add one question for the scribe who wrote it, what would you ask?

EXPERIMENT: KEEPING THE RECORD: SPOKEN CHAIN VERSUS WRITTEN CHAIN

Genesis is a written record with dates and measurements; most flood legends were spoken for centuries before anyone wrote them down. You will measure how much a record loses when it travels by mouth compared with when it is copied by hand.

Question: Does a story passed by speaking lose more details than one passed by copying? Prediction: write how many of 12 details you think will survive each way. What we change: the method, spoken or written. What we keep the same: the story, the number of passes, the people and the waiting time. What we measure: the number of the 12 details that reach the end correctly.

You will need

- Index cards and pencils
- A timer or clock
- At least three people (family members or friends); the same people take part in both chains
- A master story card with exactly 12 checkable details (below)

Steps

1. Write the master story on one card. Use this one or make your own with 12 details: “A man named Noah, aged 600, built a box 300 cubits long with 3 decks. On the 17th day of the 2nd month the rain began and fell 40 days. The water stood 15 cubits over the hills for 150 days. The box rested on the mountains of Ararat. He sent out a raven, then a dove, which brought back an olive leaf. Eight people came out.” Number the 12 details on a checklist: name, age, length, decks, day, month, days of rain, cubits over hills, days prevailed, mountain, birds and leaf, number of people.
2. Spoken chain: person 1 reads the card silently twice, then puts it away and waits 5 minutes. Person 1 tells it from memory to person 2, who waits 5 minutes and tells

person 3. The last person writes down what they heard. With three people, do two passes; if you have more, do more passes but record how many.
3. Score the spoken result: give one point for each of the 12 details that arrived exactly right. Record the score.
4. Written chain: person 1 copies the card by hand, waits 5 minutes, and gives only the copy to person 2, who copies it and passes the copy on. Use the same number of passes. Score the final copy the same way.
5. Repeat both chains two more times with a different starting person. Make a table: trial, method, passes, details correct out of 12.
6. Compute the average for each method and draw a bar graph.
7. Write a paragraph: which details were lost first (numbers? names? order?), which method kept more, and what this suggests about why Genesis keeps dates and cubits while most legends do not.

Tips

- Numbers are usually the first details to drift. Watch for 40 becoming 7 or 300 becoming 100.
- Do not let the spoken chain hear each other; send people to another room while they wait.

Check your work

- My master card has exactly 12 numbered details.
- My table shows three trials for each method with the same number of passes.
- My bar graph compares the averages with labeled axes.
- My paragraph names which kinds of details were lost first.

FIELD NOTEBOOK

1. Draw the Babylonian cube boat (120 cubits each side) and the Genesis Ark (300 × 50 × 30 cubits) side by side at the same scale, and label the volume of each.
2. Make a world map sketch and mark Nineveh, Greece (Mount Parnassus), northern India, and the island of Hawaii, with one line under each naming its flood hero.
3. Copy the six-by-six data table of flood features from this lesson into your notebook, then add a seventh row for any flood story you find in a book at home, with a note of where you found it.

> **From history.** After his 1872 announcement, the Daily Telegraph newspaper gave George Smith a thousand guineas to go to Nineveh and look for the missing parts of the flood story. He reached the mound of Kuyunjik in 1873 and, within days of starting to dig, picked up a fragment that filled a gap of some seventeen lines in the account. He made two more journeys, published The Chaldean Account of Genesis in 1876, and died that same summer of fever at Aleppo, aged thirty-six, on his way home.

WORKED EXAMPLES

Example 1. The data table in this lesson lists six flood accounts. A vessel appears in all 6, a divine warning in 5, birds sent out in 2, and a landing on a mountain in 5. Express each as a percent of the six accounts.

(Use the map or drawing “Read the counts from the bar heights.” shown earlier in this lesson.)

1. Vessel: 6 ÷ 6 = 1.00 = 100%.
2. Warning: 5 ÷ 6 = 0.833 = about 83%.
3. Birds: 2 ÷ 6 = 0.333 = about 33%.
4. Mountain: 5 ÷ 6 = about 83%.

Answer: Vessel 100%, warning 83%, mountain 83%, birds 33%. The birds are the rarest motif, found only in Genesis and the Babylonian epic, which is one reason scholars link those two most closely.

Example 2. Utnapishtim’s boat was a cube 120 cubits on each side. Noah’s Ark was 300 × 50 × 30 cubits. Find the volume of each in cubic cubits, the ratio of the two volumes, and each vessel’s length-to-width ratio.

1. Cube: 120 × 120 × 120 = 1,728,000 cubic cubits.
2. Ark: 300 × 50 × 30 = 450,000 cubic cubits.
3. Ratio: 1,728,000 ÷ 450,000 = 3.84, so the cube holds nearly four times as much.
4. Length to width: cube 120 : 120 = 1 : 1; Ark 300 : 50 = 6 : 1.

Answer: The cube is 1,728,000 cubic cubits, the Ark 450,000, a ratio of about 3.8 to 1. The cube’s 1 : 1 shape is the kind that rolls badly in waves; the Ark’s 6 : 1 shape is the stable barge shape of Lesson 4.2. Bigger is not better if it capsizes.

Example 3. The Flood Tablet was copied for Ashurbanipal's library in about 650 BC, and George Smith read it in AD 1872. The Atrahasis copies date from about 1650 BC. How many years passed between each copy and Smith's reading?

1. Years BC and years AD are counted from the same point, so add them (there is no year zero, which changes the total by only one year).
2. Flood Tablet: 650 + 1872 = 2,522, about 2,520 years.
3. Atrahasis: 1650 + 1872 = 3,522, about 3,520 years.
4. Difference between the two copies: 1650 − 650 = 1,000 years.

Answer: About 2,520 years for the Flood Tablet and about 3,520 years for Atrahasis. The Atrahasis copy is a thousand years older than the one Smith read, yet both tell the same story, which shows how long a written text can hold its details.

PRACTICE

1. EASY Who was George Smith, and what did he announce on December 3, 1872?
2. EASY Name the flood hero in each: the Babylonian epic, the Greek story, the Indian story.
3. EASY Which three birds did Utnapishtim send out, and in what order? Which did Noah send?
4. MEDIUM State the three explanations scholars give for why so many peoples have flood stories.
5. MEDIUM Data reading. Use the table: Account, warning, vessel, survivors, birds, mountain, offering. Genesis: Y Y Y Y Y Y. Sumerian (Ziusudra): Y Y Y not preserved, not preserved, Y. Babylonian (Utnapishtim): Y Y Y Y Y Y. Greek (Deucalion): Y Y Y N Y Y. Indian (Manu): Y Y Y N Y Y. Hawaiian (Nu'u): not told, Y Y N Y Y. (a) Which account matches Genesis in all six features? (b) Which feature is found in the fewest accounts? (c) Why should "not preserved" be treated differently from "N"?
6. MEDIUM Data reading. Storm lengths in the accounts: Genesis, rain 40 days; Babylonian, 6 days and 7 nights; Sumerian, 7 days and 7 nights; Greek (Apollodorus), 9 days and nights. (a) How many times longer is the Genesis rain than the Babylonian storm, counting the Babylonian storm as 7 days? (b) The Genesis waters also prevailed 150 days. If a storyteller remembered only "the storm," which number would most likely be lost?
7. HARD A critic says: "The Gilgamesh tablets are older than any Bible manuscript, so Genesis must have copied Gilgamesh." Explain the flaw in this reasoning.
8. HARD Give two differences between the Babylonian flood account and Genesis that a Christian would point to as signs that Genesis is the accurate record, and explain each.
9. HARD Experiment design. You want to test whether numbers are lost faster than names when a story is passed by word of mouth. Describe how you would set up the test, what you would change, what you would keep the same, what you would count, and how you would make the result fair.

10. CHALLENGE Write a short paragraph: How does Genesis 9:19 and the account of Babel in Genesis 11 explain the worldwide spread of flood stories, and what would you expect the stories to look like if that explanation is right?

COMMON MISTAKES

- Thinking that an older surviving copy means an older story. The Flood Tablet is a copy of a copy; the date of the clay is not the date of the account.
- Thinking every flood legend is a full match to Genesis. Most keep only a few motifs; the point is the pattern across hundreds of stories, not any single one.
- Thinking Christians must dismiss the legends. They are evidence to be read carefully; the Christian claim is that they are distorted memories of a real event, not that they are worthless.

> **Make it a game · Motif Match.** Make six cards for the six accounts (Genesis, Sumerian, Babylonian, Greek, Indian, Hawaiian) and six cards for the motifs (warning, vessel, survivors, birds, mountain, offering). Shuffle both piles. Draw one of each. If the motif appears in that account according to the lesson's table, say one detail about it to score a point; if it does not, say "not there" to score a point. A wrong call loses a point. Draw again. First to ten wins, and anyone who can give the hero's name for an account scores a bonus.

> **Scripture.** "These are the three sons of Noah: and of them was the whole earth overspread." (Genesis 9:19, KJV)

Every nation began with people who had heard about the Flood from the family that lived through it. That one sentence explains why a story of the waters can be found on every continent.

Practice answers

1. A self-taught British Museum cuneiform expert, originally a banknote engraver, who announced that a tablet from Nineveh contained a Babylonian account of the Flood (Tablet XI of the Epic of Gilgamesh).
2. Utnapishtim (Babylonian); Deucalion, with his wife Pyrrha (Greek); Manu (Indian).
3. Utnapishtim: dove, swallow, raven. Noah: a raven, then a dove three times (Genesis 8:7–12).
4. Borrowing (one story copied from another, usually said to be from Mesopotamia); independent invention (every people made up its own after local floods); common memory (all peoples descend from survivors of one real flood and carried the memory as they scattered).
5. (a) The Babylonian account. (b) Birds sent out, found only in Genesis and the Babylonian account. (c) "Not preserved" means the tablet is broken at that point, so we do not know whether the feature was there; "N" means the text survives and the feature is absent. Counting unknowns as absent can understate the match.
6. (a) 40 ÷ 7 = 5.7, about six times longer. (b) The 150 days of prevailing water, which is a quiet stretch with no dramatic storm to remember; the shorter, more vivid storm number survives, which is what we see in the legends.

7. The age of a surviving copy is not the age of the account it preserves. The Flood Tablet is itself a copy of older texts, and Genesis could likewise preserve an older account through later copies. Which version is the original must be judged by other evidence: internal consistency, sober detail (dates, workable proportions), and how the versions relate to each other; a later copy can hold the earlier and truer form.
8. Any two: the Babylonian boat is a cube that would roll, while the Ark is a seaworthy 6 : 1 box; the Babylonian storm is a week, too short to drown the earth, while Genesis gives 40 days of rain and 150 days of prevailing waters; Genesis gives dates for every stage, the epic gives none; in the epic the flood is sent by quarrelling gods who are frightened by their own storm and crowd around the sacrifice like flies, while Genesis presents one righteous God acting with purpose and making a covenant afterward.
9. Write a story card with the same number of numbers and names, say six of each, of similar length and importance. Pass it through a spoken chain of the same people with the same waiting time between passes. Change nothing but the kind of detail you are counting. Keep the story, the people, the number of passes and the waiting time the same. Count how many of the six numbers and how many of the six names arrive correct. Run at least three trials with different starting people and compare the averages. To be fair, mix the order of names and numbers in the story so position does not favor one kind.
10. Sample answer: Genesis 9:19 says the whole earth was peopled from Noah’s three sons, and Genesis 11 says their descendants were scattered from Babel into different languages. If so, every nation began with people who knew the Flood from their own family history, and each carried the story away in its own tongue. We would expect flood stories almost everywhere, with the core kept (a warning, a vessel, survivors, a mountain, a new beginning) but details drifting, numbers shrinking, local mountains and animals substituted, and the one God replaced by local gods, while the written record kept in the line of Abraham preserved the exact dates and measures. That is close to what the table shows.

4.4 What a Global Flood Would Leave Behind

OBJECTIVES

- Tell the story of J Harlen Bretz and the Channeled Scablands and list the landforms that a known catastrophic flood left behind: coulees, dry falls, giant current ripples and erratic boulders.
- State at least four things creation geologists expect a worldwide flood to have left in the rock record, and match each to something that can be observed today.
- Run a dam-burst test in a sediment tray, measure channel width and depth for fast and slow water, and explain how rate changes what water leaves behind.

Warm-up. Fill a clear jar two-thirds with water. Add a handful of mixed material: gravel, sand and a spoon of garden soil. Shake hard for ten seconds and set it down. Watch and count seconds. What settles first, second, last? By the time the water is clear, how many layers do you see from one shake? Write the number down; you will come back to it.

Video. Coming soon. Channeled Scablands, glacial Lake Missoula floods and J Harlen Bretz; Dry Falls and the giant ripples at Camas Prairie; look for USGS, National Park Service Ice Age Floods National Geologic Trail, Washington State Parks, Nova or university geology channels, and drone footage of coulees.

KEY TERMS

catastrophism
The view that much of the rock record was shaped by rare, violent events such as great floods, rather than only by slow everyday processes.

uniformitarianism
The view, made popular by Charles Lyell in 1830, that the past should be explained only by the slow processes we watch today, acting at today’s rates.

scabland
Bretz’s word for land stripped to bare rock by floodwater, cut by dry channels called coulees, as in eastern Washington.

giant current ripple
A ripple of gravel many meters high and tens of meters apart, the large-scale version of the ripples in a creek bed, made by very deep, fast water.

erratic
A boulder of a rock type foreign to the place where it lies, carried there by ice or by floating ice in floodwater.

water gap
A notch where a river cuts straight through a ridge instead of going around it, as at the Delaware Water Gap.

CORE IDEAS

The story. In the summer of 1922 a University of Chicago geologist named J Harlen Bretz walked the dry country of eastern Washington and found a landscape that made no sense. Dry canyons, which the locals called coulees, were cut into solid basalt hundreds of meters deep with no river in them. At the head of one, Dry Falls, stood a horseshoe cliff 120 m high and 5.6 km wide, the bones of a waterfall with no water. Boulders of granite lay on hills where no granite belonged. In 1923 Bretz published his conclusion: the whole region had been swept by a flood of unimaginable size, so fast and deep that it tore the ground to bedrock. He called it the Channeled Scablands. Geologists were appalled; floods of that size were exactly what Lyell's uniformitarian rules forbade. In January 1927 Bretz presented his evidence to the Geological Society of Washington and was answered by a row of critics, none of whom had seen the ground.

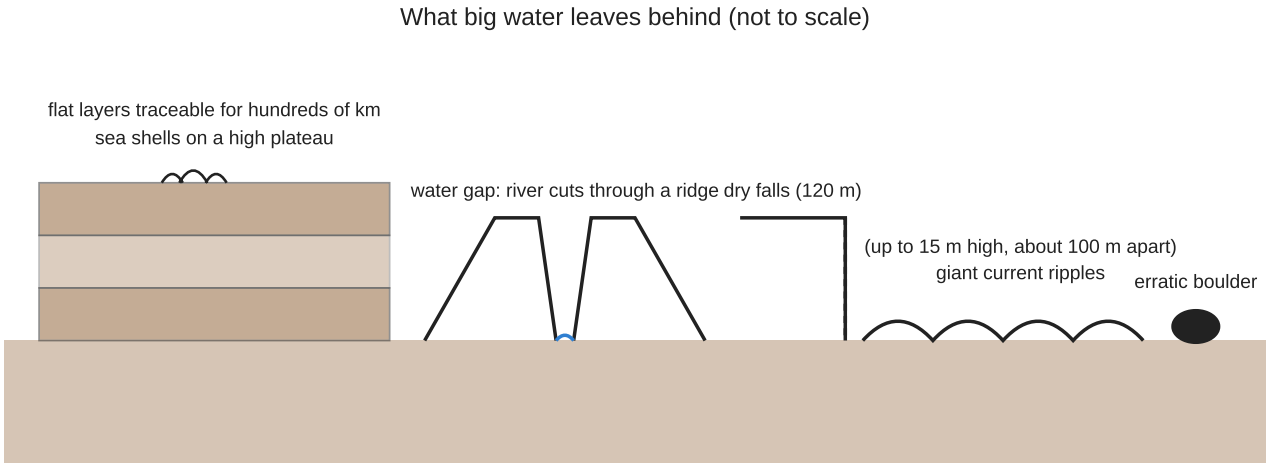
How they figured it out. Bretz had the landforms but no source for the water. The source came from Joseph Pardee of the United States Geological Survey, who had long studied glacial Lake Missoula in western Montana. A lobe of ice had dammed the Clark Fork River, backing up a lake as much as 600 m deep holding about 2,100 cubic kilometers of water. In 1940 Pardee showed that the hills of Camas Prairie, Montana, were covered with giant current ripples, ridges of gravel up to about 15 m high and roughly 100 m apart, which only enormously deep, fast water can make. The ice dam had failed, and the lake had emptied across Idaho and Washington in a matter of days. That was Bretz's flood. Later mapping convinced most geologists that the dam formed and failed many times. In 1979, at the age of 96, Bretz was given the Penrose Medal, the highest award in American geology, and remarked to his son that all his old opponents were dead, so he had no one left to gloat over.

The big idea. The scablands teach a method: a flood leaves fingerprints, and you can predict them before you look. Fast, deep water strips land to bedrock, cuts channels straight across whatever lies in its path, piles gravel into giant ripples, and drops boulders where they do not belong. Now scale the question up. If the Flood of Genesis 7 covered the earth for about a year, what should it have left? Creation geologists make a list. First, water-laid sediment in enormous sheets, thick, flat and traceable across whole continents, as the Tapeats-type sandstones and the great limestones are (Unit 2). Second, sea fossils high up and far inland, as on the Grand Canyon rim at 2,100 m and in the limestone near the summit of Mount Everest. Third, rapid burial: a fish fossilized while swallowing another fish, as in the Green River Formation of Wyoming, or an ichthyosaur fossilized while giving birth, as at Holzmaden in Germany, cannot have been buried slowly. Fourth, mass graves of jumbled bones of many kinds. Fifth, planed-off surfaces and rivers that cut through ridges at water gaps.

In the world today. What would a global flood *not* leave? It would not leave one layer labeled "Flood." Your jar in the warm-up made several sorted layers from one shake, and Berthault's flume (Lesson 2.3) made many layers from one current. A year of rising and falling water would leave hundreds of layers, sorted by grain size and by the creatures living at each level (Lesson 3.2). That is why two geologists can stand at the same cliff and read the same layers so differently: one expects one year of changing water, the other vast ages of

slow deposit. The textbook's expectation is often stated as if it were an observation, and Bretz's story is a warning against that habit. For forty years the rule "only slow processes" kept good geologists from believing a flood they could have walked across in an afternoon. Observation won in the end, and the signs at Dry Falls now tell visitors about a flood ten times the flow of all the rivers of the world.

God's handiwork. Peter wrote that in the last days scoffers would say "all things continue as they were from the beginning of the creation," and would willingly be ignorant that the world of that time, "being overflowed with water, perished" (2 Peter 3:4–6). He wrote that long before Lyell, yet he described uniformitarianism exactly. The lesson is not that slow processes are false; rain, rivers and tides work every day, and we measure them. The lesson is that a world made and judged by God has a history with real events in it, and the rocks are allowed to record them. A student who looks at a coulee and asks "what made this, and how fast?" is doing just what Bretz did, and Steno before him: reading the earth honestly.



Fingerprints of big water, drawn schematically: flat continent-scale layers, sea fossils on high ground, a water gap, a dry falls, giant current ripples and an erratic boulder. The last three are seen today in the Channeled Scablands.

⏳ Thinking About Time

What the sign says. What the sign says: the signs at Dry Falls say the Missoula floods swept through about 15,000 years ago at the end of the last Ice Age, and the textbooks say the sediment layers of the continents built up slowly over hundreds of millions of years with no worldwide flood.

What we observe. What we observe: coulees cut to bedrock, a dry waterfall 120 m high and 5.6 km wide, gravel ripples up to 15 m high, and granite boulders far from any granite, all made by water moving for days, not ages. Across the continents we observe flat sediment sheets traceable for hundreds of kilometers, marine fossils on high plateaus and mountain summits, and fossils buried so fast that a meal or a birth was frozen in stone. These are observations anyone can check with a map, a hand lens and a hammer.

How Christians read it. How Christians read it: the Flood of Genesis 7–8 would leave exactly such fingerprints on a global scale, and creation geologists read the great sediment sheets and fossil beds as its work, about 4,400 years ago by the Bible's genealogies. The Missoula floods they place in the one Ice Age that followed the Flood (Unit 5), within the centuries after it. The date on the sign depends on assuming slow, steady rates in the ice and the sediment; the landforms themselves show only that the water was fast and deep.

Try it. On a sketch of a creek bed, draw a sand ripple 1 cm high and 10 cm apart. Beside it, at a scale of 1 cm = 10 m, draw a Camas Prairie ripple 15 m high and 100 m apart. What kind of water made the second one?

2 Peter 3:6

PICTURE STUDY



The Subsiding of the Waters of the Deluge, Thomas Cole, 1829 · Oil on canvas · Smithsonian American Art Museum, Washington, D.C.

Thomas Cole, the English-born founder of the Hudson River School of American landscape painting, painted this in 1829 when he was 28. Instead of the storm, he chose the morning after: the waters are going down, the sky is clearing, and far away on the calm sea sits the Ark.

Cole was a careful observer of rocks and weather. Look at how he imagined the land the water left behind: bare, broken, scoured and still wet. Then compare it with what Bretz found in Washington a century later.

Look closely

- Find the Ark. Why do you think Cole painted it so small and so far away?
- Look at the rocks in the foreground. Are they smooth and rounded, or sharp and freshly broken? What does that suggest about the water that just left?
- Find the skull and the torn tree. What are they telling the viewer about the world before the Flood?
- Find the light. Where is it coming from, and what feeling does it give the scene?

Talk about it

1. If you were a geologist walking into Cole's landscape the next day, what three things would you measure or collect?
2. Cole shows one skull but no layers of sediment. From what you learned in this lesson, what would the ground really be covered with after a year of floodwater?
3. Genesis 8:13 says Noah looked out and saw the ground dry. Does Cole's scene match that moment, or an earlier one? Explain from the picture.

> **Safety first.** This project uses water and loose sand outdoors or over a large tray. Work outside or on a tarp, keep the water away from electrical outlets, do not pour sand down any drain, and wash hands afterward.

EXPERIMENT: DAM BURST IN A TRAY: FAST WATER VERSUS SLOW WATER

You will build a small landscape of layered sediment in a tray and release the same volume of water two ways: as a slow trickle and as a sudden dam burst. Then you will measure what each one leaves behind.

Question: Does the same amount of water cut a wider, deeper channel when it is released all at once than when it trickles? Prediction: write your expected channel width and depth for each. What we change: how fast the water is released. What we keep the same: the amount of water, the sediment, the slope and the starting point. What we measure: channel width, depth and length, and the spacing of any ripples.

You will need

- A large shallow tray, plastic storage-box lid or baking sheet with a rim (at least 40 cm long)
- About 2 liters of play sand, plus a cup of fine soil or flour for a contrasting layer
- A 1-liter measuring pitcher and a cup with a small hole punched near the bottom (for the trickle)
- A small board or book to tilt the tray, and a ruler
- A short strip of cardboard to use as a dam, a notebook and pencil, and a camera if you have one

Steps

1. Fill the tray with sand about 3 cm deep. Sprinkle a thin layer of soil or flour over it, then another 1 cm of sand, so you have visible layers. Smooth the top flat. Tilt the tray by placing the board under one end so the slope is gentle, about 5 cm of rise over the length of the tray.
2. Trickle run: set the cup with the hole at the high end and pour 500 mL of water into it so it trickles out over several minutes. When the water has run through, measure the channel it cut: width at its widest, depth at its deepest, and length. Sketch the channel shape and note whether the layers show in its sides. Record everything in a table.
3. Smooth the sand flat again and rebuild the same layers. Build a cardboard dam across the high end and pour 500 mL of water behind it. Pull the dam away quickly so the water releases all at once. Measure width, depth and length the same way, and look for small ripples or a fan of sand at the low end; measure the ripple spacing if you find any.
4. Repeat each run twice more (three trickle runs, three burst runs), rebuilding between runs. Average your measurements.
5. Draw a bar graph comparing average width and average depth for trickle versus burst.
6. Look at the sand at the low end of the tray after a burst run. Did it sort, with coarser grains first and finer on top or farther out? Note it.
7. Write a paragraph connecting your results to the scablands: what does the same volume of water do when it moves fast, and what would it leave for a geologist to find?

Tips

- Keep the slope exactly the same for all runs; mark the board position with tape.
- If the burst run washes out the whole tray, use a smaller volume, such as 250 mL, for both methods, and record the change.

Check your work

- My table has three trickle runs and three burst runs with width, depth and length in centimeters.
- My bar graph compares the averages with labeled axes and units.
- I rebuilt the same layers and used the same slope and volume for every run.
- My paragraph explains the result in terms of water speed and names at least two scabland landforms.

FIELD NOTEBOOK

1. Draw Dry Falls in profile with its 120 m height marked, and beside it a person 1.7 m tall at the same scale (use 1 cm = 10 m).
2. Make a two-column list: “What a global flood would leave” and “Where we observe it,” with at least five pairs from the lesson.
3. Sketch your settling jar from the warm-up with its layers labeled coarse to fine, and write the number of seconds each took to settle.

From history. Joseph Pardee had actually hinted at a sudden draining of Lake Missoula as early as 1910, but it was his 1940 talk on the giant ripples at Camas Prairie, Montana, that gave Bretz his water. The ripples are so large that they were not recognized as ripples from the ground; they show best from the air. In 1979, when Bretz received the Penrose Medal of the Geological Society of America at age 96, the story had become a favorite teaching example of how a careful field observer can be right while the experts of his day are wrong.

WORKED EXAMPLES

Example 1. Glacial Lake Missoula held about 2,100 km^3 of water. If the ice dam failed and the lake emptied in about 2 days, what was the average flow in cubic meters per second? Compare it with the Amazon River, whose average flow is about 200,000 m^3/s.

(Use the map or drawing "Water on this scale made the dry falls and giant ripples shown here." shown earlier in this lesson.)

1. Convert the volume: 1 km^3 = 1,000,000,000 m^3, so 2,100 km^3 = 2.1×10^{12} m^3.
2. Convert the time: 2 days × 24 h × 3,600 s = 172,800 s.
3. Divide: 2.1×10^{12} m^3 ÷ 172,800 s = 1.2×10^7 m^3/s, about 12 million cubic meters per second.
4. Compare: 12,000,000 ÷ 200,000 = 60.

Answer: About 12 million m^3/s, roughly 60 times the Amazon. Geologists' detailed estimates are of this same order, which is why the sign says the flood exceeded all the world's rivers combined.

Example 2. Sand ripples in a creek are about 1 cm high and 10 cm apart. The giant current ripples at Camas Prairie are up to 15 m high and about 100 m apart. How many times larger are the giant ripples in height and in spacing? Dry Falls is 5.6 km wide and 120 m high; Niagara's Horseshoe Falls is about 790 m wide and 57 m high. How do they compare?

1. Ripple height: 15 m = 1,500 cm, and 1,500 ÷ 1 = 1,500 times higher.
2. Ripple spacing: 100 m = 10,000 cm, and 10,000 ÷ 10 = 1,000 times farther apart.
3. Falls width: 5,600 m ÷ 790 m = 7.1 times wider.
4. Falls height: 120 m ÷ 57 m = 2.1 times higher.

Answer: The giant ripples are about 1,000 to 1,500 times the size of creek ripples, and Dry Falls is about 7 times wider and 2.1 times higher than Horseshoe Falls. Since ripple size grows with the depth and speed of the water, these are measurements of how big the water was.

Example 3. A sandstone layer is 100 m thick. (a) If it formed at a textbook rate of 0.1 mm per year, how long did it take? (b) If it formed at a flood-stage rate of 1 m per day, how long did it take? What does the comparison show?

1. (a) Convert: 100 m = 100,000 mm. Time = 100,000 mm ÷ 0.1 mm/year = 1,000,000 years.
2. (b) Time = 100 m ÷ 1 m/day = 100 days, about three months.
3. The thickness is the observation; the rate is the assumption. Changing the assumed rate changes the answer by a factor of about 3.6 million.

Answer: (a) About a million years. (b) About 100 days, which fits inside the Flood year. The layer itself does not tell you which rate to use; that must be argued from other evidence, such as the lack of erosion between layers and the fossils buried rapidly within them.

PRACTICE

1. EASY Who was J Harlen Bretz, and what did he claim in 1923 about eastern Washington?
2. EASY Name four landforms or deposits that the Missoula floods left behind.
3. EASY What is uniformitarianism, and who made it popular?
4. MEDIUM List four things creation geologists expect a worldwide flood to have left, and for each give one place or example where it is observed.
5. MEDIUM Why would a worldwide flood not leave a single layer labeled “Flood”? Use your warm-up jar in the answer.
6. MEDIUM Data reading. A table of Missoula flood figures: lake depth at the dam, 600 m; lake volume, 2,100 km^3; Dry Falls height, 120 m; Dry Falls width, 5.6 km; giant ripple height, up to 15 m; giant ripple spacing, about 100 m. (a) How many times deeper was the lake than Dry Falls is high? (b) Which of these figures is a direct measurement of a landform today, and which is an estimate of something that no longer exists?
7. MEDIUM Data reading. In a settling-jar test, a student recorded the time for each material to settle after one shake: gravel, 3 s; coarse sand, 12 s; fine sand, 45 s; silt, 8 min; clay, still cloudy after 2 h. (a) Describe the relationship between grain size and settling time. (b) How many sorted layers would you expect at the bottom after 10 minutes, and which material would still be in the water?
8. HARD Explain why Bretz’s critics in 1927 rejected his flood, and what finally changed most geologists’ minds.
9. HARD Experiment design. You want to test whether a steeper slope makes a dam-burst channel deeper. Describe your setup: what you change, three things you keep the same, what you measure, and how many trials.
10. CHALLENGE Write a short paragraph: A textbook says a 100 m sandstone took a million years to form; a creation geologist says it took months. Using the worked example, explain what each is assuming, what both can observe, and what evidence could help decide between them.

COMMON MISTAKES

- Thinking that a thick layer must have taken a long time. Thickness is an observation; the time depends on the assumed rate, and floods lay meters of sediment in hours.
- Thinking the Missoula floods are the Flood of Genesis. They are a much smaller, later event; the point is that they show what fast, deep water does and that geologists resisted even that for decades.
- Thinking catastrophism means slow processes never happen. Rain, rivers and tides really do work every day; the question is which processes made which features, and at what rate.

Make it a game · Fingerprint Detective. Write each of these on a card: coulee, dry falls, giant ripple, erratic boulder, continent-wide sand sheet, sea shells on a mountain, fish buried mid-meal, water gap, mud cracks, tree roots in a layer. One player draws a card and describes the feature without naming it. The others must say what made it (fast deep water, slow exposure on dry land, or ice) and give one reason. A correct call scores a point; naming a real place where it is seen scores a bonus. First to eight wins.

Scripture. “For this they willingly are ignorant of, that by the word of God the heavens were of old, and the earth standing out of the water and in the water: Whereby the world that then was, being overflowed with water, perished:” (2 Peter 3:5–6, KJV)

Peter says the scoffers of the last days will be ignorant on purpose, insisting that nothing ever happened but what happens today. The scablands are a small reminder that the earth’s history has real events in it, and the honest observer looks for their marks.

Practice answers

1. A University of Chicago geologist who claimed that the Channeled Scablands had been carved by an enormous, sudden flood, not by slow rivers.
2. Any four: coulees (dry channels cut to bedrock), Dry Falls (a dry waterfall cliff), giant current ripples of gravel, erratic boulders, scoured bare rock, gravel bars and fans.
3. The view that the past should be explained only by the slow processes we see today acting at today’s rates; made popular by Charles Lyell in 1830.
4. Any four: continent-scale flat sediment sheets (the Tapeats-type sandstones and Grand Canyon limestones); marine fossils high and inland (Kaibab Limestone at 2,100 m; Everest summit limestone); rapid burial (Green River fish swallowing a fish; Holzmaden ichthyosaur giving birth); mass bone beds of many kinds; water gaps and planed surfaces (Delaware Water Gap).
5. Moving water sorts sediment by size and lays it in many layers; one shake of a jar made several layers, and a year of rising and falling currents would leave hundreds, each sorted by grain size and by the creatures living where the water reached, not one mixed deposit.
6. (a) 600 ÷ 120 = 5 times. (b) Dry Falls height and width and the ripple height and spacing are direct measurements of landforms that exist today. The lake depth and volume are estimates of a lake that is gone, worked out from old shorelines on the hills and from the land’s shape.

7. (a) The smaller the grain, the longer it takes to settle; the times grow very quickly as grains get finer. (b) Four layers (gravel, coarse sand, fine sand, silt) from bottom to top, with the clay still suspended in the cloudy water.
8. They held the uniformitarian rule that landforms must be explained by slow, ordinary processes, and a flood of that size seemed to break it; most had not seen the scablands. Pardee's 1940 evidence of giant current ripples at Camas Prairie supplied a source, glacial Lake Missoula and a failed ice dam, and later mapping and aerial photographs confirmed the flood features. Observation in the field outweighed the rule.
9. Use the same tray, sand layers and 500 mL of water released by pulling the same dam. Change only the slope: for example, 2 cm, 5 cm and 8 cm of rise at the high end, marked with tape. Keep the same sediment and layering, the same water volume, the same release method and the same starting point. Measure the deepest point of the channel with a ruler (and width and length as well). Run each slope three times, rebuilding between runs, and compare the average depths.
10. Sample answer: Both observe the same 100 m of sandstone. The textbook assumes a slow rate like today's quiet settling, about 0.1 mm a year, which gives a million years. The creation geologist assumes a flood-stage rate, such as a meter a day, which gives about 100 days. The thickness cannot choose between them, so other evidence must: whether the contacts between layers show soil, roots, burrows and erosion gullies that take long exposure, or are flat and clean; whether the fossils inside are buried whole and fast; and whether the layer spreads in one sheet across a continent, which running water in flood does and a quiet pond does not. Flume tests like Berthault's show what fast water can do, and the scablands show that fast water did act on the earth.

Unit 4 review

Answer each question. Show your work for calculations, label units, and use complete sentences for explanations. The test is worth 60 points.

1. (5 pts) Multiple choice. On the day the Flood began, Genesis 7:11 says two things happened. Which pair is correct? (a) The rain began and the Ark was finished. (b) The fountains of the great deep were broken up and the windows of heaven were opened. (c) The Ark rested and the raven was sent. (d) The mountains were covered and the dove returned.
2. (5 pts) Using 30-day months, how many days passed from the start of the Flood (month 2, day 17) to the day the Ark rested (month 7, day 17)? How many days from the start to the day the earth was dried (month 2, day 27 of the next year)? Show your work.
3. (5 pts) Multiple choice. Which proportions describe the Ark in Genesis 6:15? (a) A cube, 120 cubits on each side. (b) 300 cubits long, 50 wide, 30 high. (c) 100 cubits long, 100 wide, 10 high. (d) 300 cubits long, 30 wide, 50 high.
4. (6 pts) Using a 45 cm cubit, convert the Ark’s dimensions to meters and find its volume in cubic meters. Then find the mass of fresh water (1,000 kg/m³) it would displace at a draft of 6.75 m, in tonnes.
5. (6 pts) Diagram. Draw the Ark in side view to scale at 1 cm = 20 cubits, showing its three decks, the door in the side, and a dashed waterline at 15 cubits. Label the length, height and the ratio of length to width.
6. (5 pts) Multiple choice. What did George Smith announce in London on December 3, 1872? (a) He had found Noah’s Ark on Mount Ararat. (b) He had dug up a flood layer at Ur. (c) He had read a Babylonian account of the Flood on a clay tablet from Nineveh. (d) He had translated the Greek story of Deucalion.
7. (6 pts) Data reading. Six flood accounts were checked for six features. A vessel appears in 6 of 6, a divine warning in 5, a landing on a mountain in 5, an offering afterward in 6, a few survivors in 6, and birds sent out in 2. (a) What percent of the accounts include birds? (b) Which two accounts share the bird motif, and why do scholars link them most closely? (c) Name one way in which the Babylonian account differs from Genesis.
8. (5 pts) State the three explanations scholars give for why so many peoples have flood stories, and say which one Christians who read Genesis as history hold and why.
9. (5 pts) Multiple choice. Which of these is NOT a feature the Missoula floods left in the Channeled Scablands? (a) Coulees cut to bare basalt. (b) Giant current ripples of gravel. (c) A single thin layer of clay over the whole region. (d) Erratic boulders carried by floating ice.
10. (6 pts) Glacial Lake Missoula held about 2,100 km³ of water. If it drained in 2 days, what was the average flow in m³/s? (1 km³ = 1,000,000,000 m³; 1 day = 86,400 s.) Round to two significant figures.
11. (6 pts) Written explanation. A museum sign says a 100 m sandstone took a million years to form. In a paragraph, state what the sign is assuming, what anyone can observe

about the layer, and how a Christian who reads Genesis 6–9 as history would read the same layer. Be fair to both readings.

UNIT PROJECT: THE FLOOD YEAR LOGBOOK

Make a logbook of the Flood year as if you were the ship's recorder. Part 1 is a scale timeline from Genesis 7:11 to 8:14 with every dated event, the day count, and the water rising and falling. Part 2 is a scale drawing or model of the Ark with its dimensions in cubits and meters, its volume and displacement worked out, and a summary of what the 1994 study tested and found. Part 3 is your data table of six flood accounts with a bar graph of shared features and a paragraph on the three explanations. Part 4 is a "fingerprints" page: five things a global flood would leave, where each is observed, and a photograph or drawing of your dam-burst tray with its measurements.

Close the logbook with one Thinking About Time box of your own, written for a museum sign you have seen or read about: what the sign says, what is observed, and how Christians read it.

- **Accuracy**: Dates, day counts, cubit conversions, volumes and flood-account features are correct and match the verses and the lessons.
- **Measurement and data**: The timeline and Ark drawing are to a stated scale; the data table, bar graph and tray measurements have units and labeled axes.
- **Reasoning**: The paragraphs state what is observed, what is assumed, and how each side reads it, fairly and in the student's own words.
- **Care**: The logbook is neat, complete, in order, and shows the student's own drawings and handwriting.

Answer key

1. (b)
2. 5 months × 30 = 150 days to the Ark resting. 12 months × 30 = 360 days plus 10 days = 370 days to the earth dried.
3. (b)
4. 135 m × 22.5 m × 13.5 m; volume 41,006 m^3, about 41,000 m^3. Displaced volume at 6.75 m draft: 135 × 22.5 × 6.75 = 20,503 m^3, so about 20,500 tonnes of water, which is the total mass the loaded Ark could have at that draft.
5. A rectangle 15 cm long and 1.5 cm high with two horizontal lines dividing it into three stories, a door drawn on the side, and a dashed line 0.75 cm up from the bottom labeled "15 cubits." Labels: 300 cubits (135 m) long, 30 cubits (13.5 m) high, length to width 6 : 1.
6. (c)
7. (a) 2 ÷ 6 = 33%. (b) Genesis and the Babylonian Epic of Gilgamesh; they share the rarest and most specific details, such as the birds and the landing on a mountain. (c) Any one: the Babylonian boat is a cube of 120 cubits; its storm lasts six days and seven nights; it gives no dates; the flood is sent by quarrelling gods who are frightened by it.
8. Borrowing (the stories were copied from one source, usually said to be Mesopotamia); independent invention (local floods inspired separate stories); common memory (all peoples descend from survivors of one real flood and carried the memory as they scattered).

Christians hold common memory, because Genesis 9:19 and Genesis 11 say the nations spread from Noah’s sons after Babel, and because the stories appear in places with no link to Mesopotamia.

9. (c)
10. 2,100 km^3 = 2.1 × 10^{12} m^3; 2 days = 172,800 s; 2.1 × 10^{12} ÷ 172,800 = 1.2 × 10^7 m^3/s, about 12 million cubic meters per second.
11. Sample answer: The sign assumes the sand settled at a slow, steady rate like a quiet pond today, about 0.1 mm a year, which gives a million years for 100 m. What anyone can observe is the thickness, the grain size, the flat contacts above and below, any fossils inside, and how far the layer can be traced. A Christian who reads Genesis as history expects the Flood year to have laid such sheets rapidly, at rates of meters per day seen in floods and in flume tests, which would make the layer a matter of months. The thickness alone cannot decide; the evidence that can is whether the contacts show long exposure (soil, roots, gullies) or are clean and flat, and whether the fossils were buried fast. Both readings should be stated with their assumptions named.

UNIT 5

Ice Age

Scratched bedrock, house-sized boulders sitting on the wrong kind of rock, long ridges of mixed rubble across the farmland of the Midwest: these are the marks of ice. In 1837 a young Swiss naturalist named Louis Agassiz stood before a scientific society and said that glaciers had once covered far more of the earth than anyone imagined. He was right about the ice, and this unit begins by learning to read the marks it left, matching each one to a living glacier doing the same work today.

Then the unit asks harder questions. What were the woolly mammoths doing in Siberia, in numbers so great that their ivory has been traded for centuries, and how were they buried with grass still in their mouths? What makes an ice age at all, when cold air is dry air? And when scientists drill 3,000 m into Greenland and count layers, which layers are counted, which are modeled, and what has to be assumed? You will meet the mainstream answers as they appear on museum signs and in textbooks, stated fairly, and the creation reading of one ice age in the centuries after the Flood, worked out by the meteorologist Michael Oard.

Every lesson in this unit carries a Thinking About Time box, because the ice age is where the age question comes up most plainly. The goal is not to win an argument. It is to be able to walk into any museum, read the Pleistocene gallery sign accurately, point to what was observed, name what was assumed, and explain how a Christian who takes Genesis as history reads the same ice.

BEFORE YOU BEGIN

- Can apply Steno’s principles (superposition, original horizontality) and the idea of matching a mark to a known cause (Unit 1)
- Knows the three parts of a Thinking About Time box: what the sign says, what we observe, how Christians read it (Units 2 to 4)
- Can compute a rate from distance and time, convert between meters and centimeters, and read a bar graph or data table
- Knows the outline of the Flood year from Genesis 6–9 (Unit 4)

MASTERY CHECKLIST

- I can name the four marks of a glacier (striations, polished bedrock, erratics, moraines) and explain how Agassiz and Charpentier matched them to living ice.
- I can describe the woolly mammoth from its remains and explain what frozen carcasses do and do not tell us.
- I can state the two conditions an ice age needs and explain Oard’s model of warm oceans and volcanic ash beside the mainstream orbital model.
- I can explain how ice core layers are counted near the surface, checked with marker layers, and modeled at depth.

- I can compute a glacier speed, an accumulation rate and a layers-per-year age estimate and show how assumptions change the result.
- I can state the mainstream claim about ice age dates fairly and give the young-earth reading beside it without mocking either.

OPTIONAL BOOKS AND RESOURCES

- **National Snow and Ice Data Center (NSIDC)** (https://nsidc.org/): Free. Clear pages on glaciers, ice sheets, permafrost and how ice cores are drilled and stored, with photographs and current measurements of today's ice. Good for Lessons 5.1 and 5.4.
- **NOAA Paleoclimatology data and ice core pages** (https://www.ncei.noaa.gov/products/paleoclimatology): Free. The archive where ice core measurements are published. Parents can show students an actual data table of depth, layer thickness and oxygen isotope values. The ages listed are the mainstream modeled ages; use them for the "what the sign says" column.
- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free. Online collections and exhibit pages on mammoths and ice age mammals, useful for reading a real museum sign in Lesson 5.2 and practicing the three-part box.

5.1 Agassiz and the Glaciers (1837) ★

OBJECTIVES

- Tell how Louis Agassiz came to argue in 1837 that ice once covered far more land than it does today, and name the two men whose field evidence he built on.
- Identify the four classic marks a glacier leaves behind: striations, polished bedrock, erratic boulders and moraines, and explain how each forms.
- Compute a glacier's speed from distance and time, and separate what is measured about glaciers today from what is inferred about the past.

Warm-up. Freeze a few grains of sand into the bottom of an ice cube overnight. Press the sandy side onto a bar of soap or a scrap of soft wood and drag it slowly in one direction. Look at the marks. Now try dragging the sand grains with your fingertip. Which one left straighter, longer scratches, and why?

Video. Coming soon. Louis Agassiz glaciers ice age evidence striations erratics moraines; search USGS, National Snow and Ice Data Center, Smithsonian, PBS Eons style explainers, nature footage of Alpine glaciers, Moody Science classics

KEY TERMS

glacier
A thick mass of ice on land that forms where snow piles up faster than it melts, and that slowly flows downhill under its own weight.

striations
Long, parallel scratches cut into bedrock by stones frozen into the bottom of a moving glacier.

erratic
A boulder carried by ice and dropped far from the bedrock it came from, often sitting on rock of a completely different kind.

moraine
A ridge or pile of rock, gravel and clay dumped by a glacier, especially along its sides and at its melting end (terminal moraine).

till
The unsorted mix of clay, sand, pebbles and boulders left behind when glacier ice melts.

ice age
A museum and textbook word for a time when glaciers covered much more of the earth's land than they do now.

CORE IDEAS

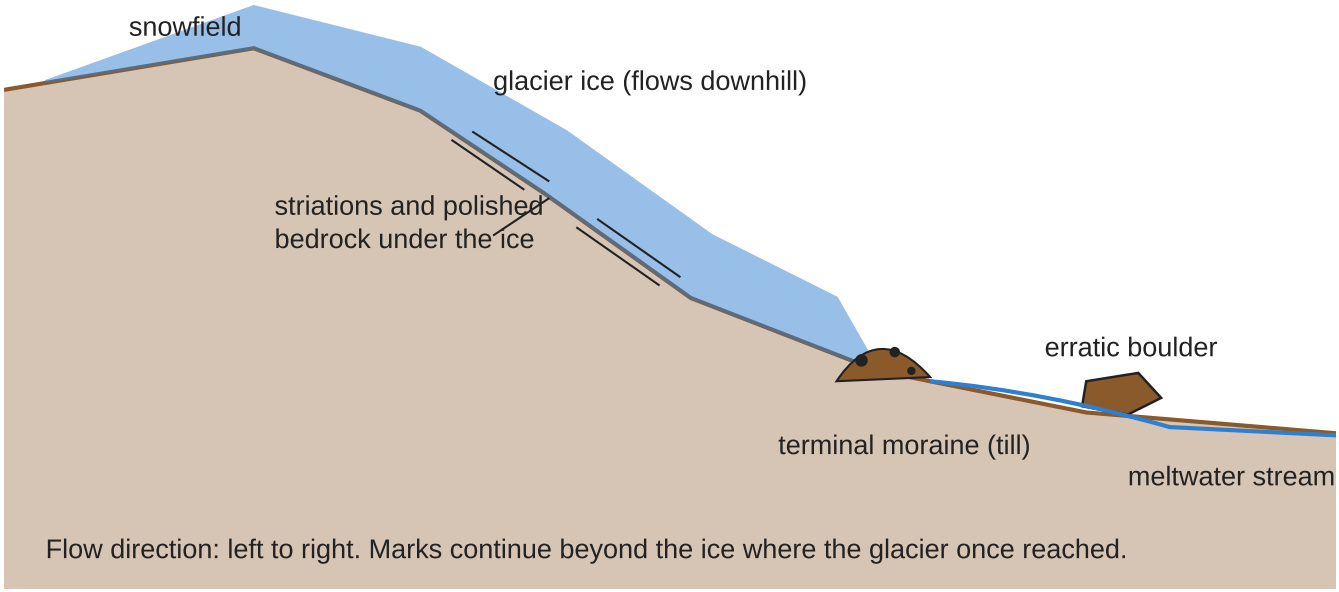
The story. On July 24, 1837, a 30-year-old Swiss naturalist named Louis Agassiz stood up to open the yearly meeting of the Swiss Society of Natural Sciences in Neuchâtel. The members expected to hear about fossil fish, the subject that had made him famous. Instead he told them that the Alps had once been buried under ice far thicker and wider than any glacier they knew, and that this ice had reached out across the lowlands of Switzerland and beyond. Many in the room were shocked. Agassiz had not thought of the idea alone. A road engineer, Ignaz Venetz, and a mining engineer, Jean de Charpentier, had been showing him strange boulders and scratched rocks in the Rhone valley for years, and had argued that only ice could explain them. That same year a friend, the botanist Karl Schimper, coined the German word *Eiszeit*, "ice age." Agassiz had the gift of making a bold case in public, and the name stuck.

How they figured it out. The argument rested on four kinds of marks that living glaciers make today. First, **striations**: when a glacier slides, stones frozen into its base act like sandpaper and cut long parallel scratches into the bedrock. Second, **polished bedrock**, smoothed and rounded where the ice ground over it. Third, **erratics**: huge boulders of granite sitting on limestone hillsides far from any granite, some the size of a house. Rivers cannot roll such blocks uphill, but ice can carry them anywhere it flows. Fourth, **moraines**: long ridges of unsorted rubble (**till**) that glaciers push along their sides and dump where their ends melt. Charpentier's key step was simple and very scientific: he walked up to the snouts of living glaciers, watched them making exactly these marks, then walked down the valley and found the same marks kilometers past where the ice now ends. Same marks, same cause.

Measuring the ice. Agassiz did not stop at a speech. In 1840 he published *Études sur les glaciers*, and from 1840 to 1845 he camped each summer on the Unteraar Glacier under an overhanging boulder his team nicknamed the "Hôtel des Neuchâtelois." He drove rows of stakes across the ice and measured them again each year. The stakes in the middle moved farther than those at the edges, so the glacier flows like a very slow river. He also had a check from the past. In 1827 a geologist named Franz Joseph Hugi had built a stone hut on the glacier's medial moraine. By 1840 the hut had ridden the ice about 1,400 m downhill, roughly 110 m a year, or about 30 cm a day. Agassiz even had himself lowered on a rope down a well-like shaft in the ice to see its layers from the inside. These were real numbers, measured by a man standing on the ice with a tape and a notebook.

The big idea. Agassiz used a rule you already know from Steno: match the mark to a cause you can watch making that mark today. Where you find striations, polished rock, erratics and moraines, ice has been. Using this rule, geologists mapped till and moraines across northern Europe and, after Agassiz moved to America in 1846, across Canada and the northern United States. Long Island and Cape Cod are largely moraine. The Great Lakes sit in basins deepened by ice. Boulders from Canada rest in Ohio fields. Everyone agrees on these marks. The disagreement, which we will meet in this unit, is over *when* and *how long* and *how many times* the ice came. The marks themselves do not carry a date.

God’s handiwork. Job was asked, “Out of whose womb came the ice?” Agassiz, who never accepted Darwin’s theory and spoke all his life of species as thoughts of God, would have said the answer was plain. Ice is only water obeying the laws its Maker gave it, yet it carved the fjords of Norway, polished the granite of Yosemite and scattered boulders like a sower scattering seed. Learning to read those marks is learning to read a chapter of history written in stone by a very patient hand.



The four marks of ice that Agassiz and Charpentier matched to living glaciers: striations, polished bedrock, erratics and moraines.

⏳ Thinking About Time

What the sign says. Textbooks and park signs say that during the Pleistocene epoch, which they date from about 2.6 million to about 11,700 years ago, ice sheets grew and shrank many times, and that the most recent ice sheets reached their largest size about 20,000 years ago, covering nearly 30 percent of the land.

What we observe. We observe striations, polished bedrock, erratics, till and moraines far beyond today’s glaciers, and we watch living glaciers making the same marks now. A glacier’s speed, thickness and snowfall can be measured today. No one can measure how long the old ice sat there or how many times it came.

How Christians read it. Creation geologists agree the ice was real and very large. They read it as a single ice age that followed the Flood and lasted a few hundred years, because the Flood left warm oceans and ash-filled skies, the conditions for heavy snow and cool summers. Multiple glaciations are read as advances and retreats of that one ice age.

Try it. Look at a map of your region and find the nearest moraine, kettle lake or erratic. Many northern states and provinces have them within a day’s drive.

> *Job 38:29*

PICTURE STUDY



The Grindelwald Glacier, Thomas Fearnley, 1838 · Oil on canvas · National Museum of Art, Architecture and Design, Oslo

Thomas Fearnley was a Norwegian landscape painter who traveled through the Alps sketching outdoors. He painted the Grindelwald Glacier in 1838, the year after Agassiz's famous speech and in the very valleys where Venetz and Charpentier had been pointing to scratched rocks and misplaced boulders. Fearnley's glacier is not a smooth white blanket. It is a cracked, flowing, dirty mass of ice shouldering its way between cliffs.

Painters of this time loved the Alps because the ice made people feel small. Look for the tiny figure near the ice and you will see why.

Look closely

- Find the crevasses, the deep cracks in the glacier's surface. Why would a flowing mass of ice crack?
- Look at the edges where the ice meets the rock. Is the ice clean or streaked with rubble? What is that rubble going to become?
- Find the human figure. About how many times taller than a person is the ice front?
- Look at the valley walls. Are they jagged or smooth and rounded near the ice? What might have smoothed them?

Talk about it

1. If you could walk to the snout of this glacier, what would you expect to find on the ground in front of it?

2. Agassiz said glaciers once reached far beyond this valley. What marks would you look for on the hills below to test his claim?
3. Fearnley painted this ice as something powerful and alive. Is that a fair way to picture a glacier? Why?

> **Safety first.** Use a butter knife or a spoon, not a sharp blade, for scraping. Wipe up melted ice so no one slips, and wash hands after handling sand and soap.

EXPERIMENT: SANDPAPER GLACIER: WHAT MARKS DOES MOVING ICE LEAVE?

Question: Does ice with rock frozen into its base leave different marks than clean ice? Prediction: write what you think, then test it. You will model the base of a glacier with ice cubes, some clean and some gritty, and drag them across a soft surface under the same weight.

You will need

- Ice cube tray, water, a pinch of coarse sand and a few small pebbles
- Two bars of soft soap or two smooth pieces of modeling clay rolled flat (the “bedrock”)
- A small book or can to use as a steady weight
- Ruler, pencil, lab notebook, a magnifier if you have one

Steps

1. Freeze two sets of ice cubes: one clean, one with sand and tiny pebbles settled on the bottom.
2. Lay a soap bar or clay slab flat. Place a clean ice cube on it and set the same small weight on top each time.
3. Drag the cube slowly in a straight line for 10 cm, taking about 10 seconds. Repeat with a gritty cube on a fresh patch, same weight, same distance, same speed.
4. Measure and record: number of scratches in a 2 cm wide band, longest scratch length, and whether the scratches are parallel.
5. Now set one gritty cube at the end of the slab and let it melt completely. Look at what it leaves behind. That pile is your model of till.
6. Repeat each test twice more and average your counts.
7. Write a conclusion: which cube left striations, and what you kept the same so the comparison was fair.

Tips

- Glaciers move centimeters a day, so slower dragging is a better model. Rushing tears the clay instead of scratching it.
- Look at your striations with the magnifier. Real striations, like yours, run in the direction the ice moved and are the same width along their whole length.

Check your work

- I can explain why striations tell you the direction a glacier moved.
- I can name the variable I changed, the variables I kept the same and what I measured.
- I can explain how a melted glacier leaves a pile of unsorted till.

FIELD NOTEBOOK

1. Draw a side view of a valley glacier and label snow zone, ice, striations under the ice, erratic, moraine and meltwater stream. Add one sentence under each label telling how you would recognize it on a hike.
2. Copy Hugi's hut data into a small table (year, distance moved) and sketch the hut riding the moraine down the glacier, 1827 to 1840.
3. Find a photograph of an erratic boulder (many state parks post them). Sketch it and write where its rock type came from and how far the ice carried it.

> **From history.** Agassiz took his idea on the road. In 1840 he traveled through Scotland with the Oxford geologist William Buckland, pointing out moraines and polished rock, and Buckland, who had been a skeptic, became a supporter. Agassiz moved to the United States in 1846, became a professor at Harvard in 1847, founded its Museum of Comparative Zoology and taught a generation of American naturalists his motto: study nature, not books. Lake Agassiz, a vast former meltwater lake whose flat bed is now the Red River valley of Minnesota, North Dakota and Manitoba, was later named in his honor.

WORKED EXAMPLES

Example 1. Hugi's hut was built on the Unteraar Glacier in 1827. In 1840 Agassiz found it about 1,400 m downhill. Find the glacier's average speed in meters per year and in centimeters per day.

1. Time elapsed: $1840 - 1827 = 13$ years.
2. Speed per year: $1{,}400 \text{ m} \div 13 \text{ years} \approx 108 \text{ m per year}$.
3. Convert to centimeters: $108 \text{ m} = 10{,}800 \text{ cm}$.
4. Per day: $10{,}800 \text{ cm} \div 365 \text{ days} \approx 30 \text{ cm per day}$.

Answer: About 108 m per year, or roughly 30 cm per day. A rate you could actually watch over a week with a stake and a tape.

Example 2. Glaciers today cover about 10 percent of the earth's land, roughly 15 million km². A museum sign says ice once covered nearly 30 percent of the land. How much land is that, and how many times today's ice cover is it?

1. If 10 percent is 15 million km², then 1 percent is 1.5 million km².
2. 30 percent = 30 × 1.5 million km² = 45 million km².
3. Ratio: 45 million ÷ 15 million = 3.

Answer: About 45 million km², three times today's glacier area. Note that the area of ice marks is measured from till and moraines; the 30 percent is a mainstream reconstruction from those marks.

Example 3. A granite erratic in an Ohio field measures about 2.0 m long, 1.5 m wide and 1.5 m high. Granite has a density of about 2,700 kg/m³. Estimate its mass in tonnes.

1. Volume (treating it as a box): 2.0 × 1.5 × 1.5 = 4.5 m³.
2. Mass = volume × density = 4.5 m³ × 2,700 kg/m³ = 12,150 kg.
3. 1 tonne = 1,000 kg, so 12,150 kg ≈ 12 tonnes.

Answer: About 12 tonnes. A river in Ohio cannot roll a 12-tonne block hundreds of kilometers from Canada, but ice can carry it frozen inside and set it down gently when it melts.

PRACTICE

1. EASY Name the four classic marks that glaciers leave on the land.
2. EASY Who were Ignaz Venetz and Jean de Charpentier, and what did they contribute to Agassiz's 1837 speech?
3. EASY Why can a glacier carry a boulder that a river cannot move?
4. MEDIUM A stake on a glacier moves 45 m in a year. How far does it move in a day, in centimeters?
5. MEDIUM Striations on a bedrock outcrop in Minnesota run from northeast to southwest. What does this tell you, and what does it not tell you?
6. MEDIUM Data reading. A field team measures stake movement across a glacier in one summer: Stake A (near the edge) 2.1 m, Stake B 4.0 m, Stake C (center) 5.2 m, Stake D 3.9 m, Stake E (far edge) 2.0 m. What pattern do the data show, and which conclusion is best supported? (a) The glacier is melting. (b) The center of the glacier flows faster than its edges. (c) The glacier is thickest at the edges. (d) The glacier moved 17.2 m.
7. MEDIUM Data reading. The table gives the depth to bedrock measured at four points along a glacier: Point 1: 85 m; Point 2: 190 m; Point 3: 265 m; Point 4: 120 m. Which point is most likely nearest the center of the valley, and what is the difference in ice thickness between the thickest and thinnest points?

8. HARD Experiment design. You want to find out whether a heavier glacier scratches bedrock more deeply. Using ice cubes with sand, clay slabs and small weights, describe the independent variable, the dependent variable, two things you would keep the same and how you would measure the result.
9. HARD A geologist finds a layer of till containing granite boulders lying on top of limestone bedrock in Illinois. The nearest granite outcrops are in Canada, about 800 km north. Write two or three sentences explaining what Agassiz's method says about this find, and name one question the till cannot answer by itself.
10. CHALLENGE Hugi's hut moved about 1,400 m in 13 years. If the Unteraar Glacier kept that speed, how long would it take a boulder on it to travel 20 km down the valley? Then explain why real glaciers would not keep a steady speed over that whole distance.

COMMON MISTAKES

- Thinking a glacier is frozen solid and does not move. Glaciers flow, usually centimeters to a meter or more a day, and that motion is what carves and carries.
- Thinking an erratic was left by a flood of water. Water sorts what it carries by size and cannot lift house-sized blocks uphill; unsorted till with giant boulders is a signature of ice.
- Thinking the marks of ice carry a date. Striations and moraines show that ice was there and which way it moved; the age and number of ice advances are interpretations added to the marks.

> **Make it a game · Mark the Ice.** One player describes a feature seen on a hike without naming it: "a long low ridge of mixed clay and boulders curving across the valley," or "a granite boulder the size of a car sitting on a limestone hill." The others race to name the feature (moraine, erratic, striations, polished bedrock, till) and say one thing it tells and one thing it cannot tell. First to five correct answers wins. Add a bonus point for naming the man who measured a glacier's speed with stakes.

> **Scripture.** "Out of whose womb came the ice? and the hoary frost of heaven, who hath gendered it? The waters are hid as with a stone, and the face of the deep is frozen." (Job 38:29–30, KJV)

God asks Job where ice comes from, as a thing too great for a man to make. Agassiz measured ice that moved mountains' worth of rock, and the measuring only made the question larger.

Practice answers

1. Striations (scratches), polished bedrock, erratic boulders and moraines (ridges of till).
2. Two Swiss engineers who had studied glacier marks in the Rhone valley and argued that ice once reached far beyond today's glaciers. Agassiz learned the evidence from them and presented the idea boldly in public.
3. Ice carries rock frozen inside or on top of it, so the boulder rides along no matter its weight. A river can only roll or push stones along its bed, and big boulders are too heavy for the

current.

4. 45 m = 4,500 cm; 4,500 ÷ 365 ≈ 12 cm per day.
5. It tells the direction the ice moved along that line (toward the southwest, judging from other marks like erratic sources). It does not tell when the ice was there or how long it lasted.
6. (b). Movement is largest at the center (5.2 m) and smallest at the edges (about 2 m), so the center flows faster, just as Agassiz found. The other choices are not supported: melting and thickness were not measured, and adding the stakes' movements together is meaningless.
7. Point 3 (265 m) is probably nearest the center, since valley glaciers are thickest in the middle. Difference: 265 − 85 = 180 m.
8. Independent variable: the weight placed on the cube (for example 0, 200 g, 400 g). Dependent variable: depth or number of scratches. Keep the same: the amount and size of sand, dragging distance and speed, the same clay slab type. Measure scratch depth with a toothpick and ruler or count scratches per 2 cm band, repeating each trial three times and averaging.
9. By matching the mark to a known cause, the unsorted till and far-traveled granite erratics show that ice flowed from the north across Illinois, carrying Canadian rock and dropping it as it melted. Living glaciers do exactly this. The till cannot tell us by itself how long ago the ice was there or how many years it stayed; those are inferences that need other assumptions.
10. Speed ≈ 108 m/yr. 20,000 m ÷ 108 m/yr ≈ 185 years. Real glaciers slow where the valley flattens or widens, speed up on steep stretches, and melt at their ends, so the boulder would be dropped at the snout long before 20 km unless the glacier itself extended that far.

5.2 Woolly Mammoths ★

OBJECTIVES

- Describe the woolly mammoth from its remains: size, hair, tusks, teeth and the frozen stomach contents that show what it ate.
- Tell the story of the Berezovka mammoth of 1901 and explain what a frozen carcass can and cannot tell us.
- Use scale and rate calculations to compare a mammoth with living elephants, and state the mainstream and creation readings of when and how mammoths lived and died.

Warm-up. Measure the longest hair on your head, on a dog or cat, and on a wool sweater fiber (pull one loose). Woolly mammoth guard hairs reached about 90 cm. Lay a string 90 cm long on the floor next to your measurements. What would a coat of hair that long be good for, and what would be hard about it?

Video. Coming soon. woolly mammoth frozen carcass Siberia Berezovka Lyuba anatomy tusks teeth; search Smithsonian National Museum of Natural History, Field Museum, Natural History Museum London, Royal BC Museum, PBS Eons style explainers, documentary footage of permafrost excavations

KEY TERMS

woolly mammoth
An extinct elephant kind (Mammuthus primigenius) with a thick hairy coat, small ears, a fatty hump and long curved tusks, known from bones, tusks, frozen carcasses and cave paintings.

permafrost
Ground that stays frozen all year, found across Siberia, Alaska and northern Canada; it can preserve flesh, hair and plants for a very long time.

carcass
The body of a dead animal. Frozen mammoth carcasses keep skin, hair, muscle and stomach contents.

loess
Fine wind-blown silt that piles up in thick blankets; many mammoth remains in Siberia and Alaska are buried in frozen loess.

tusk
A very long upper incisor tooth made of ivory. Mammoth tusks grew all their lives and curve more strongly than elephant tusks.

kind
A group of creatures that reproduce together. Mammoths, Asian elephants and African elephants all belong to one elephant kind.

CORE IDEAS

The story. In the summer of 1900 a Siberian hunter following his dogs along the Berezovka River, far to the northeast in the Russian Empire, found a mammoth's head and one foreleg poking out of a thawing riverbank. Word reached the Academy of Sciences in St. Petersburg, and in 1901 the zoologist Otto Herz and the taxidermist Eugen Pfizenmayer made the long journey by rail, river and horse to dig it out before wolves and summer finished it. They worked for weeks in a log hut built over the carcass, lighting fires to thaw the frozen mud. The animal had died with food still in its mouth. Grasses, sedges and other plants, some with seeds, filled its stomach. Pfizenmayer carried the whole carcass back across Siberia in sledges, and today the Berezovka mammoth stands, mounted in the pose it was found in, in the Zoological Museum of St. Petersburg.

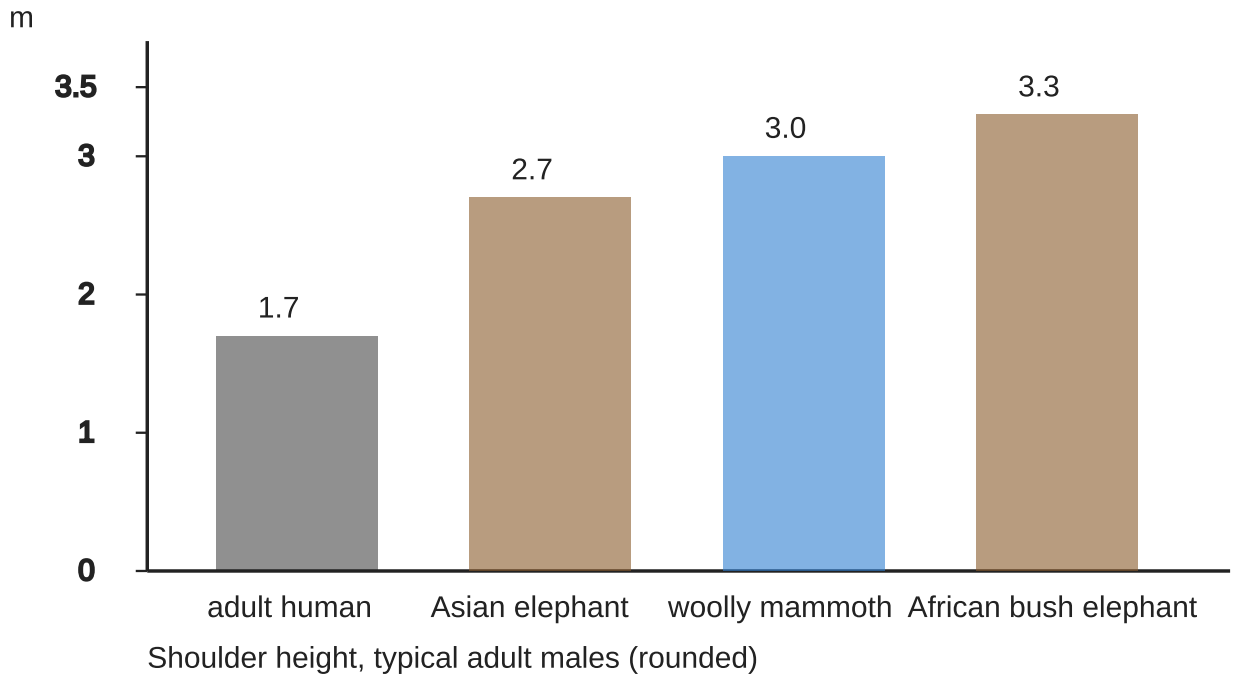
How they figured it out. A frozen mammoth is a scientist's dream, because almost nothing is left to guess. Measurements of complete skeletons give a shoulder height of about 3 m, close to an Asian elephant and a bit under a large African bull. Frozen skin shows a coat with two layers: an undercoat of fine wool and a shaggy outer layer of guard hairs up to 90 cm long, in colors from blond to dark brown. The ears are small, about a tenth the size of an African elephant's, which saves heat. The tusks curve inward in a great spiral and reach 3 m or more. Behind the trunk sits a fatty hump. The teeth are the most telling: like elephants, a mammoth had just one huge grinding molar in use on each side of each jaw, with up to six sets in a lifetime, and the ridged tops are worn in a pattern that shows a diet of grasses. Stomach contents from Berezovka and other finds confirm it: grass, sedges, mosses, twigs of willow and flowers such as buttercups.

The big idea. Mammoth remains are astonishingly common. For centuries Siberian traders have sold mammoth ivory dug from riverbanks, and tusks still turn up every summer as permafrost thaws. Alaska gold miners washing frozen silt found so many bones that they called the mammoth bone beds "muck." Mammoth bones have been dredged from the floor of the North Sea, found under London and in Ohio and Nebraska, and painted on cave walls in France. The cave of Rouffignac in France alone has about 150 mammoth drawings, showing the humped back and small ears exactly as the frozen carcasses do. People saw these animals alive. Two facts stand out: mammoths lived across a huge sweep of the north in large numbers, and then they stopped. Explaining the stopping is where the readings divide.

Reading the carcasses. Most frozen mammoths are not whole. Many are partial bodies with torn skin and broken bones, buried in frozen loess, the fine wind-blown silt. Some, like the baby mammoth Lyuba found by a reindeer herder on the Yamal Peninsula in 2007, are nearly complete, and her airway was packed with mud, as if she drowned or suffocated in a muddy place. Food in the stomach shows a death in a season of growing plants. Burial in silt shows dust and mud moving over the land at the time. Mainstream scientists read the carcasses as animals caught in mudflows, bogs and riverbank collapses at various times over tens of thousands of years, with the last mainland herds disappearing as the ice age ended and the grasslands changed. Creation geologists read the same carcasses as part of one short, violent chapter: as the post-Flood ice age ended, drier, windier weather drove huge

dust storms across the steppe, burying animals in loess that then froze, which explains why so many lie in silt and so few in actual ice.

God's handiwork. The mammoth was a masterpiece of cold-weather design. Small ears, a thick fat layer, a double coat, a tail short enough not to freeze, and a tiny flap of skin over the anus to hold heat in: every part fitted a life on windy grassland. Elephants and mammoths vary in coats and ears and tusk shape, but they are all plainly one kind, the kind that walked off the Ark and spread to fill a changed earth. Noah was told to bring every living thing out "that they may breed abundantly in the earth." The mammoth herds of Siberia show how abundantly they did.



Shoulder heights to scale. The woolly mammoth was elephant-sized, not a giant; its tusks, not its body, were the oversized part.

⏳ Thinking About Time

What the sign says. The museum sign says woolly mammoths lived from about 400,000 years ago until about 4,000 years ago, when the last small population on Wrangel Island in the Arctic Ocean died out, and that most mainland mammoths vanished around 10,000 years ago as the last ice age ended.

What we observe. We observe tusks, bones, cave paintings and frozen carcasses with hair, skin and stomach contents still in place, buried mainly in frozen wind-blown silt. Carbon-14 is measured in the bones and gives ages that depend on assumptions you will study in Unit 7. No one observed a mammoth being buried.

How Christians read it. Creation geologists hold that mammoths descended from the elephant kind on the Ark, multiplied across the north during the post-Flood ice age, when the grassland was rich, and died in great numbers as that ice age ended a few centuries

later, buried by dust storms in loess that froze. Their carbon-14 dates are read in light of a changing atmosphere after the Flood.

Try it. Find a mammoth tusk or skeleton photograph online or in a museum and estimate its shoulder height from a person standing beside it.

Genesis 8:17

PICTURE STUDY



Woolly Mammoths, Charles R. Knight, 1916 · Mural (oil on canvas) · American Museum of Natural History, New York

Charles R. Knight was the first great painter of prehistoric animals. He studied living elephants at the zoo for weeks before he painted a single mammoth, and he worked from the Berezovka carcass and other finds to get the hump, the sloping back and the small ears right. His mammoth murals hung in the American Museum of Natural History from 1916 and set the picture of the mammoth in millions of minds.

Knight was nearly blind in one eye and painted with his face close to the canvas, yet his animals move with real weight.

Look closely

- Look at the shape of the lead mammoth’s back. Where is the highest point, and how is that different from an African elephant?
- Find the ears. Compare their size with the head. Why would small ears matter in the cold?
- Follow the curve of the tusks. Do they sweep outward like an elephant’s or inward in a spiral?
- Look at the ground and sky. What kind of land is Knight showing? Is there enough grass here to feed a herd?

Talk about it

1. Knight painted from frozen carcasses and living elephants. Which parts of this picture are observation and which are the artist's guesses?
2. The cave artists of Rouffignac drew mammoths with the same hump and small ears thousands of years before Knight. What does that tell you?
3. If you were updating this mural with what we know from Lyuba and other finds, what would you change?

EXPERIMENT: HAIR, FAT AND COLD: WHICH COAT KEEPS THE HEAT IN?

Question: Which model coat slows heat loss most, a layer of fat, a layer of wool, or both together, as on a mammoth? Prediction: rank the three before you start. You will wrap warm-water "bodies" in different coats and measure how fast they cool.

You will need

- Four identical small jars or cans with lids
- A thermometer (kitchen or lab)
- Solid shortening or lard (the "fat"), about half a cup
- Wool scraps, cotton balls or a wool sock (the "hair")
- Rubber bands, plastic wrap, warm tap water (not hotter than 50 °C), a timer, lab notebook

Steps

1. Prepare four jars: (1) bare, (2) coated in a 1 cm layer of shortening held on with plastic wrap, (3) wrapped in a 1 cm layer of wool, (4) shortening layer with wool over it, the mammoth coat.
2. Fill each jar with the same amount of warm water at the same starting temperature (about 45 °C). Record the start temperature for each.
3. Set all four in the same cool place, such as a refrigerator shelf or a cold porch, side by side.
4. Measure and record each jar's temperature every 5 minutes for 30 minutes.
5. Plot temperature against time for all four jars on one graph, a different color for each.
6. Find how many degrees each jar lost in 30 minutes and rank the coats.
7. Write a conclusion: did your prediction hold? What did you keep the same so the test was fair?

Tips

- Use the same thermometer and wipe it between jars, or measure in the same order each time so the delay is equal.
- Real mammoth fat was up to about 9 cm thick and the hair much longer than your wool, so your model understates the effect.

Check your work

- I can name the independent variable (type of coat) and dependent variable (temperature drop).
- I can read my cooling graph and say which jar cooled slowest.
- I can explain why a double coat of fat and hair fits a grassland animal in a cold, windy climate.

FIELD NOTEBOOK

1. Draw a woolly mammoth in profile next to an Asian elephant at the same scale (1 cm = 50 cm). Label hump, small ears, guard hair, spiral tusks and short tail.
2. Draw a mammoth molar from a photograph and count the ridges across its top. Write what the ridges tell about diet.
3. Make a map of the north (Siberia, Alaska, Canada, Europe) and mark five places mammoth remains have been found: the Berezovka River, the Yamal Peninsula, Alaska, the North Sea floor and Rouffignac cave in France.

> **From history.** The first nearly complete mammoth skeleton known to science, the Adams mammoth, was spotted in 1799 by a Siberian hunter named Ossip Shumachov in the Lena River delta. It took several summers to thaw free, and in 1806 the botanist Mikhail Adams reached it, by which time wolves and foxes had eaten most of the flesh. He shipped the skeleton, much of the skin and about 16 kg of hair to St. Petersburg, where it was mounted in 1808, the first mammoth skeleton ever displayed. For a century afterward, Siberian mammoth ivory was a regular export, carved into piano keys, billiard balls and chess sets across Europe.

WORKED EXAMPLES

Example 1. You are drawing a woolly mammoth with a shoulder height of 3.0 m and a tusk 3.5 m long at a scale of 1:40. How tall will the shoulder be on paper, and how long the tusk? Add a 1.5 m tall student for comparison.

1. At 1:40, every 40 cm of real length becomes 1 cm on paper.
2. Shoulder: 3.0 m = 300 cm; 300 ÷ 40 = 7.5 cm.
3. Tusk: 3.5 m = 350 cm; 350 ÷ 40 = 8.75 cm, so about 8.8 cm.
4. Student: 1.5 m = 150 cm; 150 ÷ 40 = 3.75 cm.

Answer: Shoulder 7.5 cm, tusk about 8.8 cm, student about 3.8 cm. The mammoth is twice the student’s height and its tusk is longer than its body is tall.

Example 2. A large elephant eats about 150 kg of plants a day. Estimate how much grass and sedge one mammoth ate in a year, and how much a herd of 20 ate in a year, in tonnes.

1. One mammoth per year: 150 kg × 365 days = 54,750 kg.
2. Convert: 54,750 kg ÷ 1,000 = 54.75 tonnes, about 55 tonnes.
3. Herd of 20: 20 × 54.75 tonnes = 1,095 tonnes, about 1,100 tonnes.

Answer: About 55 tonnes per mammoth per year, about 1,100 tonnes for a herd of 20. A land full of mammoths had to be a land full of grass, not a frozen desert.

Example 3. Elephants grow six sets of grinding molars in a lifetime, and mammoth jaws show the same pattern. A mammoth that lived about 60 years and wore through all six sets used each set for how long, on average? If a jaw shows the fourth set in use, about how old was the animal?

1. Average time per set: 60 years ÷ 6 sets = 10 years per set.
2. Fourth set in use means three sets are worn away and gone: 3 × 10 = 30 years passed, and the animal is somewhere in the fourth decade.
3. So the estimate is roughly 30 to 40 years old.

Answer: About 10 years per set; a jaw in its fourth set belonged to a mammoth roughly 30 to 40 years old. Real sets are not equal in length, so scientists use detailed wear charts, but the method is the same.

PRACTICE

1. EASY List four body features of the woolly mammoth that suited it to a cold, windy grassland.
2. EASY What was found in the mouth and stomach of the Berezovka mammoth, and what does it show?
3. EASY Most frozen mammoths are buried in loess. What is loess, and what does it tell about conditions when the animals were buried?
4. MEDIUM A mammoth tusk is 3.2 m long. On a drawing at 1:25 scale, how long is it in centimeters?
5. MEDIUM Data reading. Shoulder heights: adult human 1.7 m, Asian elephant 2.7 m, woolly mammoth 3.0 m, African bush elephant 3.3 m. Which statement is supported by the data? (a) Mammoths were far larger than any living elephant. (b) The mammoth was taller than an Asian elephant but shorter than an African bush elephant. (c) Mammoths were twice as tall as African elephants. (d) Humans are one third the height of a mammoth.
6. MEDIUM Data reading. In the cooling experiment, one student recorded temperature drops over 30 minutes: bare jar 18 °C, fat only 12 °C, wool only 10 °C, fat and wool 6

°C. Which coat kept the most heat, and how many times smaller was its loss than the bare jar’s?

7. MEDIUM Explain why the discovery of mammoth drawings in Rouffignac cave matters for understanding what mammoths looked like.
8. HARD Experiment design. You want to test whether hair length affects heat loss. Describe how you would set up jars, what you would change, what you would keep the same, and what you would measure.
9. HARD Write two or three sentences comparing how mainstream scientists and creation geologists explain the mammoth carcasses buried in frozen loess, and name one observation both sides accept.
10. CHALLENGE Suppose a mammoth herd needs 1,100 tonnes of grass a year and a hectare of northern grassland grows 2 tonnes of edible plant material a year. How many hectares must the herd range over, and how many square kilometers is that? (1 km^2 = 100 hectares.) What does the answer suggest about the climate where mammoths thrived?

COMMON MISTAKES

- Thinking mammoths were giants towering over elephants. Woolly mammoths were about elephant-sized; the Columbian mammoth of the southern United States was larger, but the woolly mammoth stood about 3 m.
- Thinking frozen mammoths are found in blocks of clear ice. Nearly all are in frozen silt and mud (loess) that thawed along riverbanks; the ground, not an ice cube, preserved them.
- Thinking mammoths and elephants are unrelated. They are one kind with the same tooth pattern, trunk, tusk growth and body plan; hair, ear size and tusk curve are variations within the kind.

> **Make it a game · Mammoth or Elephant?.** One player reads a clue card: “ears about one tenth the size of an African elephant’s,” “tusks spiral inward,” “lives in Africa today,” “found frozen in Siberian loess,” “six sets of molars in a lifetime.” Players call out Mammoth, Elephant or Both. A right answer scores one point; a right answer with the reason scores two. Mix in a few “Neither” cards (“has horns,” “lays eggs”) to keep everyone honest. Play to twelve points.

> **Scripture.** “Bring forth with thee every living thing that is with thee, of all flesh, both of fowl, and of cattle, and of every creeping thing that creepeth upon the earth; that they may breed abundantly in the earth, and be fruitful, and multiply upon the earth.” (Genesis 8:17, KJV)

God’s command after the Flood was to multiply and fill the earth. The mammoth herds whose bones fill the riverbanks of Siberia and Alaska are a picture of how fully the elephant kind obeyed.

Practice answers

1. Any four: thick fat layer, double coat of woolly underfur and long guard hairs, small ears, short tail, fatty hump, skin flap over the anus.
2. Grasses, sedges and other plants, some with seeds and flowers. It shows the mammoth was a grazer and died in the growing season, quickly enough that the food never digested.
3. Loess is fine wind-blown silt. Thick loess means strong winds were carrying dust across a dry, open landscape when the mammoths were buried.
4. 320 cm ÷ 25 = 12.8 cm.
5. (b). 3.0 m is between 2.7 m and 3.3 m. Humans at 1.7 m are a little over half a mammoth's height, not one third, and the mammoth is not larger than every living elephant.
6. Fat and wool together lost only 6 °C, the least. 18 ÷ 6 = 3, so its heat loss was one third of the bare jar's, three times smaller.
7. The cave artists saw living mammoths, and their drawings show the hump, sloping back, small ears and curved tusks that match the frozen carcasses. They are eyewitness records that confirm the reconstruction from bones and skin.
8. Wrap identical jars of warm water at the same starting temperature in wool layers of different thickness (for example 0.5 cm, 1 cm, 2 cm) to represent hair length. Independent variable: coat thickness. Keep the same: jar size, water volume and temperature, room, timing, thermometer. Dependent variable: temperature drop over 30 minutes, measured every 5 minutes and graphed. Repeat each trial twice.
9. Mainstream scientists read the carcasses as animals caught in mud, bogs and bank collapses at many different times over tens of thousands of years, with the herds dying out as the ice age ended. Creation geologists read them as victims of a short, stormy end to one post-Flood ice age, when dust storms buried animals in loess that then froze. Both accept that the animals were buried quickly enough to preserve skin, hair and stomach contents, and that most lie in wind-blown silt rather than clear ice.
10. 1,100 ÷ 2 = 550 hectares; 550 ÷ 100 = 5.5 km^2 at minimum, and much more in practice since animals do not eat every blade. Mammoths needed vast productive grasslands with real growing seasons, so the north where they thrived was windy and cold in winter but not a lifeless icebox.

5.3 One Post-Flood Ice Age (Oard)

OBJECTIVES

- State the two conditions any ice age needs, heavy snowfall and cool summers, and explain why cold air alone cannot build an ice sheet.
- Describe Michael Oard's model of a single ice age caused by warm post-Flood oceans and volcanic ash, and compare it with the mainstream orbital-cycle explanation.
- Use the relationship between air temperature and water vapor to calculate how much more moisture warm air can carry, and estimate snow accumulation rates.

Warm-up. Breathe out slowly onto a cold window or a glass of ice water and watch the fog form. Now breathe onto a warm glass. Where does the water appear, and where did it come from? Write one sentence explaining what happens when warm, wet air meets something cold.

Video. Coming soon. what causes an ice age snowfall cool summers Milankovitch cycles explained, lake-effect snow warm water cold air; search NOAA SciJinks, National Weather Service, NASA Climate Kids, PBS Eons style explainers, nature footage of volcanic ash clouds and heavy snow

KEY TERMS

evaporation
Water turning into vapor from a surface. Warm water evaporates far faster than cold water.

water vapor capacity
The most water vapor air can hold at a given temperature. It roughly doubles for every 10 °C of warming.

lake-effect snow
Heavy snow that falls when cold air blows across warm open water, picks up moisture and dumps it downwind. The Great Lakes do this every winter.

volcanic aerosols
Tiny ash and sulfur droplets thrown high into the atmosphere by eruptions; they reflect sunlight and cool the ground below.

Milankovitch cycles
Slow changes in the earth's orbit and tilt that mainstream scientists use to explain repeated ice ages. A museum word to recognize.

ice sheet
A glacier so large it covers a whole region, like those on Greenland and Antarctica today.

CORE IDEAS

The story. Michael Oard spent his career as a meteorologist with the United States National Weather Service in Montana, forecasting storms and reading weather maps. Weather forecasters know one thing in their bones: to get a big snowstorm you need two things at once, a supply of moisture and air cold enough to turn it into snow. In 1990 Oard published a book called *An Ice Age Caused by the Genesis Flood*. His question was a forecaster's question. If Agassiz was right that ice once buried much of North America and Europe, where did all that snow come from? Cold air by itself is dry. Antarctica is the coldest place on earth and also one of its driest deserts. Something had to feed the snow clouds for a very long time.

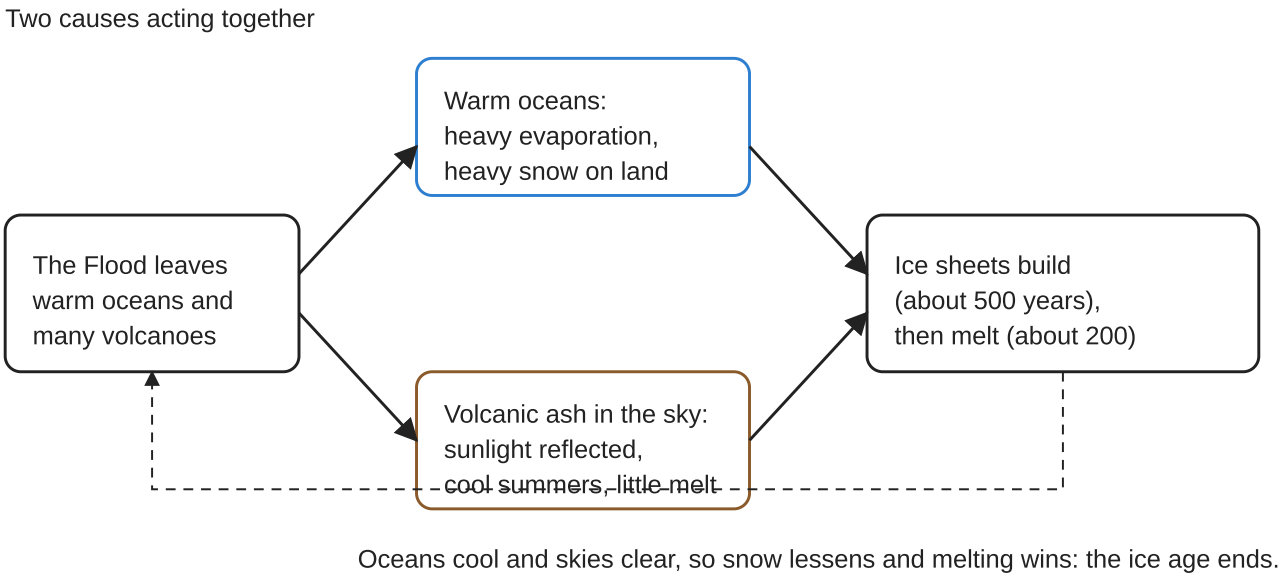
How they figured it out. Mainstream geologists noticed the same puzzle. Their answer, worked out by the Serbian engineer Milutin Milanković in the 1920s and 1930s, is that slow wobbles in the earth's orbit and tilt, on cycles of roughly 100,000, 41,000 and 23,000 years, shift how much summer sunlight reaches the far north. Cooler summers let winter snow survive, and over thousands of years the snow builds into ice. Textbooks say this happened again and again through the Pleistocene. Oard argued that the orbital changes are real but small, and that they do not solve the moisture problem. He pointed instead to what the Flood would have left behind. Genesis says "the fountains of the great deep" broke open and the earth was reshaped. Hot water from the deep, lava on the sea floor and enormous volcanic activity would have left the oceans warm from pole to pole, perhaps 30 °C instead of today's cold polar seas. Warm water evaporates fast. Cold continents next to warm oceans is the recipe for lake-effect snow on a planetary scale.

The big idea. Oard's model has two parts that work together. First, **warm oceans supply the snow.** Air at 30 °C can hold about seven times as much water vapor as air at 0 °C, so a warm sea under cold air pours moisture into the sky, which falls as snow over the land. Second, **volcanic ash makes cool summers.** The Flood year and the centuries after would have had many eruptions, and their ash and sulfur droplets high in the air reflect sunlight. We have seen this on a small scale: after Tambora erupted in 1815, New England had snow in June and killing frosts in July and August of 1816, the year without a summer. Cool summers mean last winter's snow does not melt before the next winter adds more. Oard estimated that the ice would build for about 500 years, until the oceans had cooled and the skies cleared, and then melt back over roughly 200 years, a single ice age of about 700 years, within human history, a few centuries after Noah.

Testing the model. A good model makes predictions you can check against the rocks. Oard's model predicts that the ice sheets were thinner than the 3,000 m some textbooks show, since 500 years of snowfall, even heavy, builds a thinner sheet. It predicts a mild, wet climate at the ice margins and in Siberia, which fits the mammoth grasslands you studied in Lesson 5.2. It predicts a fast meltdown with huge floods, which fits features such as the Channeled Scablands of Washington state, carved when glacial Lake Missoula burst. Mainstream geologists accept the Missoula floods but read them as repeated events over thousands of years, and they read the many layers of till in the Midwest as several separate ice ages rather than one ice age that pulsed. Both sides look at the same till, the same

scablands and the same mammoth bones. The difference is the starting point: a slow earth driven by orbit, or a Flood-wrecked earth healing over centuries.

God's handiwork. After the Flood God promised that "cold and heat, and summer and winter" would continue while the earth remains. An ice age sounds like a catastrophe, but in Oard's model it was also the earth settling back toward the steady seasons God promised. The oceans cooled, the skies cleared, the ice drew back, and the land it uncovered, rich with ground-up rock flour and dotted with lakes, became some of the best farmland on earth. The wheat fields of the northern plains grow in the leftovers of the ice.



Oard's model of one post-Flood ice age. Two causes work together, and both fade as the earth recovers.

⏳ Thinking About Time

What the sign says. Textbooks say the earth has had many ice ages over the past 2.6 million years, each glacial cycle lasting about 100,000 years, driven by Milankovitch orbital cycles, and that the most recent ice sheets melted back between about 20,000 and 10,000 years ago.

What we observe. We observe that heavy snow needs warm water and cold air together (lake-effect snow), that volcanic eruptions such as Tambora in 1815 cool summers, that ice sheets exist today in Greenland and Antarctica, and that layers of till and scoured landscapes lie far south of them. The length of the ice age is not observed; it is inferred from a model.

How Christians read it. Creation geologists, following Oard, read the evidence as a single ice age of roughly 700 years, caused by warm oceans and ash-filled skies left by the Flood, building for about five centuries and melting back in about two. The repeated till layers are read as the one ice sheet advancing and retreating.

> **Try it.** On a cold morning, find a pond, river or even a warm puddle with mist rising from it. That mist is the engine of Oard's ice age in miniature.
>
> *Genesis 8:22*

PICTURE STUDY



Cotopaxi, Frederic Edwin Church, 1862 · Oil on canvas · Detroit Institute of Arts

Frederic Edwin Church was the great American painter of wild places. He traveled to South America twice and climbed into the Andes to sketch the volcano Cotopaxi, one of the highest active volcanoes in the world. In this painting, finished in 1862, the volcano is erupting, and its ash plume stretches across the whole sky, turning the sun blood-red and dimming the light over the land below.

Church was a careful observer of clouds and light. This picture is a record of what a large eruption does to the sky, and that is exactly the effect Oard's ice age model depends on.

Look closely

- Follow the ash plume from the crater across the sky. How much of the sky does it cover?
- Look at the sun. Why does it look red and dim? What is between you and it?
- Look at the land in the foreground. Is it brightly lit or shaded? Which direction is the light coming from?
- Find the water: the lake and the waterfall. Would warm water under a dim, ash-filled sky still give off vapor?

Talk about it

1. If one volcano can do this to the sky for a few days, what might hundreds of eruptions over many years do to summer temperatures?
2. Church painted this during the American Civil War, and some people see the dark sky as a picture of that trouble. Can a painting be both an accurate observation and a message?
3. Oard's model needs ash to cool the land while the oceans stay warm. Does this painting help you imagine that? Why or why not?

> **Safety first.** An adult handles hot water. Keep the water below 60 °C, use oven mitts for the warm pan and keep ice and water off the floor to prevent slips.

EXPERIMENT: WARM SEA, COLD SKY: DOES WARM WATER MAKE MORE FROST?

Question: Does a warm pool of water send more moisture into cold air than a cool pool does? Prediction: write it down. You will model Oard's warm ocean with pans of water at different temperatures, hang a cold "sky" over each, and measure the frost or dew that collects.

You will need

- Three identical shallow pans or bowls
- Three identical metal lids or small baking sheets, chilled in the freezer for an hour (the cold "sky")
- Thermometer, kitchen scale that reads grams, timer
- Warm water (about 50 °C), room-temperature water, ice water
- Three pairs of chopsticks or pencils to hold each lid about 3 cm above its pan, paper towels, lab notebook

Steps

1. Weigh each chilled lid and record the mass. Fill the three pans with the same amount of water: one at about 50 °C, one at room temperature (about 20 °C), one at about 5 °C with ice.
2. Record each water temperature. Set a cold lid over each pan on the pencil supports, all three at the same time.
3. Wait 10 minutes. Carefully lift each lid and look at its underside. Describe what you see: frost, heavy dew, light dew or dry.
4. Weigh each lid again right away. The gain in grams is the water that evaporated from the pan and condensed on the cold lid.
5. Record the results in a table: water temperature, description, mass gained.
6. Repeat the whole test once more with freshly chilled lids and average.
7. Make a bar graph of mass gained against water temperature and write a conclusion in two sentences.

Tips

- Lift the lids carefully so drops do not fall off before weighing.

- If your scale is not sensitive enough, compare the lids by how far the dew spreads or by wiping each with a dry paper towel and weighing the towel.

Check your work

- I can state the independent variable (water temperature), the dependent variable (water collected) and two controls.
- I can explain why warm water under cold air gives more snow than cold water does.
- I can connect my result to Oard's claim about warm post-Flood oceans.

FIELD NOTEBOOK

1. Draw the flow diagram of Oard's model in your own hand, with arrows and a short label on each box. Add a second small diagram showing the mainstream orbital model for comparison.
2. Make a table of water vapor capacity at 0, 10, 20 and 30 °C (3.8, 7.6, 14.7 and 27 grams of water per kilogram of air) and plot the points. Describe the shape of the curve.
3. Draw the sky from Church's Cotopaxi and label ash plume, dimmed sun and shaded land. Under it write how this picture connects to cool summers.

> **From history.** The eruption of Mount Tambora in Indonesia in April 1815 was the largest in recorded history. Ash and sulfur spread around the globe, and in 1816 New England saw snow in June and killing frosts in July and August, while crops failed across Europe. People called it the year without a summer, and the gloomy, rainy weather in Switzerland that year kept a party of English visitors indoors, where Mary Shelley began writing *Frankenstein*. One eruption cooled the whole Northern Hemisphere for a year, which is why both mainstream and creation geologists take volcanic aerosols seriously as a climate factor.

WORKED EXAMPLES

Example 1. Air can hold about 3.8 g of water vapor per kilogram of air at 0 °C and about 27 g per kilogram at 30 °C. How many times more moisture can the warm air hold? If 1 kg of saturated 30 °C air rose over a cold continent and cooled to 0 °C, how much water would fall out?

1. Ratio: 27 ÷ 3.8 ≈ 7.1, so about 7 times more.
2. Water that must condense when the air cools: 27 g − 3.8 g = 23.2 g per kilogram of air.
3. That is about 23 g of water from every kilogram of air, falling as rain or snow.

Answer: Warm air holds about 7 times as much water vapor; cooling a kilogram of it from 30 °C to 0 °C wrings out about 23 g of water. Multiply by the trillions of kilograms of air blowing off a warm ocean and you have Oard's snow supply.

Example 2. Suppose an ice sheet averaged 700 m thick and built up over 500 years. What average thickness of ice was added each year? Fresh snow packs down to ice at about 10 to 1. How much snow is that per year? Compare with the record single-season snowfall at Mount Baker, Washington, of about 29 m in 1998–99.

1. Ice per year: 700 m ÷ 500 years = 1.4 m of ice per year.
2. Snow per year: 1.4 m × 10 = 14 m of fresh snow per year.
3. Compare: 14 m is about half the Mount Baker record of 29 m in one season.

Answer: About 1.4 m of ice, or about 14 m of fresh snow, each year. That is heavy, but a single mountain in Washington has recorded twice that in one winter, so the rate is not impossible when warm water lies upwind.

Example 3. A textbook gives a glacial cycle of about 100,000 years. Oard's model gives about 700 years. How many times longer is the textbook estimate? If both models must explain the same 700 m of ice, what average ice build-up per year does each require over its build-up time? (Use 500 years for Oard and 90,000 years for the textbook's build-up.)

1. Ratio of lengths: 100,000 ÷ 700 ≈ 143 times longer.
2. Oard: 700 m ÷ 500 years = 1.4 m per year.
3. Textbook: 700 m ÷ 90,000 years ≈ 0.0078 m per year, about 8 mm of ice per year.

Answer: The textbook cycle is about 143 times longer. Oard's model needs about 1.4 m of ice a year; the long model needs only about 8 mm a year. Neither rate is observed directly for the past; each follows from its starting assumptions about the oceans and the sky.

PRACTICE

1. EASY What two conditions must happen together for an ice sheet to grow?
2. EASY Why is Antarctica, the coldest continent, also one of the driest places on earth? What does this teach about ice ages?
3. EASY In Oard's model, where does the heat come from that warms the oceans after the Flood, and what cools the summers?
4. MEDIUM Air at 20 °C can hold about 14.7 g of water per kilogram; at 10 °C about 7.6 g. If saturated 20 °C air cools to 10 °C, how much water per kilogram condenses?
5. MEDIUM Data reading. A student's warm-sea experiment gave these masses of water collected on a cold lid in 10 minutes: water at 5 °C, 0.3 g; at 20 °C, 1.1 g; at 50 °C, 4.6 g. Which conclusion do the data best support? (a) Water temperature has no effect on evaporation. (b) Evaporation rises slowly and evenly with temperature. (c) Evaporation rises faster and faster as water gets warmer. (d) Cold water evaporates fastest.
6. MEDIUM Data reading. Average monthly snowfall at a station downwind of a large lake: November 40 cm, December 95 cm, January 110 cm, February 60 cm, March 25 cm. The lake freezes over in early February most years. Using the lake-effect idea, explain the drop from January to February and March.
7. MEDIUM Name one way Oard's model and the mainstream Milankovitch model agree and one way they differ.
8. HARD Experiment design. Design a test of the claim that ash in the air cools the ground beneath. Describe the setup with two identical trays of soil, a lamp, a thermometer, and a sheet of tissue paper or fine screen, and name the variables and controls.
9. HARD The Channeled Scablands of Washington were carved by floods from glacial Lake Missoula. Write two or three sentences on how each reading (mainstream and Oard's) explains these floods and what both agree on.
10. CHALLENGE Suppose the post-Flood ocean averaged 30 °C and cooled to 10 °C over 500 years. What was the average cooling per century? Then explain in a sentence why snowfall in Oard's model would decrease as the centuries passed, and what that means for when the ice age ended.

COMMON MISTAKES

- Thinking an ice age only needs cold. Cold, dry air builds almost no ice; a large source of moisture, warm water, is needed for heavy snow.
- Thinking volcanoes warm the earth because they are hot. Their ash and sulfur droplets in the upper air reflect sunlight and cool the surface, as the year after Tambora in 1815 showed.
- Thinking Oard rejects the ice age. He accepts all of Agassiz's evidence that great ice sheets existed; he disagrees about their cause, number and length.

Make it a game · Build an Ice Age. Players take turns drawing cards labeled with conditions: warm ocean, cold ocean, ash-filled sky, clear sky, cold continent, warm continent, lots of volcanoes, few volcanoes. On each turn a player lays down two cards

and must say whether that pair would build ice, melt ice or do nothing, and why. The group judges with thumbs up or down. A correct call with a correct reason scores a point. The first to collect a complete ice-building pair (warm ocean plus ash-filled sky plus cold continent) and explain it wins the round.

Scripture. “While the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease.” (Genesis 8:22, KJV)

God promised Noah that the seasons would keep their order as long as the earth lasts. The ice age, in the creation reading, was the earth settling into that promised rhythm after the Flood had shaken it.

Practice answers

1. Heavy snowfall (a large moisture supply) and summers cool enough that the snow does not melt away before the next winter.
2. Cold air holds very little water vapor, so there is little to fall as snow. Cold alone cannot build an ice sheet quickly; a moisture source is needed.
3. Heat from the fountains of the deep, sea-floor volcanic activity and lava warms the oceans; volcanic ash and sulfur aerosols high in the air reflect sunlight and cool the summers.
4. 14.7 − 7.6 = 7.1 g of water per kilogram of air.
5. (c). Going from 5 to 20 °C added 0.8 g, but going from 20 to 50 °C added 3.5 g, so the increase grows steeply with temperature, matching the doubling of vapor capacity every 10 °C.
6. Once the lake freezes, cold air crossing it no longer picks up moisture from open water, so lake-effect snow shuts off. Snowfall drops sharply (110 cm to 60 cm to 25 cm) even though February and March are still cold. Open warm water, not just cold air, drives the heavy snow.
7. Agree: both say an ice age needs cool summers so snow survives, and both accept the till, moraines and scablands as real evidence of ice. Differ: the mainstream model uses slow orbital cycles over hundreds of thousands of years and many ice ages; Oard uses warm post-Flood oceans and volcanic ash to produce one ice age of about 700 years.
8. Set two identical trays of soil the same distance under identical lamps (or the same lamp in two trials). Over one, hang a sheet of tissue or fine screen to model an ash layer; leave the other clear. Independent variable: shading layer present or not. Dependent variable: soil temperature after 20 minutes, measured at the same depth. Controls: same soil, lamp distance and wattage, starting temperature, time. Repeat three times and compare averages.
9. Both agree a glacial ice dam held back a vast lake and that when it failed, torrents carved channels, giant ripple marks and dry falls across eastern Washington. Mainstream geologists read the layered flood deposits as dozens of separate outburst floods over several thousand years at the end of the last glaciation. Oard’s reading puts the floods within the rapid 200-year meltdown of one post-Flood ice age, with fewer and larger outbursts. The landforms are the same; the number and spacing of floods is the interpretation.
10. Cooling: 30 − 10 = 20 °C over 5 centuries = 4 °C per century. As the oceans cooled, less water evaporated and the air carried less moisture, so snowfall fell off while the skies also cleared and summers warmed. Once melting outpaced snowfall, the ice sheets shrank, ending the ice age after a few centuries.

5.4 Ice Cores and How Layers Are Counted

OBJECTIVES

- Describe how an ice core is drilled and what scientists see in it: visible bands, dust, volcanic ash and oxygen isotope cycles.
- Explain the methods used to count layers as years, and identify the assumptions in each method, especially the assumption of one layer per year and the use of flow models deep in the core.
- Calculate accumulation rates from depth and time, and show how the number of layers per year changes an age estimate.

Warm-up. Take a clear glass and build “snow years” in it: a spoonful of flour, then a pinch of cocoa for a dusty spring, then more flour. Make five years. Now press down hard with the back of a spoon. Count your layers from the side. Did pressing change the number of layers or only their thickness? Which layer is oldest?

Video. Coming soon. ice core drilling Greenland Antarctica how annual layers are counted dust volcanic ash oxygen isotopes; search National Science Foundation Ice Core Facility, NASA, NOAA paleoclimatology, National Snow and Ice Data Center, British Antarctic Survey, PBS and Smithsonian explainers, footage of core drilling camps

KEY TERMS

ice core
A long cylinder of ice, about 10 cm across, drilled from an ice sheet in sections and stored frozen so its layers can be studied.

firn
Old snow that has packed down but not yet turned into solid glacier ice; the top 60 to 100 m of an ice sheet.

annual layer
The band of ice thought to represent one year, usually a coarse summer layer and a fine winter layer, often marked by a spring dust peak.

oxygen isotopes
Two forms of oxygen, oxygen-16 and the heavier oxygen-18. Snow that falls in cold conditions holds a little less oxygen-18, so the ratio swings between summer and winter.

marker layer
A layer from a known event, such as ash and acid from the Laki eruption of 1783, used to check a layer count.

flow model
A mathematical model of how ice thins and spreads as it is squeezed under new snow, used to assign ages where layers can no longer be counted.

CORE IDEAS

The story. In 1966 a crew of United States Army engineers at Camp Century, a base tunneled into the ice of northwest Greenland, finished something no one had done before. Their drill reached bedrock through 1,387 m of ice and brought the whole column up in sections. Scientists found they could read it. Near the top, bands of coarser and finer ice alternated like tree rings. Between 1989 and 1993 a larger team drilled the Greenland Ice Sheet Project 2 core, called GISP2, at the Summit of the ice sheet, reaching bedrock at 3,053 m. In Antarctica the Russian Vostok core reached 3,623 m in 1998, and the European Dome C core 3,270 m. Each core is stored in freezers, such as the National Science Foundation's ice core facility in Colorado, where scientists saw it into slabs, hold it up to light, melt measured pieces and read the frozen record year by year.

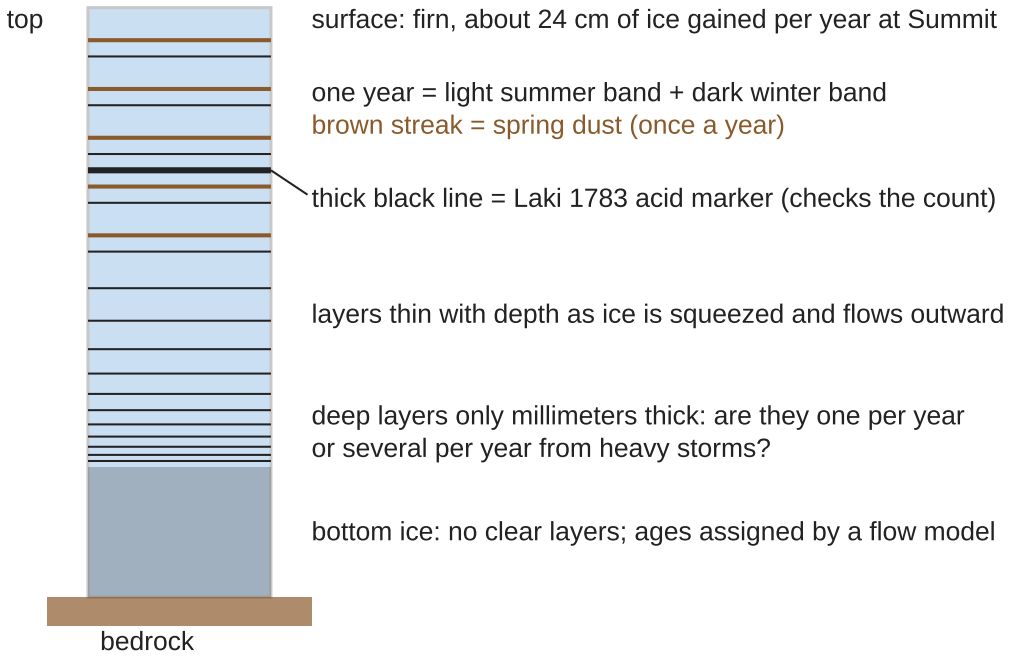
How they figured it out. How do you count a year in ice? Scientists use several clues and look for agreement. **Visible bands:** summer sun forms coarse-grained, bubbly layers at the surface, winter snow is finer, so a light band and a dark band often make one year. **Dust:** spring winds carry dust onto the ice, giving a dusty streak once a year. **Oxygen isotopes:** summer snow holds slightly more heavy oxygen-18 than winter snow, so the ratio swings up and down once per year; a laboratory melts small samples and measures the swing. **Electrical conductivity:** acids from summer sunlight chemistry make the ice slightly more conductive, another yearly wiggle. Where all these agree, the count is considered solid. Then scientists check against **marker layers**. The Icelandic volcano Laki erupted in 1783 and the sulfur it threw up fell on Greenland as an acid layer. Tambora, 1815, left another. If the count from the surface down to the Laki layer comes out close to the right number of years, the method is working in that part of the core.

The big idea. Near the surface, counting is honest observation checked by history. At GISP2 the ice sheet gains about 24 cm of ice each year, and the Laki and Tambora layers land where the count says they should. But the deeper you go, the thinner the layers get, because the weight of new snow squeezes each old layer and spreads it sideways as the ice slowly flows toward the edges. A layer that began as 24 cm may be a few millimeters at 2,000 m and thinner still below. There, visible bands fade, isotope swings blur as molecules slowly diffuse, and scientists switch to a **flow model** that calculates how much thinning should have happened and assigns ages mathematically. GISP2 scientists reported counting about 110,000 annual layers down the core, with the deepest ice dated by models. Vostok and Dome C ice are dated almost entirely by models, matched to other records, giving the textbook figures of 420,000 and 800,000 years. These are the numbers you will see on museum signs.

Where the readings differ. Everyone agrees on the counted layers near the top. The disagreement is about what a thin deep layer means. Mainstream scientists assume one layer per year all the way down, with past snowfall at the Summit roughly like today's, and read the thinning as the squeeze of long time. Creation scientists who have studied the cores, such as the atmospheric physicist Larry Vardiman and the meteorologist Michael Oard, point out that during a post-Flood ice age with warm oceans, snowfall would have been many times heavier, and each big storm can leave its own band, so several visible

layers and even several isotope wiggles can form in one year. They also note that the oxygen isotope signal, which is partly a temperature record, is read assuming the temperature pattern of today. In their reading, thick ice built quickly during the ice age, with many sub-annual layers, and the lower part of the cores records a few thousand years, not hundreds of thousands. The Lost Squadron is a reminder of how fast ice can bury things. Six P-38 fighters and two B-17 bombers landed on the Greenland ice in 1942, and when one was recovered in 1992 it lay under about 80 m of snow and ice, though that was near the coast where snowfall is much heavier than at the Summit.

God's handiwork. God asked Job, "Hast thou entered into the treasures of the snow?" The ice cores are exactly that: treasures of snow laid up layer upon layer, holding dust from deserts, ash from volcanoes and air from skies long past. Reading them well takes patience and honesty about which parts are counted and which are modeled. That honesty is a Christian virtue as much as a scientific one.



An ice core from top to bottom. Layers are counted and checked against marker layers near the surface; deep ice is dated by a flow model and assumptions about layers per year.

⏳ Thinking About Time

What the sign says. Museum signs and textbooks say the GISP2 core from Greenland records about 110,000 years of annual layers, that the Vostok core from Antarctica reaches back about 420,000 years, and that the Dome C core reaches about 800,000 years, with the deepest ages assigned by ice-flow models.

What we observe. We observe visible bands, dust streaks, oxygen isotope swings and acid spikes that match known eruptions such as Laki in 1783 near the top of the cores, where accumulation today is about 24 cm of ice a year at Summit. We observe layers

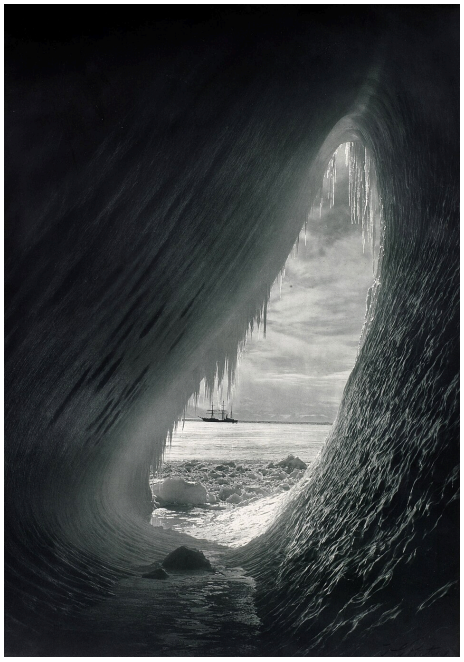
growing thinner with depth. The number of layers per year in deep ice is not observed; it is assumed.

How Christians read it. Creation scientists accept the counted upper layers and read the deep ice as the product of a post-Flood ice age with far heavier snowfall, when storms laid down several bands in a single year. On that reading, the Greenland and Antarctic ice sheets formed within a few thousand years, and the thin deep layers record storms more than centuries.

Try it. Make the flour-and-cocoa jar from the warm-up again, but this time add three white layers between two cocoa layers. If a visitor counted every white band as a year, how far off would the count be?

Job 38:22

PICTURE STUDY



Grotto in an Iceberg, Terra Nova in the Distance, Herbert Ponting, January 5, 1911 · Photograph · Taken near Cape Evans, Antarctica, during Captain Scott's Terra Nova expedition; prints in the Scott Polar Research Institute, Cambridge, and other collections

Herbert Ponting was the official photographer of Robert Falcon Scott's expedition to Antarctica in 1910 to 1913. He carried heavy glass-plate cameras across the ice and waited hours for the right light. On January 5, 1911, he climbed into a cavern hollowed in a grounded iceberg and photographed the expedition ship through its mouth, with two of his companions, Taylor and Wright, posed at the opening.

Look closely at the walls of the grotto and you can see the grain and banding of the ice itself, the same kind of layering scientists now read in cores.

Look closely

- Look at the walls of the ice cave. Can you see bands or layers? Which way do they run?
- Find the two men. How thick is the ice above their heads compared with their height?
- Look at the ship. Why would an explorer want a photograph that showed both the ice and his ship?
- Notice the light. Where is it coming from, and how does ice change it?

Talk about it

1. This iceberg broke off a glacier or ice shelf. Where did the ice in its walls begin, and what was it before it was ice?
2. Ponting had to work in the cold with slow cameras and fragile glass plates. How is that like, and unlike, drilling and storing a 3,000 m ice core?
3. If you could cut a core from the wall of this grotto, what would you look for first?

> **Safety first.** Freezers and dry ice are not needed; use ordinary ice. Keep spilled water wiped up and have an adult handle any sharp tools for trimming the core model.

EXPERIMENT: BUILD AND READ A MODEL ICE CORE

Question: Can a reader who did not watch the layers form recover the true number of years from a core? Prediction: write what you expect. You will build a layered “ice sheet” in a tall clear container, including a known marker layer and some storm layers, then hand it to someone else to count.

You will need

- A tall clear container (a clear plastic tumbler or a 1-liter bottle with the top cut off by an adult)
- White flour or baking soda (snow), fine cocoa or cinnamon (spring dust), a pinch of colored sprinkles or glitter (volcanic ash marker)
- Spoon, ruler, a card or a flat object for pressing layers, lab notebook
- Optional: a clear drinking straw to push into the finished model and pull out a mini core

Steps

1. Decide secretly how many years to build, between 6 and 12. Write it in your notebook and hide it.
2. For each year, add one thick white layer (winter) and one dust streak (spring). Press gently and record the total height after each year.
3. In two of your years, add an extra storm: a second white layer within the same year, with no dust between.
4. In one year, which you record, add a thin line of sprinkles as the ash marker for a “known eruption.” Tell the reader this year’s number only.

5. Press the whole stack firmly with the card to model the squeeze of overlying snow. Measure layer thicknesses near the top and bottom.
6. Hand the model to a reader. Ask them to count years by dust streaks alone, then by white layers alone, and to use the marker to check the count.
7. Compare the counts with the true number. Record which method worked, why the storm layers fooled the count, and how the marker layer helped.

Tips

- Keep the container still while pressing or the layers will tilt and mix.
- The straw core shows how a real core is a narrow sample of a huge sheet: you see only what the straw happens to pass through.

Check your work

- I can explain how counting dust streaks differs from counting white layers.
- I can explain how a marker layer of known date checks a count.
- I can state the assumption that is needed when counting deep layers as years.

FIELD NOTEBOOK

1. Draw an ice core column from your model showing thick layers at top and thinner layers below. Label winter snow, spring dust, storm layer and ash marker.
2. Make a two-column table: Counted (observed) and Modeled (assumed). Sort these into the columns: visible bands near the top, Laki 1783 marker, ages at 2,900 m depth, 24 cm per year accumulation, one layer per year in deep ice.
3. Sketch a seasonal oxygen isotope wiggle for three years and mark where you would draw each year boundary.

> **From history.** Camp Century, where the first core to bedrock was drilled in 1966, was a United States Army base built inside tunnels cut in the Greenland ice in 1959 and 1960. It housed up to 200 men and was powered by a small portable nuclear reactor. The engineers discovered the hard way that ice flows: the tunnels slowly squeezed shut and the camp had to be abandoned in 1967. Its drill crew, led by the American engineer Lyle Hansen of the Army’s cold regions laboratory, proved that a complete ice sheet could be sampled from top to bottom. The Danish geophysicist Willi Dansgaard then measured the oxygen isotopes in that core, and every deep ice core since has followed their lead.

WORKED EXAMPLES

Example 1. At Summit, Greenland, the ice sheet gains about 24 cm of ice each year. If layers were not squeezed thinner, how many years would be in the top 120 m of ice? About how deep would the Laki eruption layer of 1783 lie if the core was drilled in 1993?

1. Convert: 120 m = 12,000 cm.
2. Years: 12,000 cm ÷ 24 cm per year = 500 years.
3. Years from 1783 to 1993: 1993 − 1783 = 210 years.
4. Depth of Laki layer: 210 years × 24 cm = 5,040 cm ≈ 50 m.

Answer: About 500 years in the top 120 m, and the Laki marker about 50 m down. Real firn near the top is fluffier than ice, so the true depth is a bit greater, but the count landed close enough to confirm the method there.

Example 2. The Lost Squadron planes landed on the Greenland ice in 1942 and were dug out in 1992 from under about 80 m of snow and ice. Find the burial rate in meters per year and compare it with the Summit accumulation of 0.24 m of ice a year.

1. Time: 1992 − 1942 = 50 years.
2. Rate: 80 m ÷ 50 years = 1.6 m per year.
3. Compare: 1.6 ÷ 0.24 ≈ 6.7, so about 7 times the Summit rate.

Answer: About 1.6 m per year, roughly 7 times the Summit rate. The planes sat near the southeast coast where storms dump far more snow, and much of the 80 m was still loosely packed firn. The lesson is that accumulation varies enormously from place to place and time to time, which is exactly the point creation scientists make about the ice age.

Example 3. A 10 m section deep in a core shows layers averaging 1 cm thick. (a) How many layers is that? (b) If each layer is one year, how many years does the section hold? (c) If heavy ice-age storms laid down an average of 3 layers per year, how many years does it hold? (d) If a surface layer at this site started at 24 cm, by what factor has each layer been thinned?

1. (a) 10 m = 1,000 cm; 1,000 cm ÷ 1 cm = 1,000 layers.
2. (b) One layer per year: 1,000 years.
3. (c) Three layers per year: 1,000 ÷ 3 ≈ 333 years.
4. (d) Thinning factor: 24 cm ÷ 1 cm = 24.

Answer: 1,000 layers; 1,000 years if one per year, about 333 years if three per year; each layer has been squeezed to one twenty-fourth of its starting thickness. The layer count is the same for everyone; the years-per-layer assumption divides the readings.

PRACTICE

1. EASY Name three kinds of yearly signals scientists look for in an ice core.
2. EASY What is a marker layer, and why is the Laki 1783 layer useful?
3. EASY Why do layers get thinner with depth in an ice sheet?
4. MEDIUM An ice sheet site gains 30 cm of ice per year. How many years are in the top 90 m, assuming no thinning?
5. MEDIUM Data reading. Layer thickness measured in a core: 100 m depth, 22 cm; 500 m, 15 cm; 1,000 m, 9 cm; 2,000 m, 3 cm; 2,800 m, 0.4 cm. Which statement is best supported? (a) Snowfall decreased steadily through history. (b) Layers thin with depth, so the deep ice holds many more layers per meter than the shallow ice. (c) The core is 2,800 years old. (d) Layers are thickest at the bottom.
6. MEDIUM Data reading. A count of dust streaks from the surface to the Tambora (1815) acid layer in a core drilled in 1993 gives 176 streaks. How far off is the count from the known number of years, and what does that tell you about the method in this part of the core?
7. MEDIUM Explain in two sentences the difference between a counted age and a modeled age in an ice core.
8. HARD Experiment design. Design a test of whether a reader can tell storm layers from annual layers in a model core. State what you would vary, what you would keep the same, how many trials you would run and how you would judge success.
9. HARD Write two or three sentences on why the Lost Squadron burial rate does not by itself settle the age of the Greenland ice sheet, and what it does fairly show.
10. CHALLENGE Suppose the lower 1,500 m of a core has layers averaging 0.5 cm thick. Compute the number of layers. Then give the age of that section under two assumptions: one layer per year, and five layers per year during a stormy ice age. Finally, state one observation that could help decide between the two assumptions.

COMMON MISTAKES

- Thinking every visible band in an ice core is observed to be a year. Near the surface that is checked against history; deep in the core it is an assumption, and storms can lay down more than one band a year.
- Thinking the deep ages on a museum sign were counted. The deepest parts of the Greenland core and nearly all of the Antarctic cores are dated by flow models and matching, not by counting.
- Thinking ice cores record only snow. They also hold dust, volcanic ash, sea salt and trapped bubbles of ancient air, which is why scientists value them so highly.

Make it a game · Counted or Modeled?. Make a set of cards with statements about ice cores: “Laki 1783 acid layer found at 50 m,” “bottom of the core is 110,000 years old,” “24 cm of ice gained per year at Summit today,” “layers at 2,900 m are 2 mm thick,” “each thin deep layer is one year,” “the Dome C core is 800,000 years old.” Players sort each card into Observed, Counted and Checked, or Modeled and Assumed, and explain

their choice in one sentence. The group votes. A card placed correctly with a good reason scores two points. Finish with a bonus round: each player names one assumption that, if changed, would change a modeled age.

Scripture. “Hast thou entered into the treasures of the snow? or hast thou seen the treasures of the hail, Which I have reserved against the time of trouble, against the day of battle and war?” (Job 38:22–23, KJV)

God speaks of snow as a treasure He has stored. The ice cores are a storehouse of snow thousands of meters deep, and reading them teaches both wonder at the record and humility about how much of it we can truly count.

Practice answers

1. Any three: visible coarse and fine bands, spring dust streaks, oxygen isotope swings, electrical conductivity (acidity) wiggles.
2. A layer left by an event of known date. Laki’s acid fell on Greenland in 1783, so the count of layers from the surface down to it can be checked against the known number of years.
3. The weight of snow above squeezes each layer and the ice slowly flows outward toward the edges, stretching layers sideways and making them thinner.
4. 90 m = 9,000 cm; 9,000 ÷ 30 = 300 years.
5. (b). The data show thinning with depth; at 2,800 m there are about 250 layers per meter compared with fewer than 5 per meter at 100 m. Snowfall history is not shown by thickness alone, since squeezing also thins layers, and the age cannot be read from these numbers without an assumption about layers per year.
6. Known years: 1993 − 1815 = 178. The count of 176 is off by 2, about 1 percent. The dust-streak method works well near the surface, where it can be checked.
7. A counted age comes from actually tallying visible or chemical layers down to a depth, and can be checked against marker layers of known date. A modeled age comes from a mathematical flow model that estimates how much thinning has happened, used where layers are too thin or blurred to count, and depends on assumptions about past snowfall and layers per year.
8. Build several flour-and-cocoa cores with the same number of years but different numbers of extra storm layers (0, 2, 4). Keep the same: container, layer thickness, dust amount, pressing force, the reader. Give each core to the reader blind and record their count. Run at least three cores per storm level. Success is measured by the difference between the reader’s count and the true number; if the error grows with storm layers, the method cannot tell storms from years.
9. The planes lay near the coast, where snowfall is several times heavier than at the Summit, and much of the 80 m was loose firn, not dense ice, so applying 1.6 m per year to the whole sheet would be unfair. What it fairly shows is that accumulation rates vary greatly with place and weather, so the assumption of steady, Summit-like snowfall through the past is itself a choice, and heavier ice-age snowfall would mean fewer years in the deep ice.
10. 1,500 m = 150,000 cm; 150,000 ÷ 0.5 = 300,000 layers. One per year: 300,000 years. Five per year: 60,000 years. A deciding observation might be finding in the deep ice the dust-and-isotope pattern of a single season spread across several visible bands, or checking whether known closely spaced eruptions fall the right number of layers apart.

Unit 5 review

Answer each question. Show your work for calculations and use complete sentences for explanations. Where a question asks for the mainstream view, state it fairly; where it asks for the creation reading, state it clearly. The test is worth 60 points.

1. (4 pts) Multiple choice. Which of these is NOT one of the classic marks of a glacier? (a) striations (b) erratic boulders (c) ripple marks sorted by grain size (d) moraines
2. (5 pts) Hugi's hut rode the Unteraar Glacier about 1,400 m between 1827 and 1840. Find the glacier's average speed in meters per year, and explain in one sentence how this measurement supported Agassiz's claim that glaciers can carry boulders far from their source.
3. (5 pts) Explain Charpentier's method of matching marks to causes, and name one question about the old ice that the marks cannot answer by themselves.
4. (4 pts) Multiple choice. The Berezovka mammoth, excavated in 1901, was found with (a) a clear block of ice around it (b) grasses and sedges in its mouth and stomach (c) no hair or skin remaining (d) tusks that pointed straight forward.
5. (5 pts) A large elephant eats about 150 kg of plants a day. Estimate how many tonnes one mammoth ate in a year, and state in one sentence what this implies about the climate of the land where mammoth herds lived.
6. (6 pts) Write a short paragraph (3 to 4 sentences) giving the mainstream reading and the creation reading of how the Siberian mammoths were buried in frozen loess, and name one observation both readings accept.
7. (4 pts) Multiple choice. Oard's model says a post-Flood ice age was driven by (a) cold air alone (b) a change in the earth's orbit (c) warm oceans supplying snow plus volcanic ash cooling the summers (d) the sun dimming.
8. (5 pts) Air at 0 °C holds about 3.8 g of water vapor per kilogram; at 30 °C about 27 g. How many times more water can the warm air hold? Explain why this matters for building an ice sheet.
9. (6 pts) Compare the mainstream Milankovitch explanation of ice ages with Oard's model in a short paragraph: one thing they agree on, two things they differ on, and the length each gives to the ice age.
10. (5 pts) At Summit, Greenland, the ice sheet gains about 24 cm of ice per year. A core drilled in 1993 finds the Laki (1783) acid layer. Assuming no thinning, at about what depth should it lie, and what does finding it near there show?
11. (6 pts) Diagram item. Draw and label an ice core from surface to bedrock. Show: thick annual bands near the top, a spring dust streak, a labeled volcanic marker layer, layers thinning with depth, and the zone where ages come from a flow model. Then write one sentence stating the assumption that divides the mainstream and creation readings of the deep layers.
12. (5 pts) A 20 m section deep in a core has layers averaging 0.5 cm thick. How many layers is that? Give its age if there is one layer per year and if there are four layers per year. Which of these numbers is observed and which are interpreted?

UNIT PROJECT: ICE AGE EVIDENCE BOARD: OBSERVED, CLAIMED, READ

Make a large three-column display board titled “The Ice Age.” In the first column, Observed, mount your own drawings and photographs of glacier marks (striations, erratics, moraines, till), a mammoth to scale next to a person, and your model ice core with its layers labeled, each with a caption stating only what can be seen or measured. In the second column, What the Sign Says, copy accurately three real museum or textbook statements about ice age dates (for example the Pleistocene dates, the mammoth extinction date, and the GISP2 age), each with its source named. In the third column, How Christians Read It, write a paragraph for each row giving the creation reading: one post-Flood ice age, mammoths of the elephant kind buried in loess as it ended, and ice core layers laid down fast under heavy snowfall.

Attach your lab records from the sandpaper glacier, the warm-sea frost test and the model ice core, including your data tables and graphs, and finish with a short paragraph explaining which parts of the ice age story everyone agrees on and where the readings part ways.

- **Accuracy**: Glacier marks, mammoth features and ice core parts are correctly drawn and labeled; mainstream statements are quoted fairly with sources; numbers and units are right.
- **Observation versus interpretation**: Each item is placed in the correct column, and captions in the Observed column contain no dates or assumptions.
- **Lab records**: All three experiments are recorded with question, prediction, variables, data table, graph and conclusion.
- **Explanation and tone**: The closing paragraph states both readings clearly and respectfully, names the key assumption that divides them, and is written in complete sentences.

Answer key

1. (c). Sorted ripple marks are made by flowing water; glaciers leave unsorted till, striations, polished rock, erratics and moraines.
2. 1,400 ÷ 13 ≈ 108 m per year. A glacier that visibly carries a stone hut over a kilometer in 13 years can carry boulders many kilometers over longer periods, so erratics far from their bedrock are explained by ice transport.
3. He watched living glaciers making striations, polish, erratics and moraines, then found the same marks far down the valley where there is no ice now, and concluded ice had been there. The marks cannot tell by themselves how long ago the ice came, how long it stayed or how many times it advanced.
4. (b). It still had plant food in its mouth and stomach, showing a grazer that died quickly in the growing season.
5. 150 × 365 = 54,750 kg ≈ 55 tonnes per year. Such herds needed vast productive grasslands with growing seasons, so the mammoth country was cold and windy but not a lifeless frozen desert.
6. Mainstream scientists read the carcasses as animals trapped in mud, bogs and bank collapses at many different times over tens of thousands of years, with herds dying out as the ice age ended. Creation geologists read them as victims of great dust storms at the end of one post-Flood ice age a few centuries long, buried in wind-blown silt that then froze. Both accept that

burial was fast enough to preserve hair, skin and stomach contents, and that most remains lie in frozen silt, not clear ice.

7. (c).
8. 27 ÷ 3.8 ≈ 7 times. Heavy snow needs a large moisture supply; warm oceans under cold air load the air with vapor that falls as snow over the land, which cold air alone cannot do.
9. Both agree an ice age needs cool summers so winter snow survives, and both accept the till, moraines and scablands as evidence of real ice. They differ on the cause (slow orbital and tilt cycles versus warm post-Flood oceans and volcanic ash) and on the number of ice ages (many versus one that advanced and retreated). Textbooks give glacial cycles of about 100,000 years over the last 2.6 million years; Oard gives one ice age of about 700 years, roughly 500 building and 200 melting.
10. 1993 − 1783 = 210 years; 210 × 24 cm = 5,040 cm ≈ 50 m. Finding the marker near the predicted depth shows the layer count works in the upper part of the core, where it can be checked against history.
11. The drawing should show a vertical column with wide bands at the top growing narrower downward, a dust streak once per band, a marker layer labeled with an eruption and date (such as Laki 1783), and a lower zone labeled as modeled ages, with bedrock at the bottom. Sentence: the mainstream reading assumes one layer per year with snowfall like today’s all the way down, while the creation reading holds that heavy ice-age storms laid down several layers per year, so the deep ice records far fewer years.
12. 20 m = 2,000 cm; 2,000 ÷ 0.5 = 4,000 layers. One per year: 4,000 years. Four per year: 1,000 years. The 4,000 layers are observed (counted); the two ages are interpretations that depend on the assumed number of layers per year.

UNIT 6

Dinosaurs in Depth

Dinosaurs are where the rocks speak most plainly and where museum signs say the most. In this unit you will learn to read dinosaurs the way a careful anatomist does: by their hips and stance, their eggs and nests, the stories people told about great reptiles, and the feathers and filaments pressed into fine grey slabs from China. You will meet Richard Owen, who named the Dinosauria in 1842 from three broken English skeletons; Roy Chapman Andrews and George Olsen, who found the first accepted dinosaur eggs at the Flaming Cliffs of Mongolia in 1923; the sculptor of the Klagenfurt dragon, who modeled his monster on a rhinoceros skull dug up in 1335; and the farmer Li Yumin, who split open *Sinosauropteryx* in 1996.

Each lesson separates what the bones, eggs and slabs show from what is said about them. You will sort dinosaurs with a key, measure eggs and feathers, scale giant lizards against a person, and weigh legends with a checklist. You will also learn the Bible's unit of classification, the **kind**, and see why it matters for the Ark; how creation geologists account for nests inside Flood layers; and how the feathered fossils of Liaoning are read by mainstream paleontologists, by their critics, and by Christians who begin from Genesis 1.

Period names such as Jurassic and Cretaceous appear throughout as museum words you must be able to read accurately. Every lesson has a Thinking About Time box so that you can state the sign's claim fairly, name what is observed, and give the creation reading beside it without mocking either side.

BEFORE YOU BEGIN

- Can sort statements on a museum sign into observations, inferences and interpretations (Unit 3)
- Knows that most fossils required rapid burial and can explain why (Unit 3)
- Can compute ratios, percents and scale-model lengths and read a bar graph
- Knows that volume grows with the cube of length for objects of the same shape

MASTERY CHECKLIST

- I can tell how Richard Owen defined the Dinosauria and sort dinosaurs into the major groups using the two hip types and a key.
- I can explain the difference between a species, a genus and a created kind, and give an example of two dinosaur names that turned out to be one animal.
- I can describe what fossil eggs and nests show, explain why only an embryo proves whose egg it is, and compare egg volumes by cubing the length ratio.
- I can weigh a dragon legend with a five-question checklist and state fairly how mainstream historians and creation researchers account for such legends.
- I can name the parts of a feather, measure vane asymmetry, and tell a true vaned feather from a filament on a fossil.

- I can state what museum signs claim about birds and dinosaurs, list observations both sides accept, and give the creation reading with respect.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History, David H. Koch Hall of Fossils – Deep Time (online)** (https://naturalhistory.si.edu/exhibits/david-h-koch-hall-fossils-deep-time): Free. Photographs and label text from the Smithsonian fossil hall, useful for the sign-reading exercises and for finding real labels to sort into observation, inference and interpretation.
- **Dinosaur National Monument, National Park Service** (https://www.nps.gov/dino/): Free. Pages on the Quarry Exhibit Hall in Utah, where about 1,500 dinosaur bones lie exposed in a single tilted sandstone layer, a fine example of a mass burial to discuss with Lesson 6.1 and 6.2.
- ***Micrographia* by Robert Hooke (free at Project Gutenberg)** (https://www.gutenberg.org/ebooks/15491): Free. Hooke's 1665 book with its engravings. Read Observation 36 on feathers alongside Lesson 6.4 and compare his drawing with a real feather under a hand lens.

6.1 Dinosaur Kinds and Classification ★

OBJECTIVES

- Tell how Richard Owen named the Dinosauria in 1842 from three English fossils, and list the skeletal features that make an animal a dinosaur.
- Use the two hip types and a simple key to sort dinosaurs into the major groups found on museum signs, and name four famous animals that are not dinosaurs.
- Explain the difference between a named species, a genus and a created kind, and give a real example of two dinosaur names that turned out to be one animal.

Warm-up. Empty a drawer of kitchen tools onto the table: spoons, forks, a whisk, a ladle, a spatula. Sort them into groups any way you like, then sort them a second way. Write down the one feature you used each time. Which sorting would help a stranger find a soup spoon fastest? Scientists sorting bones face the same choice.

Video. Coming soon. Search for a short explainer on how dinosaurs are classified (saurischian and ornithischian hips, theropods, sauropods, ornithopods, ceratopsians, stegosaurs, ankylosaurs), the story of Richard Owen naming the Dinosauria, and the Crystal Palace dinosaurs of 1854. Good sources: Smithsonian channels, Natural History Museum (London), American Museum of Natural History, SciShow Kids, Homeschool Pop (Alternate), museum footage.

KEY TERMS

Dinosauria
The name Richard Owen gave in 1842 to a group of large fossil reptiles with upright legs. It means “fearfully great lizards.” Today it names all dinosaurs.

classification
Sorting living things into groups by shared features, from large groups such as kingdom and class down to genus and species.

species
The smallest common group in classification, given a two-part Latin name such as Triceratops horridus. For fossils, a species is a judgment made from bones.

genus
A group of closely related species that shares the first part of the Latin name, such as Triceratops.

kind
The Bible’s word for a group of creatures that reproduce after their own sort (Genesis 1:24–25). A kind is usually broader than a species and may include a whole genus or family.

saurischian and ornithischian

Two hip arrangements used since 1887 to sort dinosaurs. Saurischian (“lizard-hipped”) hips have the pubis pointing forward; ornithischian (“bird-hipped”) hips have it pointing backward along the ischium.

CORE IDEAS

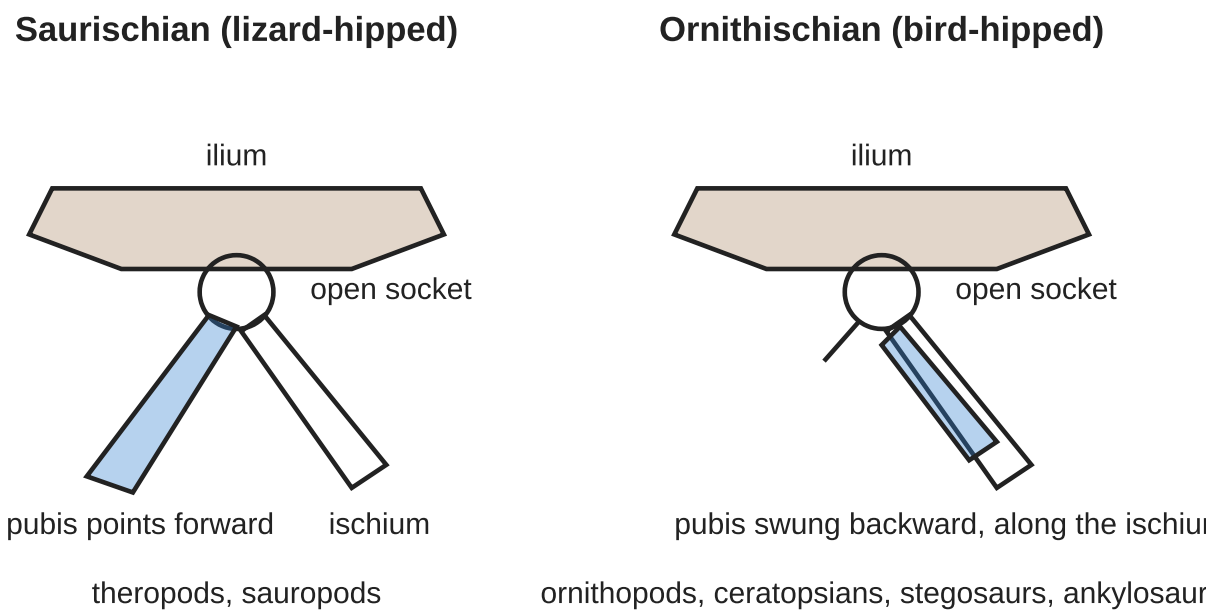
The story. In August 1841 the British Association for the Advancement of Science met in the seaport of Plymouth, England. One speaker was Richard Owen, a young anatomist from the Royal College of Surgeons who had spent two years examining every fossil reptile in Britain. Three of them puzzled him. *Megalosaurus*, a meat-eater described by William Buckland from a quarry at Stonesfield in 1824; *Iguanodon*, a plant-eater known from teeth that Gideon Mantell had found in Sussex in the 1820s; and *Hylaeosaurus*, an armored animal Mantell described in 1833. Lizards sprawl, with their legs out to the side. These three had hip and leg bones built like an elephant’s, to hold the body up high off the ground, and their hip bones were fused to five vertebrae instead of two. Owen decided they belonged together in a new group. In his printed report of 1842 he named it **Dinosauria**, from the Greek *deinos*, “fearfully great,” and *sauros*, “lizard.”

How they figured it out. Classification is the habit of sorting by shared features, and dinosaurs are sorted by their skeletons. Every dinosaur stands with its legs directly beneath its body, like a horse, not splayed to the side like a crocodile. Every dinosaur has a hip socket with a hole through the middle, so the ball of the thighbone sits in a ring of bone, and every one has an extra ridge on the upper arm bone where big muscles attach. These features also tell you what is *not* a dinosaur. Flying pterosaurs, long-necked plesiosaurs, dolphin-shaped ichthyosaurs and the sail-backed *Dimetrodon* all turn up in dinosaur toy sets, and none of them is a dinosaur. In 1887 Harry Seeley, a lecturer at Cambridge, noticed that dinosaur hips come in two patterns. In one, the pubis bone points forward and down, as in lizards; he called these **saurischians**. In the other it swings backward to lie along the ischium, as in birds; he called these **ornithischians**. Museum signs still use his two words. Saurischians include the two-legged meat-eating *theropods* (*Tyrannosaurus*, *Allosaurus*) and the long-necked *sauropods* (*Diplodocus*, *Brachiosaurus*). Ornithischians include the duck-billed *ornithopods*, the horned *ceratopsians*, the plated *stegosaurs*, the armored *ankylosaurs* and the dome-headed *pachycephalosaurs*.

The big idea. Scientists name a new **species** when a skeleton seems different enough from every known one. About a thousand dinosaur species have been named, but the count keeps changing, because bones are a hard place to draw lines. In 1879 Othniel Marsh named *Brontosaurus*; in 1903 Elmer Riggs decided it was only a grown-up *Apatosaurus*, and the name was dropped for a century, until a 2015 study of hundreds of bones argued the two were different after all. In 2010 John Scannella and Jack Horner proposed that *Torosaurus*, with its long frill, was simply an old *Triceratops* whose frill had thinned and lengthened with age; other scientists disagree, and the debate is still open. Young and old, male and female, and crushed or well-preserved skeletons of one animal can all look like different species. A good reader of museum signs knows that a species name is an inference from bones, open to revision, while the bones themselves stay the same.

In the world today. The Bible uses a different unit: the **kind**. God made living things to bring forth “after their kind,” and Noah took two of every kind of land animal into the Ark. A kind is the group whose members can breed together, and it is usually much wider than a species. Dogs, wolves, coyotes and jackals are many species but one kind; lions and tigers can produce ligers, so they are one kind too. Creation researchers who sort dinosaurs by body plan rather than by small differences in horns or frills count the dinosaur kinds in the dozens, roughly fifty to sixty, not in the hundreds. That number matters for the Ark: a few dozen pairs of young dinosaurs, most of them smaller than a cow, take far less room than a thousand full-grown species would.

God’s handiwork. Sorting dinosaurs well teaches humility and wonder at once. The same hip socket, the same upright stance and the same arm ridge appear in a chicken-sized *Compsognathus* and a 26 m *Diplodocus*, a shared pattern stretched across an enormous range of sizes. Each group also has its own gifts: the shearing tooth batteries of the duck-bills, with hundreds of teeth packed into a grinding surface; the hollow, bird-like bones of the fast theropods; the massive pillar legs of the sauropods. When you sort bones into groups you are doing what Adam did when he named the animals: looking closely and giving each creature its proper place.



Harry Seeley’s two hip patterns (1887). Both have the open hip socket that all dinosaurs share; the difference is which way the pubis points.

⏳ Thinking About Time

What the sign says. What the sign says: museum labels place dinosaurs in the Mesozoic Era, the “age of dinosaurs,” divided into the Triassic, Jurassic and Cretaceous Periods, and give dates from about 230 million to 66 million years ago for the layers that hold their bones.

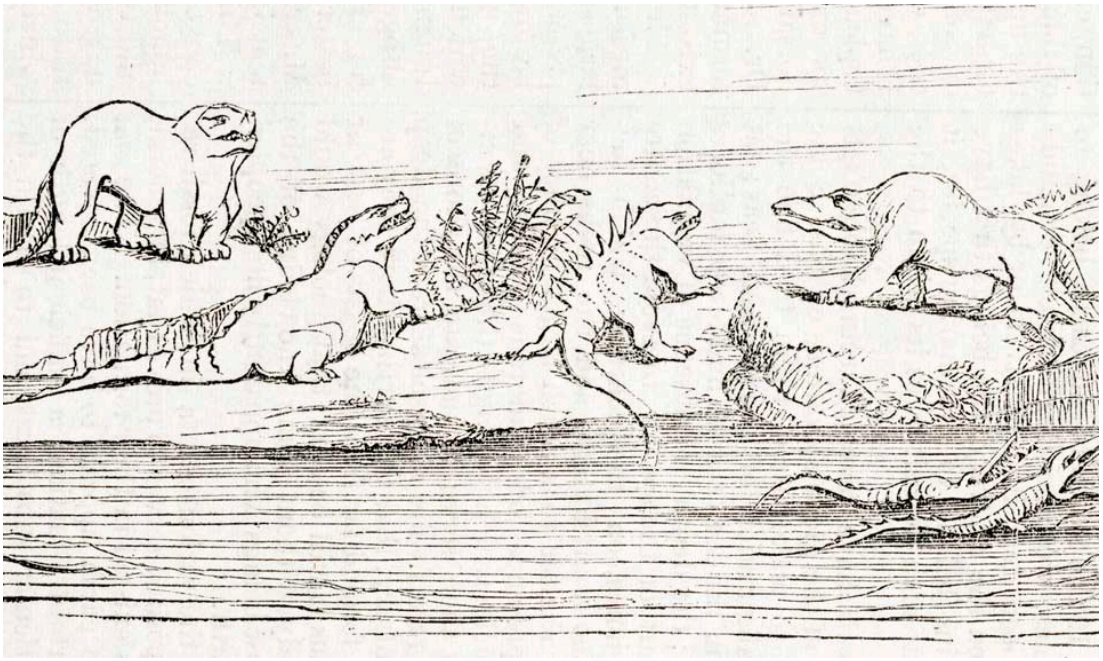
What we observe. What we observe: dinosaur bones occur in particular sets of sandstone, mudstone and shale layers around the world, with certain groups (such as stegosaurs) found mostly in lower layers and others (such as ceratopsians) mostly in higher ones. The layer names are useful labels for where a fossil was found; the dates come from decay measurements plus assumptions that Unit 7 examines.

How Christians read it. How Christians read it: Triassic, Jurassic and Cretaceous are museum words for real stacks of rock, and students should use them accurately. Creation geologists read these stacks as deposits of the Flood year and the years after it, buried a few thousand years ago, and read the order of animals in them as the order in which habitats were overwhelmed, not as ages passing.

Try it. On a museum website, find three dinosaur labels and write the period name from each next to the actual rock formation it names.

Genesis 7:14

PICTURE STUDY



The Crystal Palace Dinosaurs: Megalosaurus, Iguanodon and Hylaeosaurus (concept drawing), Benjamin Waterhouse Hawkins, 1854 · Engraved illustration printed with Hawkins' paper "On Visual Education as Applied to Geology" · Journal of the Society of Arts, vol. 2, London, 1854 (copies in many libraries, including the Linda Hall Library, Kansas City)

Benjamin Waterhouse Hawkins was a natural-history artist who built the first life-size dinosaur sculptures in the world for the grounds of the Crystal Palace in south London, with Richard Owen as his adviser. This drawing, published in 1854, shows the animals as Hawkins planned them: the very three fossils Owen had used to define the Dinosauria in 1842, Megalosaurus, Iguanodon and Hylaeosaurus. On New Year's Eve 1853 Hawkins held a

dinner for twenty-one scientists inside the mold of his Iguanodon, and when the park opened in 1854 crowds came by train to see the monsters.

Hawkins worked from the bones then known: teeth, some limb bones, a few vertebrae and, for Iguanodon, a single cone-shaped spike. He placed the spike on the nose like a rhinoceros horn. In 1878 miners at Bernissart, Belgium, found dozens of nearly complete Iguanodon skeletons, and the spike turned out to be a thumb claw. Hawkins' picture is an honest record of what careful people inferred from very little, and of how new bones corrected them.

Look closely

- Find the spike on the Iguanodon's nose. Knowing it is really a thumb spike, where would you move it?
- Look at how the animals stand. Do they sprawl like lizards, or carry their bodies high off the ground as Owen said dinosaurs did?
- Find all three of Owen's dinosaurs: the meat-eater Megalosaurus, the plant-eater Iguanodon and the armored Hylaeosaurus. Which parts of each did Hawkins have real bones for, and which did he have to guess?
- Compare the Iguanodon here with a modern museum Iguanodon, which stands partly on its hind legs. What changed, and what caused the change?

Talk about it

1. Why did Hawkins and Owen get the thumb spike wrong? Was it a careless mistake or a reasonable inference from the evidence they had?
2. What does this drawing teach you about trusting a reconstruction built from a few bones?
3. Which parts of a modern dinosaur reconstruction do you think are most likely to change in the future?

EXPERIMENT: BUILD A DINOSAUR KEY

Museum scientists sort bones with a dichotomous key: a series of yes-or-no questions that leads to one group. You will make a key for the seven major dinosaur groups and test whether it works for someone who has never seen it.

Question: can a key of six yes-or-no questions sort any dinosaur picture into the right group? Prediction: write yours. What we change: who uses the key (you, then a family member who has not studied dinosaurs). What we keep the same: the key and the set of pictures. What we measure: the number of pictures each person sorts correctly.

You will need

- Twelve pictures of dinosaurs printed from a museum or encyclopedia website, with names hidden on the back
- Index cards, a pencil and a ruler
- Your lab notebook

- The hip diagram from this lesson

Steps

1. List the seven groups: theropods, sauropods, ornithopods, ceratopsians, stegosaurs, ankylosaurs, pachycephalosaurs. Under each, write two features you can see in a picture (two legs or four, long neck, horns and frill, plates, armor, dome skull, duck bill).
2. Write question 1 on a card: “Does it walk on two legs with a long tail and grasping hands?” Yes leads to theropod. No leads to question 2. Build five more questions in the same way until every group has a card leading to it.
3. Test the key yourself on all twelve pictures. Record how many you sort correctly by checking the names on the back.
4. Give the cards and the pictures to a family member who has not studied this lesson. Let them sort all twelve using only your questions. Record their score.
5. Compare the two scores. For each picture sorted wrongly, write down which question failed and why. Rewrite that question.
6. Add a final card: “Is this animal a dinosaur at all?” Include one pterosaur and one plesiosaur among your pictures and make the key send them to “not a dinosaur.”
7. Write a conclusion of three sentences: did the key work, which question was weakest, and what feature of real bones would a scientist use that a picture cannot show?

Tips

- Good key questions ask about one feature at a time and can be answered from what you see, not from what you already know.
- Juvenile dinosaurs often lack the horns, domes or frills of adults. If your key fails on a young animal, you have discovered the species-naming problem for yourself.

Check your work

- I can sort a dinosaur into one of seven groups using visible features.
- I tested my key on another person and recorded both scores.
- I can explain why a pterosaur and a plesiosaur are not dinosaurs.

FIELD NOTEBOOK

1. Draw the two hip types from the figure, label ilium, ischium and pubis on each, and write the name of one dinosaur under each hip.
2. Make a family-tree style chart of the seven dinosaur groups with one small drawing per group and a scale bar showing its usual adult length.
3. Draw Hawkins’ Iguanodon from 1854 and a modern Iguanodon side by side. Circle every difference and write what new evidence caused each change.

> **From history.** Richard Owen went on to lead the natural history collections of the British Museum and fought for years to give them their own building. The result, the Natural

History Museum in South Kensington, London, opened in 1881. A bronze statue of Owen stood on its central staircase until 2009, when Darwin's statue was returned to that place and Owen's was moved elsewhere in the museum. Owen never accepted Darwin's theory, and the two men quarreled publicly, but even his opponents admitted that no one of his day knew bones better.

WORKED EXAMPLES

Example 1. Use this key to classify a skeleton with the following features: the pubis points backward along the ischium; it walks on four legs; it has a large frill and three horns on the skull. Key: 1. Pubis points forward (saurischian) → go to 2; pubis points backward (ornithischian) → go to 3. 2. Two legs, sharp teeth → theropod; four legs, long neck → sauropod. 3. Two legs, duck bill → ornithopod; four legs → go to 4. 4. Horns and frill → ceratopsian; plates along back → stegosaur; low armored body → ankylosaur.

1. Question 1: the pubis points backward, so the animal is an ornithischian. Go to 3.
2. Question 3: it walks on four legs, so go to 4.
3. Question 4: it has horns and a frill, so it is a ceratopsian.
4. Check against a known animal: Triceratops has exactly these features, and museum signs list it as a ceratopsian.

Answer: Ornithischian, four-legged, ceratopsian (a Triceratops-type animal).

Example 2. Diplodocus was about 26 m long and Compsognathus about 1 m long. (a) At a scale of 1 : 100, how long is each on a wall chart? (b) How many Compsognathus laid nose to tail would equal one Diplodocus? (c) If you drew Diplodocus 52 cm long, what scale would that be?

1. (a) Convert to centimeters: 26 m = 2,600 cm; 1 m = 100 cm. Divide by 100: Diplodocus = 26 cm, Compsognathus = 1 cm.
2. (b) Ratio of lengths = 26 m ÷ 1 m = 26. Twenty-six Compsognathus equal one Diplodocus.
3. (c) Scale = real length ÷ drawn length = 2,600 cm ÷ 52 cm = 50. The scale is 1 : 50.

Answer: (a) 26 cm and 1 cm. (b) 26. (c) 1 : 50.

Example 3. Suppose a review of 120 dinosaur species named before 1950 finds that 54 are still valid, 42 turned out to be the same as an earlier-named species, and 24 rest on bones too poor to decide. What percent of the old names fall in each group? If this rate held for 1,000 named species, how many would you expect to be valid?

1. Valid: 54 ÷ 120 = 0.45, so 45%.
2. Same as another species: 42 ÷ 120 = 0.35, so 35%.
3. Too poor to decide: 24 ÷ 120 = 0.20, so 20%. Check: 45 + 35 + 20 = 100.
4. Apply 45% to 1,000 names: 0.45 × 1,000 = 450 valid species.

Answer: 45% valid, 35% duplicates, 20% doubtful; about 450 of 1,000 names would be valid at that rate.

PRACTICE

1. EASY Who named the Dinosauria, in what year, and what does the name mean?
2. EASY Name the three fossil animals Owen used to define the group and who first described each.
3. EASY Which of these is a dinosaur? (a) Pteranodon (b) Plesiosaurus (c) Stegosaurus (d) Dimetrodon (e) Ichthyosaurus
4. MEDIUM State the difference between a saurischian hip and an ornithischian hip, and name one dinosaur group in each.
5. MEDIUM Tyrannosaurus rex was about 12 m long. At a scale of 1 : 40, how long is the drawing in centimeters? If a classmate draws it 60 cm long, what scale did he use?
6. MEDIUM Data reading. A museum table lists dinosaur groups found in one rock formation: theropods 8 species, sauropods 5, ornithopods 12, ceratopsians 9, ankylosaurs 4, stegosaurs 0, pachycephalosaurs 2. (a) How many species in total? (b) What percent are ornithischians? (c) Which hip type dominates this formation?
7. MEDIUM Data reading. A bar graph shows the number of valid Triceratops-group species recognized over time: 1900, 16 species; 1950, 11; 1990, 4; 2010, 2. Describe the trend and give one reason bones first named as different species were later combined.
8. HARD Experiment design. You want to test whether a dichotomous key sorts dinosaur pictures better than a one-page description of each group. Describe what you would change, keep the same, measure, and how many testers you would use.
9. HARD In three or four sentences, explain the difference between a species, a genus and a kind, and tell why the number of kinds matters for the Ark.
10. CHALLENGE The Brontosaurus name was dropped in 1903 and revived in 2015, and the Torosaurus debate is still open. Write a paragraph explaining what these stories show about how science works, and about what stays fixed and what changes on a museum sign.

COMMON MISTAKES

- Thinking every large extinct reptile is a dinosaur. Pterosaurs, plesiosaurs, ichthyosaurs, mosasaurs and Dimetrodon are not; dinosaurs are defined by their upright stance and skeleton, not by size or age.
- Thinking "bird-hipped" dinosaurs are the ones most like birds. Seeley's names describe hip shape only; the theropods, which museums link to birds, are lizard-hipped.
- Thinking a species name is a fact dug from the ground. Names are inferences from bones, and many have been combined or revived as new skeletons were compared.

> **Make it a game · Hip Check.** A parent calls out dinosaur names, including a few non-dinosaurs such as Pteranodon or Plesiosaurus. For each one you have five seconds to give the group (theropod, sauropod, ornithopod, ceratopsian, stegosaur, ankylosaur, pachycephalosaur) or shout "not a dinosaur!" Score one point for the group, a second point for the correct hip type, and lose a point for calling a pterosaur a dinosaur. Play to twenty points, then switch roles.

> **Scripture.** "They, and every beast after his kind, and all the cattle after their kind, and every creeping thing that creepeth upon the earth after his kind, and every fowl after his kind, every bird of every sort." (Genesis 7:14, KJV)

Genesis sorts the animals that entered the Ark by kind. When you group dinosaurs by shared body plan, you are using the Bible's own unit of classification, and it is the unit that makes the Ark's cargo list reasonable.

Practice answers

1. Richard Owen, in his report published in 1842 (presented in 1841). It means "fearfully great lizards," from the Greek deinos and sauros.
2. Megalosaurus (William Buckland, 1824), Iguanodon (Gideon Mantell, 1825) and Hylaeosaurus (Gideon Mantell, 1833).
3. (c) Stegosaurus only. Pteranodon is a flying pterosaur, Plesiosaurus and Ichthyosaurus are marine reptiles, and Dimetrodon is a sail-backed synapsid.
4. In a saurischian hip the pubis points forward and down (theropods, sauropods). In an ornithischian hip the pubis points backward along the ischium (ornithopods, ceratopsians, stegosaurs, ankylosaurs, pachycephalosaurs).
5. 12 m = 1,200 cm; 1,200 ÷ 40 = 30 cm. For 60 cm: 1,200 ÷ 60 = 20, so 1 : 20.
6. (a) 8 + 5 + 12 + 9 + 4 + 0 + 2 = 40 species. (b) Ornithischians: 12 + 9 + 4 + 0 + 2 = 27; 27 ÷ 40 = 67.5%. (c) Ornithischian (bird-hipped) groups dominate.
7. The number of recognized species fell steadily from 16 to 2 as more skeletons were compared. Reason: differences first read as separate species (frill shape, horn length, size) turned out to be growth stages, individual variation, or crushing during burial.
8. Change: the sorting aid (key versus description). Keep the same: the twelve pictures, the time allowed, the testers' prior knowledge (use people who have not studied dinosaurs). Measure: number of pictures sorted correctly and time taken. Use at least six testers, three with each

aid, or have each tester use both aids on two different picture sets so one tester’s skill does not bias the result.

9. A species is the smallest named group, such as Triceratops horridus, and for fossils it is a judgment from bones. A genus groups close species under one first name, such as Triceratops. A kind is the biblical group that breeds together and is usually broader than a species, often a whole genus or family. If dinosaurs make up only a few dozen kinds, Noah needed a few dozen pairs of mostly young, small animals, which is far less space than a thousand species.
10. The bones never changed; the names and groupings did, as scientists compared more skeletons and asked whether differences came from age, sex or crushing. This shows science as a process of inference open to revision, where honest experts can disagree while agreeing on the observations. On a museum sign, measurements of the bones are the fixed part; species names, family trees and dates are interpretations that may be rewritten as evidence grows.

6.2 Dinosaur Eggs and Nests

OBJECTIVES

- Tell the story of the first recognized dinosaur eggs at the Flaming Cliffs of Mongolia in 1923 and explain how the “egg thief” Oviraptor was cleared seventy years later.
- Describe what fossil eggs, eggshell and nests actually show (shape, size, shell pores, clutch arrangement, embryos) and what must be inferred.
- Use volume scaling and growth rates to compare dinosaur eggs and hatchlings with living birds, and explain how creation geologists account for nests within Flood layers.

Warm-up. Hold a chicken egg and look at it under a lamp with a hand lens. Find the tiny pores in the shell (a drop of water on the shell makes them easier to see). Guess how many pores a whole shell has; a chicken egg has several thousand. Why would a living egg need holes in its shell? Write your idea, then keep the egg for the project.

Video. Coming soon. Search for footage of the Flaming Cliffs (Bayanzag) in Mongolia and the American Museum of Natural History Central Asiatic Expeditions of the 1920s, the brooding oviraptorid “Big Mama” fossil, Egg Mountain and Maiasaura in Montana, and the titanosaur egg field at Auca Mahuevo in Argentina. Good sources: American Museum of Natural History, Smithsonian channels, Museum of the Rockies, Natural History Museum (London), SciShow Kids, nature footage.

KEY TERMS

clutch
The set of eggs laid in one nest by one mother at one time.

embryo
A young animal developing inside its egg. Fossil embryos inside dinosaur eggs are rare and prove which animal laid the egg.

eggshell pores
Tiny channels through an eggshell that let oxygen in and carbon dioxide and water vapor out. Their number and size hint at whether an egg was buried or sat in open air.

oviraptorid
A group of beaked, mostly toothless theropods from Mongolia and China, first named Oviraptor, “egg seizer,” in 1924, and later found brooding their own nests.

nesting horizon
A single layer of rock in which many nests of the same kind of egg are found, read as one nesting ground.

brooding
Sitting on a clutch of eggs to warm or shelter them, as birds do. Several oviraptorid skeletons were found in this posture over their eggs.

CORE IDEAS

The story. In the summer of 1923 a line of Dodge motor cars and camel caravans from the American Museum of Natural History crossed the Gobi Desert of Mongolia under the leadership of Roy Chapman Andrews. At a place of red sandstone bluffs the team called the Flaming Cliffs, their paleontologist Walter Granger was collecting skulls of a small horned dinosaur, *Protoceratops*. On July 13, assistant George Olsen came back to camp saying he had found fossil eggs. The others laughed until they saw them: a cluster of elongated eggs about 15 cm long, their shells cracked and grey, lying in the rock where they had been laid. They were the first eggs scientists everywhere accepted as a dinosaur's. Since *Protoceratops* skulls were everywhere, the eggs were assigned to it. Lying over one nest was the skeleton of a toothless theropod with a beak. In 1924 Henry Fairfield Osborn named it *Oviraptor philoceratops*, a name meaning egg seizer, lover of ceratopsian eggs, and for seventy years museum signs called it a nest robber caught in the act.

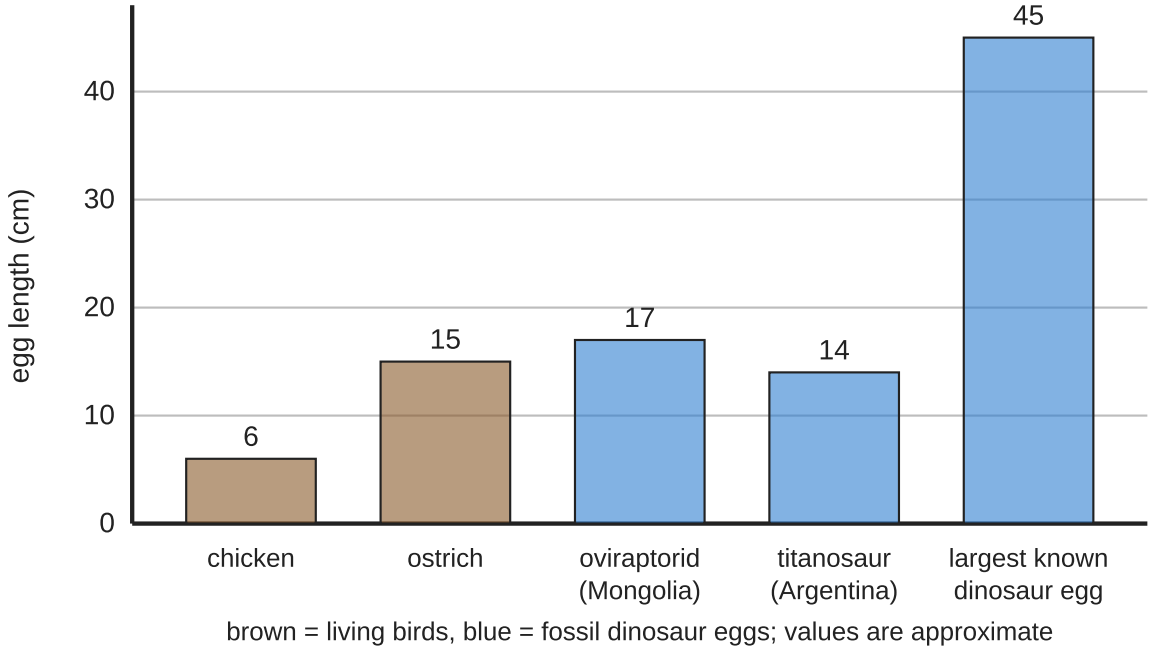
How they figured it out. In 1993 another American Museum expedition, led by Mark Norell and Michael Novacek, found an egg of the same type at Ukhaa Tolgod with a tiny skeleton still inside. The embryo was not a *Protoceratops*. It was an oviraptorid. The "egg thief" had been sitting on its own eggs. In 1995 the team described a complete oviraptorid skeleton crouched over a ring of eggs with its arms spread around them, exactly as a brooding bird sits; it was nicknamed Big Mama. One embryo overturned a seventy-year-old label. The rule for fossil eggs follows: shell shape can suggest a family, but only an embryo inside proves it. In 1978 Jack Horner and Bob Makela, following a tip from a rock-shop owner near Choteau, Montana, found nests of a duck-billed dinosaur with the bones of young still inside them. They named it *Maiasaura*, "good mother lizard," and the site became known as Egg Mountain. In 1997 Luis Chiappe and Rodolfo Coria walked across a field in Patagonia called Auca Mahuevo that was covered with thousands of round sauropod eggs, 13 to 15 cm across, some holding embryos with patches of fossilized skin.

The big idea. What does an egg site actually show? First, the eggs themselves: theropod eggs are long and often laid in pairs; sauropod and hadrosaur eggs are nearly round. Second, the shell: under a microscope, dinosaur eggshell is calcium carbonate arranged in columns, like a bird's, and pierced by pores. Eggs with many large pores lose water fast and must have been buried in damp sand or plant matter, like a crocodile's; eggs with fewer pores could sit in open nests. Third, the arrangement: oviraptorid eggs in rings with an open center, *Maiasaura* eggs in bowl-shaped hollows about 2 m across, sauropod eggs in scattered clutches. Fourth, the hatchlings: *Maiasaura* babies were about 30 to 40 cm long at hatching, and growth lines in their bones, studied like tree rings, suggest that they reached their 9 m adult size in roughly eight years, a growth rate more like a bird or mammal than a lizard. How long the eggs were sat on, and whether parents fed the young, is inference.

In the world today. Eggs raise a fair question for the Flood reading. Nesting takes time: a mother must find ground, lay, and often the eggs must sit for weeks. Yet many egg sites lie within thick stacks of sediment that creation geologists read as Flood deposits. The geologist Michael Oard, whom you met in Unit 5, proposed that during the Flood year the water did not rise steadily everywhere. Earth movements and tides repeatedly exposed fresh sediment

for days or weeks, so surviving animals laid eggs in haste on bare mud before the next surge buried them. Several observations fit that picture. Nests are usually shallow or absent; eggs lie on flat sediment with little plant debris; embryos are rare, as if most clutches never hatched; and the same nesting horizons often sit a short distance beneath marine fossils. Mainstream geologists read the same sites as river floodplains used season after season. Both readings make predictions you can test on a dig: look for soil, roots and plant beds around nests, which long-used floodplains should have in abundance.

God's handiwork. A dinosaur egg is an engineering marvel. Its shell had to be strong enough to carry a sitting parent yet thin enough for a hatchling to break, and porous enough to breathe yet tight enough to keep water in. Job reminds us that God asked who gave the ostrich her wings and who taught her to leave her eggs warming in the dust. The eggs in the rocks were laid by creatures that knew how to nest from the start, and the shells they left behind still show the care built into them.



Egg lengths compared. Most dinosaur eggs were only ostrich-sized; the biggest known are about 45 cm long. A sphere of twice the diameter holds eight times the volume.

⏳ Thinking About Time

What the sign says. What the sign says: the Flaming Cliffs eggs come from the Djadokhta Formation, labeled Late Cretaceous, about 75 million years old; Egg Mountain is labeled about 75 million years old as well; and the sign reads the stacked nesting layers as a floodplain used by returning herds over thousands of years.

What we observe. What we observe: eggs, eggshell fragments, a few embryos and hatchlings lying in sandstone and mudstone layers; nests that are shallow hollows or bare rings on flat surfaces; growth lines in hatchling bones; and several nesting horizons

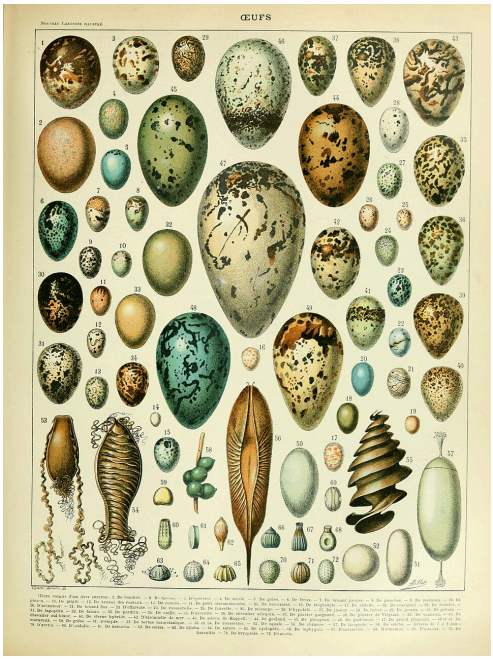
stacked one above another with little soil, few roots and sparse plant debris between them.

How Christians read it. How Christians read it: creation geologists read the stacked egg layers as surfaces exposed briefly during the Flood year and then buried, which fits the shallow nests, the rarity of embryos and the lack of real soils. The dates on the sign come from decay measurements in ash beds plus assumptions, which Unit 7 examines. Either way, the eggs themselves are real, and the animals that laid them nested with care.

Try it. On a museum website, find a photo of a dinosaur nest and list three things you can see and two things the caption infers.

Genesis 8:17

PICTURE STUDY



Œufs (Eggs), plate from the Nouveau Larousse illustré, Adolphe Millot, 1897–1904 · Chromolithograph · Nouveau Larousse illustré, Paris (published encyclopedia plate)

Adolphe Millot was a French natural-history painter who drew hundreds of plates for the great Larousse encyclopedia around 1900: butterflies, fish, mushrooms, shells and this page of eggs. Each egg is painted at the same scale and numbered so a reader could compare a wren's egg with an ostrich's at a glance.

Paleontologists do with fossil eggs exactly what Millot did with living ones: lay them side by side, measure length and width, study shell texture and group them. His plate shows how much an egg alone can tell you, and how much, such as the bird that laid it, you must learn from elsewhere.

Look closely

- Find the largest and the smallest egg on the plate. Estimate how many of the smallest would fit inside the largest.
- Notice the shapes: some eggs are nearly round, some pointed at one end. Which shape would roll in a circle rather than off a cliff ledge?
- Look at the colors and speckles. Fossil eggs are always grey or brown. What information about an egg is lost when it becomes a fossil?
- Find an egg whose owner you could never guess from the egg alone. How would a scientist find out?

Talk about it

1. Why does a scientist need a specimen with an embryo inside before naming which dinosaur laid an egg?
2. What features of an egg can a fossil preserve, and which cannot survive?
3. How does putting things at the same scale on one page help a scientist think?

> **Safety first.** Raw eggs can carry bacteria. Wash hands after handling them, do not eat anything in the work area, and clean the table afterward. Throw the eggs away when the experiment ends; do not eat them.

EXPERIMENT: EGGSHELL PORES AND WATER LOSS

Fossil eggshell is studied for its pores because pores control how fast an egg loses water. You will test whether blocking an eggshell's pores changes how much water the egg loses in warm air, the same reasoning paleontologists use to decide whether an egg was buried or sat in the open.

Question: does sealing the pores of an eggshell slow its water loss? Prediction: write yours. What we change: whether the shell is sealed with a thin coat of petroleum jelly or left bare. What we keep the same: egg size, warm place, length of time. What we measure: mass lost in grams over three days.

You will need

- Four raw chicken eggs of similar size
- A kitchen scale that reads to 1 g (or 0.1 g if you have one)
- Petroleum jelly and a paper towel
- A warm, dry spot such as the top of a refrigerator, or a sunny windowsill
- A hand lens, your lab notebook and a pencil

Steps

1. Label the eggs A, B, C and D with a pencil. Look at each shell under the hand lens and sketch the pore pattern you see.
2. Weigh each egg and record its starting mass to the nearest gram in a table with columns for Day 0, Day 1, Day 2 and Day 3.

3. Coat eggs C and D completely with a thin layer of petroleum jelly, sealing the pores. Leave A and B bare.
4. Place all four eggs together in the warm spot in an open egg carton.
5. Weigh each egg at the same time each day for three days and record the masses.
6. Calculate the total mass lost by each egg and the average for the bare pair and the sealed pair. Plot both averages on one line graph with days on the horizontal axis.
7. Write a conclusion: which pair lost more water, by how many grams, and what this suggests about why a buried crocodile egg can afford more pores than an open bird's nest egg.

Tips

- Water leaves through the pores as vapor, so the bare eggs should grow lighter. If your scale only reads whole grams, run the test for a full week to see a clearer difference.
- Using two eggs in each group and averaging them is how scientists reduce the effect of one odd egg.

Check your work

- I recorded a prediction, four days of masses and a line graph.
- I can explain what eggshell pores do for a living egg.
- I can explain how pore counts help scientists infer whether a fossil egg was buried.

FIELD NOTEBOOK

1. Draw the three nest arrangements from the lesson at the same scale: an oviraptorid ring, a Maiasaura bowl about 2 m across and a scattered sauropod clutch. Add a 1 m scale bar.
2. Sketch a cross-section of eggshell as seen in a microscope, with columns of calcium carbonate and pores running through, and label the direction water vapor leaves.
3. Make a timeline card for the Oviraptor story: 1923 eggs found, 1924 named egg thief, 1993 embryo found, 1995 brooding skeleton described. Under each date write one sentence on what changed.

> **From history.** Dinosaur eggshell was actually described in France in 1859, when the priest and naturalist Jean-Jacques Pouech reported giant eggshell fragments in the foothills of the Pyrenees, and in 1869 Philippe Matheron described eggs near Aix-en-Provence that he thought might belong to a giant bird or to the sauropod Hypselosaurus. No one connected them firmly to dinosaurs until the Mongolian finds of 1923 made the idea impossible to ignore.

WORKED EXAMPLES

Example 1. A chicken egg is about 6 cm long and a titanosaur egg from Auca Mahuevo about 14 cm across. Treating both as spheres, about how many times more volume does the dinosaur egg hold? (Volume of a sphere grows with the cube of its diameter.)

1. Find the ratio of diameters: 14 ÷ 6 = 2.33.
2. Cube the ratio to get the volume ratio: 2.33 × 2.33 × 2.33 = 12.7.
3. Check with a round number: a sphere twice as wide holds 2 × 2 × 2 = 8 times the volume; 2.33 times as wide should be somewhat more than 8, and 12.7 fits.

Answer: About 13 times the volume of a chicken egg, even though it is only a little over twice as long.

Example 2. A Maiasaura hatchling was about 35 cm long. Bone growth lines suggest it reached about 9 m in about 8 years. (a) How many times longer did it grow? (b) What was its average growth in centimeters per year? (c) Per month?

1. (a) Convert to the same unit: 9 m = 900 cm. Ratio = 900 ÷ 35 = 25.7, about 26 times longer.
2. (b) Total growth = 900 − 35 = 865 cm. Average rate = 865 ÷ 8 = 108 cm per year.
3. (c) 108 ÷ 12 = 9 cm per month on average. Real growth was faster in early years and slower later, so this is only an average.

Answer: (a) About 26 times. (b) About 108 cm per year. (c) About 9 cm per month.

Example 3. Use the egg-length bar graph. The largest known dinosaur egg is about 45 cm long and an ostrich egg about 15 cm. (a) What is the ratio of lengths? (b) If both were the same shape, how many ostrich eggs’ worth of volume would the giant egg hold? (c) Why is the answer to (b) not simply 3?

(Use the map or drawing “Read the bar heights to the nearest centimeter before computing ratios.” shown earlier in this lesson.)

1. (a) 45 ÷ 15 = 3. The giant egg is three times as long.
2. (b) Volume scales with the cube of length for the same shape: 3 × 3 × 3 = 27 ostrich-egg volumes.
3. (c) Length is one dimension; volume is three. Tripling every dimension multiplies volume by 3 three times.

Answer: (a) 3 : 1. (b) About 27 times the volume. (c) Because volume grows with the cube of length, not in proportion to it.

PRACTICE

1. EASY Where and in what year were the first widely accepted dinosaur eggs found, and who led the expedition?
2. EASY Why was Oviraptor named “egg seizer,” and what discovery in 1993 changed that story?
3. EASY What is the only sure way to know which dinosaur laid a fossil egg?
4. MEDIUM An egg 10 cm across and another 20 cm across have the same shape. How many times more volume does the larger hold? Show the reasoning.
5. MEDIUM A hatchling 40 cm long grows to 3 m in its first year. What is its average growth per month?
6. MEDIUM Data reading. A table lists eggshell pore density: crocodile (buried nest) 150 pores per cm^2; chicken (open nest) 60 per cm^2; fossil egg type X 140 per cm^2; fossil egg type Y 55 per cm^2. Which fossil egg type was more likely buried in sediment or plant matter, and why?
7. MEDIUM Data reading. A graph of your egg experiment shows bare eggs losing 0.0, 0.8, 1.6 and 2.4 g on days 0 to 3, and sealed eggs losing 0.0, 0.1, 0.2 and 0.3 g. (a) What is the daily loss rate for each group? (b) How many times faster did the bare eggs lose water? (c) What would you predict for day 6?
8. HARD Experiment design. Design a test of whether damp sand or dry sand keeps an egg from losing water faster. State the question, what you change, what you keep the same, what you measure, and one control you would include.
9. HARD In three or four sentences, explain why nests within Flood layers are a fair question for the Flood reading, and how Michael Oard’s proposal answers it.
10. CHALLENGE Write a paragraph comparing what the oviraptorid brooding skeleton (Big Mama) shows with what it does not show. Then explain how the Oviraptor story is a lesson about museum signs.

COMMON MISTAKES

- Thinking dinosaur eggs were huge. Most were ostrich-sized, and even the largest known, about 45 cm long, is far smaller than the animal that laid it, because a bigger egg would need a shell too thick for the hatchling to break.
- Thinking a skeleton near a nest proves it was a predator or a parent. Only an embryo inside the egg proves whose eggs they were; everything else about behavior is inference.
- Thinking an egg must have hatched because it is a fossil. Most fossil eggs show no sign of hatching, and unhatched clutches are what rapid burial would leave behind.

Make it a game · Clutch Count. Set out twelve small objects as “eggs” (walnuts, bottle caps) in a ring, a bowl shape or a scatter while your partner looks away. Your partner has five seconds to look, then must name the arrangement (ring, bowl or scatter), estimate the count and say which dinosaur group used it. One point for each correct answer. Then

swap, and on the second round include one object that is “not an egg” the other player must spot. Play to twelve points.

Scripture. “Which leaveth her eggs in the earth, and warmeth them in dust, And forgetteth that the foot may crush them, or that the wild beast may break them.” (Job 39:14–15, KJV)

God points Job to the ostrich, which nests on the ground and leaves her eggs in the warm sand. The dinosaur nests in the rocks show the same ground-nesting care, built into creatures by the One who asked Job the question.

Practice answers

1. At the Flaming Cliffs (Bayanzag) in the Gobi Desert of Mongolia, in 1923, on the American Museum of Natural History expedition led by Roy Chapman Andrews. George Olsen found them.
2. Its skeleton lay over a nest of eggs thought to be Protoceratops eggs, so it was named as an egg thief in 1924. In 1993 an egg of that type was found with an oviraptorid embryo inside, showing the eggs were its own.
3. Finding an embryo (a developing skeleton) inside an egg of that type. Shell shape and texture only suggest a family.
4. The diameter ratio is 2, and volume scales with the cube: 2 × 2 × 2 = 8 times the volume.
5. 3 m = 300 cm; growth = 300 − 40 = 260 cm; 260 ÷ 12 = about 22 cm per month.
6. Type X. Its pore density is close to the crocodile’s, and high pore counts let water escape quickly, which an egg can only afford if it is kept in damp, covered material. Type Y matches open-nest birds.
7. (a) Bare: 0.8 g per day. Sealed: 0.1 g per day. (b) 0.8 ÷ 0.1 = 8 times faster. (c) Bare about 4.8 g, sealed about 0.6 g, if the rates stay steady.
8. Question: does burial in damp sand slow an egg’s water loss compared with dry sand? Change: dampness of the sand. Keep the same: egg size, depth of burial, container, temperature, time. Measure: mass lost in grams per day over a week. Control: an unburied egg in the same room, to compare both buried groups against open air.
9. Laying and sitting on eggs takes days or weeks, so nests seem to need quiet time, yet many sit inside thick sediment stacks that creation geologists read as Flood deposits. Oard proposed that during the Flood year, earth movements and tides exposed fresh sediment surfaces briefly before the next surge buried them. Surviving animals laid eggs hastily on bare mud, which fits the shallow nests, rare embryos, lack of soils and nearby marine fossils. Mainstream geologists read the same sites as floodplains used for many seasons, so both sides can test their reading by looking for real soils and plant beds.
10. The skeleton shows an adult crouched over a ring of its own kind of eggs with arms spread around them, so it shows the posture and the fact that this animal sat on a clutch. It does not show how long it sat, whether it warmed the eggs, whether both parents took turns, or whether it died protecting them or was simply buried in place by a sandstorm or flow. The Oviraptor story shows that a confident label, “egg thief,” stood for seventy years on a reasonable guess and was overturned by one embryo. Good readers of signs separate what the fossil shows from the story told about it.

6.3 Dragon Legends: Weighing the Stories

OBJECTIVES

- Tell how the Klagenfurt Lindwurm of 1590 came to have a rhinoceros face, and describe how fossil bones shaped at least one other legend.
- List the common features of dragon legends from Europe, China and the Americas and sort them into details that match real animals and details that do not.
- Weigh a legend as evidence using a checklist of questions, and state fairly how mainstream historians and creation researchers each account for dragon stories.

Warm-up. Without looking anything up, draw a dragon in two minutes. Then list every feature you drew: legs, wings, scales, fire, horns, size. Put a check beside each feature that some living animal actually has (a crocodile has scales, a bat has wings). Which features are left with no check? Keep the list; you will compare it with legends from three continents.

Video. Coming soon. Search for a short documentary on dragon legends around the world and their possible sources (fossil bones, crocodiles, Komodo dragons), the Klagenfurt Lindwurm fountain, Chinese “dragon bones” and the discovery of oracle bones in 1899, and the Komodo dragon’s description in 1912. Good sources: Smithsonian channels, Natural History Museum (London), British Museum, nature footage of monitor lizards and crocodiles, Homeschool Pop (Alternate).

KEY TERMS

legend
A traditional story handed down by a people, often about a real place or person, that mixes memory with retelling.

lindwurm
The German word for a wingless or two-legged dragon in Central European legends, such as the one on the Klagenfurt fountain.

dragon bones
The Chinese name (longgu) for fossil bones and teeth, mostly of mammals, dug up and sold by apothecaries for centuries.

primary source
A record made by someone at the time, such as Herodotus’ own text or a dated carving, as opposed to a later retelling.

corroboration
Support for a story from a second, independent line of evidence, such as a bone, a carving or another writer.

monitor lizard

A family of large lizards including the Komodo dragon, which grows to about 3 m, and the extinct Australian Megalania, estimated at 5 m or more.

CORE IDEAS

The story. In the main square of Klagenfurt, Austria, stands a dragon fountain carved from a single block of green stone. The sculptor Ulrich Vogelsang began it in 1583, and the finished monument was set up in 1590. According to the city's legend, a lindwurm once lived in the marshes where the town now stands and devoured travelers until brave men killed it with a baited hook. The strange thing is the dragon's face. In 1335 workers digging gravel near the town had unearthed a huge, heavy skull with a bony snout, and the city fathers kept it in the town hall as the head of the slain lindwurm. In 1914 the Austrian paleontologist Othenio Abel examined the skull and identified it as a woolly rhinoceros, an Ice Age animal whose bones are common in European gravels. Abel noticed that Vogelsang had copied the skull's proportions for his dragon. It shows, in stone, how a real bone can grow a legend.

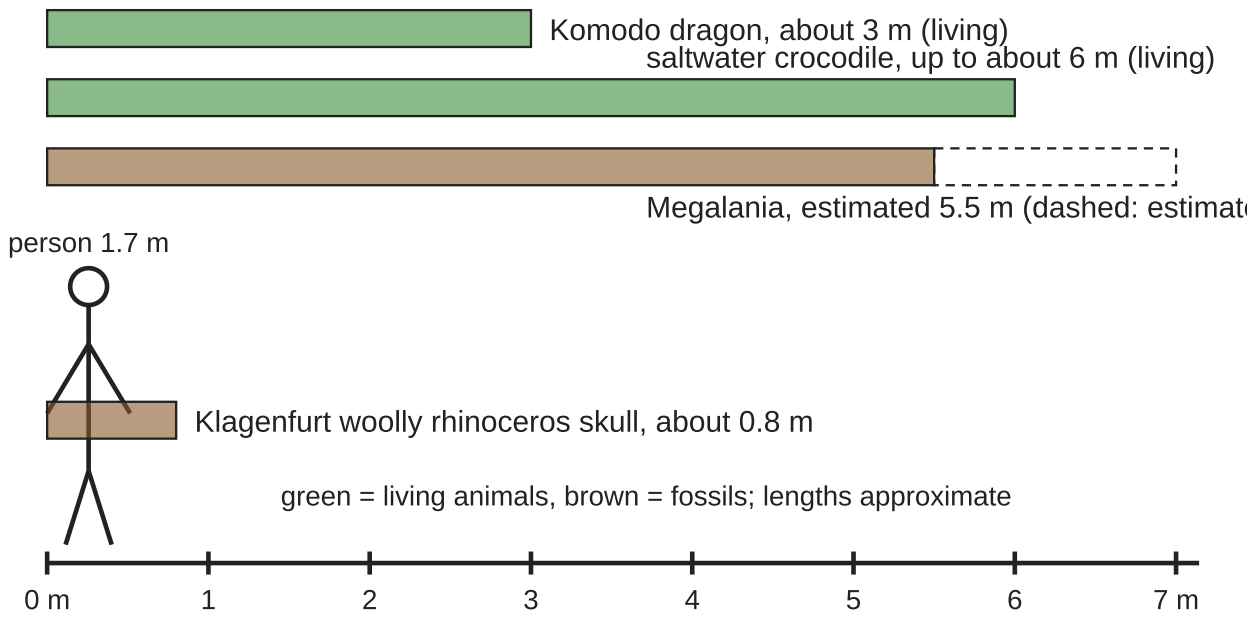
How they figured it out. Historians who study dragon legends begin by collecting them. Herodotus, writing in Greece around 430 BC, reported that winged serpents in Arabia were killed by the sacred ibis birds when they flew toward Egypt. A fourth-century Chinese writer, Chang Qu, recorded that "dragon bones" were dug up in Wucheng in Sichuan, the earliest known written mention of fossil bones in China. In 1899 a Chinese scholar named Wang Yirong noticed ancient writing scratched into "dragon bones" sold at a Beijing pharmacy, which led to the discovery of the Shang dynasty oracle bones. Europe told of Saint George and of Beowulf's fire-breathing dragon, and Mexico honored the feathered serpent Quetzalcoatl. The historian Adrienne Mayor showed in 2000 that the griffin of Greek art, a lion-sized beast with a beak and a frill, matches the skulls of *Protoceratops* that lie exposed along the old gold routes of Central Asia. Her method is worth copying: put the legend beside the bones and ask what fits.

The big idea. How do you weigh a story as evidence? Use a checklist. Who recorded it, and how long after the event? Is there a **primary source**, or only retellings? Is there **corroboration** from bones, carvings or a second writer? Does the creature match a real animal in size and shape? Do the fantastic parts, such as fire or speech, look like additions to an ordinary core? Run the Klagenfurt legend through the list and you find a real skull, a real dragon statue, but no eyewitness of a living lindwurm; the fossil explains the face better than a living monster does. Run the Komodo dragon through the same list. Sailors' reports of giant lizards on small Indonesian islands were dismissed until Peter Ouwens, director of the zoological museum at Buitenzorg in Java, described the animal in 1912. It grows to about 3 m and 70 kg, kills deer and buffalo, and is a true "dragon" that legend got right. Herodotus' winged serpents, on the other hand, have never been matched to any animal. A good historian keeps all three verdicts, confirmed, explained and unexplained, and does not force them into one.

In the world today. Here the two readings part. Mainstream museums hold that dinosaurs died out long before people existed, so no human ever saw one; dragon legends must come from fossils, from large living reptiles such as crocodiles and pythons, and from imagination

and fear. Creation researchers point out that if dinosaurs were on the Ark, as land animals created on the sixth day would be, then people living after the Flood could have met their descendants, and some dragon stories could preserve dim memories of real animals. Both sides agree on the facts of each case above. The honest creation position is modest. Legends are weak evidence by themselves. They can be checked against bones and carvings, and each case must be judged on its own. A carving at the temple of Ta Prohm in Cambodia, built about 1186, is often said to show a stegosaur; others see a rhinoceros or a chameleon against a background of leaves. That dispute is a checklist exercise, not a proof for either side.

God's handiwork. The Bible itself describes enormous creatures without calling them myths. In Job 40 God points to *behemoth*, which eats grass like an ox, has bones like bars of iron, and "moveth his tail like a cedar." Some Christians think of a hippopotamus or an elephant; others, noting the cedar-like tail, think of a sauropod. The text does not say, and we should not claim more than it does. What it does say is that God made this creature and counts it among the chief of His works. Every great bone in the ground and every great lizard still alive is a reminder that the Maker's creatures were larger and stranger than our daily experience, and that wonder, not fear, is the right response.



Real animals behind "dragon" reports, drawn to one scale. Legends grew around creatures and bones of these sizes.

⏳ Thinking About Time

What the sign says. What the sign says: museum labels state that non-bird dinosaurs died out about 66 million years ago, tens of millions of years before any humans, so dragon legends can only come from fossils, living reptiles and imagination, never from eyewitnesses.

What we observe. What we observe: dragon stories exist on every inhabited continent; some match real animals (Komodo dragons, crocodiles) and some match fossils (the Klagenfurt rhinoceros skull, the Protoceratops griffin); no dinosaur bone has been found with human tools in the same undisturbed layer; and the gap of 66 million years on the sign is a date derived from decay measurements and assumptions, not from the legends or the bones themselves.

How Christians read it. How Christians read it: if land animals of every kind were preserved through the Flood, people of the early post-Flood world could have known some dinosaur kinds before they died out, and a few legends might carry faint memories of them. Creation researchers treat this as a possibility to test case by case, not as proof, and mainstream historians treat it as excluded by the dates. Both can agree on what each skull, statue and carving actually shows.

Try it. Pick one dragon legend and run it through the five checklist questions in writing.

Job 40:15

PICTURE STUDY



Saint George and the Dragon, Paolo Uccello, about 1470 · Oil on canvas · National Gallery, London

Paolo Uccello was a Florentine painter fascinated by perspective and pattern. His Saint George shows the moment from the medieval Golden Legend when the knight spears the dragon that has terrorized a city, while the princess it was about to devour stands by, already leading it on a leash. The painting is a fine example of how a legend looked to the people who told it: not a nature study, but a picture of good conquering evil.

Look at the dragon as a naturalist would. Uccello gave it two legs, bat-like wings with round eyespots like a moth's, a curling tail and a lizard's head. He had never seen such an animal. Every part is borrowed from something he had seen: a bird's legs, a bat's wings, a butterfly's spots, a crocodile's jaws. That is how legends build a creature.

Look closely

- Count the dragon's legs and look at its wings. Which living animals supplied each part?
- Find the princess's leash. What does it tell you about how the storyteller wanted you to feel about the dragon's power?
- Look at the dragon's cave. Legends often place dragons in caves and marshes, exactly where bones are found. Why might that be?
- Notice the storm cloud spiraling behind the knight. Is it weather, or a sign of something more?

Talk about it

1. If you ran this dragon through the lesson's checklist, which features would match a real animal and which would not?
2. Why do legends about dragons so often become stories about courage and rescue rather than reports about an animal?
3. What would a painter need in order to paint a dragon from life rather than from borrowed parts?

EXPERIMENT: THE LEGEND SCORECARD

Historians weigh stories with rules, not feelings. You will build a scorecard for weighing legends and test whether two people using it reach the same verdict about the same stories.

Question: does a written checklist make two judges agree more often than their first impressions do? Prediction: write yours. What we change: whether the judges use the checklist or first impressions. What we keep the same: the legends, the judges, the time allowed. What we measure: how many of six legends the two judges score within one point of each other.

You will need

- Short summaries (five to eight sentences each) of six legends: the Klagenfurt Lindwurm, the Greek griffin, Herodotus' winged serpents, the Komodo dragon reports, Saint George, and one dragon or giant-serpent legend from the Americas, copied from an encyclopedia
- Index cards and a pencil
- Your lab notebook and a second judge (parent or sibling)

Steps

1. Before building the scorecard, each judge reads the six legends and gives each a quick 0 to 10 score for “probably remembers a real animal.” Record these first-impression scores in two columns.
2. Build the scorecard on a card with five questions, each worth 0, 1 or 2 points: Is there a primary source close to the event? Is there corroboration from bones, carvings or a second writer? Does the creature’s size and shape match a known animal? Are the fantastic parts separable from an ordinary core? Is the place where it was told a place where large reptiles or large bones occur?
3. Each judge scores all six legends again using only the card, out of 10. Record these in two more columns.
4. For each legend, find the difference between the two judges’ scores for the first impressions, then for the scorecard round. Count how many legends in each round differ by 1 point or less.
5. Plot a two-bar graph: number of agreements with first impressions versus with the scorecard.
6. For the Klagenfurt legend, write one sentence under each checklist question giving your evidence.
7. Write a conclusion of three sentences: did the checklist raise agreement, which legend was hardest to score, and what one extra piece of evidence would most change its score?

Tips

- A high score means the legend probably remembers a real animal, not necessarily a dinosaur. The Komodo dragon should score high; it is a real lizard.
- If the two judges disagree by 3 or more on one question, that question is badly worded. Rewrite it and score again.

Check your work

- I built a five-question scorecard and used it on six legends.
- I compared agreement before and after the scorecard with a bar graph.
- I can state how mainstream historians and creation researchers each account for dragon legends.

FIELD NOTEBOOK

1. Draw the Klagenfurt Lindwurm’s head from a photograph beside a woolly rhinoceros skull. Mark three matching features.
2. Make a world map and place a small dragon symbol on Austria, Greece, China, England, Scandinavia, Indonesia and Mexico. Beside each, write the creature’s local name and one feature.
3. Draw the four animals from the scale figure at 1 : 50 along a single baseline, with a person for comparison, and label each length.

From history. Marco Polo, returning from China in 1295, described huge “serpents” in the province of Carajan (Yunnan) that were ten paces long, thick as a barrel, with two short legs near the head and jaws big enough to swallow a man; hunters killed them with stakes hidden along their trails. Most scholars think he was describing crocodiles, which do live in southern China, though the length is exaggerated. His account is a useful test case: a real traveler, a plausible core, and numbers stretched in the telling.

WORKED EXAMPLES

Example 1. A Komodo dragon is about 3 m long and weighs about 70 kg. Megalania, the extinct Australian monitor lizard, is estimated at about 5.5 m. If Megalania had the same shape, how much would it have weighed? (Mass scales with the cube of length for the same shape.)

1. Length ratio = 5.5 ÷ 3 = 1.83.
2. Mass ratio = 1.83 × 1.83 × 1.83 = 6.1.
3. Mass = 70 kg × 6.1 = 430 kg. Published estimates for Megalania vary widely because the length itself is uncertain, so this is one reasonable figure, not a measurement.

Answer: About 430 kg, roughly six times a Komodo dragon’s mass, if the length estimate of 5.5 m is right.

Example 2. In a class survey, 40 dragon or giant-serpent legends were sorted by features. 36 described a scaly reptile-like body, 22 said it lived in water or marsh, 18 gave it wings, 14 said it breathed fire and 9 said it could speak. What percent of legends had each feature? Which features look like a real-animal core, and which look like additions?

1. Scaly body: 36 ÷ 40 = 90%. Water or marsh: 22 ÷ 40 = 55%. Wings: 18 ÷ 40 = 45%. Fire: 14 ÷ 40 = 35%. Speech: 9 ÷ 40 = 22.5%.
2. Features that living reptiles share (scales, living in water) appear in most legends; features no reptile has (fire, speech) appear in a minority.
3. A fair reading: the common core looks like a large reptile; the rarer features look like additions in retelling.

Answer: 90%, 55%, 45%, 35%, 22.5%. Scales and water-dwelling form a core that matches real reptiles; fire and speech are likely additions.

Example 3. The Klagenfurt skull was dug up in 1335 and the fountain finished in 1590. Abel identified the skull in 1914. (a) How many years did the skull sit in the town hall before the dragon was carved? (b) For how many years was it believed to be a dragon’s skull before it was identified? (c) If one generation is about 25 years, how many generations retold the legend between the find and the statue?

1. (a) $1590 - 1335 = 255$ years.
2. (b) $1914 - 1335 = 579$ years.
3. (c) $255 \div 25 = 10.2$, about ten generations.

Answer: (a) 255 years. (b) 579 years. (c) About ten generations, each able to add to the story.

PRACTICE

1. EASY What animal’s skull was kept in Klagenfurt as the head of the lindwurm, and who identified it in 1914?
2. EASY What are Chinese “dragon bones,” and what discovery did they lead to in 1899?
3. EASY Name a “dragon” from legend that turned out to be a real living animal, and the year it was described by science.
4. MEDIUM A crocodile is 5 m long and a similar-shaped lizard is 2.5 m long. If the lizard weighs 50 kg, about how much does the crocodile weigh?
5. MEDIUM List the five checklist questions for weighing a legend as evidence.
6. MEDIUM Data reading. A table lists legends and the nearest matching evidence: Klagenfurt lindwurm, rhinoceros skull found 1335; griffin, Protoceratops skulls along gold routes; Komodo dragon, living animal described 1912; Herodotus’ winged serpents, no match. Sort each legend as confirmed, explained by fossils, or unexplained, and justify one sorting.
7. MEDIUM Data reading. A bar graph shows the number of legends by region in a survey: Europe 14, East Asia 11, Middle East 6, Americas 7, Africa 2. (a) What is the total? (b) What percent came from Europe? (c) Give one reason the count may say more about which stories were written down than about where dragons were “seen.”
8. HARD Experiment design. You want to test whether a story changes more when passed by word of mouth through ten people than through three. Describe the setup, what you change, keep the same and measure.
9. HARD In three or four sentences, state how mainstream historians and creation researchers each account for dragon legends, and name one point where they agree.
10. CHALLENGE Read Job 40:15–19 and write a paragraph on what the text actually says about behemoth, which features point toward a particular animal, and why a careful Christian should not claim more than the text states.

COMMON MISTAKES

- Thinking a legend proves a dinosaur was seen. Legends are weak evidence by themselves; they must be checked against bones, carvings and primary sources, and most dragon features are borrowed from living animals.
- Thinking that because some legends are fanciful, none can remember a real animal. The Komodo dragon was dismissed as a sailors' tale until 1912.
- Thinking "dragon bones" in China were dinosaur bones. Most were fossil mammals such as rhinoceros, horse and deer, and the Shang oracle bones were cattle shoulder blades and turtle shells.

Make it a game · Confirmed, Explained or Unexplained. A parent reads a short creature report, real or invented, such as "sailors said a lizard on an island ate goats" or "a bard sang of a worm that spoke riddles." You have ten seconds to call "confirmed" (a real animal fits), "explained" (a fossil or a known animal explains the story) or "unexplained," and to give one checklist question that supports your call. One point per correct call with a reason. After ten reports, swap roles. Play to fifteen points.

Scripture. "Behold now behemoth, which I made with thee; he eateth grass as an ox. Lo now, his strength is in his loins, and his force is in the navel of his belly." (Job 40:15–16, KJV)

God answers Job by pointing to a huge, real, grass-eating animal that He made. Whatever behemoth was, the passage teaches that the greatest creatures are God's works, made to show His power and to humble us.

Practice answers

1. A woolly rhinoceros skull, dug up in 1335 and identified by the Austrian paleontologist Othenio Abel in 1914.
2. Fossil bones and teeth, mostly of mammals, sold by apothecaries. In 1899 Wang Yirong noticed ancient writing on some of them, leading to the discovery of the Shang dynasty oracle bones.
3. The Komodo dragon, a monitor lizard of Indonesia up to about 3 m long, described by Peter Ouwens in 1912.
4. Length ratio 2; mass ratio $2 \times 2 \times 2 = 8$; 8×50 kg = 400 kg.
5. Who recorded it and how long after? Is there a primary source? Is there corroboration from bones, carvings or another writer? Does the creature match a real animal in size and shape? Are the fantastic parts separable from an ordinary core?
6. Komodo dragon: confirmed (a living animal). Klagenfurt and griffin: explained by fossils (a rhinoceros skull and Protoceratops skulls supplied the shapes). Winged serpents: unexplained (no animal or bone matches). Example justification: the Klagenfurt dragon's face copies the proportions of the rhinoceros skull kept in the town hall.
7. (a) 40. (b) $14 \div 40 = 35\%$. (c) Regions with long written traditions and more surviving books (Europe, China) will have more recorded legends, and the surveyors may read those

languages better, so the count reflects records and the survey’s reach, not the number of original sightings.

8. Write a short description of an animal with ten details. Change: the number of people in the chain (3 versus 10). Keep the same: the starting story, the time each person has to hear and retell it, no notes allowed. Measure: how many of the ten original details survive at the end, and how many new details appear. Run each chain length at least twice with different people and average the results.
9. Mainstream historians hold that dinosaurs died out tens of millions of years before humans, so legends come from fossils, living reptiles and imagination. Creation researchers hold that land animals of every kind survived the Flood on the Ark, so early post-Flood people could have met some dinosaur kinds, and a few legends might preserve memories of them, though legends alone are weak evidence. Both agree the Klagenfurt skull is a rhinoceros, the griffin matches Protoceratops and the Komodo dragon is real.
10. The text says God made behemoth, that it eats grass like an ox, has great strength in its loins and belly, moves its tail like a cedar, has bones like brass and iron, and is chief of God’s works. Grass-eating and a riverside habitat fit a hippopotamus or elephant; a tail compared to a cedar fits a sauropod better, since those animals have small tails. Because the Hebrew word is untranslated and the passage is poetry praising God’s power, the honest conclusion is that behemoth was a real, huge, grass-eating animal whose identity the text leaves open, and we should present the sauropod reading as a possibility, not a proof.

6.4 Feathers and Birds: What the Evidence Shows

OBJECTIVES

- Tell the story of Sinosauropteryx, found in Liaoning, China, in 1996, and explain why its dark filaments are read differently by different scientists.
- Name the parts of a true feather and distinguish a pennaceous flight feather, a down feather and a simple filament, using measurements of vane asymmetry.
- State accurately what museums claim about birds and dinosaurs, list the observations both sides accept, and give the creation reading of feathered fossils.

Warm-up. Find a feather outdoors, or pull one from a feather duster or pillow. With a hand lens, look at the central shaft and the branches coming off it. Gently pull two branches apart, then stroke them back together and feel them re-zip. Try to do the same with a strand of hair or a piece of fur. Write one sentence on the difference you feel.

Video. Coming soon. Search for close-up footage of feather structure under magnification (barbs, barbules, hooklets), the Liaoning fossil beds and Sinosauropteryx, Microraptor and Caudipteryx, and a fair explainer on the debate over whether dinosaur filaments were feathers or collagen. Good sources: Smithsonian channels, American Museum of Natural History, Natural History Museum (London), Cornell Lab of Ornithology, SciShow Kids, nature footage of birds.

KEY TERMS

rachis
The stiff central shaft of a feather, running from the hollow base (calamus) to the tip.

barbs and barbules
Barbs are the branches off the rachis; barbules are tiny side branches off each barb, with hooklets that zip neighboring barbs together into a flat vane.

pennaceous feather
A feather with a stiff rachis and a closed, flat vane, such as a flight feather or body contour feather.

vane asymmetry
In flight feathers, the vane on the leading edge is narrower than the vane on the trailing edge. Symmetrical vanes mark a feather not used for flight.

filament
A simple hair-like structure with no rachis or vane. Dark filaments on some dinosaur fossils are read by most paleontologists as simple feathers and by some ornithologists as collagen fibers from skin.

theropod
The group of two-legged, mostly meat-eating dinosaurs such as Tyrannosaurus and Velociraptor, which museum signs name as the closest relatives of birds.

CORE IDEAS

The story. In the summer of 1996 a farmer named Li Yumin, who dug fossils near the village of Sihetun in Liaoning Province, northeastern China, split a slab of fine grey rock and found a small skeleton about a meter long, curled with its tail over its back. Along the spine and tail ran a fringe of dark, hair-like marks. Ji Qiang of the National Geological Museum in Beijing recognized the skeleton as a small theropod dinosaur and named it *Sinosauropteryx*, "Chinese lizard wing." That October, at a meeting of vertebrate paleontologists in New York, he showed a photograph to Philip Currie of Canada. For the first time a dinosaur, not a bird, had been found with what looked like feathers. Within two years Liaoning produced *Caudipteryx*, a turkey-sized animal with true vaned feathers on its arms and tail, and in 2003 *Microraptor*, a crow-sized animal with long flight-type feathers on all four limbs.

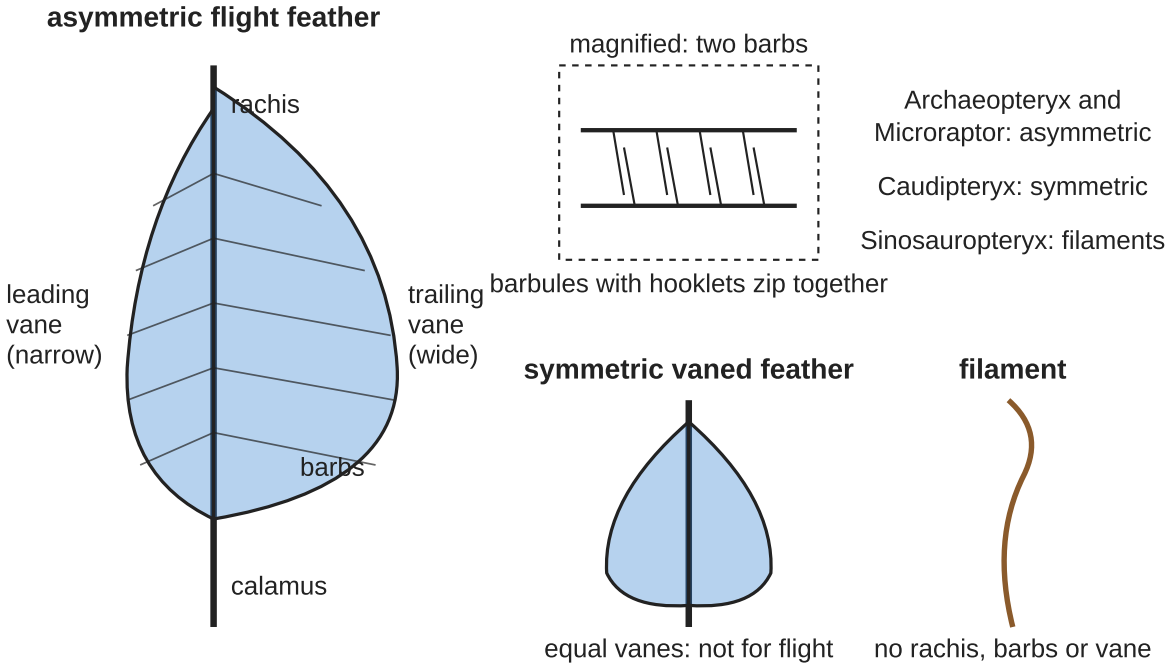
How they figured it out. To judge these fossils you must first know what a feather is. A true **pennaceous** feather has a hollow base, a stiff shaft called the **rachis**, and rows of **barbs** branching off it. Each barb carries dozens of tiny **barbules**, and the barbules on one side carry hooklets that catch the barbules of the next barb, zipping the whole surface into a flat, airtight **vane**. This is why your feather re-zipped in the warm-up and the hair did not. A down feather has a soft base and loose barbs with no hooks. A flight feather has one more mark: its vane is **asymmetric**, narrow on the leading edge and wide on the trailing edge. *Archaeopteryx*, which you met in Unit 3, has fully formed, asymmetric flight feathers. *Microraptor* has them too. *Caudipteryx* has vaned feathers that are symmetric, so it could not fly. *Sinosauropteryx* has none of these: only dark filaments a few centimeters long, with no rachis, no barbs and no vane that anyone has clearly shown.

The big idea. That is where the argument lives. Most paleontologists read the filaments as "protofeathers," simple first-stage feathers, and in 2010 a team reported tiny color-bearing bodies, melanosomes, in them, suggesting a reddish-brown animal with a striped tail. A smaller group, led by the ornithologist Alan Feduccia of the University of North Carolina and the microscopist Theagarten Lingham-Soliar, examined the same kind of fossil and argued in 2007 that the filaments are frayed collagen fibers from the skin. The lesson for you is a careful one: when a sign says "feathered dinosaur," ask which kind of feather. Vaned feathers on *Caudipteryx* and *Microraptor* are real feathers by any definition. Filaments on *Sinosauropteryx* or on the 9 m *Yutyrannus* of 2012 are observations whose meaning is still debated. Feduccia and others also note an awkward order in the rocks: *Archaeopteryx*, a true bird, comes from the Solnhofen limestone of Germany, which museums label Late Jurassic, while most of the feathered theropods come from the Liaoning beds, labeled Early Cretaceous, above it. Mainstream scientists answer that older relatives simply have not been found yet, and point to *Anchiornis*, a feathered animal from Jurassic-labeled layers described in 2009.

In the world today. Museum signs now say that birds *are* dinosaurs, the last living theropods. The evidence they list is real and you should know it: a wishbone (furcula) in theropods, hollow bones, three-fingered hands, a half-moon shaped wrist bone that lets the hand fold sideways, brooding oviraptorids sitting on nests, and feathers. The creation reading starts from Genesis 1, where God made winged fowl on the fifth day and the beasts

of the earth on the sixth, each after its kind. Shared features such as wishbones and hollow bones are read as common design. Fossils with true feathers are read as birds, including flightless birds, just as the ostrich, kiwi and dodo are birds that do not fly. Filaments on undoubted dinosaurs are read as skin structures, or as the open question they still are. What no fossil shows is a half-made feather with a half-made hook system, and every feather ever found, from *Archaeopteryx* onward, is complete.

God's handiwork. Whatever you decide about the slabs from Liaoning, look again at the feather in your hand. A single pigeon flight feather about 10 cm long carries several hundred barbs, and each barb carries hundreds of barbules, so one feather zips together with tens of thousands of hooks, yet weighs a fraction of a gram. It sheds water, traps warm air, bends without breaking and is grown fresh each year from a tiny follicle in the skin. The psalmist saw the same thing without a lens: God covers His people as a bird covers her young "under his wings." The feather is one of the best-engineered objects in creation, and it was already perfect in the first feathers in the rocks.



Three things a "feathered" fossil might show: an asymmetric flight feather, a symmetric vaned feather, or a bare filament. Only the first two are feathers by any definition.

⏳ Thinking About Time

What the sign says. What the sign says: Archaeopteryx comes from Late Jurassic limestone dated about 150 million years ago, and Sinosauropteryx, Caudipteryx and Microraptor come from Early Cretaceous beds in Liaoning dated about 125 million years ago; birds are said to have descended from small theropods over tens of millions of years, with filaments slowly developing into vaned feathers.

What we observe. What we observe: finely preserved skeletons in volcanic-ash-rich lake sediments; true vaned feathers, some asymmetric, on Archaeopteryx, Caudipteryx and

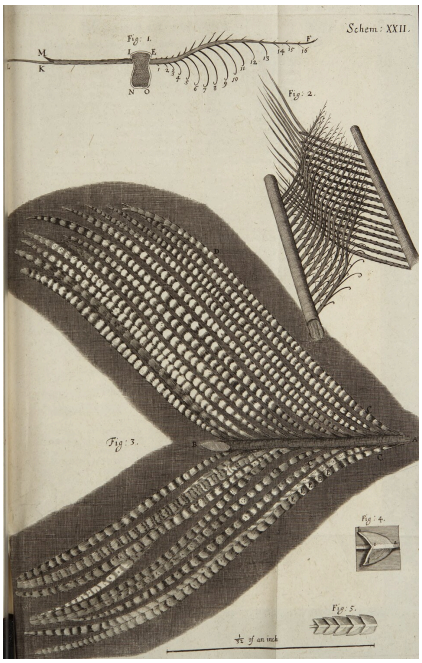
Microraptor; dark filaments without rachis or barbs on Sinosauropteryx and Yutyrannus; melanosome-like bodies in some filaments; and Archaeopteryx lying in layers below most of the feathered theropods.

How Christians read it. How Christians read it: birds were made on the fifth day and land animals on the sixth, each after its kind, so a creature with true feathers is read as a bird, flying or flightless, and filaments on dinosaurs as skin structures or as an open question. The fine preservation of whole animals with soft parts points to rapid burial under ash and sediment, which fits the Flood year. The dates on the sign rest on decay measurements and assumptions studied in Unit 7.

Try it. Measure the leading and trailing vane widths of a real feather at its midpoint and decide whether it was a flight feather.

Genesis 1:20

PICTURE STUDY



Of Peacocks, Ducks and Other Feathers of Changeable Colours (Observation 36, Micrographia), Robert Hooke, 1665 · Copperplate engraving · Micrographia, published by the Royal Society, London

Robert Hooke was the Royal Society's curator of experiments and one of the first people to draw what a microscope showed. His 1665 book Micrographia contained engravings of a flea, a fly's eye, cork cells (he coined the word "cell") and this plate of feathers, where he traced how the tiny branches of a feather lock together and how the shimmering colors of a peacock's feather change with the angle of light.

Hooke worked more than three centuries before anyone argued about feathered dinosaurs, but his method is exactly what the argument needs: look closely, draw exactly what you see,

and name each part. He saw that the feather's strength comes from its interlocking parts and wondered at the maker's skill.

Look closely

- Find the central shaft and the branches coming off it. Which lesson terms do they match?
- Look at the finest structures Hooke drew. Can you see how neighboring branches hook to one another?
- Hooke drew by candlelight through a single-lens instrument. What details could he see, and what would need a modern microscope?
- Compare this engraving with the lesson's diagram. What did Hooke get right?

Talk about it

1. Why does careful drawing matter when scientists disagree about what a fossil shows?
2. What would Hooke need to see in the Sinosauropteryx filaments to call them feathers by his own standards?
3. How does the feather's zip-together design serve a bird in rain, cold and flight?

EXPERIMENT: MEASURING FEATHERS FOR FLIGHT

Paleontologists decide whether a fossil feather was a flight feather by measuring its vane asymmetry. You will measure real feathers the same way and test whether feathers from the wing differ from feathers from the body.

Question: are wing feathers more asymmetric than body feathers? Prediction: write yours. What we change: where the feather came from (wing or body). What we keep the same: the bird species if possible, the place on the feather where you measure (the midpoint). What we measure: the ratio of trailing-vane width to leading-vane width.

You will need

- At least six feathers: craft-store or farm feathers work well; include some long, stiff ones (wing or tail) and some soft, rounded ones (body)
- A ruler with millimeters, a hand lens, tape
- Graph paper, your lab notebook and a pencil

Steps

1. Tape each feather flat to graph paper and number it. Beside each, record whether you think it is a wing, tail or body feather, and why.
2. Measure the total length of each feather in millimeters from base to tip.
3. Find the midpoint of the rachis. At that point, measure the vane width on each side in millimeters: the narrower side (leading) and the wider side (trailing).
4. Compute the asymmetry ratio: trailing width ÷ leading width. A ratio near 1.0 means symmetric; flight feathers of living birds are often 2 or more.

5. Record all measurements in a table: Feather, Length, Leading width, Trailing width, Ratio, Type.
6. Make a bar graph of the ratios, grouping wing or tail feathers together and body feathers together.
7. With the hand lens, pull two barbs apart on one stiff feather and one soft feather and try to re-zip them. Record which re-zips and relate it to the barbule hooks.
8. Write a conclusion of three sentences: did stiff feathers have higher ratios, what was the largest ratio you measured, and what would you conclude about a fossil feather with a ratio of 1.0?

Tips

- Measure at the same point on every feather. A ratio measured near the tip is not comparable to one measured at the base.
- Down feathers have no real vane; record them as “no vane” rather than forcing a ratio.

Check your work

- I measured and recorded at least six feathers with asymmetry ratios.
- I can name the rachis, barbs, barbules, hooklets and vane on a real feather.
- I can explain what vane asymmetry tells a scientist about a fossil feather.

FIELD NOTEBOOK

1. Draw a flight feather at life size and a magnified inset of two barbs zipped by barbules. Label calamus, rachis, barb, barbule, hooklet and vane.
2. Draw Sinosauropteryx from a museum photograph, showing the fringe of filaments along the back and tail, and write beneath it the two readings in two columns: protofeathers; collagen fibers.
3. Make a layered column with Solnhofen (Archaeopteryx) below and Liaoning (Sinosauropteryx, Caudipteryx, Microraptor) above, with museum labels on one side and the observation “a true bird lies lower than the feathered theropods” on the other.

> **From history.** Alan Feduccia, who taught ornithology at the University of North Carolina for decades, is not a creationist; he holds that birds descended from some earlier reptile group, just not from the theropod dinosaurs. His long dispute with most paleontologists shows that the “birds are dinosaurs” label is still argued among evolutionary scientists themselves, and that a student who reports the arguments on both sides is doing what good scientists do.

WORKED EXAMPLES

Example 1. At its midpoint, a feather's leading vane is 6 mm wide and its trailing vane is 15 mm wide. A second feather measures 11 mm and 12 mm. Compute the asymmetry ratio of each and decide which was more likely a flight feather.

1. Feather 1: trailing ÷ leading = 15 ÷ 6 = 2.5.
2. Feather 2: 12 ÷ 11 = 1.09.
3. Flight feathers of living birds are strongly asymmetric, often with ratios of 2 or more. Feather 1 fits; feather 2 is nearly symmetric, like a tail or body feather of a non-flyer.

Answer: Feather 1 (ratio 2.5) was likely a flight feather; feather 2 (ratio 1.09) was not.

Example 2. A pigeon flight feather is 100 mm long. Along the vaned part, about 80 mm, barbs are spaced about 0.4 mm apart on each side of the rachis. Each barb carries about 250 barbules. Estimate the number of barbs and the number of barbules on the feather.

1. Barbs per side = 80 mm ÷ 0.4 mm = 200. Both sides: 200 × 2 = 400 barbs.
2. Barbules = 400 barbs × 250 barbules per barb = 100,000 barbules.
3. Check the order of magnitude: a few hundred barbs and about a hundred thousand barbules on a feather weighing well under a gram. Real counts vary with the species, but this is the right scale.

Answer: About 400 barbs and roughly 100,000 barbules on one feather.

Example 3. A museum sign dates the Solnhofen limestone (Archaeopteryx) at about 150 million years and the Liaoning beds (Sinosauropteryx, Microraptor) at about 125 million years. (a) Taking the sign's numbers as given, how many million years separate them, and which is lower in the rock column? (b) Why does this order raise a question for the sign's story, and how is it answered?

1. (a) $150 - 125 = 25$ million years on the sign's scale. The Solnhofen limestone, with the true bird Archaeopteryx, is the lower (older-labeled) layer.
2. (b) The sign's story has filaments developing into feathers before birds appear, yet the fully feathered bird lies below most of the filament-bearing and feathered theropods. Mainstream scientists answer that ancestors in lower layers have not yet been found and point to Anchiornis in Jurassic-labeled layers.
3. Creation reading: the order in the layers records burial order in the Flood, not ancestry, so a bird below a dinosaur raises no difficulty.

Answer: (a) 25 million years on the museum scale; Solnhofen is lower. (b) A true bird lies below most feathered theropods; mainstream scientists appeal to undiscovered ancestors, while the creation reading sees burial order rather than descent.

PRACTICE

1. EASY Where and when was Sinosauropteryx found, who found it, and what did the fossil show along its back?
2. EASY Name the parts of a pennaceous feather from the base outward and explain what hooklets do.
3. EASY Which of these fossils has true vaned feathers? (a) Sinosauropteryx (b) Caudipteryx (c) Yutyrannus (d) Microraptor
4. MEDIUM A feather's leading vane is 5 mm and trailing vane 14 mm at the midpoint. What is its asymmetry ratio, and what does it suggest?
5. MEDIUM A feather's vaned portion is 60 mm long with barbs every 0.5 mm on each side. How many barbs does it have?
6. MEDIUM Data reading. A table gives midpoint vane widths (leading, trailing) in millimeters for four fossil feathers: A (4, 12), B (9, 10), C (6, 13), D (8, 8). Compute each ratio, rank them, and state which feathers were likely flight feathers.
7. MEDIUM Data reading. A chart lists what each fossil shows: Archaeopteryx, asymmetric vaned feathers, teeth, bony tail; Caudipteryx, symmetric vaned feathers, short tail; Sinosauropteryx, filaments only; Microraptor, asymmetric vaned feathers on arms and legs. Which animals could the data alone show were fliers, which were feathered but flightless, and which remain debated as to whether they had feathers at all?
8. HARD Experiment design. Design a test of whether a zipped feather sheds water better than one whose barbs have been pulled apart. State what you change, keep the same, measure and how you would make the result fair.

9. HARD In three or four sentences, state the mainstream claim about birds and dinosaurs, list two observations both sides accept, and give the creation reading.
10. CHALLENGE Write a paragraph on the Sinosauropteryx filament debate that presents the protofeather reading and the collagen reading fairly, names one observation that would settle it, and explains why honest disagreement among experts is part of science.

COMMON MISTAKES

- Thinking every “feathered dinosaur” on a sign had feathers like a bird’s. Some show true vaned feathers; others show only filaments, whose nature is debated.
- Thinking a symmetric vaned feather proves flight. Flight feathers are asymmetric; symmetric vanes mark feathers used for display or warmth, or a flightless animal.
- Thinking a wishbone or hollow bones can only mean descent. Shared features are observations; whether they come from common ancestry or common design is an interpretation.

Make it a game · Feather, Filament or Fur. A parent describes a structure from a fossil or a living animal in one sentence, such as “a stiff shaft with branches that hook together into a flat blade” or “a soft hair with no branches at all” or “a shaft with loose branches and no hooks.” You have five seconds to call “flight feather,” “down feather,” “filament” or “fur,” and a bonus point if you can say whether it would be asymmetric. One point per correct call. After twelve rounds, swap roles. Play to fifteen.

Scripture. “And God said, Let the waters bring forth abundantly the moving creature that hath life, and fowl that may fly above the earth in the open firmament of heaven.” (Genesis 1:20, KJV)

Birds appear on the fifth day of creation, before the beasts of the earth on the sixth. The creation reading of feathered fossils begins here: flying creatures were made as flying creatures, complete with the feathers that carry them.

Practice answers

1. Near Sihetun in Liaoning Province, China, in 1996, by the farmer Li Yumin. A fringe of dark, hair-like filaments ran along the spine and tail.
2. Calamus (hollow base), rachis (shaft), barbs (branches), barbules (side branches of barbs). Hooklets on the barbules catch neighboring barbules and zip the barbs into a flat vane.
3. (b) Caudipteryx and (d) Microraptor. Sinosauropteryx and Yutyrannus show only filaments.
4. 14 ÷ 5 = 2.8. Strongly asymmetric, which suggests a flight feather.
5. 60 ÷ 0.5 = 120 per side; 120 × 2 = 240 barbs.
6. A: 12 ÷ 4 = 3.0; C: 13 ÷ 6 = 2.17; B: 10 ÷ 9 = 1.11; D: 8 ÷ 8 = 1.0. Ranked A, C, B, D. A and C were likely flight feathers; B and D were symmetric and not used for flight.
7. Fliers (asymmetric flight feathers): Archaeopteryx and Microraptor. Feathered but flightless (symmetric vanes): Caudipteryx. Debated: Sinosauropteryx, whose filaments lack rachis and barbs and are read as protofeathers by some and collagen by others.

8. Change: the feather’s condition (barbs zipped versus pulled apart). Keep the same: the same feather or matched feathers, the same volume of water dropped from the same height, the same angle of the feather. Measure: mass of water remaining on the feather (weigh before and after) or number of drops that roll off out of ten. Repeat each condition at least three times and use several feathers so one feather’s quirks do not decide the result.
9. Museum signs say birds are living theropod dinosaurs that descended from small feathered theropods. Both sides accept that Archaeopteryx and Microraptor have asymmetric flight feathers, that theropods have wishbones and hollow bones, and that Sinosauropteryx shows filaments without rachis or barbs. The creation reading holds that birds were made on day five and land animals on day six, each after its kind, so true-feathered fossils are birds, flying or flightless, shared features are common design, and filaments are skin structures or an open question.
10. Most paleontologists read the dark filaments on Sinosauropteryx as simple first-stage feathers, and the report of melanosome-like bodies in 2010 is their strongest support. Feduccia, Lingham-Soliar and colleagues argued in 2007 that the filaments are frayed collagen fibers from skin, pointing to similar patterns on decayed modern animals and to the lack of any rachis or barbs. A filament clearly showing a hollow base and branching barbs, or a chemical test proving feather keratin rather than collagen, would settle the matter. Science advances by exactly this kind of argument over the same slab, and a student should report both readings and the observation each rests on rather than the label alone.

Unit 6 review

Answer each question. Show your work for calculations and use complete sentences for explanations. Where a question asks for both readings, state the museum claim fairly before giving the creation reading. The test is worth 60 points.

1. (4 pts) Multiple choice. Who named the Dinosauria, and in what year was the name published? (a) Gideon Mantell, 1825 (b) Richard Owen, 1842 (c) Harry Seeley, 1887 (d) Othniel Marsh, 1879
2. (5 pts) Diagram. Draw two side-view dinosaur hips. On one, show and label the saurischian pubis; on the other, the ornithischian pubis. Label the ilium, ischium and the open hip socket on each, and write one dinosaur group under each hip.
3. (5 pts) Diplodocus was about 26 m long. (a) How long is it at a scale of 1 : 200? (b) A student draws Tyrannosaurus (12 m) 30 cm long. What scale did she use?
4. (5 pts) Explain in two or three sentences the difference between a species and a kind, and why the number of dinosaur kinds matters for the Ark.
5. (5 pts) Tell what was found at the Flaming Cliffs in 1923, why Oviraptor was named “egg seizer,” and what evidence in the 1990s changed the story.
6. (5 pts) A chicken egg is 6 cm long and a fossil egg of the same shape is 18 cm long. How many times more volume does the fossil egg hold? Show your work.
7. (5 pts) Data reading. Four eggshell types have pore densities of 150, 140, 60 and 55 pores per cm². Living crocodiles (buried nests) are near 150 and living open-nesting birds near 60. Which fossil types were likely buried, and what reasoning connects pores to burial?
8. (5 pts) Multiple choice. The Klagenfurt Lindwurm statue of 1590 has a face modeled on: (a) a crocodile skull (b) a woolly rhinoceros skull found in 1335 (c) a Protoceratops skull (d) a Komodo dragon. Then explain in one sentence what this case teaches about legends.
9. (5 pts) A Komodo dragon is 3 m long and about 70 kg. A legend describes a lizard of the same shape 6 m long. Estimate its mass and explain the rule you used.
10. (5 pts) In three or four sentences, state how mainstream historians and creation researchers each account for dragon legends, and name one case on which they agree.
11. (5 pts) Data reading. Midpoint vane widths (leading, trailing) in mm for three fossil feathers: P (5, 14), Q (9, 9), R (7, 15). Compute each asymmetry ratio and tell which were likely flight feathers.
12. (6 pts) Write a paragraph on Sinosauropteryx: where and when it was found, what the fossil shows, the two readings of its filaments, what museum signs claim about birds and dinosaurs, and the creation reading.

Unit project: a field guide to the dinosaur kinds

Make a hand-drawn field guide, at least twelve pages, for a younger reader visiting a museum. Include: a page on how Owen defined dinosaurs with your two-hip diagram; a scale chart of the seven major groups along one baseline; your dichotomous key with test results;

an egg page with your egg-length bar graph, your pore experiment graph and the Oviraptor timeline; a legend page with your scorecard and the Klagenfurt case; and a feather page with a labeled flight feather, your asymmetry table and the two readings of Sinosauropteryx.

Every page that uses a period name or a museum date must carry a short Thinking About Time box in three lines: what the sign says, what we observe, how Christians read it. Finish with a one-paragraph introduction telling your reader how to read a dinosaur sign accurately and kindly.

- **Accuracy**: Hip types, groups, egg facts, legend cases and feather parts are correct and match the lessons; dates and names are right.
- **Measurement and data**: Scale chart, egg graph, pore graph and asymmetry table are complete, labeled with metric units and computed correctly.
- **Two readings**: Each Thinking About Time box states the museum claim fairly, names what is observed, and gives the creation reading without mocking either side.
- **Care and clarity**: Drawings are neat and labeled, pages are in order, and a younger reader could use the guide at a museum.

Answer key

1. (b) Richard Owen, 1842.
2. Saurischian: pubis points forward and down (theropods or sauropods). Ornithischian: pubis swung backward along the ischium (ornithopods, ceratopsians, stegosaurs, ankylosaurs or pachycephalosaurs). Both show the ilium above, the ischium pointing back, and a socket drawn as an open ring. Full credit for correct direction of the pubis, all labels, and groups.
3. (a) 2,600 cm ÷ 200 = 13 cm. (b) 1,200 cm ÷ 30 cm = 40, so 1 : 40.
4. A species is the smallest named group, judged for fossils from bones and often revised; a kind is the biblical group that breeds together and is usually broader, often a genus or family. If dinosaurs form only a few dozen kinds, Noah needed a few dozen pairs of mostly young, small animals rather than a thousand species, which fits easily in the Ark.
5. Elongated dinosaur eggs about 15 cm long, the first widely accepted dinosaur eggs, found by George Olsen on Roy Chapman Andrews' expedition. A toothless theropod skeleton lay over a nest thought to hold Protoceratops eggs, so Osborn named it Oviraptor as an egg thief. In 1993 an egg of that type was found with an oviraptorid embryo inside, and in 1995 a skeleton was described brooding over its own eggs.
6. Length ratio 18 ÷ 6 = 3; volume ratio 3 × 3 × 3 = 27 times.
7. The 150 and 140 types were likely buried; the 60 and 55 types likely sat in open nests. Many pores let water escape quickly, which an egg can afford only in damp, covered material; open-air eggs need fewer pores to keep from drying out.
8. (b). A real fossil bone can supply the shape of a legendary monster, so legends must be checked against bones and other evidence rather than taken as eyewitness reports.
9. Length ratio 2; mass scales with the cube, 2 × 2 × 2 = 8; 8 × 70 kg = 560 kg. For objects of the same shape, mass grows with the cube of length.
10. Mainstream historians hold that dinosaurs died out tens of millions of years before humans, so legends arise from fossils, living reptiles and imagination. Creation researchers hold that land animals of every kind survived the Flood on the Ark, so early post-Flood people may have met some dinosaur kinds, and some legends might preserve faint memories, though legends

alone are weak evidence. Both agree, for example, that the Klagenfurt skull is a rhinoceros, that the griffin matches Protoceratops skulls, and that the Komodo dragon is a real animal.

11. P: 14 ÷ 5 = 2.8; Q: 9 ÷ 9 = 1.0; R: 15 ÷ 7 = 2.14. P and R are strongly asymmetric and were likely flight feathers; Q is symmetric and was not used for flight.
12. Sinosauropteryx was found in 1996 near Sihetun in Liaoning, China, by farmer Li Yumin, and described by Ji Qiang. The meter-long theropod skeleton has a fringe of dark filaments along the back and tail with no rachis, barbs or vane. Most paleontologists read them as protofeathers, supported by melanosome-like bodies reported in 2010; Feduccia, Lingham-Soliar and colleagues read them as frayed collagen fibers from skin. Museum signs say birds are living theropod dinosaurs, citing wishbones, hollow bones, brooding and feathers. The creation reading holds that birds were made on the fifth day and land animals on the sixth, each after its kind, so fossils with true vaned feathers are birds, flying or flightless, shared features are common design, and filaments on dinosaurs are skin structures or an open question.

UNIT 7

Dating Methods

Every museum sign you have read in this course carries a number: 66 million years, 300 million, 4.5 billion. This unit opens the box those numbers come from. You will begin where the science began, with Henri Becquerel's fogged photographic plate in Paris in 1896, and learn how Rutherford and Soddy found the law of radioactive decay. You will roll dice and shake pennies to see a **half-life** appear on your own graph paper, then learn the halving arithmetic that turns a measured ratio of parent and daughter isotopes into a number of years.

Then you will look at what the arithmetic needs besides a measurement. Every radiometric date rests on **three assumptions**: known starting amounts, a constant rate and a closed system. You will build a drip clock and break each assumption on purpose to see what it does to the answer. In the last two lessons you will study two cases where the assumptions were tested against something known: coal and diamonds that still contain measurable carbon-14, reported by the RATE project in 2005, and dacite from the Mount St. Helens lava dome that hardened in 1986 and was dated in 1996 at hundreds of thousands to millions of years. In each case you will learn the mainstream explanation accurately and the creation reading beside it.

The course holds that God created the heaven and the earth (Genesis 1:1) and that the Flood of Genesis 6 through 9 is history. It also holds that a decay rate measured today is a fact to be respected. The skill of this unit is keeping those two things, measurement and history, clearly apart: saying exactly what an instrument read, exactly what was assumed, and exactly where Scripture gives a witness the rocks cannot.

BEFORE YOU BEGIN

- Can halve a number repeatedly and work with fractions such as 1/2, 1/4, 1/8 and 1/16, and with percents
- Can multiply and divide large numbers with a calculator and read numbers in millions and billions
- Can read a data table, a bar graph and a line graph and compute an average
- Can state the difference between an observation and an interpretation (Units 2 and 3)

MASTERY CHECKLIST

- I can explain radioactive decay, parent and daughter isotopes and half-life, and read a half-life from a decay graph.
- I can find how much of an isotope remains after a given number of half-lives, and work backward from a fraction remaining to a number of half-lives and years.
- I can state the three assumptions behind every radiometric date and show with numbers how an unknown starting amount or a leak changes the answer.

- I can describe the carbon-14 cycle, convert a percent-modern-carbon reading to a conventional age, and explain the difference between zero and below the detection limit.
- I can explain potassium-argon dating, excess argon and discordant dates, and decide whether two dates agree within their error ranges.
- I can state the mainstream and the creation readings of the RATE carbon-14 results and the Mount St. Helens dates fairly, and say which assumption each case tests.

OPTIONAL BOOKS AND RESOURCES

- **USGS: Mount St. Helens (Cascades Volcano Observatory)** (https://www.usgs.gov/volcanoes/mount-st.-helens): Free. The official record of the 1980 eruption and the growth of the 1980 to 1986 and 2004 to 2008 domes, with photographs, maps and dates. Use it to check the facts of Lesson 7.4 and to see the dome whose dacite was dated.
- **USGS: Geologic Time, Radiometric Time Scale** (https://pubs.usgs.gov/gip/geotime/radiometric.html): Free. A short USGS page stating the mainstream account of radiometric dating in plain language. Read it as the "What the sign says" side, and practice finding the three assumptions in its sentences.
- **Marie Curie, *Radio-active Substances* (free at Project Gutenberg)** (https://www.gutenberg.org/ebooks/search/?query=Curie+radio-active+substances): Free. Curie's 1903 doctoral thesis in English, describing how she measured radioactivity and found radium. A parent may choose the opening pages to read aloud; the rest is for strong readers.

7.1 Radioactive Decay and Half-Life: A Lab with Dice ★

OBJECTIVES

- Describe radioactive decay as a parent isotope changing into a daughter isotope at a rate measured by its half-life, and tell how Henri Becquerel discovered it in 1896.
- Use halving steps to find how much of a sample remains after a given number of half-lives, and work backward from a fraction remaining to a number of half-lives.
- Run a decay lab with pennies and dice, graph the results, read the half-life from the graph and explain why the real curve is smooth while the lab curve wobbles.

Warm-up. Put 20 pennies in a cup, shake, and dump them on the table. Take away every penny showing heads. Count what is left and write it down. Put the survivors back in the cup and repeat until none are left. How many shakes did it take to get down to about 10? To zero? Now have a brother, sister or parent do the same thing. Did they get exactly the same numbers? Keep your list; you will need it later.

Video. Coming soon. Radioactive decay and half-life explained for middle school, Becquerel and the Curies, and a penny or dice decay simulation; look for SciShow, Crash Course, TED-Ed, Khan Academy, PBS Learning Media, NIST and university physics outreach channels.

KEY TERMS

isotope
A form of an element with a particular number of neutrons in its nucleus. Carbon-12 and carbon-14 are both carbon, but carbon-14 has two extra neutrons and is unstable.

radioactive decay
The change of an unstable nucleus into a different nucleus, giving off a particle or energy as it does so.

parent isotope
The unstable isotope that decays, such as uranium-238 or carbon-14.

daughter isotope
The isotope produced by the decay, such as lead-206 from uranium-238 or nitrogen-14 from carbon-14.

half-life
The time it takes for half of the parent atoms in a sample to decay. Each half-life cuts what is left in half again.

decay curve
A graph of the amount of parent remaining against time. It drops by half every half-life, steep at first and flatter later.

CORE IDEAS

The story. In the last week of February 1896, the sky over Paris stayed gray for days, and that spoiled an experiment. Henri Becquerel, a Paris physics professor, was testing whether minerals that glow after sitting in sunlight might also give off the new X-rays that Wilhelm Röntgen had announced a few weeks earlier. He wrapped a photographic plate in black paper so no light could reach it, laid a crystal of a uranium salt on top and set the package in the sun; when he developed the plate, there was a shadowy image of the crystal. The sun seemed to be the key. Then the clouds came. Becquerel put a wrapped plate, with its uranium crystals and a small copper cross resting on it, into a dark drawer to wait. On March 1 he developed it anyway, expecting almost nothing. Instead the image was strong, with the sharp shadow of the cross. The uranium had been giving off invisible rays by itself, in the dark, with no sun at all. He reported it to the Académie des Sciences on March 2, 1896. Two years later Marie Curie named the effect **radioactivity**, and she and her husband Pierre found two new radioactive elements, polonium and radium.

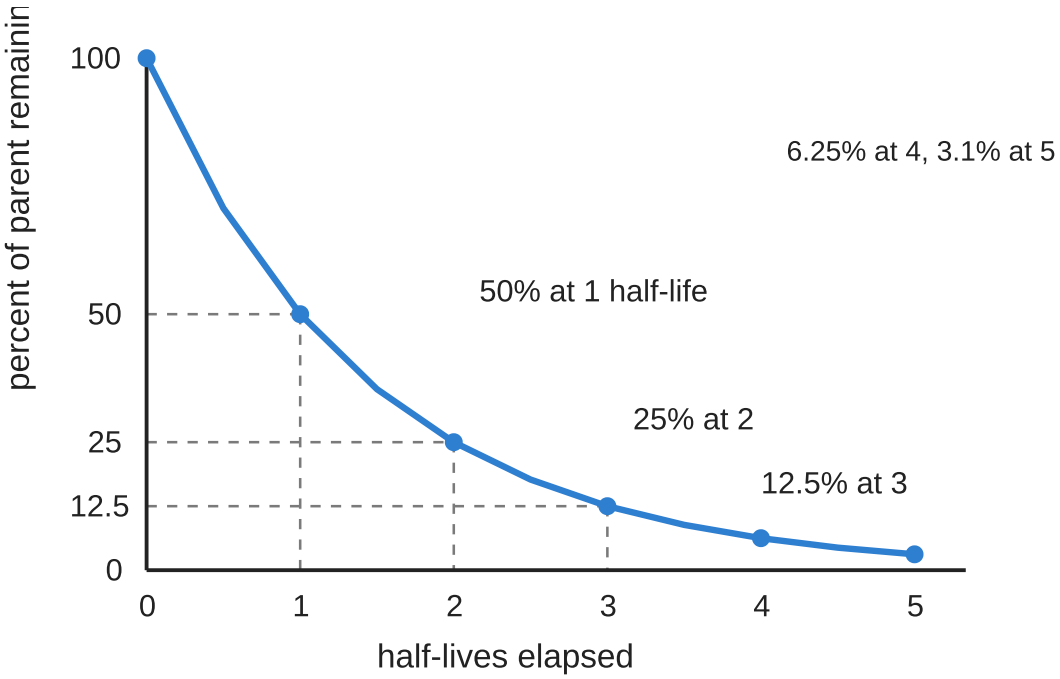
How they figured it out. Between 1902 and 1903, at McGill University in Montreal, Ernest Rutherford and the chemist Frederick Soddy worked out the answer: the atoms were changing. An unstable nucleus, the **parent**, throws off a particle and becomes the nucleus of a different element, the **daughter**. Uranium-238 ends up, after a chain of fourteen steps, as lead-206. Potassium-40 becomes argon-40 (a gas) or calcium-40. Carbon-14 becomes nitrogen-14. Rutherford and Soddy also found the rule for the speed of decay. You can never say when one particular atom will go, but in a large crowd a fixed fraction decays in any given stretch of time, so the time for half the atoms to decay is always the same for a given isotope, however big the sample. This time is the **half-life**. Textbooks list carbon-14 at 5,730 years, potassium-40 at 1.25 billion years and uranium-238 at 4.47 billion years. Long half-lives are not measured by waiting; a lab counts decays per second from a known number of atoms and calculates from the rate.

The big idea. Decay works by halving steps. Start with 100 grams of a parent isotope. After one half-life, 50 grams are left and 50 have become daughter. After two half-lives, 25 grams; after three, 12.5; after four, 6.25; after ten, about 0.1 gram. On a graph this makes a **decay curve** that falls steeply at first and then flattens, never quite reaching zero until the last atom goes. The arithmetic also runs backward. If you measure that one eighth of the parent remains and seven eighths has become daughter, that is three halving steps, so three half-lives have passed; multiply by the half-life and you have a number of years. This simple idea is the engine behind every radiometric date on every museum sign. The measuring is real and careful. But the backward step needs more than a measurement: it needs you to know how much parent and daughter were there at the start, that the rate never changed and that nothing leaked in or out. Those three assumptions are the subject of the next lesson.

Try it and see. You cannot watch uranium atoms, but you can watch dice. Let each die be an atom, and say a die has decayed when it lands showing a one. On every roll each die has a one-in-six chance of going, just as each atom has a fixed chance of decaying in a given year. Roll a cup of 60 dice, remove the ones, count the survivors and roll again. On average the number falls to five sixths of what it was each roll, so it takes a little under four rolls to reach

half: the half-life of a six-sided die is about 3.8 rolls. Pennies are the same game with a one-in-two chance, so a penny's half-life is exactly one shake. Your curve will wobble, because 60 dice are a small crowd and chance shows. A gram of uranium holds about 2,500 million trillion atoms, a crowd so vast that the wobble vanishes and the curve is perfectly smooth. That is why decay rates can be measured so precisely.

God's handiwork. Becquerel expected sunlight and found instead a steady, hidden order inside matter itself, a rule every atom obeyed. The Lord speaks of "the ordinances of heaven and earth" that He has appointed (Jeremiah 33:25), and the half-life is one of them. A Christian scientist can measure a decay rate with delight and confidence, because the world is a made thing, orderly all the way down. Measuring the rate today is observation, and this course takes it as settled. What the rate tells us about the distant past is a question of history, and history needs a witness. Genesis gives one. The rest of this unit is about keeping those two things, measurement and history, clearly apart.



The decay curve. Every half-life cuts the parent in half again, so the curve is steep at first and flattens later. Read it either way: from half-lives to percent, or from percent back to half-lives.

⏳ Thinking About Time

What the sign says. What the sign says: the textbook says the half-life of uranium-238 is 4.47 billion years, and that measuring uranium and lead in certain rocks and meteorites gives the earth an age of about 4.54 billion years.

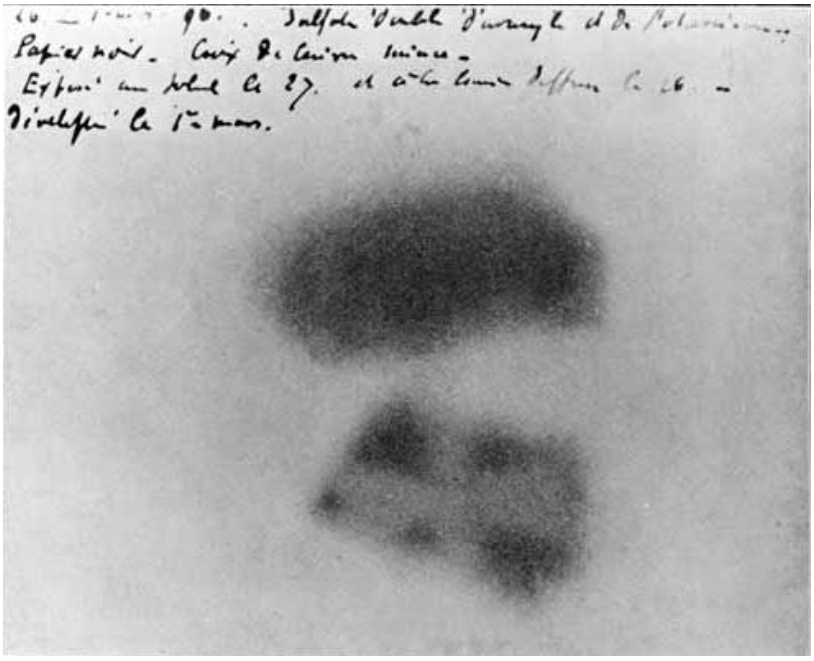
What we observe. What we observe: decay rates have been measured in laboratories since 1896 by counting decays per second from known masses, and the measured half-lives are steady from year to year. We also measure today's amounts of parent and daughter isotopes in a rock. No one has measured a rate over millions of years, and no one measured the starting amounts.

How Christians read it. How Christians read it: Christians who hold to a recent creation accept the measured rates and the measured ratios. They point out that turning a ratio into an age requires assumptions about the starting amounts and about rates in the unobserved past, and that Scripture gives an eyewitness account of beginnings that the rocks cannot give. Scientists who hold the long ages reply that the assumptions can be cross-checked between methods. Both sides agree on what the instruments read; they differ on the history behind the reading.

Try it. Write today's date on your decay-lab graph and the words "measured" next to the curve and "assumed" next to the starting point of 100 percent.

Psalm 90:4

PICTURE STUDY



Becquerel's Photographic Plate, Henri Becquerel (photograph of the original plate), Developed March 1, 1896 · Photographic plate, fogged by uranium salts · Original plate preserved in Paris; photograph widely reproduced

This is not a painting but a piece of evidence. It is the plate Becquerel took out of his drawer on March 1, 1896, the first picture ever made by radioactivity. The pale smudges are where the uranium salt crystals rested on the black paper that wrapped the plate. Rays from the crystals went straight through the paper and fogged the plate underneath, but a small copper cross laid between a crystal and the plate blocked them and left its shadow.

Becquerel wrote the details of the experiment on the plate itself, as a careful scientist labels every specimen. Look at it the way he did, asking what the picture proves and what it does not.

Look closely

- Find the two pale patches. What was lying on the plate at those spots?
- Find the shadow of the cross. Why does a shadow prove that something was traveling in straight lines from the crystal to the plate?
- The plate was in a drawer, in the dark, for several days. What does that rule out as the source of the rays?
- Read the handwriting if you can. Why does a scientist write the conditions of an experiment on the result itself?

Talk about it

1. Becquerel expected a faint image and got a strong one. What should a scientist do when a result is the opposite of what was expected?
2. This plate shows that uranium gives off rays. Does it show how fast uranium decays, or how old the uranium is? What more would you need to measure?
3. Name one thing in this picture that is an observation and one claim about it that would be an interpretation.

EXPERIMENT: THE DICE AND PENNY DECAY LAB

You will model radioactive decay twice, once with pennies (half-life of one shake) and once with dice (half-life of about 3.8 rolls), graph both decay curves and read the half-life from each graph.

Question: Does a crowd of “atoms” that each have a fixed chance of decaying produce a curve that halves in equal steps of time? Prediction: write how many shakes you think it will take for 100 pennies to fall to 50, 25 and 12, and how many rolls for 60 dice to fall to 30.

You will need

- 100 pennies (or other identical coins) and a large cup or jar with a lid
- As many dice as you can gather, ideally 30 to 60 (pool the family’s board games); if you have only 10, roll them six times per “roll” and treat the six rolls together as one
- Graph paper, pencil, ruler and a calculator
- A data table with columns: shake or roll number, number removed, number remaining

Steps

1. Pennies first. Count 100 pennies into the cup. Record 100 at shake 0.
2. Shake, dump, and remove every penny showing heads; those have “decayed.” Count the survivors and record them beside shake 1. Return only the survivors to the cup.
3. Repeat until no pennies remain. Record every shake, even the ones where nothing changes.
4. Now dice. Count your dice and record the number at roll 0. Roll them all. Remove every die showing a one. Count the survivors and record. Repeat until none remain, or for at least 15 rolls.

5. Graph each experiment on its own axes: shakes or rolls along the bottom, number remaining up the side. Plot the points and join them with a smooth curve.
6. Read the half-life from each graph: find the point where the curve crosses half of the starting number, and read across to the number of shakes or rolls. Then find where it crosses one quarter, and check that the second halving took about the same number of steps as the first.
7. Compare your measured half-lives with the expected values: 1 shake for pennies and about 3.8 rolls for dice. Write two sentences on why your numbers are close but not exact, and what would happen with a million pennies.

Tips

- Keep the removed pennies in a separate pile; count the pile at the end to make sure removed plus remaining always equals 100.
- Draw the expected curve (100, 50, 25, 12.5, 6.25) in a second color on the penny graph so you can see your wobble around it.
- If two people run the dice lab, plot both sets of points on one graph. Chance makes the lines differ, but both should halve near every 3.8 rolls.

Check your work

- My tables record every shake and roll, including the number removed and the number remaining.
- My graphs have labeled axes with units and a smooth curve through the points.
- I read a half-life from each graph and compared it with the expected value.
- I explained in writing why a huge number of atoms gives a smoother curve than 100 pennies.

FIELD NOTEBOOK

1. Draw Becquerel’s plate from memory: the two smudges and the shadow of the cross. Beneath it write the date, March 1, 1896, and one sentence on what it proved.
2. Make a halving ladder: a column of boxes labeled 0 to 10 half-lives, with the percent remaining in each (100, 50, 25, 12.5, 6.25, 3.125, 1.5625, 0.78, 0.39, 0.195, 0.098).
3. Copy the three isotopes from the lesson in a table: parent, daughter, half-life as listed in textbooks, and what kind of thing each is used to date (carbon-14 for once-living things; potassium-40 and uranium-238 for igneous rock).

> **From history.** Becquerel, Pierre Curie and Marie Curie shared the 1903 Nobel Prize in Physics for the discovery of radioactivity, and Marie Curie won a second Nobel Prize, in Chemistry, in 1911 for isolating radium and polonium. Ernest Rutherford, who worked out the decay law in Montreal, received the 1908 Nobel Prize in Chemistry, which amused him, since he thought of himself as a physicist. Marie Curie’s doctoral thesis of 1903, published in English as Radio-active Substances, is still readable today and describes how she measured the faint electric currents that radioactive samples produce in air.

WORKED EXAMPLES

Example 1. A sample contains 80 grams of carbon-14. Textbooks give its half-life as 5,730 years. How much carbon-14 would remain after three half-lives, and how many years is that?

1. Halve once: 80 ÷ 2 = 40 g after one half-life.
2. Halve again: 40 ÷ 2 = 20 g after two half-lives.
3. Halve again: 20 ÷ 2 = 10 g after three half-lives.
4. Time: 3 × 5,730 years = 17,190 years.

Answer: 10 grams of carbon-14 remain after three half-lives, which is 17,190 years at the listed rate.

Example 2. You roll 60 dice and remove every die showing a one. On average, what number remains after each of the first four rolls, and between which two rolls does the count pass 30 (half the start)?

1. Each roll keeps five sixths of the dice on average, so multiply by 5/6 each time.
2. Roll 1: 60 × 5/6 = 50.
3. Roll 2: 50 × 5/6 = 41.7.
4. Roll 3: 41.7 × 5/6 = 34.7.
5. Roll 4: 34.7 × 5/6 = 28.9.
6. The count drops below 30 between roll 3 and roll 4, so the half-life is between 3 and 4 rolls, close to 4. (The exact value is about 3.8 rolls.)

Answer: About 50, 42, 35 and 29 dice. The half-life of a die that decays on a one is a little under four rolls, about 3.8.

Example 3. Use the decay curve to answer: (a) What percent of the parent remains after 2.5 half-lives? (b) A rock is measured to have 6.25 percent of its parent isotope left, assuming it started with 100 percent. How many half-lives is that, and if the isotope is potassium-40 with a listed half-life of 1.25 billion years, what age would the textbook method give?

(Use the map or drawing "Read 2.5 half-lives up to the curve and across to about 18 percent." shown earlier in this lesson.)

1. (a) Read up from 2.5 on the horizontal axis to the curve, then across: about 18 percent. (Check by arithmetic: 25 percent at 2 half-lives, 12.5 at 3, and the curve is between, nearer 18.)
2. (b) Count halvings: 100 → 50 → 25 → 12.5 → 6.25. That is four halvings, so four half-lives.
3. Age by the method: 4 × 1.25 billion years = 5 billion years.
4. Name the assumption: the answer is only right if the rock began with 100 percent parent and no daughter, if the rate never changed and if nothing was gained or lost.

Answer: (a) About 18 percent. (b) Four half-lives, which the method would report as 5 billion years, resting on the three assumptions named in the last step.

PRACTICE

1. EASY What did Henri Becquerel discover on March 1, 1896, and what had he expected?
2. EASY Define half-life in one sentence.
3. EASY Name the parent and daughter in each pair: carbon-14 and nitrogen-14; uranium-238 and lead-206.
4. MEDIUM A sample starts with 400 grams of a parent isotope. How much remains after 1, 2, 3 and 4 half-lives?
5. MEDIUM A sample has one sixteenth of its parent isotope left (assuming it began with all parent). How many half-lives have passed? If the half-life is 5,730 years, how many years is that?
6. MEDIUM Data reading. A student shook 100 pennies and recorded the survivors: shake 0: 100; shake 1: 53; shake 2: 24; shake 3: 13; shake 4: 5; shake 5: 3; shake 6: 1. (a) Between which shakes did the count first fall below 50? (b) Between which shakes did it first fall below 25? (c) Which statement do the data best support? (A) The half-life of a penny is about 3 shakes. (B) The count halves about every shake, with some wobble. (C) The count falls by the same number each shake. (D) Pennies decay faster when fewer are left.
7. MEDIUM Data reading. A table lists half-lives as given in textbooks: carbon-14, 5,730 years; potassium-40, 1.25 billion years; uranium-235, 704 million years; uranium-238, 4.47 billion years. (a) Which isotope loses half its atoms soonest? (b) How many half-lives of carbon-14 fit into one half-life of uranium-235? (c) Which isotope would be useless for dating a piece of wood from a shipwreck 300 years old, and why?

8. HARD A gram of uranium has about 2,500 million trillion atoms, while your lab had 60 dice. Explain why the uranium decay curve is smooth and the dice curve is bumpy.
9. HARD Experiment design. You want to test whether the decay rule changes the half-life. Plan an experiment using dice where a die “decays” on a one in Trial A and on a one or a two in Trial B. State the independent variable, the dependent variable, three things you keep the same, and what result you predict.
10. CHALLENGE Write a short paragraph explaining to a younger student the difference between measuring a half-life today and using it to find the age of a rock. Include the words measurement and assumption.

COMMON MISTAKES

- Thinking that after two half-lives all of the parent is gone. Two half-lives leave one quarter, not zero; each half-life halves what is left, so the parent never quite reaches zero until the last atom.
- Thinking a half-life is measured by waiting for half of a sample to decay. For long-lived isotopes it is calculated from the number of decays per second in a known mass.
- Confusing the measured half-life with the age of a rock. The half-life is a property of the isotope, measured today. The age is a calculation that adds assumptions about the past.

Make it a game · Half-Life Hop. Lay out ten sheets of paper in a line and write a half-life number on each, 0 through 9. A parent calls out a starting amount, such as 800 grams, and an isotope’s half-life, such as 5,730 years. Hop from sheet to sheet, calling out the amount remaining at each hop (800, 400, 200 and so on). When the parent shouts “Stop,” say the number of years that have passed at your sheet. Score a point for each correct amount and a bonus for the right number of years. Then reverse: the parent names a fraction left, such as one eighth, and you hop to the right sheet.

Scripture. “For a thousand years in thy sight are but as yesterday when it is past, and as a watch in the night.” (Psalm 90:4, KJV)

Moses, who wrote this psalm, reminds us that God stands outside time and sees all of it at once. We measure time in half-lives and shakes of a cup; He appointed the rates and knows the whole history, including the parts no instrument can reach.

Practice answers

1. He found that uranium salts fogged a wrapped photographic plate in a dark drawer, with no sunlight. He had expected the rays to depend on sunlight and expected only a faint image.
2. The half-life is the time it takes for half of the parent atoms in a sample to decay.
3. Carbon-14 is the parent, nitrogen-14 the daughter. Uranium-238 is the parent, lead-206 the daughter.
4. 200 g, 100 g, 50 g, 25 g.
5. 1 → 1/2 → 1/4 → 1/8 → 1/16 is four halvings, so four half-lives. 4 × 5,730 = 22,920 years.
6. (a) Between shake 0 and shake 1 (100 to 53). (b) Between shake 1 and shake 2 (53 to 24). (c) (B).

7. (a) Carbon-14. (b) 704,000,000 ÷ 5,730 ≈ 122,862, about 123,000 half-lives. (c) Uranium-238 (or any of the long-lived ones): in 300 years almost none of it would decay, so there would be nothing to measure; also wood does not contain uranium in a usable way. Carbon-14 is the isotope used for once-living things.
8. Each die or atom decays by chance. With only 60 dice, a run of luck (more or fewer ones than expected) changes the count noticeably, so the curve wobbles. With trillions upon trillions of atoms, the lucky and unlucky runs average out, and the fraction that decays each half-life is almost exactly one half, so the curve is smooth.
9. Independent variable: the decay rule (one face out of six versus two faces out of six). Dependent variable: the half-life in rolls, read from the graph. Keep the same: the number of dice at the start, the same dice and cup, the same way of rolling and counting, and the same person recording. Prediction: Trial B decays faster, with a half-life of about 1.7 rolls instead of about 3.8, because each die has twice the chance of going on every roll.
10. Example: Scientists measure a half-life by counting how many atoms decay each second in a known amount of an isotope; that is a measurement anyone can repeat today. To turn a rock’s parent and daughter amounts into an age, they must also assume how much of each was there at the start, that the rate never changed and that nothing leaked in or out. The half-life is measured; the age rests on assumptions about a past no one watched. Keeping the two apart is honest science.

7.2 The Three Assumptions

OBJECTIVES

- State the three assumptions behind every radiometric date: known starting amounts, a constant decay rate and a closed system, and explain each with the hourglass picture.
- Tell how Rutherford, Boltwood, Holmes and Patterson built the radiometric time scale between 1904 and 1956, and what mainstream geologists do to test the assumptions.
- Calculate how an unknown starting amount or a leak changes a calculated age, and separate what is measured from what is assumed in a published date.

Warm-up. Find a timer that runs by sand or water if you have one, or draw an hourglass. Imagine you walk into a room and see an hourglass with sand in the bottom. Write down every question you would need answered before you could say how long ago it was turned over. Keep the list; the lesson will give you three big ones.

Video. Coming soon. How radiometric dating works, the assumptions of radiometric dating, Arthur Holmes and the age of the earth, Clair Patterson and the meteorite lead measurements; look for USGS, Smithsonian, PBS, Crash Course, Khan Academy and university geology outreach channels.

KEY TERMS

radiometric dating
Calculating an age from the measured amounts of a parent isotope and its daughter in a rock, using the half-life.

initial conditions
The amounts of parent and daughter present when the rock formed. These must be assumed or argued for, since no one measured them.

constant rate
The assumption that the half-life has been the same throughout the rock’s history as it is in the lab today.

closed system
The assumption that no parent or daughter atoms entered or left the rock after it formed.

uniformitarianism
The principle that the processes and rates we see today are the key to the past. It is a useful working rule and also a philosophical assumption.

zircon
A hard, durable mineral that takes in uranium when it crystallizes but very little lead, which is why geologists prefer it for uranium-lead dating.

CORE IDEAS

The story. In the spring of 1904 Ernest Rutherford stood up to lecture on radium at the Royal Institution in London, and in the audience sat the most famous physicist alive, William Thomson, Lord Kelvin, then 79 years old. Kelvin had argued for forty years, from the physics of a cooling globe, that the earth could be only a few tens of millions of years old. Rutherford saw him in the front rows and worried, because radium gave off heat, and heat from radioactivity could keep the earth warm far longer than Kelvin's cooling clock allowed. So Rutherford said that Kelvin had limited the age of the earth only on the condition that no new source of heat was found, and that this wise condition pointed to the very thing under discussion that night, radium. The old man, he recalled, beamed at him. The new physics soon did more than loosen Kelvin's limit. In 1907 Bertram Boltwood at Yale used the ratio of lead to uranium in minerals to compute ages of hundreds of millions to two billion years. In 1911 Arthur Holmes, a London student in his early twenties, published the first careful uranium-lead date for a rock layer, about 370 million years. And in 1956 Clair Patterson, using lead isotopes in the Canyon Diablo meteorite, announced about 4.55 billion years for the earth, the number still printed in textbooks.

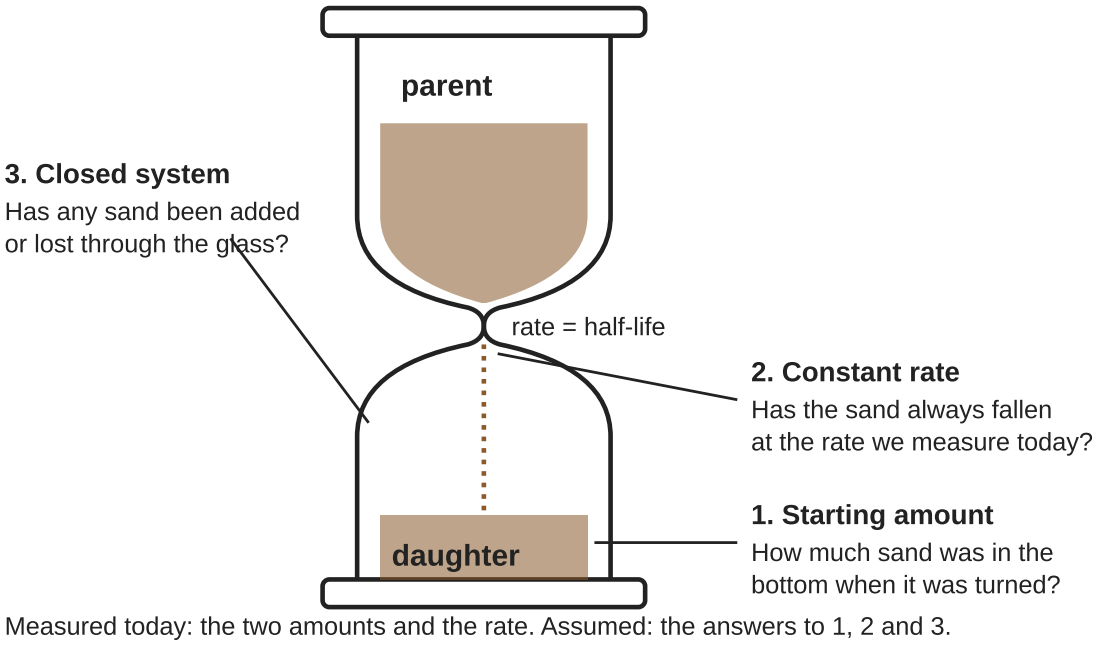
How they figured it out. Every one of those dates used the arithmetic you learned in Lesson 7.1, run backward: measure the parent, measure the daughter, count the halving steps, multiply by the half-life. Picture it as an **hourglass**. The sand in the top is the parent; the sand in the bottom is the daughter; the neck lets sand through at a fixed rate. To tell how long ago the glass was turned over, you measure the sand in the bottom and divide by the rate. But the moment you try it, three questions appear. **First, how much sand was in the bottom at the start?** If some daughter was already in the rock when it formed, the rock reads older than it is. **Second, has the sand always fallen at this rate?** The half-life is measured today; the assumption is that it never changed. **Third, has any sand been added or lost?** If daughter atoms leaked out, the rock reads too young; if parent leaked out or daughter leaked in, too old. These are the three assumptions: **known initial conditions, a constant rate, and a closed system.**

The big idea. Mainstream geologists do not ignore these assumptions; they work hard to get around them. For the first, they choose minerals like **zircon**, which accept uranium into their crystal structure but push lead out, so a fresh zircon should start with almost no daughter. They also use a method called an isochron that compares several minerals from the same rock to estimate the starting amount. For the third, they look for signs of weathering or heating that might have opened the system and reject such samples. For the second, they point to physics: decay rates have been tested under heat, pressure and strong fields and barely budge, and dates from different isotopes sometimes agree with each other. When two methods agree, they say, it would be a strange coincidence unless both were right. That is a real argument, and you should be able to state it as clearly as a geology professor would.

How Christians read it. Creation geologists answer that the cross-checks test the assumptions against each other, not against a witness: an isochron still assumes the minerals began alike and stayed closed, and two methods can share a common error. The second

assumption, a constant rate across all of time, is exactly the one Peter warned about when he described scoffers who say that “all things continue as they were from the beginning of the creation,” forgetting the creation itself and the Flood (2 Peter 3:4–6). A rate measured for 120 years is a fact. A rate extended over billions of unobserved years is a belief about history. Scripture gives a short history with a creation week and a world-covering Flood, events no laboratory can repeat. On this reading the rocks hold real parent and daughter atoms, measured correctly, but their starting amounts were set by the Creator. Some creation scientists have proposed that decay was much faster during creation week or the Flood year; that is a hypothesis under study, not a measurement, and this course says so.

In the world today. From now on, whenever you read a radiometric date, do three things. Write down what was measured: the parent and daughter amounts, and the half-life. Write down what was assumed: the starting amounts, the constant rate, the closed system. Then ask what the writer did to check each assumption. You will find that good scientific papers answer those questions in the open, and that museum signs almost never do. A sign that says “4.4 billion years, from zircon crystals” is reporting a measurement plus three assumptions in five words. You can now unpack it. That is not disrespect; it is reading carefully, which is the first duty of a student of nature.



The hourglass picture of radiometric dating. The amounts of sand and the rate at the neck are measured today; the three questions can only be answered by assumption or by a witness.

⏳ Thinking About Time

What the sign says. What the sign says: the textbook says the earth is about 4.54 billion years old, based on lead isotopes in meteorites measured by Clair Patterson in 1956, and that the oldest earth minerals, zircon crystals from the Jack Hills of Western Australia, are about 4.4 billion years old.

What we observe. What we observe: the present amounts of uranium and lead isotopes in meteorites and zircons, measured with great precision, and decay rates measured in laboratories over the last 120 years. The starting amounts of lead, and the rates during the unobserved past, are not measured.

How Christians read it. How Christians read it: Christians who hold to a recent creation accept the measurements and question the three assumptions, especially that the starting amounts and the rates are known across a history that includes creation and the Flood. Mainstream geologists answer that zircon starts nearly lead-free and that different methods often agree. A student should be able to state both answers and say exactly which parts are measured and which are assumed.

Try it. Pick any date from a museum or textbook and write it as a three-line note: measured, assumed, checked.

2 Peter 3:5

PICTURE STUDY



Still-Life with a Skull (Vanitas), Philippe de Champaigne, about 1671 · Oil on panel · Musée de Tessé, Le Mans, France

Philippe de Champaigne was a painter from Brussels who worked for the French court and later for the quiet, serious Christians of the Port-Royal community near Paris. This small panel is a vanitas, a kind of picture meant to remind the viewer that life is short: a tulip that will wilt, a skull, and an hourglass. The three objects stand in a row like three words of a sentence.

For this lesson, look hardest at the hourglass. The painter shows sand in the lower bulb and some still in the upper. It is a clock, but a clock with no face. You can only read it if you know how it was set.

Look closely

- Find the hourglass. Is more sand in the top or the bottom? What would you need to know to say how long ago it was turned?
- Look at the tulip. How does a flower keep time differently from an hourglass?
- The three objects are the same size and evenly spaced. Why might the painter have arranged them that way?
- Where does the light come from? What does it leave in shadow?

Talk about it

1. Suppose someone told you the hourglass was turned over exactly one hour ago. Which of the three assumptions would you be relying on to believe them, and which could you check by looking?
2. A vanitas painting is about time passing. How does Psalm 90 or 2 Peter 3 speak to the same subject?
3. Why might a Christian painter put a clock with no numbers beside a skull? What is he asking the viewer to think about?

> **Safety first.** The drip-clock project uses water. Work over a tray or sink, keep water away from electrical outlets and devices, and wipe up spills at once so no one slips.

EXPERIMENT: THE DRIP CLOCK: TESTING THE THREE ASSUMPTIONS

You will build a simple water clock and then try to read the time from it under three conditions: a fair start, a secretly pre-filled cup and a leak. You will see how each assumption changes the answer.

Question: Can a clock be read correctly if you do not know its starting amount, its rate and whether it was closed? Prediction: write how far off you expect each unfair trial to be, and whether the rate will stay constant as the bottle empties.

You will need

- An empty plastic water bottle with its cap, a pushpin, a marker and a ruler
- A clear measuring cup or a kitchen measuring jug marked in milliliters
- A stopwatch or phone timer, a tray, a towel and a spoon
- Notebook with a data table: trial, level, time, milliliters collected, calculated time, true time

Steps

1. Make the clock. Poke one small hole near the bottom of the bottle with the pushpin. Cover the hole with a finger, fill the bottle to a line you mark 15 cm above the hole, and set it on the tray with the measuring cup under the hole.
2. Measure the rate. Uncover the hole and collect water for exactly 1 minute. Record the milliliters. Refill to the line and repeat twice more. Average the three readings: this is your rate in mL per minute at the full line.
3. Test the rate assumption. Refill to the line and let the clock run, recording the milliliters collected during minute 1, minute 3 and minute 5 separately (empty the cup between readings). Does the rate stay the same as the level drops? Record and explain.
4. Fair trial. Refill to the line, cover the hole, and have a partner start the clock while you leave the room. When you return, cover the hole, measure the milliliters in the cup and divide by your minute-1 rate to calculate the elapsed time. Compare with the true time your partner recorded.
5. Unknown starting amount. Repeat, but this time your partner secretly pours 30 mL into the cup before starting the clock. Calculate the time from the total in the cup. How far off are you, and in which direction?
6. Open system. Repeat, but this time your partner secretly removes two spoonfuls from the cup during the run (or adds them). Calculate again. How far off are you now?
7. Write a conclusion that names the three assumptions, says which trial broke each one, and tells what a geologist would have to do to catch each problem in a rock.

Tips

- Keep the hole small; a pushpin hole gives a steady drip that is easy to measure. If the stream is too fast, tape over the hole and poke a smaller one.
- Write the calculated time and the true time side by side for each trial so the error is obvious.
- The rate test (step 3) is the most important part. A real hourglass runs at a steady rate; a water clock slows as the level drops. Which one is a radioactive isotope more like, and how do we know?

Check your work

- I measured the drip rate three times and averaged it.
- I recorded whether the rate changed as the level dropped and explained why.
- I have calculated and true times for the fair trial, the pre-filled trial and the leak trial.
- My conclusion matches each unfair trial to one of the three assumptions.

FIELD NOTEBOOK

1. Draw a large hourglass and label it like the lesson figure: parent, daughter, rate. Beside it write the three questions in your own words.
2. Make a timeline strip from 1896 to 1956 with five marks: Becquerel 1896, Rutherford at the Royal Institution 1904, Boltwood 1907, Holmes 1911, Patterson 1956. Write one line under each.

3. Copy a radiometric date from a textbook, museum website or news article, and write it as three lines: what was measured, what was assumed, what was checked.

> **From history.** Clair Patterson, who published the 4.55 billion year figure in 1956, had to build the cleanest laboratory in the world to make his lead measurements, because lead from gasoline, paint and dust was everywhere. That experience turned him into the scientist who proved how much lead pollution was in the air and oceans, and his work led to the removal of lead from gasoline in the United States, a phase-out that began in the 1970s and was completed in 1996. The same care that made his meteorite measurements so precise also protected the health of millions of children.

WORKED EXAMPLES

Example 1. An hourglass drops sand at 2 grams per minute. You find 60 grams in the bottom. (a) If the bottom was empty at the start, how long ago was it turned? (b) If 20 grams were already in the bottom when it was turned, how long ago was it really turned, and how far off was your first answer?

1. (a) Time = amount ÷ rate = 60 g ÷ 2 g/min = 30 minutes.
2. (b) Only the sand that fell since the turn counts: 60 g − 20 g = 40 g.
3. Time = 40 g ÷ 2 g/min = 20 minutes.
4. Error: 30 − 20 = 10 minutes too old, which is 50 percent more than the true time.

Answer: (a) 30 minutes. (b) 20 minutes; the first answer was 10 minutes (50 percent) too old because of the unknown starting amount.

Example 2. A rock is measured to contain 1 unit of parent isotope and 3 units of daughter. (a) Assuming no daughter at the start, how many half-lives have passed? (b) Suppose 1 of the 3 daughter units was already present when the rock formed. Now how many half-lives have passed? (c) With a half-life of 1.25 billion years, what two ages result?

(Use the map or drawing "Question 1 is the one that changes the answer here: how much was in the bottom a" shown earlier in this lesson.)

1. (a) If no daughter was present at first, the original parent was 1 + 3 = 4 units. The fraction remaining is 1/4, which is two halvings: 2 half-lives.
2. (b) Only 3 − 1 = 2 units of daughter came from decay. Original parent = 1 + 2 = 3 units. Fraction remaining = 1/3.
3. 1/3 is between 1/2 (1 half-life) and 1/4 (2 half-lives), closer to 1/4. Using a calculator, the number of half-lives is about 1.6.
4. (c) Ages: 2 × 1.25 = 2.5 billion years; 1.6 × 1.25 = 2.0 billion years.

Answer: (a) 2 half-lives. (b) About 1.6 half-lives. (c) 2.5 billion years versus 2.0 billion years. The same measurement gives ages half a billion years apart, depending on an assumption about the start that no one can measure directly.

Example 3. A rock truly formed 2 half-lives ago with no daughter at the start, so today it holds 1 unit of parent and 3 units of daughter. Groundwater then leaches out one third of the daughter (1 unit). What age will a lab now calculate, assuming a closed system?

1. After the leak: parent 1, daughter 3 − 1 = 2.
2. Assumed original parent: 1 + 2 = 3 units. Fraction remaining = 1/3.
3. 1/3 remaining is about 1.6 half-lives (between 1 and 2, closer to 2).
4. The true age is 2 half-lives, so the leak makes the rock read about 0.4 half-life too young.

Answer: About 1.6 half-lives instead of the true 2.0, so the rock reads about 20 percent too young. Losing daughter makes a rock look younger; losing parent would make it look older.

PRACTICE

1. EASY Name the three assumptions behind a radiometric date.
2. EASY In the hourglass picture, what stands for the parent isotope, the daughter isotope and the half-life?
3. EASY Why did Rutherford think radium mattered for Lord Kelvin's age of the earth?
4. MEDIUM An hourglass drops 5 grams of sand per minute, and you find 150 grams in the bottom. (a) How long since it was turned, if it started empty? (b) If it started with 50

grams in the bottom?

5. MEDIUM A rock holds 1 unit of parent and 7 units of daughter. Assuming no daughter at the start, how many half-lives have passed? If the half-life is 704 million years (uranium-235, as listed), what age results?
6. MEDIUM Data reading. A student measured a drip clock's rate at different water levels: 15 cm above the hole, 40 mL/min; 10 cm, 33 mL/min; 5 cm, 23 mL/min; 2 cm, 15 mL/min. (a) By how much did the rate drop from the 15 cm level to the 2 cm level? (b) If the student assumed 40 mL/min for the whole run and collected 200 mL, what time would be calculated? (c) Which conclusion do the data support? (A) The rate is constant. (B) The rate falls as the level drops, so a time calculated from one rate will be wrong. (C) The rate rises as the level drops. (D) The data do not show any pattern.
7. MEDIUM Data reading. A geologist dates four minerals from one granite sample and gets: zircon 1,020 million years; biotite mica 760 million; feldspar 810 million; whole rock 950 million. (a) What is the range between the highest and lowest result? (b) Which mineral does the lesson say is preferred for uranium-lead dating, and why? (c) The geologist says the mica and feldspar lost daughter atoms during a later heating. Which assumption is that explanation about?
8. HARD A geologist says, "Two different isotope methods gave the same age for this rock, so the assumptions must be right." Give one reason this is a strong argument and one reason it is not a proof.
9. HARD Experiment design. Design a test of the claim "the decay rate of an isotope does not change with temperature." State what you would change, what you would measure, what you would keep the same and how many trials you would run.
10. CHALLENGE Write a paragraph for a museum visitor explaining what a sign that reads "4.4 billion years, from zircon crystals" is actually saying. Name what was measured, the three assumptions, one check mainstream geologists make, and the creation reading, respectfully.

COMMON MISTAKES

- Thinking a radiometric date is read directly off an instrument like a thermometer. The instrument measures amounts of isotopes; the age is calculated from those amounts plus three assumptions.
- Thinking mainstream geologists have never thought about the assumptions. They have, and they test them in several ways; the question is whether those tests can reach a past no one observed.
- Thinking that if daughter atoms leak out a rock reads older. Losing daughter makes it read younger; losing parent or gaining daughter makes it read older.

Make it a game · Hourglass Detective. One player secretly sets up an hourglass case on paper: a rate in grams per minute, a starting amount in the bottom (which may be zero), and whether any sand was added or removed during the run. The player tells the detective only the rate and the final amount in the bottom. The detective calculates the time, then asks up to three yes-or-no questions (such as "Did it start empty?" or "Was any

sand removed?") and revises the answer. Score three points for the right time with no questions, two with one question, one with two questions. Switch roles after each case.

Scripture. "And saying, Where is the promise of his coming? for since the fathers fell asleep, all things continue as they were from the beginning of the creation." (2 Peter 3:4, KJV)

Peter describes people who assume that the present is the only key to the past. In the next two verses he reminds them of two events that broke the pattern: the creation of the heavens and the earth by the word of God, and the Flood that overflowed the world that then was. A Christian measures today's rates carefully and still remembers that history has a witness.

Practice answers

1. Known starting amounts of parent and daughter (initial conditions), a constant decay rate, and a closed system with nothing added or lost.
2. Sand in the top is the parent, sand in the bottom is the daughter, and the rate of sand through the neck is the half-life.
3. Kelvin's estimate assumed the earth was simply cooling with no new heat source. Radium gives off heat, so radioactivity inside the earth could keep it warm far longer, removing Kelvin's limit.
4. (a) 150 ÷ 5 = 30 minutes. (b) (150 − 50) ÷ 5 = 100 ÷ 5 = 20 minutes.
5. Original parent = 8 units; 1/8 remains, which is 3 half-lives. 3 × 704 million = 2,112 million, about 2.1 billion years.
6. (a) 40 − 15 = 25 mL/min, a drop of more than half. (b) 200 ÷ 40 = 5 minutes, which would be too short, since the real average rate was lower. (c) (B).
7. (a) 1,020 − 760 = 260 million years. (b) Zircon, because it takes in uranium but rejects lead when it crystallizes, so it should start with almost no daughter. (c) The closed-system assumption: the explanation says those minerals leaked daughter and so read too young.
8. Strong: if the assumptions were badly wrong, two independent methods with different half-lives and chemistry would be unlikely to land on the same number by accident. Not a proof: both methods share the assumption of constant rates over the whole past, and both would be shifted together by any condition that affected all decay alike or that set the starting amounts of several isotopes at once. Agreement rules out some errors but cannot rule out a shared one.
9. Change: the temperature of identical samples (for example, in a freezer, at room temperature and in a warm oven). Measure: the number of decays per second with a counter over the same length of time for each sample. Keep the same: the isotope, the mass of each sample, the distance to the counter, the counting time and the counter itself. Run at least three trials at each temperature and compare the averages. Note: this tests today's rate over a range of temperatures; it cannot test rates in the unobserved past.
10. Example: The sign reports that scientists measured the amounts of uranium and lead in tiny zircon crystals and counted the halving steps using the uranium half-life measured in the lab. To turn that into 4.4 billion years, they assume the crystals began with almost no lead, that the decay rate never changed, and that no uranium or lead leaked in or out. Geologists check the first by choosing zircon, which rejects lead as it grows, and they compare results from different isotopes. Christians who hold to a recent creation accept the measurements but note

that rates and starting conditions across creation and the Flood were never observed, and they read the history from Genesis. The number on the sign is a careful measurement joined to assumptions about a past no one watched.

7.3 Carbon-14 in Diamonds and Coal: The RATE Project (2005)

OBJECTIVES

- Explain how carbon-14 forms in the upper air, enters living things and decays, and why textbooks say it cannot be detected in anything older than about 100,000 years.
- Describe the RATE project's carbon-14 measurements on coal and diamonds (2003 to 2005), what the instruments read, and how mainstream scientists and creation scientists each explain the readings.
- Convert a percent-modern-carbon reading into a number of half-lives and a conventional carbon-14 age, and explain the difference between zero and below the detection limit.

Warm-up. Put one drop of food coloring into half a cup of water and stir. Pour half of it into a second cup and fill that cup back to the same level with plain water. Repeat into a third cup, a fourth and so on, halving the color each time. Set a cup of plain water at the end of the row. At which cup can you no longer tell the colored water from the plain water? Is the coloring gone from that cup, or just too faint for your eyes?

Video. Coming soon. How carbon-14 dating works, Willard Libby, accelerator mass spectrometry explained, how coal and diamonds form; look for Smithsonian, NIST, PBS, SciShow, Crash Course, Khan Academy and university chemistry and geology outreach channels.

KEY TERMS

carbon-14
A radioactive isotope of carbon with 6 protons and 8 neutrons. It forms in the upper atmosphere, is taken in by living things, and decays to nitrogen-14 with a half-life of 5,730 years.

cosmic rays
Fast particles from space that strike the upper atmosphere and knock loose neutrons, which turn some nitrogen-14 atoms into carbon-14.

percent modern carbon (pMC)
A sample's carbon-14 level compared with a living thing today. Living wood is 100 pMC; a sample with half as much is 50 pMC.

accelerator mass spectrometry (AMS)
A method that counts carbon-14 atoms one by one with a particle accelerator and magnets, instead of waiting for them to decay. It needs only a few milligrams of carbon.

detection limit

The smallest amount an instrument can tell apart from zero. A reading below it is reported as “not detected,” which is not the same as none.

contamination
Modern carbon that gets into a sample during collection, storage or preparation, which would make an old sample read younger than it is.

CORE IDEAS

The story. In 2003 John Baumgardner, a geophysicist at Los Alamos National Laboratory in New Mexico, did something most carbon-14 laboratories would call a waste of money. He ordered ten samples of coal from the United States Department of Energy’s coal sample bank at Pennsylvania State University, from seams whose textbook ages ranged from about 34 million to about 300 million years, and sent them to one of the world’s leading carbon-14 laboratories to be measured for carbon-14. By the textbook, coal that old should contain none at all. Baumgardner was part of a team of creation scientists called RATE, short for Radioisotopes and the Age of the Earth, an eight-year study sponsored by the Institute for Creation Research. The team presented its coal results in Pittsburgh in August 2003, added a set of diamonds, and published the whole study in 2005. Every coal sample contained measurable carbon-14. So, at lower levels, did the diamonds.

How they figured it out. Why the surprise? Carbon-14 dating, which Willard Libby worked out at the University of Chicago and published in 1949, runs like this. High in the atmosphere, **cosmic rays** knock neutrons loose, and when a neutron strikes a nitrogen-14 nucleus it becomes **carbon-14**. That carbon joins oxygen to make carbon dioxide, mixes through the air and is taken in by every plant and every animal that eats plants. In living things about one carbon atom in a trillion is carbon-14. When a plant or animal dies it stops taking in fresh carbon, and the carbon-14 it holds decays to nitrogen-14 with a half-life of 5,730 years. A sample’s level compared with living carbon is its **percent modern carbon**. Since the late 1970s, **accelerator mass spectrometry** has counted the carbon-14 atoms directly, one at a time, from a few milligrams of carbon. Now climb the halving ladder. After 10 half-lives (57,300 years) a sample is at 0.1 pMC. After 18 (about 103,000 years) it is at 0.0004 pMC, below what any instrument can detect. After 36 (about 206,000 years) a gram of carbon would not hold a single carbon-14 atom. Coal assigned 300 million years (more than 52,000 half-lives), and diamonds said to have formed deep in the earth one to three billion years ago, should be the deadest carbon on the planet.

The big idea. The ten coal samples averaged about 0.25 pMC, and samples from the three textbook ages did not sort by age. Run 0.25 pMC up the ladder and it corresponds to about 8.6 half-lives, a conventional carbon-14 age of roughly 50,000 years, the same for coal said to be 34 million and coal said to be 300 million years old. The diamonds read lower, mostly a few hundredths of one percent, close to the level of the laboratory’s blanks. Mainstream scientists give three answers. First, **contamination**: a few millionths of a gram of modern carbon, from air, handling or preparation chemicals, can produce readings at this level, and laboratories have long reported tiny readings in supposedly dead graphite and marble and subtract them as background. Second, neutrons from uranium decaying in coal seams can

make a little new carbon-14 in place, though calculations show this is far too small for most coals. Third, the instrument itself has a floor; in 2007 two carbon-14 specialists, Taylor and Southon, measured natural diamonds on their own, found readings in the same range, and treated them as the machine's background. The RATE team answered that the coal readings were well above the blank, that the diamonds were measured as cleaned whole crystals, and that an instrument floor should not differ from one coal seam to another.

How Christians read it. Creation scientists read the carbon-14 in coal as what you would expect if the plants that became coal were buried in the Flood a few thousand years ago. They add a second point. A conventional age of 50,000 years assumes the plant started at 100 pMC. If the world before the Flood held far more living carbon than today, as its vast buried forests suggest, carbon-14 would have been spread thinner, and a pre-Flood plant might have started at a few percent of modern carbon. Fewer halvings would then be needed to reach 0.25 pMC, and the 50,000 conventional years would shrink to a few thousand. That is a model, not a measurement, and this course says so plainly. The honest summary: the instruments read carbon-14 in coal and diamonds; one side explains it as contamination and background, the other as real carbon-14 from a recent burial. Both explanations are testable, and the testing continues.

In the world today. Carbon-14 dating is one of the finest tools in archaeology, and this course honors it. It dated the Dead Sea Scrolls and the beams of ancient buildings, usually within a few hundred years when checked against tree rings and written records, because such samples still hold plenty of carbon-14 to count. The argument in this lesson is about the far end of the scale, where readings are tiny and the question is whether "very small" means "contaminated" or "young." A good scientist on either side runs blanks, splits samples between laboratories and publishes the numbers. Your dilution cups taught the key idea: there is a difference between a cup that holds no color and a cup whose color you can no longer see, and only careful measurement can tell which is which.

half-lives	years	percent modern carbon
0	0	100
1	5,730	50
2	11,460	25
5	28,650	3.1
10	57,300	0.098 (about 0.1)
18	about 103,000	0.0004: below detection
36	about 206,000	less than 1 atom per gram
52,000	300 million (textbook coal)	none at all

RATE coal average
0.25 percent
8 to 9 half-lives
about 49,000 years

Each rung halves the amount. The years column assumes a constant rate and a start at 100 percent.

The carbon-14 halving ladder. Every rung is one half-life of 5,730 years. Anything older than about 100,000 years should read as nothing; the RATE coal average sits near the ninth rung.

⏳ Thinking About Time

What the sign says. What the sign says: the textbook says the coal seams of Pennsylvania formed in the Pennsylvanian period about 300 million years ago, that diamonds crystallized deep in the mantle one to three billion years ago, and that carbon-14 dating cannot reach beyond about 50,000 to 100,000 years because by then no carbon-14 remains.

What we observe. What we observe: carbon-14 has a measured half-life of 5,730 years. Accelerator mass spectrometers read small but measurable carbon-14 in coal samples from several seams, averaging about 0.25 percent of modern carbon, and lower readings in diamonds. Laboratories also measure small readings in materials used as blanks and subtract them as background.

How Christians read it. How Christians read it: creation scientists read the carbon-14 in coal and diamonds as real and as evidence that these carbons were buried a few thousand years ago in the Flood, with conventional ages inflated by a carbon-rich pre-Flood world. Mainstream scientists read the readings as contamination and instrument background. Students should state both explanations fairly and understand that each predicts something that can be tested: whether readings change with cleaning, between labs and between seams.

Try it. Draw your warm-up cups in a row and label the one where you lost the color “detection limit.” Write beside it: not zero, just too faint to see.

> *Job 28:1*

PICTURE STUDY



The Coalmen (Les Déchargeurs de charbon), Claude Monet, about 1875 · Oil on canvas · Musée d'Orsay, Paris

Claude Monet is famous for water lilies and sunlit haystacks, but in about 1875 he painted this unusual scene at Asnières, just outside Paris, where coal barges unloaded on the Seine. Men walk in a steady line up planks from the barges, each bent under a basket of coal, while a train crosses the bridge overhead. It is one of the very few industrial scenes Monet ever painted.

Coal was the carbon that powered Monet's world: the train, the chimneys, the steamships. In this lesson it is also the carbon that holds a puzzle, because laboratories can measure what is inside it atom by atom.

Look closely

- Follow the line of men from the barges up to the bank. How does Monet show the rhythm of their steps?
- Find the train on the bridge. What is it probably burning, and where did that fuel come from?
- Look at the colors. Why is almost everything gray, brown and black? What does that say about coal and the air around it?
- Monet painted outdoors, quickly. Where can you see fast brushstrokes instead of fine detail?

Talk about it

1. Every basket in this painting holds carbon that was once a living plant. What would you need to know to say how long ago that plant died?
2. The men unloading coal never asked how old it was. Why does the age of coal matter to a scientist, and why does it matter in this course?
3. Compare this picture with an hourglass painting. Which one shows something measured, and which one shows something that must be assumed?

EXPERIMENT: THE HALVING ROW: FINDING A DETECTION LIMIT

You will model radioactive decay with serial dilution, halving a color ten times, and find the halving step at which your eye can no longer separate the sample from a blank. Then you will match each step to a carbon-14 half-life.

Question: At which halving step does a measurable amount become undetectable, and does a sharper instrument (a flashlight, a white background, a camera) push the limit farther? Prediction: write the step number where you expect to lose the color, with and without the extra help.

You will need

- Eleven identical clear cups and one extra cup for the blank
- Food coloring (blue or red works best), a measuring cup, a tablespoon and a jug of tap water
- A sheet of white paper, a flashlight and a phone camera
- Notebook with a table: cup number, halvings, fraction of color (1, 1/2, 1/4 and so on), percent, carbon-14 years, visible to the eye (yes or no), visible with flashlight (yes or no)

Steps

1. Fill cup 0 with 120 mL of water and add 4 drops of food coloring. Stir. This is 100 percent, like living carbon. Fill the blank cup with 120 mL of plain water.
2. Pour exactly 60 mL from cup 0 into cup 1, then add 60 mL of plain water to cup 1 and stir. Cup 1 is 50 percent. Refill cup 0 to 120 mL with plain water only if you need the volume to look even; its color stays as your 100 percent reference.
3. Repeat from cup 1 into cup 2, cup 2 into cup 3, and so on through cup 10. Each cup is half the one before: 50, 25, 12.5, 6.25, 3.1, 1.6, 0.8, 0.4, 0.2, 0.1 percent.
4. Line the cups up on white paper beside the blank. Starting from the strongest, record for each cup whether you can see color against the blank. Mark the first cup where you cannot: that is your eye’s detection limit.
5. Now shine the flashlight through each cup from the side, and photograph the row. Record the new limit. Did a better instrument move the limit?
6. Fill in the carbon-14 column: multiply each cup’s halving number by 5,730 years. Mark where 0.25 percent would fall (between cup 8 and cup 9).
7. Write a conclusion: what is the difference between a cup with no coloring and a cup below your detection limit, and why does a carbon-14 laboratory always measure a

blank beside its samples?

Tips

- Measure carefully; a sloppy 60 mL at one step throws off every cup after it, just as a little contamination throws off a tiny reading.
- Run a second row with a different color and compare limits. Is the limit a property of the dye, of your eye or of both?
- If you have a parent or sibling with sharper eyes, test them too; instruments differ, and so do people.

Check your work

- My table has all eleven cups with the correct fractions, percents and carbon-14 years.
- I found a detection limit by eye and a second one with the flashlight or camera.
- I marked where 0.25 percent falls on the row.
- My conclusion explains why a blank is measured and why “not detected” does not mean “none.”

FIELD NOTEBOOK

1. Draw the carbon-14 cycle in a loop: cosmic rays striking the upper air, nitrogen-14 becoming carbon-14, carbon dioxide entering a leaf, an animal eating the plant, death, and decay back to nitrogen-14. Label the half-life.
2. Copy the halving ladder from the lesson figure and add your dilution cups beside it, one cup per rung, marking your detection limit.
3. Make a two-column chart: left, the mainstream explanations of carbon-14 in coal; right, the creation explanation. Under each, write one test that could tell them apart.

> **From history.** Willard Libby tested his new method in 1949 on objects whose ages were already known from history: wood from the tomb of an Egyptian pharaoh, a piece of a redwood tree whose rings had been counted, and timbers from an ancient ship. The carbon-14 ages matched the known ages closely, and the method spread through archaeology within a decade. Libby received the Nobel Prize in Chemistry in 1960. Carbon-14 laboratories today still begin every run the way he did, with samples of known age and a blank, because a clock is only trusted after it has been checked against a calendar.

WORKED EXAMPLES

Example 1. Using a half-life of 5,730 years, (a) after how many half-lives does carbon-14 fall to 0.1 percent of modern, and how many years is that? (b) How many half-lives would coal with a textbook age of 300 million years have passed through?

(Use the map or drawing "Count the rungs from 100 percent down to 0.1 percent." shown earlier in this lesson.)

1. (a) Halve from 100 percent: 50, 25, 12.5, 6.25, 3.1, 1.6, 0.8, 0.4, 0.2, 0.1. That is 10 halvings.
2. Years: 10 × 5,730 = 57,300 years.
3. (b) Half-lives = 300,000,000 ÷ 5,730 ≈ 52,356.
4. After 52,000 halvings nothing is left; even after 36 halvings a gram of carbon would hold less than one carbon-14 atom.

Answer: (a) 10 half-lives, or 57,300 years. (b) About 52,000 half-lives, so by the textbook age the coal should contain no carbon-14 at all.

Example 2. The RATE coal samples averaged 0.25 percent of modern carbon. Convert this to a number of half-lives and a conventional carbon-14 age.

1. The sample is at 0.25 out of 100, so it has been cut to 1/400 of the starting amount (100 ÷ 0.25 = 400).
2. Find the halvings that give 400: 2 to the 8th power is 256, and 2 to the 9th is 512, so the answer is between 8 and 9 half-lives.
3. A calculator gives about 8.6 half-lives (because 2 to the 8.6 power is about 400).
4. Age: 8.6 × 5,730 ≈ 49,000 years.
5. This assumes the plant started at 100 pMC and the reading is not contamination; the number is called a conventional age for that reason.

Answer: About 8.6 half-lives, which is a conventional carbon-14 age of roughly 49,000 years for coal with textbook ages of 34 million to 300 million years.

Example 3. One gram of carbon contains about 5×10^{22} atoms. In living carbon about one atom in a trillion (10^{12}) is carbon-14. (a) How many carbon-14 atoms are in a gram of fresh carbon? (b) After how many half-lives would fewer than one remain, and how many years is that?

1. (a) $5 \times 10^{22} \div 10^{12} = 5 \times 10^{10}$, which is 50 billion carbon-14 atoms.
2. (b) Each half-life halves the count. We need 2 to some power to be bigger than 50 billion. 2 to the 35th is about 34 billion; 2 to the 36th is about 69 billion.
3. So after 36 half-lives the count has fallen below one atom.
4. Years: 36 × 5,730 = 206,280, about 206,000 years.

Answer: (a) About 50 billion carbon-14 atoms. (b) After 36 half-lives, about 206,000 years, not a single carbon-14 atom should remain in that gram of carbon.

PRACTICE

1. EASY Where is carbon-14 made, and what does it decay into?
2. EASY What does “percent modern carbon” mean? What is the pMC of living wood?
3. EASY Why does carbon-14 work for a wooden beam but not for a granite boulder?
4. MEDIUM A piece of charcoal reads 25 pMC. How many half-lives have passed, and what is its conventional age?
5. MEDIUM A sample reads 0.4 pMC. Between which two whole numbers of half-lives does it fall? About how many conventional years is that?
6. MEDIUM Data reading. A laboratory reports these readings: modern wood 100 pMC; wood from a Roman building 78 pMC; coal sample A 0.30 pMC; coal sample B 0.21 pMC; diamond 0.04 pMC; processed blank (supposedly carbon-14-free graphite) 0.06 pMC. (a) Which samples read clearly above the blank? (b) About how old is the Roman wood by the conventional method (use 5,730 years; 78 pMC corresponds to about 0.36 of a half-life)? (c) Which statement do the data best support? (A) All the samples contain the same amount of carbon-14. (B) The coal samples read several times higher than the blank, while the diamond reads below it. (C) The diamond contains more carbon-14 than the coal. (D) The blank proves that coal contains no carbon-14.
7. MEDIUM Data reading. Suppose three coal samples from seams with textbook ages of about 34 million, 70 million and 300 million years read 0.30, 0.25 and 0.22 pMC. If carbon-14 readings reflected those textbook ages, what pattern would you expect, and what pattern do the numbers show? Which explanation does this test best address: contamination, in-place production or recent burial?
8. HARD Explain in your own words why a reading of 0.25 pMC in coal is read one way by mainstream scientists and another way by creation scientists. Name one prediction each side makes that could be tested.
9. HARD Experiment design. Design a study to test whether small carbon-14 readings in coal come from contamination during sample preparation. State the independent

variable, the dependent variable, the control, what you keep the same and how you would decide the question.

10. CHALLENGE Write a short paragraph explaining to a younger student what your warm-up cups teach about the word “zero” in science. Use the terms detection limit and blank.

COMMON MISTAKES

- Thinking carbon-14 dates rocks and dinosaur bones that are said to be millions of years old. Carbon-14 is used on once-living material within a range of tens of thousands of years; long-age rock dates use other isotopes.
- Thinking a reading below the detection limit means zero. It means the instrument cannot tell the sample from its blank; the amount could be zero or merely tiny.
- Thinking a conventional carbon-14 age is a direct measurement. It is calculated from the reading using the half-life and the assumption that the sample started at 100 percent of modern carbon.

Make it a game · Rungs of the Ladder. One player calls out a percent modern carbon reading (100, 50, 25, 12.5, 6.25, 3.1, 1.6, 0.8, 0.4, 0.2 or 0.1). The other must answer with the number of half-lives and the conventional age in years within ten seconds. Then switch. For a harder round, call a reading between rungs, such as 0.25 or 10, and the answer must name the two rungs it falls between. First to ten correct answers wins; a wrong answer costs one point.

Scripture. “Surely there is a vein for the silver, and a place for gold where they fine it. Iron is taken out of the earth, and brass is molten out of the stone.” (Job 28:1–2, KJV)

Job describes miners who dig deep into the earth for metals and know exactly where to look. The chapter goes on to say that wisdom cannot be dug up the same way; it comes from the fear of the Lord. Coal and diamonds come from the same deep places, and the care we take measuring them should be matched by humility about what the measurements can and cannot tell us.

Practice answers

1. It is made in the upper atmosphere when neutrons knocked loose by cosmic rays strike nitrogen-14. It decays back into nitrogen-14.
2. A sample’s carbon-14 level compared with a living thing today. Living wood is 100 pMC.
3. Carbon-14 enters living things through the carbon they take in; a beam was once a living tree. Granite was never alive and contains almost no carbon, so there is nothing to measure.
4. 100 → 50 → 25 is two half-lives. 2 × 5,730 = 11,460 years (assuming it started at 100 pMC).
5. 100 ÷ 0.4 = 250; 2 to the 7th is 128 and 2 to the 8th is 256, so it is just under 8 half-lives. About 8 × 5,730 ≈ 45,800 years, a little less (about 45,600).
6. (a) Modern wood, Roman wood, coal A and coal B. The diamond, at 0.04, is below the blank of 0.06. (b) 78 pMC is about 0.36 of a half-life, so about 2,000 years (any answer between 1,800 and 2,200 is acceptable). (c) (B).

7. Expected: all three should read zero, and if anything the 300-million-year coal should be lowest by an enormous margin. Shown: all three read in the same narrow range, with no strong sorting by textbook age. This test bears most directly on the idea that the readings track the assigned ages; it cannot by itself distinguish contamination from recent burial, since both could give similar readings across seams. A stronger test would compare blanks, labs and cleaning methods.
8. Mainstream scientists say the reading is contamination or instrument background, not carbon-14 from the original plant, since by their dates the coal should be far past any detectable level. Creation scientists say the carbon-14 is real and the coal was buried a few thousand years ago in the Flood. Tests: if the readings are contamination, harsher cleaning and better blanks should push them down toward zero and different labs should get different numbers; if the carbon-14 is real, readings should be stable across cleaning methods and labs and should differ in a consistent way between materials.
9. Independent variable: the amount of preparation and cleaning (for example, standard cleaning versus double cleaning versus measuring unprocessed chips). Dependent variable: the carbon-14 reading in pMC. Control: a blank of material believed to contain no carbon-14, processed exactly the same way, plus a modern sample at 100 pMC. Keep the same: the coal seam and sample, the laboratory and instrument, the sample size, the operators and the day. Decision: if readings fall toward the blank as cleaning increases, contamination is likely; if readings stay the same above the blank through all cleaning levels, the carbon-14 is more likely in the coal itself. Splitting the same sample between two laboratories would strengthen the test.
10. Example: When we halved the food coloring over and over, there came a cup where we could not see any color, even though we knew coloring was still in it. That cup was below our eyes' detection limit. Scientists face the same problem with tiny amounts of carbon-14, so they always measure a blank, a sample that should have none, and compare. A reading at the blank level means "we cannot tell," not "there is none." A reading well above the blank means something is really there, and then the argument is about where it came from.

7.4 Discordant Dates: The Mount St. Helens Dacite (Austin, 1996)

OBJECTIVES

- Tell what happened at Mount St. Helens on May 18, 1980, how a lava dome grew in the crater through 1986, and what Steven Austin did with a sample of its dacite in the 1990s.
- Explain potassium-argon dating, what excess argon means, why the dome results were discordant, and how mainstream geologists and creation geologists each explain them.
- Read a table of dates with error ranges, decide whether results agree within their errors, and calculate how small an amount of argon is needed to produce a large apparent age.

Warm-up. Set a stopwatch running, hide it, and ask a family member to guess how long it has been running by looking only at the second hand of a wall clock they did not see you start. Then show them that the stopwatch had already been running for two minutes before you “started.” How far off was their answer? What would they have needed to know?

Video. Coming soon. Mount St. Helens eruption May 18, 1980 and the growth of the lava dome, potassium-argon dating explained, how volcanic rocks are dated; look for USGS Cascades Volcano Observatory, Smithsonian Global Volcanism Program, PBS, Oregon Public Broadcasting and university geology channels.

KEY TERMS

dacite
A pale volcanic rock rich in silica, between andesite and rhyolite, with crystals of feldspar, amphibole and pyroxene set in volcanic glass. The Mount St. Helens dome is made of it.

potassium-argon dating
A method that measures potassium-40 and its daughter argon-40 in a rock and calculates an age using the 1.25 billion year half-life, assuming the argon count started at zero when the lava hardened.

excess argon
Argon-40 in a rock that did not come from potassium decay after the rock hardened, but was trapped from the magma or inherited in older crystals. It makes a rock read older than it is.

phenocryst
A large crystal in a volcanic rock that grew in the magma before the eruption, often earlier than the fine-grained groundmass around it.

discordant dates

Dates from different minerals or methods on the same rock that disagree by more than their stated errors.

error range
The plus-or-minus figure printed with a date, showing how far the measurement could be off; two dates agree if their ranges overlap.

CORE IDEAS

The story. At 8:32 on the morning of May 18, 1980, a magnitude 5.1 earthquake shook Mount St. Helens in Washington State, and the whole north face of the mountain slid away in the largest landslide ever recorded. The blast that followed flattened forests across 600 square kilometers, sent ash around the world and killed 57 people, among them the USGS volcanologist David Johnston, who radioed his last words from a post 10 kilometers away. The summit dropped from 2,950 m to 2,549 m. Over the next six years thick, pasty lava squeezed up into the new crater in a series of short eruptions and built a **dacite** dome more than 250 m high, and geologists watched every one of those eruptions. That is what makes the dome so useful: its age is not a question. In 1992 the creation geologist Steven Austin collected a block of dacite from the lava that had flowed out in 1986, separated its minerals and sent the samples to a commercial laboratory for potassium-argon dating. The results, published in 1996, gave ages from 340,000 to 2.8 million years for a rock that was ten years old.

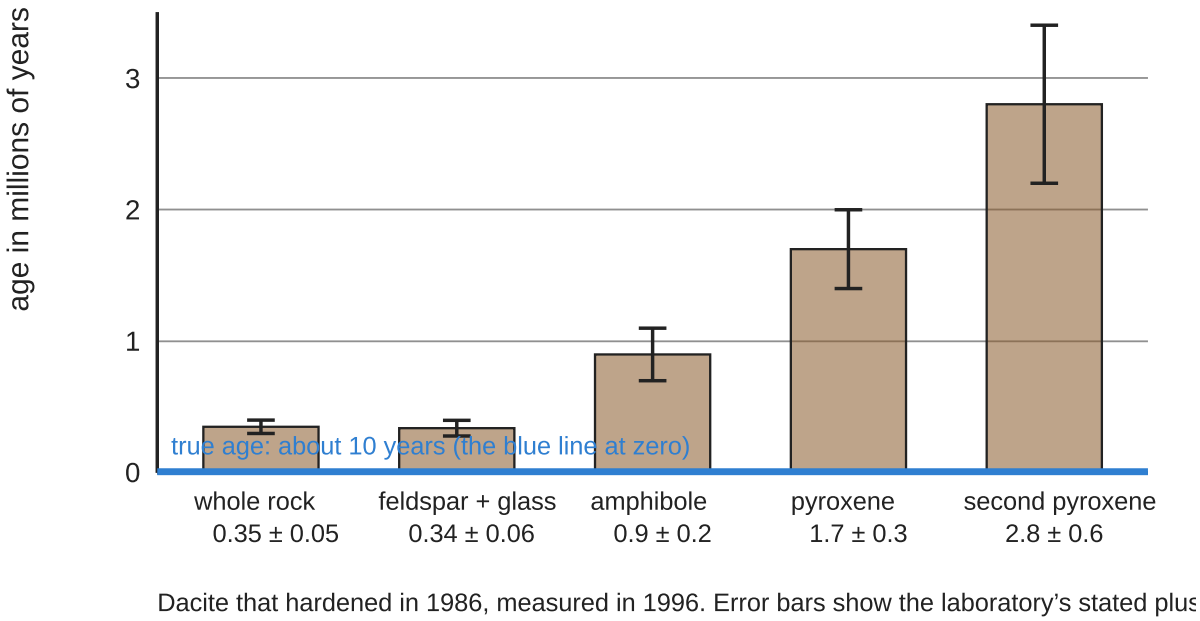
How they figured it out. Potassium-argon dating is the workhorse method for volcanic rock. Potassium-40 decays with a half-life of 1.25 billion years, and about one decay in nine produces argon-40, a gas. The method's key assumption is this: when rock is molten, argon bubbles away, so a fresh lava hardens with no argon-40 at all. From then on every argon-40 atom found locked in the crystals must have come from potassium decay. Measure the argon, measure the potassium, and the clock reads itself. Austin's laboratory measured a whole-rock sample and four mineral concentrates, and the dates were both too old and different from one another: whole rock 0.35 million years, feldspar and glass 0.34 million, amphibole 0.9 million, pyroxene 1.7 million, and a second pyroxene sample 2.8 million, each with its own error range. Dates that disagree by more than their errors are called **discordant**. For a ten-year-old rock, the starting assumption had plainly failed: the minerals held **excess argon**, trapped from the magma or carried in older crystals, from the moment they formed.

The big idea. Mainstream geologists have known about excess argon for a long time. In 1969 a USGS geologist, Brent Dalrymple, tested 26 lava flows of known historic age; most gave little or no argon, but several gave ages of hundreds of thousands to over a million years, including the 1800 to 1801 flow of Hualalai in Hawaii at about 1.6 million years. So their answer to Austin has two parts. First, the laboratory's method was built for rocks at least a few hundred thousand years old; for a ten-year-old rock, argon from the lab air and the instrument can swamp the tiny true signal, so numbers of a few hundred thousand years show only the method's floor. Second, the larger **phenocrysts** of pyroxene and amphibole grew in the magma chamber before the eruption and could have trapped argon there, so they are expected to read older. Geologists today prefer the argon-argon method, which can

often tell trapped argon from argon made in place. Austin replied that the pattern by mineral shows the magma itself carried argon, and that a method which gives millions of years to a rock known to be ten years old cannot be checked when a rock's age is unknown.

How Christians read it. The lesson a creation geologist draws is not that laboratories are careless; the measurements were real. It is that the method rests on the assumptions of Lesson 7.2, and that when the true age is known, as here, those assumptions sometimes fail by a factor of hundreds of thousands. When the true age is unknown, as for most rocks on a museum sign, the only way to spot a failed assumption is to compare dates with each other and keep the ones that agree, so the agreement of the chosen dates proves less than it seems. On this reading, a rock from the Flood year or from creation week could carry argon from the start just as the dome did, and read far older than it is. Mainstream geologists answer that historic lavas are a known trouble spot, that they have learned which samples to avoid, and that older rocks have been dated by several methods that agree. A student who can state the other side's best case is the one who has understood the question.

In the world today. Mount St. Helens is the best-studied volcano on earth, and the USGS Cascades Volcano Observatory in Vancouver, Washington, still monitors it every day; a second dome grew over the first between 2004 and 2008. Whenever you read that a volcanic layer has been dated, you now know what to ask. What method? Whole rock or a mineral? Did the dates from different minerals agree within their error ranges? If some were thrown out, why? A careful geologist asks these before publishing, and a careful reader before believing. Proverbs says that the first speaker seems right until his neighbor comes and searches him (Proverbs 18:17). Searching a date is not disrespect; it is the job.



Austin's 1996 potassium-argon results for dacite that hardened in 1986. The bars are discordant with one another and all far above the true age of about ten years, shown as the line at the bottom.

⏳ Thinking About Time

What the sign says. What the sign says: the textbook says potassium-argon dating reliably dates volcanic rocks because argon escapes from molten lava and sets the clock to zero, and that by this method the Hawaiian island of Kauai is about 5 million years old and many lava flows at other volcanoes date to hundreds of thousands or millions of years.

What we observe. What we observe: the 1980 to 1986 dome at Mount St. Helens was watched as it formed, and in 1996 potassium-argon measurements on its dacite gave ages from 0.34 million to 2.8 million years. A 1969 USGS study found excess argon in several other historic lava flows, including the 1800 to 1801 Hualalai flow at about 1.6 million years. The argon was really there; it did not come from decay since the rock hardened.

How Christians read it. How Christians read it: creation geologists read these cases as showing that a key assumption, no argon at the start, can fail badly, so that unknown-age rocks may also carry argon from the start and read far too old. Mainstream geologists read them as known exceptions that modern methods and careful sampling screen out, and point to agreement among methods for older rocks. Students should be able to explain both readings and name which assumption is at issue.

Try it. Write the five dome results on a strip of paper with their error ranges and mark which pairs overlap. Then write the true age, ten years, beside them.

Proverbs 18:17

PICTURE STUDY



Mount St. Helens Erupting at Night, Paul Kane, about 1849 to 1856, from a sketch made March 26, 1847 · Oil on canvas · Royal Ontario Museum, Toronto

Paul Kane was an Irish-born Canadian painter who traveled across the continent in the 1840s to record the peoples and landscapes of the West. In March 1847, near the mouth of the Lewis River on the Columbia, he saw Mount St. Helens smoking and sketched it. Years later in Toronto he worked the sketch into this dramatic night scene, with the summit glowing and smoke lit from beneath.

This is one of the few pictures of the mountain erupting before 1980, and it reminds us that Mount St. Helens had a long record of activity that people saw and wrote down. A volcano with eyewitnesses is a volcano whose history can be checked.

Look closely

- Find the glow at the summit and the column above it. How does Kane use light from below to show heat?
- Find the figures by the water. How big are they compared with the mountain, and what does that do to the scene?
- Kane painted a night scene years after a daytime sketch. What in the picture is observation, and what is the painter’s addition?
- Compare the cone’s shape with a photograph of the mountain after 1980. What changed?

Talk about it

1. Kane’s 1847 journal entry and his painting are eyewitness records. Why are eyewitness records so valuable in geology, and what did they make possible at the 1986 dome?

2. The 1980 eruption removed the top of the mountain. If you had only the present shape, could you tell what the mountain looked like before? What does that teach about reading the past from the present?
3. A painting can be dramatic and still be truthful. Where is the line between the two in this picture?

EXPERIMENT: ARGON FROM THE START: A PENNY MODEL OF EXCESS ARGON

You will model three “minerals” from a fresh lava flow with cups of pennies, where heads stand for argon-40 atoms and tails for potassium-40 atoms, and see how a few heads present at the start produce a large apparent age.

Question: If a rock starts with some daughter atoms already inside, how old will it appear by the potassium-argon method, even if its true age is zero? Prediction: write the apparent age you expect for a cup that starts with 8 heads out of 100, and for a cup that starts with 25.

You will need

- 300 pennies or other identical coins (or 100 pennies used three times), three cups labeled glass, amphibole and pyroxene
- A calculator, graph paper and a notebook with a table: cup, heads at start, tails at start, fraction tails, apparent shakes, apparent age

Steps

1. Set the rule: one shake is one half-life of 1.25 billion years, and a rock that has never been shaken has a true age of zero, like the 1986 lava.
2. Cup “glass”: place 100 pennies all tails up. This mineral hardened with no argon. Cup “amphibole”: place 92 tails and 8 heads. Cup “pyroxene”: place 75 tails and 25 heads. Do not shake any cup; they are all brand new.
3. A lab receives the cups without knowing their history. For each cup, count heads and tails and compute the fraction of tails (parent) remaining.
4. Convert to apparent shakes using the halving ladder: 100 percent tails is 0 shakes, 50 percent is 1 shake, 25 percent is 2 shakes. For values in between, use these values: 92 percent tails is about 0.12 shake, 75 percent is about 0.42 shake.
5. Multiply apparent shakes by 1.25 billion years to get an apparent age for each cup. Record all three. The true age of every cup is zero.
6. Now make a real one-shake rock: shake the glass cup once, remove nothing, count heads and tails. Compute its apparent age. Then imagine that cup had also started with 8 heads; add 8 heads and recompute. How much did the inherited heads add to the age?
7. Graph apparent age against heads at the start for 0, 8, 25 and 50 heads (50 heads gives 1 full shake, 1.25 billion years). Write a conclusion that explains why Austin’s minerals read differently from each other and why a tiny amount of inherited argon matters so much.

Tips

- The point of not shaking the first three cups is to see that an instrument can only count what is there; it cannot tell a head that was placed from a head that flipped.
- If 0.12 shake seems odd, remember that even a small share of heads sits somewhere on the curve between 0 and 1 half-life, and the half-life is 1.25 billion years, so a small share is a large number of years.
- Real excess argon is far smaller than 8 percent; the lesson's worked example shows that two atoms in ten thousand are enough for 350,000 years.

Check your work

- My table shows heads, tails, fraction, apparent shakes and apparent age for all three cups.
- I recorded that the true age of each unshaken cup is zero and compared it with the apparent age.
- My graph shows apparent age rising as inherited heads increase.
- My conclusion names the assumption that failed and connects it to the Mount St. Helens dates.

FIELD NOTEBOOK

1. Draw Mount St. Helens in cross-section before and after May 18, 1980, with the old summit at 2,950 m, the new crater rim at 2,549 m and the dome growing inside the crater from 1980 to 1986.
2. Copy the bar graph of the five dome dates with their error bars, and draw a line for the true age of ten years. Label which pairs of bars overlap.
3. Write a two-column note on potassium-argon dating: what is measured (potassium-40, argon-40, the half-life) and what is assumed (zero argon at the start, constant rate, closed system). Circle the assumption the dome tested.

> **From history.** David Johnston, the young USGS volcanologist who died in the 1980 eruption, had argued for keeping the area around the mountain closed to visitors because he believed a sideways blast was possible. His warning saved many lives. His last radio message to the USGS office in Vancouver, Washington, was "Vancouver! Vancouver! This is it!" The observatory that now watches the Cascade volcanoes is named in his honor, and the ridge where he stood is the site of the Johnston Ridge Observatory, from which visitors look straight into the crater at the dome.

WORKED EXAMPLES

Example 1. The whole-rock sample of the 1986 dacite read 0.35 million years in 1996, when the rock was about 10 years old. (a) By what factor is the date too old? (b) What fraction of the rock's potassium-40 would have to have decayed to produce that date, using a half-life of 1.25 billion years?

1. (a) 350,000 ÷ 10 = 35,000. The date is 35,000 times the true age.
2. (b) Half-lives elapsed = 0.35 million ÷ 1,250 million = 0.00028 half-life.
3. For a tiny number of half-lives, the fraction decayed is about 0.693 × the number of half-lives (0.693 is the natural log of 2): 0.693 × 0.00028 ≈ 0.00019.
4. That is about 0.02 percent, or 2 atoms in every 10,000 potassium-40 atoms. About one in nine of those decays makes argon, so the argon needed is smaller still.

Answer: (a) About 35,000 times too old. (b) About 0.02 percent of the potassium-40, 2 atoms in 10,000. A trace of argon that small, present from the start, is enough to produce a date of 350,000 years.

Example 2. Austin's five results were: whole rock 0.35 ± 0.05 Ma; feldspar and glass 0.34 ± 0.06 Ma; amphibole 0.9 ± 0.2 Ma; pyroxene 1.7 ± 0.3 Ma; second pyroxene 2.8 ± 0.6 Ma (Ma means million years). Which pairs agree within their error ranges, and which are discordant?

(Use the map or drawing "Error bars that do not overlap mean the dates disagree." shown earlier in this lesson.)

1. Write each range: whole rock 0.30 to 0.40; feldspar and glass 0.28 to 0.40; amphibole 0.7 to 1.1; pyroxene 1.4 to 2.0; second pyroxene 2.2 to 3.4.
2. Whole rock and feldspar-glass overlap (both include 0.30 to 0.40), so they agree.
3. Amphibole (0.7 to 1.1) does not overlap either of the first two: discordant.
4. Pyroxene (1.4 to 2.0) does not overlap amphibole: discordant. Second pyroxene (2.2 to 3.4) does not overlap the first pyroxene: discordant.
5. Every result is far above the true age of 0.00001 Ma (ten years).

Answer: Only the whole-rock and feldspar-glass dates agree with each other. The amphibole, pyroxene and second pyroxene dates are discordant with those and with one another, and all five are discordant with the known age of ten years.

Example 3. The 1800 to 1801 Hualalai lava flow in Hawaii gave a potassium-argon age of about 1.6 million years when measured in the 1960s, when it was about 165 years old. (a) By what factor was the date too old? (b) In 165 years, what fraction of the flow's potassium-40 actually decayed?

1. (a) 1,600,000 ÷ 165 ≈ 9,700. The date was nearly 10,000 times too old.
2. (b) Half-lives elapsed = 165 ÷ 1,250,000,000 = 0.000000132.
3. Fraction decayed ≈ 0.693 × 0.000000132 ≈ 0.0000000915, about 9 atoms in 100 million.
4. So almost none of the argon measured could have come from decay since 1801; it was in the rock from the start.

Answer: (a) About 10,000 times too old. (b) About 9 potassium-40 atoms in every 100 million decayed, so the argon measured was almost entirely excess argon.

PRACTICE

1. EASY What happened at Mount St. Helens on May 18, 1980, and why is the lava dome of 1980 to 1986 so useful to anyone studying dating methods?
2. EASY State the key assumption of potassium-argon dating in one sentence.
3. EASY What is excess argon, and does it make a rock read too old or too young?
4. MEDIUM Two dates on the same rock are 1.2 ± 0.2 Ma and 1.5 ± 0.1 Ma. Do they agree within their error ranges? Show the ranges.
5. MEDIUM The amphibole from the dome read 0.9 million years when the rock was 10 years old. By what factor is that too old?
6. MEDIUM Data reading. Austin's results: whole rock 0.35 ± 0.05 Ma; feldspar and glass 0.34 ± 0.06; amphibole 0.9 ± 0.2; pyroxene 1.7 ± 0.3; second pyroxene 2.8 ± 0.6. (a) Which sample read oldest, and what is the ratio of the oldest to the youngest date? (b) Which two samples agree within their errors? (c) Which statement do the data best support? (A) All five dates agree within error. (B) The larger crystals (amphibole and pyroxene) read older than the whole rock and the feldspar-glass. (C) The whole rock reads oldest. (D) The dates cluster at the true age of ten years.
7. MEDIUM Data reading. Suppose a laboratory reports potassium-argon ages for four lava flows of known historic age: flow 1 (erupted 1944) 0.0 ± 0.1 Ma; flow 2 (1801) 1.6 ± 0.2 Ma; flow 3 (1792) 0.3 ± 0.1 Ma; flow 4 (1963) 0.0 ± 0.1 Ma. (a) How many flows gave ages consistent with zero? (b) What is the range of results? (c) Which conclusion fits the data? (A) Excess argon occurs in every historic flow. (B) Excess argon never occurs. (C) Some historic flows carry excess argon and some do not, so a date on an unknown flow cannot be trusted without checks. (D) Older eruptions always give older dates.
8. HARD A geologist says the Mount St. Helens dates only show that the laboratory's method cannot measure rocks younger than a few hundred thousand years. Give one way this answer explains the data and one way it falls short, using the numbers.

9. HARD Experiment design. Design a test to find out whether excess argon in a lava comes from the large phenocrysts or from the glassy groundmass. State the independent variable, the dependent variable, the control, what you keep the same and what result would support each idea.
10. CHALLENGE Write a paragraph that fairly presents both readings of the Mount St. Helens dates, then states your own view with one reason, in a tone you would be comfortable using with a geologist who disagrees.

COMMON MISTAKES

- Thinking the laboratory made a mistake. The argon was really in the rock and was measured correctly; the problem was the assumption that there was none at the start.
- Thinking excess argon shows that potassium-40 decays at a different rate. The decay rate was not in question; the starting amount of daughter was.
- Thinking that if two dates have error ranges they must be uncertain guesses. The error range shows the precision of the measurement; two precise dates can still disagree, and that disagreement is called discordance.

Make it a game · Concordant or Discordant?. One player calls out two dates with error ranges, such as “2.1 plus or minus 0.3 and 2.6 plus or minus 0.2.” The other must write both ranges, say whether they overlap, and call “concordant” or “discordant” within fifteen seconds. Score a point for a correct call and a bonus point for saying which of the three assumptions could explain a discordance (starting amount, rate or closed system). Switch after five rounds. First to ten wins.

Scripture. “He that is first in his own cause seemeth just; but his neighbour cometh and searcheth him.” (Proverbs 18:17, KJV)

A claim sounds right until someone checks it. The known age of the Mount St. Helens dome gave people a way to search a method that usually cannot be searched. Good science and good character both welcome the neighbor who comes to check.

Practice answers

1. An earthquake triggered a huge landslide and eruption that removed the top of the mountain. Over the next six years a dacite dome grew in the crater while geologists watched. Its age is known exactly, so dating methods can be tested against it.
2. That a lava hardens with no argon-40 in it, because argon escapes from molten rock, so all the argon-40 measured later came from potassium-40 decay.
3. Argon-40 in a rock that did not come from decay after the rock hardened, but was trapped from the magma or inherited in older crystals. It makes the rock read too old.
4. Ranges: 1.0 to 1.4 and 1.4 to 1.6. They just touch at 1.4, so they barely agree; any smaller error would make them discordant.
5. 900,000 ÷ 10 = 90,000 times too old.
6. (a) The second pyroxene, 2.8 Ma; 2.8 ÷ 0.34 ≈ 8.2, about eight times. (b) Whole rock and feldspar-glass. (c) (B).

7. (a) Two (flows 1 and 4). (b) From 0.0 to 1.6 Ma. (c) (C).
8. It explains the whole-rock and feldspar-glass dates of about 0.35 Ma, which sit near the level where lab argon alone could produce a reading. It falls short for the pyroxene dates of 1.7 and 2.8 Ma, which are five to eight times higher than that floor and differ from each other, so something in those minerals, most likely argon trapped in crystals that formed in the magma, is adding real argon beyond what the method's floor can explain.
9. Independent variable: which part of the rock is measured (pure phenocrysts, pure groundmass, whole rock). Dependent variable: the argon-40 measured, reported as an apparent age. Control: a sample of known age with no phenocrysts, or a laboratory blank, run the same day. Keep the same: the lava flow, the sample size, the crushing and cleaning method, the instrument and the operator. If the phenocrysts read much older than the groundmass, the excess argon is in the crystals; if both read the same, the argon is in the magma as a whole. Repeating with a second flow of known age would strengthen the result.
10. Example: In 1996 Steven Austin reported potassium-argon ages of 0.34 to 2.8 million years on dacite from the Mount St. Helens dome that formed in 1986. Mainstream geologists say the method was not built for rocks this young, that argon in the lab produces readings in the hundreds of thousands of years, and that large crystals trapped argon in the magma before erupting; they add that careful sampling and the argon-argon method avoid such problems. Creation geologists say the case shows that a rock can hold argon from the start, so that the zero-argon assumption cannot be trusted when the true age is unknown. I hold the creation reading because the dates differed by mineral in a pattern that an instrument floor alone does not explain, and because the only reason we know these dates are wrong is that people watched the lava cool. I can say that respectfully and still listen carefully to the other side.

Unit 7 review

Answer each question. Show your work for calculations with units, and use complete sentences for explanations. For the diagram item, draw neatly and label every part. Where a question asks for both readings, state each one fairly before giving your own. The test is worth 60 points.

1. (5 pts) Multiple choice. The half-life of an isotope is: (A) the time for all of its atoms to decay (B) the time for half of its atoms to decay (C) half the age of the rock it is in (D) the time it takes to measure its decay rate
2. (5 pts) A sample starts with 320 grams of a parent isotope whose half-life is 5,730 years. How much remains after three half-lives, and how many years is that? Then say how many half-lives have passed when one sixteenth remains.
3. (6 pts) Diagram. Draw a decay curve on labeled axes: half-lives from 0 to 4 along the bottom, percent of parent remaining from 0 to 100 up the side. Plot and label the points at 0, 1, 2, 3 and 4 half-lives, join them with a smooth curve, and mark on the graph where you would read the half-life of a penny experiment.
4. (5 pts) Name the three assumptions behind a radiometric date and explain each in one sentence using the hourglass picture.
5. (6 pts) A rock holds 1 unit of parent and 3 units of daughter. (a) Assuming no daughter at the start, how many half-lives have passed? (b) If 1 unit of daughter was present at the start, about how many half-lives have passed? (c) With a half-life of 1.25 billion years, what two ages result, and which assumption made the difference?
6. (5 pts) Multiple choice. Which statement about mainstream geologists and the three assumptions is accurate? (A) They have never considered the assumptions. (B) They test the assumptions by choosing minerals such as zircon, comparing methods and rejecting weathered samples, but cannot observe rates or starting amounts in the distant past. (C) They measure the starting amounts directly. (D) They assume decay rates change over time.
7. (5 pts) Describe the carbon-14 cycle in three or four sentences: where carbon-14 is made, how it gets into a plant, what happens at death, and what it decays into.
8. (6 pts) The RATE coal samples averaged 0.25 percent of modern carbon. (a) To what fraction of the starting amount has the carbon-14 been cut? (b) Between which two whole numbers of half-lives does that fall, and what conventional age results (use 5,730 years)? (c) By the textbook age of 300 million years for some of this coal, how many half-lives should have passed, and what reading would you expect?
9. (5 pts) State the mainstream explanation and the creation explanation for carbon-14 readings in coal and diamonds, one or two sentences each, and name one test that could help decide between them.
10. (6 pts) Austin’s 1996 potassium-argon results for the 1986 Mount St. Helens dacite were: whole rock 0.35 ± 0.05 Ma; feldspar and glass 0.34 ± 0.06 Ma; amphibole 0.9 ± 0.2 Ma; pyroxene 1.7 ± 0.3 Ma. (a) Write the range for each. (b) Which pairs agree within error? (c) By what factor is the pyroxene date too old for a rock that was 10

years old? (d) What is argon in a rock that did not come from decay after it hardened called?

11. (6 pts) Explain in a paragraph why the Mount St. Helens dome was a useful test of potassium-argon dating, what the results showed, how mainstream geologists explain them, and how creation geologists read them. End with one sentence on how to speak about the disagreement.

UNIT PROJECT: MY DATING METHODS CASEBOOK

Assemble a casebook with four sections, one per lesson. Section 1: your penny and dice decay graphs with half-lives read from each and a halving ladder from 0 to 10 half-lives. Section 2: a large hourglass poster showing the three assumptions, with your drip-clock data table and the error each unfair trial produced. Section 3: your halving-row photograph or drawing with the detection limit marked, a carbon-14 cycle diagram and a two-column chart of the mainstream and creation explanations of carbon-14 in coal. Section 4: a bar graph of the five Mount St. Helens dates with error bars and the true age marked, plus your penny model of excess argon.

Finish with a one-page essay titled “What the sign says, what we observe, how I read it,” taking one real museum or textbook date you have found, naming what was measured and what was assumed, giving the mainstream reading accurately, and stating the creation reading with at least one calculation from this unit and one Scripture reference.

- **Accuracy**: Half-lives, halving steps, conversions and the Mount St. Helens figures are correct, with units, and graphs are correctly plotted and labeled.
- **Lab records**: Decay, drip-clock, halving-row and penny-model data are complete, with predictions, variables named, and conclusions that answer each question.
- **Measured versus assumed**: Every date discussed is split clearly into what was measured, what was assumed and what was checked, for both the carbon-14 and the potassium-argon cases.
- **Fairness and explanation**: The essay states the mainstream reading accurately and respectfully, gives the creation reading with a calculation and Scripture, and is neat and well organized.

Answer key

1. (B).
2. 320 → 160 → 80 → 40 grams; 3 × 5,730 = 17,190 years. One sixteenth remaining is four half-lives (1/2, 1/4, 1/8, 1/16).
3. Axes labeled with units; points at (0, 100), (1, 50), (2, 25), (3, 12.5), (4, 6.25) correctly placed and joined by a curve that is steep at first and flattens; the half-life is read where the curve crosses 50 percent (at 1 half-life, or 1 shake for pennies). Full credit requires correct values, labels and a curved (not straight) line.
4. Known starting amounts: how much sand was already in the bottom when the glass was turned. Constant rate: the sand has always fallen through the neck at today’s rate. Closed system: no sand has been added or lost through the glass since the turn.

5. (a) Original parent 4, fraction remaining 1/4, so 2 half-lives. (b) Daughter from decay 2, original parent 3, fraction 1/3, about 1.6 half-lives. (c) 2.5 billion years versus about 2.0 billion years; the starting-amount (initial conditions) assumption.
6. (B).
7. Cosmic rays knock neutrons loose in the upper atmosphere; a neutron striking nitrogen-14 turns it into carbon-14. The carbon-14 joins carbon dioxide, mixes through the air and is taken in by plants during photosynthesis (and by animals that eat plants). At death the organism stops taking in fresh carbon, and its carbon-14 decays with a half-life of 5,730 years. It decays back into nitrogen-14.
8. (a) 100 ÷ 0.25 = 400, so 1/400. (b) Between 8 (256) and 9 (512) half-lives, about 8.6; 8.6 × 5,730 ≈ 49,000 years. (c) 300,000,000 ÷ 5,730 ≈ 52,000 half-lives; the expected reading is zero, nothing detectable at all.
9. Mainstream: the readings are contamination by modern carbon during handling and preparation, plus instrument background, since by their dates no carbon-14 should remain. Creation: the carbon-14 is real and the coal was buried a few thousand years ago in the Flood, with conventional ages inflated by a carbon-rich pre-Flood world. Test: compare readings under increasing levels of cleaning and between laboratories with blanks; contamination should fall toward the blank, real carbon-14 should stay stable above it.
10. (a) 0.30 to 0.40; 0.28 to 0.40; 0.7 to 1.1; 1.4 to 2.0. (b) Only whole rock and feldspar-glass. (c) 1,700,000 ÷ 10 = 170,000 times. (d) Excess argon.
11. The dome formed between 1980 and 1986 while geologists watched, so its true age was known, which let the method be checked against a calendar. The 1996 dates ranged from 0.34 to 2.8 million years and were discordant with one another, so the assumption of zero argon at the start had failed. Mainstream geologists say the method was not built for such young rocks, that laboratory argon produces readings near a few hundred thousand years, and that large crystals trapped argon in the magma; better sampling and the argon-argon method avoid such cases. Creation geologists say the case shows a rock can carry argon from the start, so the assumption cannot be trusted when the true age is unknown. A Christian student should state the other side’s best reasons accurately and kindly before giving his own.

UNIT 8

Reading a Museum

Everything you have learned this year comes to a rail in a museum hall. In front of you stands a skeleton with its catalog number; beside it hangs a sign with a name, a place, a layer and a date in millions of years. This unit teaches you to visit that hall the way a working scientist does: with a plan, a ruled notebook, a calibrated pace and a tape measure, and with the habit of sorting every sentence on the sign into what was observed, what was inferred and what was interpreted.

You will meet Charles Willson Peale, who dug a mastodon out of a New York marl pit in 1801 and built America's first great museum around it; the Carnegie Museum's *Apatosaurus*, whose sign changed three times while its bones never changed; Adam Sedgwick, who disagreed with Darwin to his face and stayed his friend; and Mary Anning, whose careful letter of 1823 convinced the greatest anatomist in Europe. Each one shows a piece of the same craft: plan, observe, read the sign fairly, speak kindly, and write it down so that someone else can check you.

The unit ends with a real report of a real visit, in person or online, with measurements, scale drawings, the signs quoted and dated, and your own reading of the layers set beside the museum's. That report is the portfolio for the year: the place where Steno's principles, the Flood, the Ice Age, the dinosaurs and the dating methods all meet a specimen you measured yourself.

BEFORE YOU BEGIN

- Can sort statements into observations, inferences and interpretations (Unit 3)
- Can name the three assumptions behind a radiometric date and explain what a laboratory actually measures (Unit 7)
- Can compute a mean, a range and a percent difference, and convert between centimeters and meters
- Can read a scale bar on a map and use a ratio such as 1 : 500

MASTERY CHECKLIST

- I can plan a museum visit from a floor plan, with a route, a time budget and a ruled observation log.
- I can calibrate my pace and estimate the length of a mounted skeleton to within a few percent of the sign.
- I can read a specimen label and separate its record lines from its story lines, and its observations from its inferences and interpretations.
- I can quote a sign exactly, date the copy, and fill a three-column box: what the sign says, what we observe, how Christians read it.
- I can state the mainstream claim about a date so fairly that a museum scientist would accept the wording, then give the creation reading beside it without mocking anyone.

- I can write a nine-part museum report with units, means and ranges, scale drawings and sources.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History, online exhibits and collections** (https://naturalhistory.si.edu/): Free. Floor plans, hall descriptions and specimen records to practice reading labels before a visit, or to visit online if no museum is nearby.
- **Smithsonian 3D Digitization** (https://3d.si.edu/): Free. Rotate and measure 3D scans of real specimens, including fossils, so you can take observations and make scale drawings from home.
- **Dinosaur National Monument, National Park Service** (https://www.nps.gov/dino/): Free. Photographs and descriptions of the Quarry Exhibit Hall wall, the source of the Carnegie Apatosaurus in Lesson 8.2, for your three-column box and bone-alignment project.

8.1 The Field Trip Guide: Planning a Museum Visit ★

OBJECTIVES

- Plan a museum visit from a floor plan: choose three halls, budget the time, and pack a field kit of notebook, pencil, tape measure and observation log.
- Read a specimen label and tell which lines are a record (name, place, layer, collector, catalog number) and which lines are a story about the past.
- Calibrate your own pace in meters and use it, with the scale on a floor plan, to estimate the length of a mounted skeleton.

Warm-up. Set six things from around the house on the table as a home museum: a seashell, a clean bone from dinner, a rock, a leaf, a coin, a feather. Write a three-line label for each: a name, where it came from, and one thing you measured with a ruler. No guesses allowed. Notice how hard it is to write a label without slipping in a story about the past.

Video. Coming soon. Search for a behind-the-scenes tour of a natural history museum fossil hall showing how skeletons are mounted, labeled and cataloged, and for a short piece on Charles Willson Peale's Philadelphia museum and his mastodon. Good sources: Smithsonian channels, National Park Service, museum collection tours, SciShow Kids, Homeschool Pop (Alternate), Moody Science classics.

KEY TERMS

specimen
One real object in a museum collection: a bone, a shell, a rock, a mounted skeleton. The specimen is the evidence; everything written about it is a reading of the evidence.

label
The card or sign beside a specimen. Its record lines (name, place found, rock layer, collector, date, catalog number) can be checked; its story lines (age, habits, relatives) are inferences and interpretations.

catalog number
The museum's unique number for a specimen, written on the bone or shell itself, so that any scientist can find the same object again and check what was said about it.

cast
A copy of a bone made in plaster or resin from a mold of the real bone. Many mounted skeletons are partly or wholly casts, painted to look like fossil bone.

docent
A trained volunteer or staff guide who answers questions in the halls. A docent is your host; a curator is the scientist in charge of a collection.

floor plan

A scale map of the museum’s halls. Its scale bar lets you turn centimeters on the map into meters in the building.

CORE IDEAS

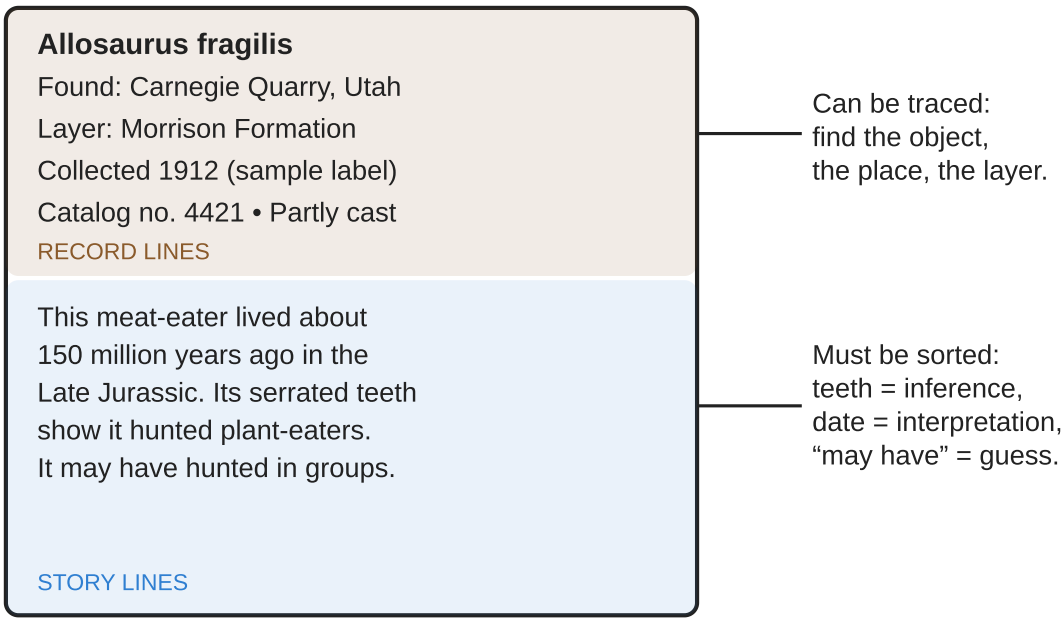
The story. In the summer of 1801 the painter Charles Willson Peale left his museum in Philadelphia and traveled to a farm near Newburgh, New York, where huge bones had been pulled out of a wet marl pit. Peale bought the bones already found and the right to dig for more, built a great wooden wheel that drove a chain of buckets to drain it, and set farmhands digging in the mud. By December he had carried the bones home and, with his son Rembrandt, mounted the skeleton on an iron frame. It was the first mounted fossil skeleton in America and one of the first anywhere. Peale called it a mammoth; later anatomists, led by Georges Cuvier in Paris, separated the mastodon, with its cone-topped grinding teeth, from the true mammoth, with its flat, ridged teeth. So even the first great museum label in America used a word that later had to be changed. In 1802 Peale moved his museum into the Long Room on the upper floor of the Pennsylvania State House, the building we now call Independence Hall. He arranged birds, minerals and bones in the order of Linnaeus, each with a label, and printed on his admission tickets a line from Job: the birds and beasts will teach thee. Twenty years later he painted himself lifting a curtain to show the visitor his Long Room, with the mastodon waiting in the shadows behind him.

How they figured it out. A museum is organized so that a careful visitor can find things and check them. Halls are grouped by theme; cases hold small specimens; mounts stand on platforms; dioramas put casts and models into painted scenes. Beside every specimen is a label, and a label has two kinds of lines. The **record lines** tell what the object is, where it was found, which rock layer it came from, who collected it and when, and its **catalog number**. These are the museum’s promise that the object can be traced. The **story lines** say how old it is, how it lived and what it is related to. In Lesson 3.1 you learned to sort those into observations, inferences and interpretations. Learn one more habit now: look for the word *cast*. A large mount is often a mixture of real bone and painted copies, and a small note, or a docent, will tell you which is which. A cast is a true copy of a real bone somewhere else, but it is not evidence you can measure for yourself, and your log should say so.

The big idea. Louis Agassiz, whom you met in Unit 5, used to set a new student in front of a preserved fish and leave him alone with it for days. Look at your fish, he said, until you have seen it. A museum visit is the same test. Ten specimens logged carefully teach more than a hundred glanced at. So pack a **field kit**: a notebook with a stiff back, two pencils, a small tape measure, a hand lens, and an **observation log** ruled into five columns. Column 1: specimen and catalog number. Column 2: what I observe, with a measurement. Column 3: what the sign claims, in its own words. Column 4: which kind of claim it is. Column 5: my question. Most mounts cannot be touched, so you will measure with your eyes and feet. Before the trip, pace a 10 m course three times and work out your pace length in meters, as in the worked examples. In the hall, walk the length of the skeleton along the rail, count your paces and multiply. Then compare with the number on the sign. Your estimate will usually land within a few percent, and when it does not, that is worth a question.

Try it and see. Divide the trip into three parts. *Before:* open the museum's website, print or sketch the floor plan, and pick three halls, usually fossils, minerals and rocks, and one hall you simply love. Measure the scale bar and work out how big each hall really is. Write a time budget: a three-hour visit, minus coat check, lunch and the shop, leaves about forty minutes per hall. Read the museum's rules about bags, photographs and touching. *During:* fill the log, make one quick sketch per hall with a scale bar, and photograph each label you copy if photographs are allowed, so you can check your copy later. Ask a docent one real question, and write the answer with the docent's own words. *After:* within a day, while you still remember, clean up the log, finish the sketches and start the report you will write in Lesson 8.4. Remember that a museum is someone's house. Curators spent years preparing what you are seeing, and creation geologists study the very same specimens. Be the kind of guest who makes them glad they opened the door.

God's handiwork. Peale believed a museum was a school of the Creator's works, which is why his ticket quoted Job. Solomon said that it is the glory of God to conceal a thing and the honor of kings to search out a matter. Every drawer in a museum is a thing searched out: a shell sorted, a bone numbered, a mineral weighed. When you walk in with a ruled notebook and a tape measure, you join that work. You are not there to argue with the signs. You are there to see what God made, to record it honestly, and to read the signs with the care they deserve.



Two kinds of lines on one label. The record lines are the museum's promise that the object can be traced. The story lines are the museum's reading of it, and they are the lines that change over time.

⏳ Thinking About Time

What the sign says. What the sign says: labels on American mastodon mounts, like the one Peale dug up in 1801, usually read "Mammut americanum, Pleistocene," and say the

animals died out about 10,000 to 13,000 years ago at the end of the Ice Age, with dates from carbon-14 measured in the bone.

What we observe. What we observe: large skeletons with cone-topped teeth, buried in marl and peat bogs of the northeastern United States that lie on top of glacial deposits; bone that still contains enough original material to measure carbon-14; and tusks and ribs that can be measured directly.

How Christians read it. How Christians read it: creation geologists place these animals in the single Ice Age that followed the Flood of Genesis, a few thousand years ago, when the bogs that trapped them formed as the ice melted. The carbon-14 ratio is a real measurement; turning it into a calendar date depends on assumptions about the starting amount of carbon-14 in the air, which Unit 7 taught you to name.

Try it. Find a mastodon or mammoth label on a museum website and copy it into your log, sorting its record lines from its story lines.

Genesis 8:22

PICTURE STUDY



The Artist in His Museum, Charles Willson Peale, 1822 · Oil on canvas · Pennsylvania Academy of the Fine Arts, Philadelphia

Charles Willson Peale was eighty-one when he painted this picture of himself. He had painted George Washington from life, fought in the Revolution, and spent forty years building the first great museum in the United States. Here he lifts the curtain on his Long Room in the Pennsylvania State House and invites you in.

Look closely and you will find the lesson of this unit in paint. Everything is sorted, cased and labeled. The mastodon bones at the front are specimens; the huge skeleton glimpsed behind the curtain is the mount; the rows of cases are the record. Peale is the docent, and you are the visitor with a notebook.

Look closely

- Find the mastodon bones at the lower right and the mounted skeleton half hidden behind the curtain at the back. Why do you think Peale shows the bones in front and the mount behind?
- Look down the length of the gallery. How are the cases of birds arranged, and what do you notice about the portraits above them?
- Find the wild turkey on the floor and the painter’s tools beside it. What two kinds of work did Peale do in one building?
- Peale painted the room with strict perspective, every case shrinking toward one point. How does that choice make the museum feel orderly?

Talk about it

1. Peale called his skeleton a mammoth, and the label later had to be changed to mastodon. Does one wrong word on a label mean the bones were wrong? What was wrong, and what was not?
2. Peale put a verse from Job on his tickets. Why might a museum founder want visitors to think about the Creator while they look at birds and bones?
3. If you could add one object from your home museum to Peale’s Long Room, what would its label say?

EXPERIMENT: CALIBRATE YOUR PACE AND BUILD YOUR FIELD TRIP GUIDE

Before you can measure a skeleton with your feet, you need to know how long your step is and how much it wobbles. In this experiment you will calibrate your pace, test it on a known length, and then assemble the guide you will carry into the museum.

Question: how consistent is my pace length, and can I measure a 4 m object by pacing to within 10 percent? Prediction: write yours before you start. What we change: walking speed, normal and slow. What we keep the same: the floor, the shoes, the starting line. What we measure: paces per 10 m course, three trials at each speed, and the error on a 4 m test length.

You will need

- A tape measure or a meter stick
- Masking tape or chalk to mark a 10 m course on a hallway, sidewalk or driveway
- A 4 m length of string or rope laid straight on the floor (your practice skeleton)
- Your lab notebook and a pencil
- The floor plan of the museum you will visit, printed from its website, or a sketch of it

- A calculator

Steps

1. Measure and mark a straight 10 m course. Rule a table in your notebook with columns: Speed, Trial, Paces, Pace length (m).
2. Walk the course at your normal speed, counting every step. Record the paces. Repeat for three trials. Then walk it slowly, three more trials.
3. For each trial, pace length = 10 m ÷ paces. Find the mean pace length for each speed and the range (largest minus smallest).
4. Lay out the 4 m rope without looking at the tape. Pace its length at normal speed, multiply by your mean pace length, and record the estimate. Find the percent error: (estimate − 4 m) ÷ 4 m × 100. Repeat twice more.
5. Write a conclusion: which speed gave the smaller range, and was your 4 m estimate within 10 percent? If not, practice until it is.
6. Now build the guide. On the floor plan, measure the scale bar and write the scale as “1 cm = ___ m.” Circle three halls and draw your route. Work out each hall’s real length and width from the map.
7. Write a time budget for the visit in minutes: entry and coat check, hall 1, hall 2, hall 3, lunch, shop and exit. Check that the minutes add up to the time you have.
8. Rule an observation log with five columns and ten rows per hall: Specimen and catalog number; What I observe (with a measurement); What the sign claims (its own words); Kind of claim (O, I or P); My question.
9. Add a page listing your field kit and the museum’s rules about bags, photographs and touching. Clip the floor plan, time budget and log together. That is your field trip guide.

Tips

- Count paces with a quiet tally, touching a finger for every ten, so you do not lose count when something interesting catches your eye.
- If no museum visit is possible this month, plan the guide for a museum with an online tour or a 3D collection, and use the worked examples to practice on its floor plan.

Check your work

- I recorded six trials, a mean pace length for each speed, and a range.
- My 4 m estimate was within 10 percent, or I know why it was not.
- My guide has a scaled floor plan with a route, a time budget that adds up, and a ruled observation log.

FIELD NOTEBOOK

1. Draw the floor plan of the museum you will visit, with the scale bar, your three halls shaded and your route marked with arrows and times.
2. Copy one real specimen label from a museum website in your best lettering. Box the record lines in one color and the story lines in another.

3. Draw your field kit laid out on a table, each item labeled with one sentence saying what it is for.

From history. Peale’s museum did not outlive him long. After his death in 1827 the collections were sold off in pieces, and many of them ended up with the showman P. T. Barnum, whose American Museum in New York burned in 1865. The mastodon itself passed from hand to hand across the Atlantic and stands today in the Hessian State Museum in Darmstadt, Germany, still traceable, two centuries later, because it was a recorded specimen and not just a story.

WORKED EXAMPLES

Example 1. You walk a 10 m course three times and count 16, 17 and 16 paces. In the museum you walk the full length of a Diplodocus mount along the rail and count 42 paces. The sign says 26 m. What is your pace length, your estimate of the mount’s length, and the percent difference from the sign?

1. Mean paces for 10 m = (16 + 17 + 16) ÷ 3 = 49 ÷ 3 = 16.3 paces.
2. Pace length = 10 m ÷ 16.3 paces = 0.61 m per pace.
3. Mount length = 42 paces × 0.61 m = 25.6 m.
4. Difference from the sign = 26 − 25.6 = 0.4 m. Percent difference = 0.4 ÷ 26 × 100 = 1.5%.

Answer: Pace length about 0.61 m; the mount is about 25.6 m by pacing, within 1.5% of the sign’s 26 m.

Example 2. On a printed floor plan the scale bar is 2 cm long and labeled 10 m. The fossil hall measures 9.0 cm by 5.0 cm on the plan, and a skeleton drawn in it is 2.4 cm long. What is the scale, the real size of the hall, and the real length of the skeleton?

1. Scale: 2 cm stands for 10 m, so 1 cm stands for 5 m. Written as a ratio, 1 cm : 500 cm, or 1 : 500.
2. Hall length = 9.0 cm × 5 m per cm = 45 m. Hall width = 5.0 cm × 5 m per cm = 25 m.
3. Skeleton length = 2.4 cm × 5 m per cm = 12 m.
4. Check: a 12 m skeleton in a 45 m hall takes about a quarter of the hall’s length, which is reasonable.

Answer: Scale 1 : 500 (1 cm = 5 m). The hall is 45 m by 25 m, and the skeleton is 12 m long.

Example 3. A sign gives a Tyrannosaurus mount as 12.0 m long with a thigh bone (femur) 1.30 m long. In the next hall a smaller meat-eater of similar build has a femur 0.85 m long, but the sign gives no total length. Use the ratio from the first mount to estimate the second animal's length.

1. Find the ratio of femur to total length on the known mount: 1.30 ÷ 12.0 = 0.108. The femur is about 11% of the body length.
2. If the smaller animal is built in the same proportions, its length = femur ÷ 0.108 = 0.85 ÷ 0.108 = 7.9 m.
3. State the assumption: this works only if the two animals have similar proportions. A long-necked or long-tailed animal would break the ratio, so write "about 8 m, assuming similar build" in your log.

Answer: About 7.9 m, or roughly 8 m, assuming the two animals share the same femur-to-length proportion.

PRACTICE

1. EASY Name four items in a museum field kit and give one sentence on what each is for.
2. EASY A label reads: "Triceratops horridus. Hell Creek Formation, Garfield County, Montana. Collected 1909. Catalog no. 4842. This plant-eater lived 66 million years ago and used its horns in contests with rivals." Which lines are record lines and which are story lines?
3. EASY Who was Charles Willson Peale, what did he dig up in 1801, and what word on his label later had to be changed?
4. MEDIUM You pace a 10 m course in 15 paces. In the hall you count 30 paces along a mount. How long is the mount by your estimate?
5. MEDIUM Data reading. A student with a 0.60 m pace logged three mounts. Diplodocus: 44 paces, sign says 26 m. Triceratops: 12 paces, sign says 8.0 m. Tyrannosaurus: 21 paces, sign says 12.0 m. Compute each paced length and percent difference from the sign. Which mount shows the largest disagreement, and what is the most likely reason?
6. MEDIUM Data reading. Four labels list the following. A: Camarasaurus, Morrison Formation, Utah, catalog 11338, "about 150 million years." B: Allosaurus, Morrison Formation, Utah, catalog 11541, "about 150 million years." C: Edmontosaurus, Hell Creek Formation, Montana, catalog 2414, "about 66 million years." D: Mastodon, bog deposit, New York, catalog 8112, "about 12,000 years." (a) Which two specimens come from the same rock layer? (b) Which column of information rests on assumptions about rates and starting amounts? (c) Which specimen has an age that comes from carbon-14 rather than from volcanic ash?
7. MEDIUM A floor plan is drawn at 1 : 400. A mount measures 6.5 cm on the plan. How long is the mount in meters?
8. HARD Experiment design. You suspect that your pace gets longer when you are looking up at exhibits instead of at the floor. Design an experiment to test it. Name the

question, what you change, what you keep the same, what you measure, and how many trials you will run.

9. HARD You have 2 hours 30 minutes at the museum. Entry takes 10 minutes, lunch 25 minutes, and the shop and exit 15 minutes. You plan three halls of equal time and want to log 8 specimens per hall. How many minutes per hall, and how many minutes per specimen?
10. CHALLENGE Write a short paragraph explaining why a catalog number matters to science, using Peale's mastodon as your example.

COMMON MISTAKES

- Thinking the whole mount is real bone. Many mounts are partly or wholly casts; look for the note, ask the docent, and record which bones you could actually measure if you were allowed to.
- Treating every line on a label as the same kind of statement. The catalog number and the locality are records; the age and the habits are readings of the evidence.
- Trying to see every hall. Ten specimens logged with measurements, sketches and questions are worth more than a hundred glanced at.

> **Make it a game · Record or Story.** A parent reads lines from real museum labels found online, one at a time. Call out "record" if the line names the object, place, layer, collector, date or number, and "story" if it tells the age, habits or relatives. One point for each correct call, and a bonus point if you can say how you would check a record line. First to twelve points wins. Then switch and read the lines yourself.

> **Scripture.** "It is the glory of God to conceal a thing: but the honour of kings is to search out a matter." (Proverbs 25:2, KJV)

A museum is a house of matters searched out: bones numbered, shells sorted, minerals weighed. To go in with a notebook and a tape measure is to take up a king's work with a servant's care.

Practice answers

1. A stiff-backed notebook for the observation log; two pencils because pens smear and may be banned; a small tape measure for things you may touch and for checking the floor plan; a hand lens for small specimens. A ruled observation log and the floor plan complete the kit.
2. Record lines: the name, the formation and county, the collection year and the catalog number. Story lines: the age of 66 million years and the claim about using the horns in contests.
3. A Philadelphia painter who founded the first great American museum. In 1801 he dug up and mounted a mastodon skeleton from a marl pit near Newburgh, New York. He called it a mammoth; later anatomists separated the mastodon from the true mammoth by its teeth.
4. Pace length = 10 ÷ 15 = 0.67 m. Length = 30 × 0.67 = 20 m.
5. Diplodocus 44 × 0.60 = 26.4 m, 1.5% over. Triceratops 12 × 0.60 = 7.2 m, 10% under. Tyrannosaurus 21 × 0.60 = 12.6 m, 5% over. The Triceratops disagrees most. Short lengths

are measured with few paces, so one pace too few makes a large percent error; the student should pace short mounts twice and average.

6. (a) A and B, both from the Morrison Formation. (b) The age column. (c) D, the mastodon; carbon-14 is measured in the bone itself and is used only for ages the museum counts in thousands of years, while the ash-bed methods give the millions-of-years numbers.
7. 6.5 cm × 400 = 2,600 cm = 26 m.
8. Question: does looking up change my pace length? Change: where I look, floor versus up at a high shelf or ceiling. Keep the same: the 10 m course, shoes, normal speed, same day. Measure: paces per 10 m, then pace length. Trials: at least three each way, then compare the mean pace lengths; if the difference is bigger than the range within each set, the effect is real.
9. Total 150 minutes. 150 − 10 − 25 − 15 = 100 minutes for halls. 100 ÷ 3 = 33 minutes per hall. 33 ÷ 8 = about 4 minutes per specimen.
10. A catalog number ties a specimen to its record so that anyone can find the same object and check what was said about it. Peale’s skeleton was labeled a mammoth; because the bones were kept and could be examined again, later anatomists compared the teeth with mammoth teeth, found the cone-topped pattern, and corrected the name to mastodon. Without a traceable specimen the label could never have been checked, and a wrong story could have lasted forever.

8.2 What the Sign Says, What We Observe: The Skull That Changed

OBJECTIVES

- Tell the story of the Carnegie Museum's Apatosaurus and explain why its sign changed three times while its bones did not.
- Fill a three-column box, "What the sign says / What we observe / How Christians read it," for a real museum sign, quoting the sign exactly and dating the copy.
- Explain what a laboratory actually measures when a sign gives an age in millions of years, and name the three assumptions that turn the measurement into a date.

Warm-up. Take a photograph or drawing of any animal and cover its head with your hand. Ask a family member to describe the animal from what is left: size, legs, tail, build. Now uncover the head. How much did the head change the description? Museums have faced exactly this problem with skeletons found without skulls.

Video. Coming soon. Search for the story of the Apatosaurus and Brontosaurus skull mix-up and the 1979 skull switch at the Carnegie Museum of Natural History, and for a tour of the Quarry Exhibit Hall at Dinosaur National Monument. Good sources: National Park Service, Carnegie Museum, Smithsonian, SciShow, PBS Eons for the mainstream account, Moody Science classics.

KEY TERMS

claim
A statement that something is true. A sign is a stack of claims; a good reader sorts them by how each one could be checked.

observation
A claim you could check with your senses or an instrument: this bone is 1.3 m long; these teeth are serrated; the skeleton lay in sandstone.

inference
A conclusion drawn by comparing observations with living things or with experiments: serrated teeth mean a meat-eater; hollow neck bones mean a lighter neck.

interpretation
A reading that depends on a framework and its assumptions: an age of 150 million years, or a claim about what the animal descended from.

framework
The set of starting assumptions a person brings to the evidence, such as "rates have always been as they are now" or "Genesis 6 to 9 is history." Two people with the same bones and different frameworks will write different story lines.

Jurassic

A museum word: the name geologists give to a set of rock layers found around the world, named for the Jura Mountains of France and Switzerland. On a sign it comes with a date; the name itself only labels the layers.

CORE IDEAS

The story. In August 1909 Earl Douglass, a collector for the Carnegie Museum of Natural History in Pittsburgh, found eight tail bones of a giant sauropod weathering out of a sandstone ridge near Jensen, Utah. The ridge became the Carnegie Quarry, and in 1915 the quarry became Dinosaur National Monument. The best skeleton from it, an *Apatosaurus*, was shipped to Pittsburgh and mounted in 1915 without a head, because no skull was found attached to the neck. The museum's director, William Holland, believed a slender, Diplodocus-like skull found nearby belonged to it, but the leading experts of the day disagreed, so the mount stood headless for years. Soon after Holland died in 1932, the museum gave the skeleton a cast of a boxy, blunt-snouted skull like that of *Camarasaurus*, matching what the American Museum in New York had put on its own famous "Brontosaurus" mount back in 1905. There the matter rested for almost fifty years. Then, in 1978, two Carnegie scientists, David Berman and John McIntosh, went back through the quarry records and the bones and showed that Holland had been right all along. In 1979 the museum lifted the wrong skull off and set the slender one on. The sign changed. The bones in the body had not changed at all.

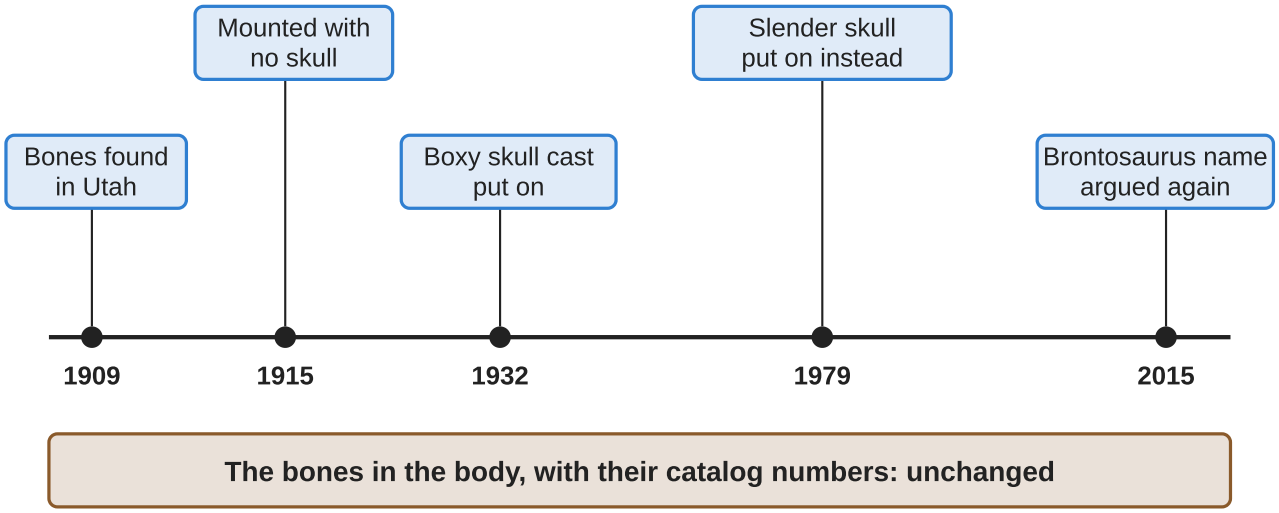
How they figured it out. Berman and McIntosh did what this lesson asks you to do: they separated what was observed from what had been assumed. The observation was that a Diplodocus-like skull lay in the quarry close to the neck of the Apatosaurus skeleton, as the dig maps showed. The assumption, made in New York in 1905 and copied for decades, was that such a huge, heavy body must have carried a heavy skull. The assumption had been printed on signs so long that it felt like a fact. The same lesson had been taught twice before. In 1903 Elmer Riggs of the Field Museum decided that Marsh's *Brontosaurus* was really a grown-up *Apatosaurus*, so the name on many signs changed, though the New York mount kept its old label for decades. In 2015 a team led by Emanuel Tschopp measured hundreds of bone features and argued that *Brontosaurus* deserved its own name after all. Some signs changed again. Notice what did not move in any of this: the bones in the drawers, with their catalog numbers, which every one of those scientists went back to.

The big idea. A museum sign is the museum's current best reading of a specimen, written by people, and it can be revised. That is not a scandal; it is how science is supposed to work. But it means you should read a sign with a pencil. Underline the verbs. "Was found," "measures," "lay in sandstone" mark **observations**. "Ate plants," "walked on four legs," "weighed about 20 metric tons" mark **inferences**, conclusions drawn by comparing bones with living animals and with formulas, and good scientists on both sides of the age question usually agree with them. "Lived 150 million years ago," "evolved from," "ancestor of" mark **interpretations**, which depend on a **framework** of assumptions. Now ask the key question of the date: what did the laboratory actually measure? Not years. It measured a ratio of atoms, usually argon to potassium, in crystals from volcanic ash beds in the Morrison Formation. The sign's number comes out only after three assumptions are added: a known

starting amount, a constant decay rate, and a crystal that neither gained nor lost atoms since it formed. You tested those assumptions in Unit 7. The measurement is real; the date is the measurement plus the framework. Copy the sign's words exactly, in quotation marks, and write the date you copied them, because the sign may not say the same thing next year.

In the world today. Drive to Dinosaur National Monument and you can see the quarry Douglass opened. The Quarry Exhibit Hall, rebuilt in 2011, encloses a tilted wall of sandstone with about 1,500 bones left in place. Stand at the rail and observe: bones from many animals of several kinds, jumbled, mostly pulled apart, mixed with logs, packed into one bed of sand. The National Park Service sign reads this as the deposit of an ancient river that gathered carcasses onto a sandbar. Creation geologists read the same wall as a deposit of fast-moving water during the Flood year or its aftermath. Look carefully at how much the two readings share. Both say the animals were carried by water and buried quickly, because a jumbled bed of whole and partial skeletons cannot form slowly. They part company on when and on how big the water was. A three-column box for this wall is mostly a list of agreements, with the real disagreement confined to the last line. That is true of most signs, and knowing it will make you both more accurate and more fair.

God's handiwork. Whichever skull sits on it, the Carnegie Apatosaurus is a marvel of engineering that you can observe directly. Its neck bones are scooped out into thin walls and deep hollows, which in life held air sacs, so that a neck several meters long weighed a fraction of what solid bone would weigh. The tall spines on the back vertebrae anchored the cables of muscle and ligament that held the neck and tail out like the arms of a crane. Hips and leg bones are solid columns. None of this appears on a sign as a date; all of it appears in the bones, and it was there before anyone wrote a label. The psalmist said the works of the Lord are great, sought out of all them that have pleasure therein. A long neck held up by hollow bones is one of those works.



Story lines above the line changed; the specimen below it did not.

What the Carnegie Museum's sign said about its Apatosaurus, decade by decade. The story lines moved; the specimen did not.

⏳ Thinking About Time

What the sign says. What the sign says: labels on Morrison Formation sauropods such as Apatosaurus read “Late Jurassic, about 150 million years ago,” a number obtained by measuring argon and potassium in crystals from volcanic ash beds between the bone-bearing layers.

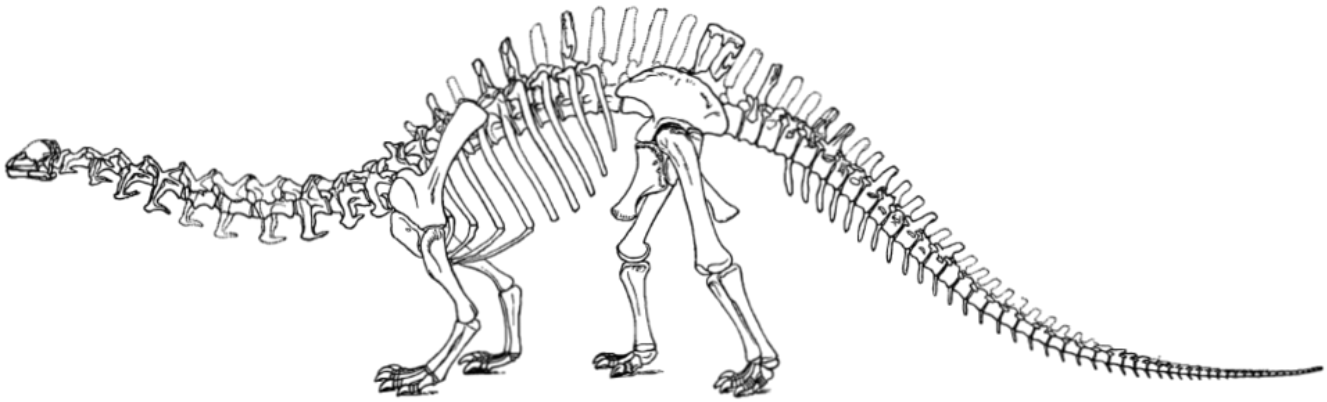
What we observe. What we observe: bones of many animals jumbled together in beds of sandstone and mudstone; ash layers above and below; measured ratios of argon to potassium in ash crystals; and bones hollowed and shaped in ways we can trace with a finger.

How Christians read it. How Christians read it: creation geologists read the Morrison bone beds as burial by fast-moving water during the Flood of Genesis and its aftermath, a few thousand years ago. The jumbled, water-sorted bones fit rapid burial, which both sides accept. The argon ratios are real measurements; the date follows only if the starting amount, the rate and a closed crystal are assumed, and Unit 7 showed each assumption can fail.

Try it. Copy one sauropod label from a museum website into a three-column box, with the sign’s words in quotation marks and today’s date.

Genesis 7:19

PICTURE STUDY



Restoration of Brontosaurus excelsus. Marsh. One-eighteth natural size.

Restoration of Brontosaurus excelsus, Othniel Charles Marsh (plate published under his direction), 1883 · Printed plate from the American Journal of Science · Published in New Haven, Connecticut, in the American Journal of Science; copies in libraries worldwide

Othniel Charles Marsh of Yale named Brontosaurus in 1879 from bones dug at Como Bluff, Wyoming. Four years later he published this plate, the first attempt anyone had made to

draw a whole sauropod skeleton standing up. It became the picture of a dinosaur for a generation of readers and guided the first mounted sauropods in museums.

It is also a museum sign in picture form. The vertebrae, limbs and hips were drawn from real bones. The head was drawn from skull bones found at a different site, which later proved to belong to another kind of sauropod. For almost a century the wrong head stayed on, in print and in halls, until scientists went back to the quarry records.

Look closely

- Trace the line of the back from the skull to the tip of the tail. Where are the bones tall and heavy, and where are they slender?
- Look at the skull. It is short and boxy. Compare it with a photograph of a modern Apatosaurus mount, whose skull is long and low. What would change about the animal’s face?
- Count the neck vertebrae you can see. How many does the plate show? Which bones look drawn from real specimens and which look filled in?
- Notice that Marsh drew every bone in outline with no flesh, no scene and no scale figure. Why might a scientist choose to draw it this way?

Talk about it

1. Which parts of this plate were observations and which were assumptions? How would you have told the difference in 1883?
2. Marsh could not have known the skull was wrong. Was it wrong of him to draw it? What should a careful scientist write beside a bone he has had to borrow from elsewhere?
3. If you drew a restoration of a skeleton from your own museum visit, how would you mark the bones you did not actually see?

> **Safety first.** Use a shallow pan outdoors or in a sink, wipe up spills at once so no one slips, and wash hands after handling sand and bones. Do not use raw bones; boil and dry chicken bones first or use clean sticks.

EXPERIMENT: DO MOVING WATERS LINE BONES UP? A THREE-COLUMN BOX YOU CAN TEST

At Dinosaur National Monument the sign says the bones were carried and sorted by water. Geologists on both sides accept this partly because moving water lines up long objects in a measurable way. You can test that claim in a pan and then write a three-column box for the real quarry wall.

Question: do long objects dropped into flowing water line up with the current? Prediction: write yours first. What we change: the speed of the water, a trickle and a steady pour. What we keep the same: the sand bed, the set of objects, the number dropped, the way they are

dropped. What we measure: how many objects end up within 20 degrees of the flow direction, using a protractor.

You will need

- A shallow baking pan or paint tray, propped up at one end on a book
- Play sand or clean soil to make a bed 1 to 2 cm deep
- Ten clean chicken bones, boiled and dried, or ten short sticks or toothpicks of similar length
- A pitcher of water and a cup
- A protractor, a ruler, a pencil and your lab notebook
- A printed photograph of the Quarry Exhibit Hall wall from the National Park Service website

Steps

1. Spread the sand bed in the pan and raise one end so water will flow from top to bottom. Draw an arrow on the pan rim showing the flow direction.
2. Scatter the ten bones onto the sand at random angles. With the protractor, measure the angle of each bone from the flow direction and record the ten angles. Count how many are already within 20 degrees of the flow. That is your starting count.
3. Trickle water slowly from a cup at the top for 60 seconds. Let it drain. Measure the ten angles again and count how many are within 20 degrees of the flow.
4. Reset the bones at random, record the starting angles, then pour steadily from the pitcher for 60 seconds. Measure and count again.
5. Repeat each speed twice more and average the counts. Make a small bar graph: trickle versus steady pour, bones aligned out of ten.
6. Now look at the quarry-wall photograph. Draw the flow direction the Park Service sign proposes and estimate how many long bones lie near it. Write the three-column box: What the sign says (quoted, dated), What we observe (your counts and the wall), How Christians read it.
7. Write a conclusion: did water align the bones, and did faster water align more? Which lines of your box do both readings share, and which line is the real disagreement?

Tips

- If the sand washes away, use a little less slope or a gentler pour. Note it in your log; a washed-out bed is a result too.
- Keep the three columns honest. The sign’s column must say what the sign says, even the parts you read differently.

Check your work

- I recorded angles before and after for six runs and averaged the aligned counts for each speed.
- My bar graph shows whether faster water aligned more bones.

- My three-column box quotes the sign exactly, with a date, and separates agreements from the real disagreement.

FIELD NOTEBOOK

1. Draw the Carnegie Apatosaurus twice in outline, once with the boxy skull it wore from 1932 to 1979 and once with the slender skull it wears now, and write the year under each.
2. Make a three-column box for one sign from a museum website. Underline the verbs on the sign in three colors for observation, inference and interpretation.
3. Sketch one of your bone-alignment runs before and after the water, with the flow arrow and the angles written beside three of the bones.

From history. The American Museum of Natural History in New York unveiled its Brontosaurus in 1905, the first mounted sauropod skeleton in the world, with a skull modeled on the boxy Camarasaurus pattern. The mount kept that head, and its old name, for ninety years. When the museum rebuilt its fossil halls in 1995, it remounted the skeleton with a slender Diplodocus-type skull and relabeled it Apatosaurus. Then, in 2015, a study measuring hundreds of bone features argued that Brontosaurus was a separate genus after all, and the name that had been dropped in 1903 came back into use. Signs keep moving; specimens stay in their drawers.

WORKED EXAMPLES

Example 1. A sauropod sign reads: “This skeleton was excavated from sandstone in Utah in 1909. It is 22 m long. Its spoon-shaped teeth show it stripped leaves from branches. It weighed about 20 metric tons. It lived 150 million years ago, in the Late Jurassic.” Sort the five sentences and find what fraction of the sign you could check with an instrument or a comparison with living animals.

1. Sentence 1, excavated from sandstone in 1909: observation, checkable against the dig records and the rock on the bones.
2. Sentence 2, 22 m long: observation, checkable with a tape measure or by pacing.
3. Sentence 3, teeth show leaf stripping: inference, checkable by comparing the teeth with living browsers.
4. Sentence 4, about 20 metric tons: inference, from a formula that relates leg-bone circumference to body mass in living animals.
5. Sentence 5, 150 million years ago: interpretation, resting on dating assumptions.
6. Checkable by instrument or comparison: 4 of 5 sentences = $4 \div 5 = 0.80$, or 80%. Only the date needs a framework.

Answer: Two observations, two inferences, one interpretation. 80% of the sign is checkable by measuring or comparing; the date is the one line that rests on a framework.

Example 2. A sign says an Apatosaurus neck was about 6 m long and contained 15 neck vertebrae. Your own neck has 7 vertebrae in about 12 cm. What is the average length of one Apatosaurus neck vertebra, one of yours, and the ratio between them?

1. Apatosaurus: 6 m = 600 cm. 600 cm ÷ 15 vertebrae = 40 cm per vertebra.
2. You: 12 cm ÷ 7 vertebrae = 1.7 cm per vertebra.
3. Ratio: 40 ÷ 1.7 = 23.5. Each of its neck bones was about 23 times the length of one of yours.
4. Note the kind of claim: both lengths are observations or simple measurements, so people on both sides of the age question will accept this ratio.

Answer: About 40 cm per Apatosaurus vertebra and 1.7 cm per human vertebra, a ratio of roughly 23 to 1.

Example 3. The sign's date of 150 million years came from potassium-40, which has a half-life of about 1.25 billion years. (a) How many half-lives is 150 million years? (b) About what fraction of the original potassium-40 would remain after that time? (c) What did the laboratory actually measure, and what had to be assumed?

1. (a) 150 million ÷ 1,250 million = 0.12 half-lives. The claimed age is a small fraction of one half-life.
2. (b) After 1 half-life, 1/2 remains; after 2, 1/4; after 3, 1/8. After only 0.12 of a half-life, far more than half remains: about 92%, so about 8% of the potassium-40 would have turned into argon-40.
3. (c) The laboratory measured the ratio of argon-40 to potassium-40 in the ash crystals today. To turn that ratio into years it assumed the crystals started with no argon, that the decay rate never changed, and that no argon leaked in or out. Unit 7.4 showed rock formed in 1986 giving argon ages of hundreds of thousands of years, which is what happens when the first assumption fails.

Answer: (a) 0.12 half-lives. (b) About 92% remains, 8% decayed. (c) A present-day argon-to-potassium ratio was measured; the starting amount, a constant rate and a closed crystal were assumed.

PRACTICE

1. EASY In what year did the Carnegie Museum replace the skull on its Apatosaurus, and which two scientists showed the old skull was wrong?
2. EASY Sort each as observation (O), inference (I) or interpretation (P): (a) "The femur is 1.8 m long." (b) "It is the ancestor of later sauropods." (c) "Hollow neck bones made the neck lighter." (d) "The bones lay in a sandstone bed with logs."
3. EASY Why should you write the date on your copy of a museum sign?

4. MEDIUM Data reading. The Carnegie sign history: no skull 1915 to 1932; boxy skull 1932 to 1979; slender skull 1979 to the present (count to 2026). For how many years did each version stand? What percent of the mount's life so far did it wear the wrong skull?
5. MEDIUM A sign gives a mass of "about 20 metric tons" from a leg-bone formula. A second formula, using a different set of living animals, gives 16 metric tons. What is the percent difference between the two estimates, using the sign's figure as the base? What kind of claim is a mass estimate?
6. MEDIUM Data reading. A student at a quarry wall measured the angle of 40 long bones from the direction the sign gives for the ancient current. Results: 0 to 20 degrees, 22 bones; 21 to 45 degrees, 9 bones; 46 to 70 degrees, 5 bones; 71 to 90 degrees, 4 bones. (a) What percent of bones lie within 20 degrees of the current? (b) If the bones had settled at random, about what percent would you expect in each of the four bins? (c) Does the data support water alignment?
7. MEDIUM Uranium-238 has a half-life of about 4.5 billion years. A sign gives an age of 150 million years from uranium-lead dating. How many half-lives is that, and roughly what fraction of the uranium-238 would have decayed?
8. HARD Experiment design. A sign says ripple marks in a sandstone slab "formed slowly on a calm ancient seabed." Design a pan experiment to test how quickly ripple marks can form in sand under moving water. State the question, what you change, what you keep the same, what you measure, and what result would count against the word "slowly."
9. HARD Explain in a paragraph why the skull mix-up is not a reason to distrust museums, and why it is a reason to read signs carefully. Use the words observation and assumption.
10. CHALLENGE Write a complete three-column box for the Quarry Exhibit Hall wall at Dinosaur National Monument. Column 1: what the Park Service sign says. Column 2: what a visitor observes. Column 3: how creation geologists read it. Then underline the one line where the two readings truly differ.

COMMON MISTAKES

- Thinking the laboratory measured years. It measured a ratio of atoms today; the years come from the ratio plus assumptions.
- Treating every line on a sign as disputed. Most lines are observations and inferences both sides accept; the disagreement is usually confined to the date and the family tree.
- Thinking a corrected sign means the bones were wrong. The bones never changed; the reading of them did, and that is what careful readers expect.

> **Make it a game · Verb Hunt.** A parent reads a real museum sign aloud, one sentence at a time, from a museum website. On each sentence, hold up one finger for observation, two for inference, three for interpretation, before the parent finishes the next sentence. Score a point for each right call and a bonus if you can name the verb that gave it away. Then trade places. Play three signs; the higher total wins.

> **Scripture.** “Prove all things; hold fast that which is good.” (1 Thessalonians 5:21, KJV)

To prove, in the old sense, is to test. A museum sign deserves neither blind trust nor scorn, but testing: sort it, measure what you can, and keep what stands.

Practice answers

1. In 1979, after David Berman and John McIntosh published their study in 1978.
2. (a) O, (b) P, (c) I, (d) O.
3. Because signs are revised. The Carnegie sign changed in 1932, 1979 and after 2015, so a dated copy records what the museum claimed at the time you read it.
4. No skull 17 years; boxy skull 47 years; slender skull 47 years. Total 111 years. Wrong skull: 47 ÷ 111 × 100 = 42%.
5. 20 − 16 = 4; 4 ÷ 20 × 100 = 20% difference. It is an inference, drawn from comparison with living animals, so it carries a range and is not a direct measurement.
6. (a) 22 ÷ 40 × 100 = 55%. (b) The bins are not equal width, but roughly: 0–20 is 20 of 90 degrees, so about 22%; the others about 28%, 28% and 22%. (c) Yes; 55% in the narrowest bin is far above the 22% random expectation, so a current aligned the bones, a point both readings share.
7. 150 ÷ 4,500 = 0.033 half-lives. Only about 2% would have decayed, so the date rests on measuring a very small amount of lead and assuming none was there at the start.
8. Question: how fast do ripples form in sand under flowing water? Change: water speed, slow trickle versus steady pour. Keep the same: sand depth and type, pan slope, run time. Measure: the time until ripples first appear and the ripple spacing in centimeters, three trials per speed. If clear ripples form within a minute or two at ordinary speeds, that counts against “slowly”; ripples might still form slowly elsewhere, but they do not require it.
9. The mix-up happened because an assumption, that a heavy body needed a heavy skull, was printed as if it were an observation, and it was corrected by museum scientists who went back to the dig maps and the bones. That shows the system working: the specimens were kept, cataloged and re-examined. But it also shows that any line on a sign may be an assumption in disguise, so a reader should sort each sentence by how it could be checked and should quote and date what the sign says.
10. Sign: an ancient river during the Late Jurassic, about 150 million years ago, gathered carcasses of many dinosaurs onto a sandbar where they were buried. Observe: about 1,500 bones of several kinds of animals, mostly separated, jumbled with logs in one bed of sandstone, many long bones lying in similar directions. Reading: fast-moving water during the Flood year or its aftermath, a few thousand years ago, swept up and buried the animals. Shared lines: water carried the bones; burial was rapid; many animals died together. The underlined difference: when it happened and how large the water was.

8.3 Talking Kindly About It

OBJECTIVES

- Tell how Adam Sedgwick disagreed with Charles Darwin in 1859 and stayed his friend, and name two habits from that story that make disagreement kind.
- Use the six-step conversation ladder (listen, ask, restate, separate, share, thank) to respond to a docent or a sign without mocking either side.
- State the mainstream claim about an age so fairly that a museum scientist would accept the wording, then state the creation reading beside it in one sentence.

Warm-up. Ask a family member to say one sentence about anything they believe about the weather tomorrow. Before you answer, repeat their sentence back in your own words and ask, “Did I get that right?” Then ask one question about how they know. Only then give your own view. Time how long you spent listening versus talking.

Video. Coming soon. Search for a short biography of Adam Sedgwick and his friendship with Darwin, for the story of Lord Kelvin’s debate with the geologists over the age of the earth, and for a museum docent explaining how to ask good questions in a gallery. Good sources: Cambridge Sedgwick Museum, Royal Society, Smithsonian, Moody Science classics, museum education channels.

KEY TERMS

common ground
The claims two people both accept. On a museum sign it is usually most of the observations and inferences, and it should be named before the disagreement is.

steelman
Stating the other person’s claim in its strongest, fairest form, so well that they would sign it. The opposite of a strawman, which is a weak version set up to be knocked down.

restate
Saying back what someone claimed in your own words and checking that you got it right, before you answer.

framework
The starting assumptions a person brings to evidence. Naming your own framework out loud (“I read Genesis 6 to 9 as history”) is honest and lets the other person name theirs.

meekness
Strength under control. In the Bible it is the manner in which a Christian is told to give a reason for his hope: firm about the truth, gentle with the person.

docent
A museum guide who answers visitors’ questions. A docent is at work and is your host, so ask one good question and thank them.

CORE IDEAS

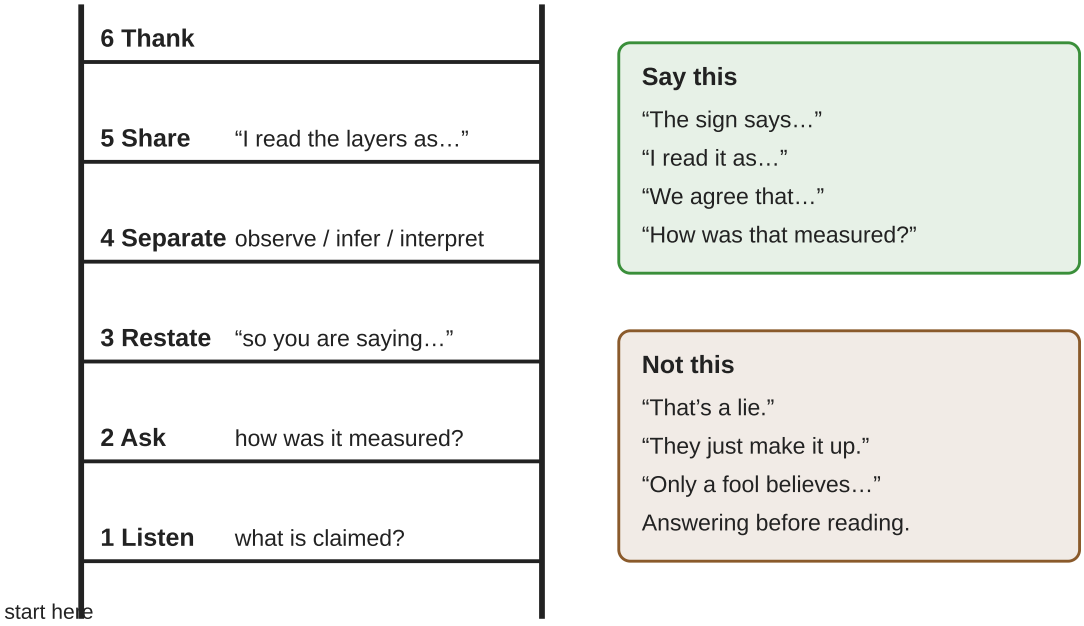
The story. In November 1859 a parcel arrived at Trinity College, Cambridge, for Adam Sedgwick, the seventy-four-year-old Woodwardian Professor of Geology. It was a copy of *On the Origin of Species*, sent by the author. Sedgwick had known Charles Darwin since Darwin was a student. In August 1831, just before the *Beagle* sailed, he had taken the young man on a walking tour of North Wales to teach him how to read rock layers in the field. Sedgwick was a clergyman as well as a geologist, the man who had named the Cambrian rocks of Wales, and he believed firmly that the world was made and governed by God. He read the book at once and wrote back on November 24. He told Darwin he had read it with more pain than pleasure. Parts of it he admired greatly; parts made him laugh until his sides ached; and parts he read with real sorrow because he thought them false and harmful. He explained why, point by point, in plain words. Then he signed himself as Darwin's old friend, with a joke about being a son of a monkey. Darwin wrote back two days later with warmth and without anger. The two men never agreed, and they never stopped being friends. When Darwin visited Cambridge in 1870, the old professor, then in his eighties, walked him around the geology museum for hours.

How they figured it out. Sedgwick's letter is a model for a hard conversation because it did four things at once. It was honest: he did not pretend to agree. It was specific: he named the exact claims he rejected and the ones he admired. It was warm: it began and ended in friendship. And it named his framework: he said openly that he read the world as the work of a Creator. Neither man mocked; neither said the other was stupid or lying. Your conversations will be shorter, at a rail in a museum, with a docent who has thirty seconds and a sign that cannot answer back. The same four habits fit in thirty seconds. Here is a six-step **ladder** to climb. *Listen*: what does the sign or the person actually claim? *Ask*: how was that measured? What would change your mind? *Restate*: "So you are saying the date comes from the ash beds, not the bones?" *Separate*: which parts are observations, which are inferences, which depend on a framework? *Share*: "I read the same layers as a Flood deposit, and here is why." *Thank*: a docent is working, and the museum kept these bones for you.

The big idea. Kindness is not weakness and it is not agreement. It is the manner in which you hold a firm claim. The first rule, from Proverbs, is that answering a matter before you hear it is folly and shame. The second rule is to find the **common ground** before the disagreement. Go back to your three-column boxes from Lesson 8.2. In nearly every one, the observations and the inferences are shared by both readings; the real difference lives in one or two lines about dates and ancestry. Say so out loud: "We agree the animals were buried fast by water. We read the when differently." The third rule is to **steelman**. State the mainstream claim so fairly that a museum scientist would nod. "The sign's date comes from measured argon-to-potassium ratios in ash crystals, using the known decay rate, on the assumption that the crystals began with no argon." Only when you can say that are you ready to add, "I think that assumption is open to question, and here is a measurement that tests it." The fourth rule is to know when to stop. If a docent is busy or a stranger is not interested, write your question in your log and look it up at home. You are a guest, not a debater.

In the world today. Scientists disagree in public all the time, and the best of them do it the way Sedgwick did. From the 1860s to the 1890s William Thomson, later Lord Kelvin, the great physicist and a devout Christian, argued with the geologists of Britain about the age of the earth. From the rate at which the earth loses heat he calculated in 1862 that it could be no more than 20 to 400 million years old, and by 1897 he had narrowed his figure to 20 to 40 million. The geologists wanted far more time for their slow rates of erosion. The argument ran for thirty years in lectures and journals, mostly with courtesy, each side naming its assumptions. Then radioactivity was discovered, heat inside the earth got a new source, and every number on both sides had to be rewritten. Two lessons follow. Even the most expert number rests on assumptions and can move by a factor of a hundred. And people who disagreed about the earth by a factor of ten could still sit in the same room and listen.

God’s handiwork. The apostle James wrote that the tongue is a little member that boasts great things, and that a very small fire kindles a great matter. Speech is one of the gifts that mark human beings as made in God’s image; no other creature in the museum ever argued about a sign. That gift can burn or it can build. Peter told Christians to be ready always to give a reason for the hope that is in them, and in the same breath told them how: with meekness and fear. A quiet question at a rail, a fair restatement, a thank-you to a docent, and a clear sentence about how you read the layers will do more for the truth than a loud victory. Aim for that.



The six-step ladder for a museum conversation. Most of the climb is listening; sharing your own reading comes fifth, and thanks comes last.

⏳ Thinking About Time

What the sign says. What the sign says: a museum’s introductory panel on earth history typically states that the earth is about 4.5 billion years old, a figure first obtained in the

1950s from lead isotopes in meteorites, and that Lord Kelvin’s nineteenth-century estimates of tens of millions of years were too low because he did not know about radioactive heating.

What we observe. What we observe: measured ratios of lead and uranium isotopes in meteorites and in earth rocks; measured decay rates in the laboratory; heat flowing out of the ground at a measurable rate; and a published record of expert estimates that changed by factors of a hundred within a single century.

How Christians read it. How Christians read it: creation geologists hold that the earth was created a few thousand years ago, as Genesis records, and that the isotope ratios are real measurements whose conversion to years depends on assumptions about starting amounts, constant rates and closed systems. The Kelvin story is a reminder, told kindly, that confident numbers have moved before. Anyone who reads the evidence differently should be talked with as Sedgwick talked with Darwin.

Try it. Write the mainstream claim about the earth’s age in two sentences a museum scientist would accept, then your reading in two sentences, and read both aloud in the same tone of voice.

Proverbs 18:13

PICTURE STUDY



A Philosopher Lecturing on the Orrery, Joseph Wright of Derby, about 1766 · Oil on canvas · Derby Museum and Art Gallery, Derby, England

Joseph Wright of Derby painted people learning. In this picture a natural philosopher demonstrates an orrery, a clockwork model of the sun and planets, with a lamp in place of

the sun so that the listeners can see how eclipses happen. The light that falls on every face comes from the lamp at the center, which you cannot see.

Look at how the people listen. No one is arguing. One man writes; one rests his head on his hand and thinks; the children lean in until their faces shine. The lecturer is explaining, not winning. It is the picture of a conversation that climbs the ladder, and the light at its center is a good image of truth that everyone in the room is facing together.

Look closely

- Find the source of the light. Why do you think the painter hid the lamp and showed only its effect on the faces?
- Look at the two children at the front. What do their hands and faces tell you about how they are listening?
- Find the man writing notes on the left. What is he doing that a good museum visitor also does?
- Count the people and notice that no one is looking at the painter. Where is every gaze fixed, and why does that make the room feel peaceful?

Talk about it

1. The lecturer is teaching a model, and models can be wrong in details. How would you ask him a question about the model without being rude?
2. If one listener in this room disagreed with the lecturer about how far the sun is from the earth, what could he do that would keep the room as calm as it looks?
3. What would change in the painting if the people were arguing instead of learning?

EXPERIMENT: THE CONVERSATION REHEARSAL: DOES A QUESTION OPEN THE DOOR?

Before you talk with a docent or a friend about a sign, practice at home and measure what works. This is an experiment on conversations, with real timing and counting.

Question: does opening with a question, instead of a statement, lead to a longer and friendlier exchange? Prediction: write yours first. What we change: the opening line, a question (“How was that date measured?”) or a statement (“That date is wrong.”). What we keep the same: the same sign, the same partner, the same topic, the same time limit of three minutes. What we measure: how many turns the conversation lasts, how many seconds your partner speaks, and your partner’s one-word rating at the end: friendly, neutral or tense.

You will need

- Six museum sign texts copied from museum websites, each with a date in millions of years
- Index cards, one opening line written on each: three questions and three statements
- A stopwatch or a phone timer
- A family member or friend willing to play the docent, with a card telling them to answer honestly and naturally

- Your lab notebook, ruled with columns: Sign, Opening type, Turns, Partner seconds, Rating

Steps

1. Give your partner the six sign texts to read. They will play a docent who believes the signs and answers as a courteous expert would.
2. Shuffle the opening cards. For each sign, draw a card and begin the conversation with that line exactly. Run the timer for three minutes.
3. During the talk, climb the ladder: listen, ask, restate, separate, share, thank. Tally each turn with a mark. Keep the timer for your partner's speaking time by stopping and starting it, or ask a third person to time it.
4. At the end your partner gives a one-word rating: friendly, neutral or tense. Record it without discussion.
5. After six conversations, average the turns and the partner-seconds for the three question openings and for the three statement openings. Make two small bars for each.
6. Write a conclusion: which opening produced more turns, more partner speaking time, and better ratings? Write one sentence on what surprised you.
7. Finally, write out your best three-minute exchange as a script, with the mainstream claim stated so fairly your partner agrees it is accurate, and your own reading stated in one clear sentence.

Tips

- If your partner laughs or gets stuck, stop the timer, reset and start that card again. A spoiled trial is not a failure; note it and rerun.
- Do not argue after the rating. The rating is data.

Check your work

- I ran six timed conversations and recorded turns, seconds and ratings for each.
- My bar graphs compare question openings with statement openings.
- My script states the mainstream claim fairly, names the assumption, and gives my reading without mockery.

FIELD NOTEBOOK

1. Draw the conversation ladder with six rungs and write, on each rung, one sentence you could actually say at a museum rail.
2. Make a two-column page titled "Sedgwick to Darwin, 1859": on the left, what Sedgwick disagreed with; on the right, what he did to stay a friend.
3. Draw a bar graph from your conversation rehearsal: average turns for question openings versus statement openings.

> **From history.** Lord Kelvin never gave up his cooling argument, but the physics moved on without rancor. In 1904 the young Ernest Rutherford lectured at the Royal Institution on

the newly discovered radioactivity and its heat, and noticed the old man in the audience. By his own account Rutherford softened his words, pointing out that Kelvin had only said his estimate held provided no new source of heat was found, and that this prophecy had now been fulfilled. Kelvin, he said, beamed. It is a small picture of how a disagreement about numbers can end in good humor on both sides.

WORKED EXAMPLES

Example 1. You tallied a ten-minute conversation at a museum rail. You asked 6 questions and made 14 statements. What fraction of your turns were questions? If you keep the 14 statements, how many more questions would you need for questions to be half of your turns?

1. Total turns = 6 + 14 = 20. Questions = 6 ÷ 20 = 0.30, or 30%.
2. For questions to be half of all turns, questions must equal statements: 14 questions.
3. More questions needed = 14 − 6 = 8.
4. Check: 14 questions + 14 statements = 28 turns, and 14 ÷ 28 = 50%.

Answer: 30% of your turns were questions. You would need 8 more questions, for 14 of 28 turns.

Example 2. Lord Kelvin’s 1897 upper figure for the age of the earth was 40 million years. Today’s textbooks give about 4.5 billion years. A common young-earth figure is about 6,000 years. By what factor does the textbook figure exceed Kelvin’s, and by what factor does Kelvin’s exceed the young-earth figure?

1. Write the numbers in the same unit: 4.5 billion = 4,500 million; 40 million; 6,000 years = 0.006 million.
2. Textbook ÷ Kelvin = 4,500 ÷ 40 = 112.5. The modern figure is about 110 times Kelvin’s.
3. Kelvin ÷ young-earth = 40,000,000 ÷ 6,000 = 6,667. Kelvin’s figure is about 6,700 times the young-earth figure.
4. Lesson: the mainstream number itself moved by a factor of a hundred within one lifetime as assumptions changed. Every figure in this problem rests on a framework, and that is worth saying calmly.

Answer: About 110 times, and about 6,700 times. Expert figures have moved by factors of a hundred before, which is a reason for humility on every side.

Example 3. A sign has 12 sentences: 5 observations, 4 inferences and 3 interpretations. You accept every observation and every inference and disagree only with the interpretations. What percent of the sign is common ground? If the museum rewrote one interpretation as an inference you also accept, what would the percent become?

1. Common ground = observations + inferences = 5 + 4 = 9 sentences. 9 ÷ 12 = 0.75, or 75%.
2. After the rewrite: 10 shared sentences. 10 ÷ 12 = 0.833, or 83%.
3. Say this first in any conversation: “We agree on three quarters of this sign.” Then name the lines that differ.

Answer: 75% common ground, rising to 83% after the rewrite.

PRACTICE

1. EASY Who was Adam Sedgwick, what did he do for Darwin in 1831, and what did he write to him in 1859?
2. EASY List the six rungs of the conversation ladder in order.
3. EASY What is a steelman, and why does it matter before you disagree?
4. MEDIUM Rewrite this opening so that it climbs the ladder instead of jumping to the top: “That sign is wrong. It wasn’t 150 million years.”
5. MEDIUM Data reading. Kelvin’s published estimates for the age of the earth: 1862, 20 to 400 million years; 1868, about 100 million years; 1897, 20 to 40 million years. (a) What is the midpoint of the 1862 range? (b) By what factor did the upper limit fall between 1862 and 1897? (c) Describe the trend and give one reason the course suggests for why it did not settle the question.
6. MEDIUM Data reading. A class ran 40 practice conversations about museum signs. Question openings: 20 trials, average 11 turns, 14 rated friendly, 5 neutral, 1 tense. Statement openings: 20 trials, average 6 turns, 6 friendly, 8 neutral, 6 tense. (a) What percent of each type was rated friendly? (b) How many times more turns did question openings produce? (c) Name one variable the class should have kept the same for the comparison to be fair.
7. MEDIUM In a 6-minute conversation your partner spoke for 1 minute 30 seconds. What percent of the time did you speak? What would a listener’s target of at least 50 percent partner time require?
8. HARD Experiment design. You want to know whether restating the other person’s claim (“So you are saying…”) before answering makes conversations friendlier. Design a fair test. Name the question, what you change, what you keep the same, what you measure, and one way to reduce bias in the rating.
9. HARD Write a four-sentence steelman of the mainstream claim that the Morrison Formation is about 150 million years old, then one sentence stating the creation reading. The steelman must be one a museum geologist would accept as accurate.

10. CHALLENGE A friend at the museum says, “Those scientists just make the dates up.” Write what you would say, in four or five sentences, that is both truthful about the assumptions and fair to the scientists.

COMMON MISTAKES

- Thinking kindness means agreeing or going silent. Sedgwick disagreed with every conclusion in Darwin’s book and said so plainly, in friendship.
- Saying scientists “made up” a date. They measured a ratio; the assumptions that turn it into years are what is open to question, and that is what you should name.
- Answering a sign before you have finished reading it. Listen first, then ask, then restate, and only then share.

Make it a game · Ladder Relay. One player reads a museum sign sentence with a date in it. The other must climb the ladder aloud in order, one rung per turn: a listening summary, a question, a restatement, a separation of observation from interpretation, a one-sentence share of the creation reading, and a thank-you. A parent referees: any rung skipped, any mocking word, or any claim stated unfairly sends the player back to the bottom. Fastest clean climb wins, then switch roles.

Scripture. “Let your speech be alway with grace, seasoned with salt, that ye may know how ye ought to answer every man.” (Colossians 4:6, KJV)

Salt preserves and gives savor; grace makes speech bearable to the one who hears it. Paul expects Christians to answer, and he tells them in what tone.

Practice answers

1. A Cambridge geology professor and clergyman who named the Cambrian rocks. In August 1831 he took Darwin on a geology walking tour of North Wales. In November 1859 he wrote that he had read the Origin of Species with more pain than pleasure, explained his disagreements point by point, and signed as Darwin’s old friend.
2. Listen, ask, restate, separate, share, thank.
3. The other side’s claim stated in its strongest, fairest form. If you cannot state it so they would accept the wording, you do not yet understand what you are disagreeing with, and the other person has no reason to listen.
4. For example: “The sign says 150 million years. Can you tell me how that number was measured? So it comes from argon in the ash beds, not from the bones themselves? I read those same layers as a Flood deposit, partly because the bones were buried so fast. Thank you for explaining it.”
5. (a) (20 + 400) ÷ 2 = 210 million years. (b) 400 ÷ 40 = 10; the upper limit fell by a factor of ten. (c) His figures narrowed and dropped over 35 years as he refined the same cooling model; then radioactivity, unknown to him, added heat inside the earth and changed the assumptions, so the whole calculation was rewritten.
6. (a) Questions: 14 ÷ 20 = 70%. Statements: 6 ÷ 20 = 30%. (b) 11 ÷ 6 = 1.8 times. (c) The same partner, the same sign and the same time limit for both kinds of opening, or the same students doing both kinds.

7. Partner time 90 s of 360 s = 25%, so you spoke 75% of the time. For the partner to speak at least 50%, they would need 180 s, so you would need to speak 90 s less and ask more questions.
8. Question: does restating before answering raise the friendliness rating? Change: whether you restate before every answer or never restate. Keep the same: partner, sign, opening line, three-minute limit. Measure: the partner’s rating (friendly, neutral, tense) and the number of turns, over at least five trials of each kind. Reduce bias: do not tell the partner which condition is being tested, and have a third person record the ratings.
9. Sample: Volcanic ash beds lie between the Morrison bone layers. Crystals in that ash contain potassium-40, which decays to argon-40 at a rate measured in laboratories. The ratio of argon to potassium in the crystals, with the assumptions that they started with no argon and have stayed sealed, gives about 150 million years. Several ash beds give similar results, which geologists take as a check. Creation reading: the same ratios are real, but creation geologists hold that the starting amount and the closed system are not established, and read the layers as deposited rapidly during the Flood year a few thousand years ago.
10. Sample: They do not make the numbers up; they measure real ratios of atoms in the ash, with careful instruments. The years come from those ratios plus three assumptions about the starting amount, the rate and whether the crystal stayed sealed. I question those assumptions, and I can show you a measurement that tests them. But the people who wrote this sign did honest work, and we agree with them about most of it, including that these animals were buried fast by water. Let’s read the sign again and sort it together.

8.4 The Report: Writing Up What You Saw

OBJECTIVES

- Tell how Mary Anning reported her plesiosaur in December 1823 and why a careful written record let other scientists check and accept it.
- Write a museum report with nine parts: title, date and place, purpose, methods, observations, what the sign says, how I read it, questions remaining, and sources.
- Report measurements properly: with units, as a mean with a range, on a scale drawing with a scale bar, and with the sign’s claims quoted and dated.

Warm-up. Pick one object from your home museum of Lesson 8.1 and, without looking at it, write a description from memory: size, color, shape, marks. Then look and measure. Count how many of your remembered details were wrong or missing. That gap is why scientists write at the specimen, not afterward.

Video. Coming soon. Search for the story of Mary Anning and the 1823 plesiosaur from Lyme Regis, for how museum curators write catalog records and condition reports, and for a short lesson on scientific drawing with a scale bar. Good sources: Natural History Museum London, Smithsonian, Lyme Regis Museum, SciShow Kids, Homeschool Pop (Alternate), Moody Science classics.

KEY TERMS

report
A written record of what was done and seen, ordered so that another person could follow it, check it and repeat it.

methods
The part of a report that says what you did and what tools you used: pacing, a floor plan at 1 : 500, a tape measure, copying signs by photograph.

scale bar
A short line on a drawing labeled with a real length, such as 1 m, so that a reader can tell the true size of anything drawn.

mean
The average of a set of measurements: add them and divide by how many there are.

range
The spread of a set of measurements: the largest minus the smallest. Reporting the range tells a reader how much to trust the mean.

source
Where a fact came from: the museum’s name, the hall, the sign’s title, the website and the date you read it. A claim without a source cannot be checked.

CORE IDEAS

The story. In December 1823, after winter storms had stripped the cliffs at Lyme Regis on the coast of Dorset, Mary Anning found a skeleton unlike anything she had dug out before. She was twenty-four, the daughter of a cabinetmaker, and had been collecting fossils to sell since childhood. This one had a small head, paddles like a turtle, and a neck so long that it carried more than thirty vertebrae. On December 26 she wrote a letter announcing the find. It was not a note of excitement; it was a report. She described the skeleton bone by bone, gave its size, and drew it in careful ink, with the bones numbered so that a reader could match her words to her picture. The drawing is still kept today. In February 1824 the geologist William Conybeare described the animal to the Geological Society of London and named it *Plesiosaurus dolichodeirus*, the long-necked near-lizard. In Paris the great anatomist Georges Cuvier, who had seen forgeries before, suspected at first that someone had joined two skeletons together, because no animal he knew had so many neck bones. He asked for details. The record held: the bones were in place, the drawing matched the specimen, and Cuvier withdrew his doubt. Anning's reputation was made, not by her luck in finding the fossil, but by the quality of her report of it.

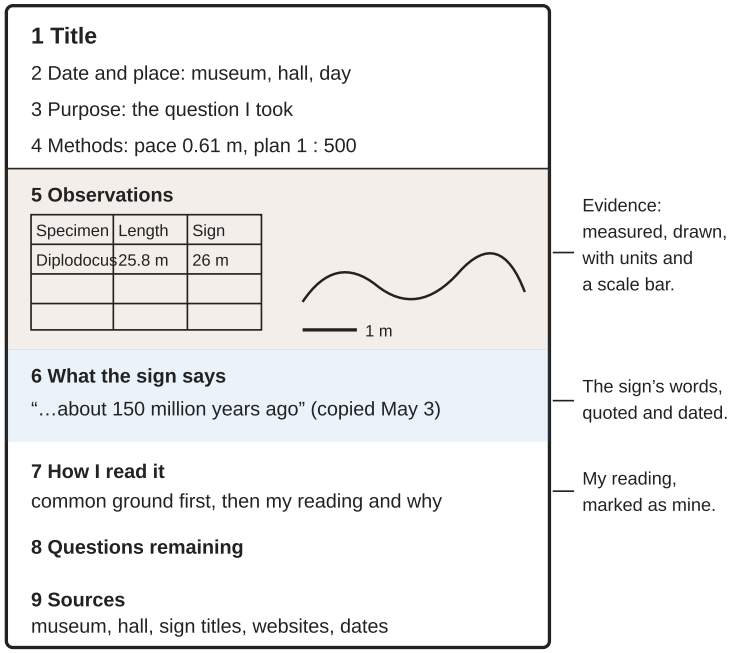
How they figured it out. Cuvier could check Anning because she had written down what a checker needs. Two hundred years later a museum report has the same nine parts. *Title*: what the report is about. *Date and place*: the museum, the hall, the day. *Purpose*: the question you went to answer, such as how much of the fossil hall's signs could be checked by observation. *Methods*: what you did and with what, including your pace length and the scale of the floor plan. *Observations*: what you saw and measured, in tables and drawings, with units. *What the sign says*: the museum's claims quoted exactly, with the date you copied them. *How I read it*: your reading, with the reasons and the assumptions named, and the common ground stated first. *Questions remaining*: what you could not see, could not measure or did not understand. *Sources*: the museum, the signs, the websites and the books you used. The order matters. Observations come before readings so that a reader can see your evidence before your conclusion, and can disagree with the conclusion while still trusting the evidence.

The big idea. Numbers in a report need three things: a unit, a method and an honest spread. Write 25.6 m, not 25.6; write "by pacing at 0.61 m per pace," not just the result; and when you measured something more than once, give the **mean** and the **range**. A reader who sees "25.8 m, range 25.2 to 26.4, three pacings" knows exactly how far to trust you, and can see at once that the sign's 26 m lies inside your range. Drawings need a **scale bar** and a label for every part you name. If you did not see a part, draw it dotted and say so, as the Marsh plate in Lesson 8.2 should have done. The hardest rule is honesty about what did not fit. If the sign said one thing and you observed another, report both. If an observation seems to favor the other reading, report it anyway. Anning did not know what Cuvier would make of so many neck bones; she drew every one. A report that hides an awkward bone is not a report.

In the world today. Every specimen in a museum drawer sits on a pile of reports: the field notes of the collector, the preparator's record of which bones are real and which are cast,

the catalog card, and the published description. When a sign changes, as the Carnegie sign did in 1979, it is because someone went back to those reports and the bones. The National Park Service writes a report on every fossil found on its land; the United States Geological Survey keeps field notebooks going back more than a century. Your museum report joins this tradition in a small way. Quote the sign exactly and date it, because signs change. Name the museum and the hall, because another student may visit next year and compare. Keep your log pages, because the log is your field notebook and the report is written from it. If you visited a museum online instead, say so in the methods, and give the web address and the date, since websites change even faster than signs.

God’s handiwork. When the prophet Habakkuk was given a vision, he was told to write it and make it plain, so that a reader could take it and run. Luke opened his Gospel by saying he had followed everything closely from the first and set it down in order. Scripture itself is given as a careful written record, with names, places and dates, so that it can be read and checked. A museum report is a humble cousin of that work: a plain account of what God made, set down in order, with the writer’s own reading marked as his own. Make it plain. Make it checkable. Then let the bones speak for themselves.



The nine parts of a museum report. Evidence comes first, the sign’s words are quoted and dated, and the writer’s reading is marked as a reading.

⏳ Thinking About Time

What the sign says. What the sign says: the label on Anning’s plesiosaur in London and the signs on the Dorset cliffs call the layers the Blue Lias of the Lower Jurassic and give an age of about 200 million years, the time when, the signs say, a warm shallow sea covered southern England.

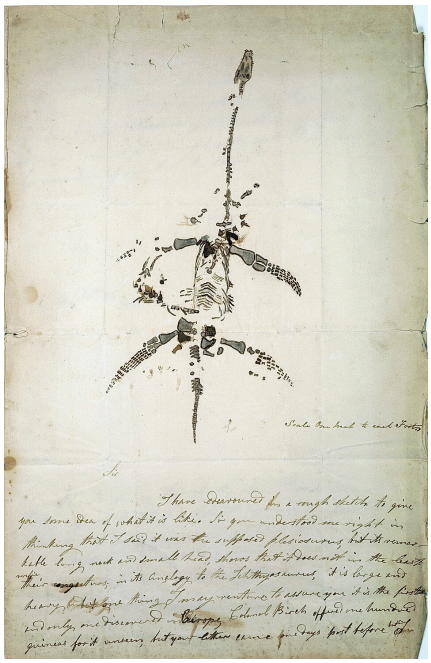
What we observe. What we observe: thin alternating beds of limestone and dark shale stacked for many meters along the cliffs; skeletons of marine reptiles lying with their bones still joined, which requires burial before the body fell apart; and ammonites and other shells packed by the thousand in single layers.

How Christians read it. How Christians read it: creation geologists read the Lias as sediment laid down rapidly by the waters of the Flood, a few thousand years ago, which explains why whole skeletons and whole beds of shells were buried before scavengers and decay could scatter them. The layers, the joined bones and the shell beds are observations both sides share; the date is the interpretation that divides them.

Try it. Draw a 10 cm column of alternating limestone and shale beds in your notebook and mark where a skeleton with joined bones would have to be buried quickly.

Genesis 7:24

PICTURE STUDY



Mary Anning's letter and drawing of the plesiosaur, Mary Anning, December 26, 1823 · Pen and ink on paper · Wellcome Collection, London

This is the letter Mary Anning wrote the day after Christmas in 1823 to announce the skeleton she had just dug from the cliffs at Lyme Regis. She was not a member of any learned society; women could not join the Geological Society in her day. What she had was the specimen, a good eye and a steady pen.

Look at it as a report rather than a picture. The drawing is a plan view, bone by bone, with the paddles spread so that every bone shows. The writing tells what was found, where and

how big. When Cuvier in Paris doubted the find, it was a record like this, matched against the bones, that answered him.

Look closely

- Find the neck. Count the vertebrae you can make out. Why would a careful reporter draw every one instead of writing “a long neck”?
- Look at the four paddles. Are the small bones drawn individually? What does that tell you about how close Anning worked to the specimen?
- Notice that the drawing has no scene, no water and no flesh, unlike De la Beche’s painting in Unit 3. What kind of claims does a drawing like this make, and what kind does it refuse to make?
- Find the handwriting. Is it neat? What does a readable hand have to do with being believed?

Talk about it

1. Cuvier suspected a forgery because of the long neck. What in a report like this could answer that suspicion?
2. Anning sold the specimen and never published a scientific paper under her own name, yet her letter survives in a museum. What made her record worth keeping?
3. If you drew a mounted skeleton in a museum hall, which of Anning’s habits would you copy?

EXPERIMENT: WRITE THE REPORT, AND TEST YOUR DRAWING METHOD

You will turn your observation log into a full museum report with nine parts. Along the way you will run a small experiment on how to draw more accurately, since your sketches are part of your evidence.

Question: does drawing on a grid give more accurate proportions than drawing freehand? Prediction: write yours first. What we change: the drawing method, freehand or over a light pencil grid. What we keep the same: the object, the viewing distance, the time allowed, the paper size. What we measure: the percent error in the ratio of two lengths on the drawing compared with the same ratio on the real object.

You will need

- Your observation log and floor plan from the museum visit, or from a museum website tour if no visit was possible
- A long object with clear parts to draw, such as a skeleton photograph, a large bone, a model dinosaur or a bicycle
- Plain paper, a ruler, a pencil, an eraser and a calculator
- A timer
- Lined paper or a word processor for the report

Steps

1. Measure two lengths on the object, such as total length and head length, and find the real ratio: total ÷ head. Record it.
2. Draw the object freehand in five minutes. Measure the same two lengths on your drawing and find the drawn ratio. Percent error = (drawn ratio − real ratio) ÷ real ratio × 100, ignoring the sign. Do this three times with fresh paper.
3. Now rule a light grid of 2 cm squares on the paper and draw the object again in five minutes, using the squares to place each part. Measure, compute the ratio and the percent error, three times.
4. Find the mean and range of the percent error for each method and write a conclusion. Use the better method for the drawings in your report.
5. Now write the report. Title. Date and place. Purpose: the question you took to the museum. Methods: pace length and how you got it, floor-plan scale, how you copied signs.
6. Observations: a table of at least eight specimens with measurements and units, and two drawings with scale bars and labels. Mark any part you did not actually see with a dotted line.
7. What the sign says: at least three signs quoted exactly, in quotation marks, with the museum, hall and date. How I read it: for each, the common ground first, then your reading and the assumption at issue, in the fair tone of Lesson 8.3.
8. Questions remaining: at least three honest ones. Sources: the museum, the signs, the websites and the dates. Read the whole report aloud to a parent and fix anything that cannot be followed.

Tips

- Write observations in the past tense and your reading in the present: “The femur measured 1.3 m” but “I read this bed as a Flood deposit.” The verbs keep the two apart.
- A short honest report beats a long padded one. Cuvier was convinced by a single careful page.

Check your work

- I ran three freehand and three grid drawings and reported the mean and range of the percent error for each.
- My report has all nine parts, in order, with units on every number and a scale bar on every drawing.
- Every sign claim is quoted exactly and dated, and every reading of mine is marked as mine with its reason.

FIELD NOTEBOOK

1. Copy Anning’s drawing habit: draw one specimen from your visit in plan view, bone by bone, with a scale bar and the bones numbered in a key.

2. Rule a page in the nine-part report layout and fill each part with one line, as a template you can reuse for any museum.
3. Draw a column of the Blue Lias cliffs at Lyme Regis from a photograph, with limestone and shale beds labeled and a note on where a joined skeleton was found.

From history. The plesiosaur Anning reported in 1823 was bought by the Duke of Buckingham and is now in the Natural History Museum in London, where it can still be compared with her drawing. Her ichthyosaurs, plesiosaurs and the first British pterosaur went to museums across Britain, and the Geological Society, which she could not join, raised money for her when she was ill and later recorded her death in its annual address. In 2010 the Royal Society named her among the ten British women who had most influenced the history of science.

WORKED EXAMPLES

Example 1. You want to draw a 2.7 m plesiosaur skeleton on a page that has 20 cm of usable width, with its 30 cm skull shown correctly. Choose a convenient scale and find the drawn lengths of the skeleton and the skull.

1. Convert to centimeters: 2.7 m = 270 cm. The smallest scale that fits: 270 ÷ 20 = 13.5, so the drawing must be at least 1 : 13.5. Choose a round scale that is a little smaller: 1 : 15.
2. Skeleton on paper: 270 ÷ 15 = 18 cm. It fits with 2 cm to spare.
3. Skull on paper: 30 ÷ 15 = 2 cm.
4. Draw a scale bar: at 1 : 15, 1 m of real length is 100 ÷ 15 = 6.7 cm on paper. Label a 6.7 cm bar “1 m.”

Answer: At 1 : 15 the skeleton is 18 cm long and the skull 2 cm, with a 6.7 cm bar labeled 1 m.

Example 2. In a hall you measured five teeth in a case of Allosaurus teeth with a ruler held against the glass: 2.8, 3.1, 3.0, 2.6 and 3.5 cm. Report the result as a scientist would.

1. Sum: 2.8 + 3.1 + 3.0 + 2.6 + 3.5 = 15.0 cm.
2. Mean: 15.0 ÷ 5 = 3.0 cm.
3. Range: 3.5 − 2.6 = 0.9 cm.
4. Write it with the method: “Mean crown length 3.0 cm (range 2.6 to 3.5 cm, five teeth, ruler against glass, so true lengths may be slightly larger).”

Answer: Mean 3.0 cm, range 2.6 to 3.5 cm, n = 5, measured through glass.

Example 3. You paced a Diplodocus mount three times and got 25.2 m, 26.4 m and 25.8 m. The sign says 26 m. Report your measurement with its spread and say whether it agrees with the sign.

1. Mean: (25.2 + 26.4 + 25.8) ÷ 3 = 77.4 ÷ 3 = 25.8 m.
2. Range: 26.4 − 25.2 = 1.2 m. Half the range is 0.6 m, so write the result as 25.8 m, give or take 0.6 m.
3. Does the sign's value fall inside your spread? 25.8 − 0.6 = 25.2 and 25.8 + 0.6 = 26.4. The sign's 26 m lies between them, so your pacing agrees with the sign.
4. Report line: "Length by pacing: 25.8 m (25.2 to 26.4, three trials). Sign: 26 m. Agreement: yes."

Answer: 25.8 m, give or take 0.6 m, which agrees with the sign's 26 m.

PRACTICE

1. EASY List the nine parts of a museum report in order.
2. EASY What did Mary Anning find in December 1823, what did she send with her letter, and why did Cuvier doubt the find at first?
3. EASY Why must every drawing in a report have a scale bar?
4. MEDIUM Four pacings of a mount gave 11.6, 12.2, 11.9 and 12.3 m. Find the mean and the range, and write the result as a report line.
5. MEDIUM A skeleton is 9.0 m long and you want it 18 cm on paper. What scale is that, and how long is a 1 m scale bar?
6. MEDIUM Data reading. A student's observation table from a fossil hall lists: Mount A, sign 12.0 m, paced 12.6 m; Mount B, sign 8.0 m, paced 7.2 m; Mount C, sign 26 m, paced 25.6 m; Mount D, sign 4.5 m, paced 5.4 m. (a) Compute the percent difference for each. (b) Which two mounts show the largest percent errors, and what do they have in common? (c) What should the student write under "questions remaining"?
7. MEDIUM Data reading. A class compared drawing methods. Freehand percent errors: 18, 25, 12, 30, 15. Grid percent errors: 6, 9, 4, 11, 5. Find the mean and range of each set and state which method is more accurate and more consistent.
8. HARD Experiment design. You want to know whether copying a sign by photograph gives fewer errors than copying it by hand. Design the test: question, what you change, what you keep the same, what you measure, and how many trials.
9. HARD Here is a line from a student report: "The Apatosaurus was about 22 long and lived 150 million years ago." Find three problems with it as a report sentence and rewrite it correctly.
10. CHALLENGE Write the "How I read it" paragraph for a sauropod bone bed, four to six sentences, that begins with the common ground, states the sign's date claim fairly, names the assumption at issue, and gives your reading with one observation that supports it.

COMMON MISTAKES

- Writing a number without a unit or a method. “22” means nothing; “22 m by pacing at 0.61 m per pace, three trials” can be checked.
- Putting the sign’s claim in your own voice. Quote it, date it and name the museum, so that a reader can tell the sign’s words from yours.
- Leaving out the bone that did not fit. A report that hides an awkward observation is not a record; Anning drew every vertebra.

Make it a game · Find the Flaw. A parent reads report sentences aloud, some sound and some flawed: a missing unit, an undated sign quotation, a reading written as an observation, a drawing with no scale bar. Shout “sound” or name the flaw within five seconds. One point per right call, two if you can say the fixed sentence. Then write three flawed sentences of your own for the parent to catch. Play to ten.

Scripture. “And the LORD answered me, and said, Write the vision, and make it plain upon tables, that he may run that readeth it.” (Habakkuk 2:2, KJV)

A record is written for a reader, plainly, so that it can be taken up and used. Your report serves the same purpose for the next student who stands at that rail.

Practice answers

1. Title; date and place; purpose; methods; observations; what the sign says; how I read it; questions remaining; sources.
2. A nearly complete plesiosaur skeleton at Lyme Regis. She sent a careful bone-by-bone drawing with a description. Cuvier doubted it because the neck had far more vertebrae than any animal he knew, and he suspected two skeletons had been joined.
3. So a reader can tell the true size of anything drawn without knowing the scale in advance; a bar labeled 1 m lets the reader measure any part.
4. Sum 48.0; mean $48.0 \div 4 = 12.0$ m. Range $12.3 - 11.6 = 0.7$ m. “Length by pacing: 12.0 m (11.6 to 12.3, four trials).”
5. $900 \text{ cm} \div 18 \text{ cm} = 50$, so 1 : 50. A 1 m bar is $100 \div 50 = 2$ cm.
6. (a) A 5%; B 10%; C 1.5%; D 20%. (b) B and D, the two shortest mounts; short lengths are covered by few paces, so one pace too many or too few is a big percent. (c) Something like: “Were my counts on the short mounts off by one pace? Repeat with half-paces or a tape if allowed.”
7. Freehand: sum 100, mean 20%, range 18. Grid: sum 35, mean 7%, range 7. The grid is both more accurate (lower mean error) and more consistent (smaller range).
8. Question: which copying method produces fewer errors? Change: the method, photograph then transcribe at home versus copy by hand at the rail. Keep the same: the signs used, the time allowed, the person copying. Measure: the number of words that differ from the original sign, checked against the museum website or a second photograph. Trials: at least five signs by each method; compare mean errors.
9. Problems: no unit on 22; the sign’s claim about age is stated as the student’s own observation without quotation marks or a date; observation and interpretation are mixed in one sentence. Rewrite: “Length by pacing: 22 m (three trials). The sign, copied May 3, reads: ‘lived about

150 million years ago, in the Late Jurassic.’ I read the Morrison bed as a Flood deposit; see How I read it.”

10. Sample: Both readings agree that these animals were carried by water and buried quickly, since the bones of many individuals lie jumbled in one sandstone bed with logs. The sign gives a date of about 150 million years, obtained from argon-to-potassium ratios in ash beds, assuming the crystals began with no argon and stayed sealed. I question that assumption, because rock of known recent age has given argon dates of hundreds of thousands of years. I read the bed as a deposit of the Flood year a few thousand years ago. The observation that supports rapid burial for both readings, the jumbled whole and partial skeletons, fits a single great event especially well.

Unit 8 review

Answer each question. Show your work for calculations and use complete sentences for explanations. Metric units throughout. The test is worth 60 points.

1. (5 pts) Multiple choice. Which line on a specimen label is a record line rather than a story line? (a) “It lived 150 million years ago.” (b) “Catalog no. 4421.” (c) “It probably hunted in groups.” (d) “It is a cousin of modern birds.”
2. (5 pts) You walk a 10 m course in 15, 16 and 17 paces. What is your pace length? You then count 36 paces along a mount. Estimate its length.
3. (5 pts) A floor plan has a scale bar 3 cm long labeled 15 m. The fossil hall is 8 cm by 6 cm on the plan. What is the scale as a ratio, and what are the hall’s real dimensions?
4. (5 pts) Who was Charles Willson Peale, and what lesson about labels does his mastodon teach?
5. (5 pts) Multiple choice. When a sign says an ash bed is 150 million years old, what did the laboratory actually measure? (a) Years. (b) The number of layers. (c) A ratio of argon-40 to potassium-40 in crystals today. (d) The thickness of the ash.
6. (5 pts) Sort each sentence from a sauropod sign as observation, inference or interpretation: (a) “The skeleton was excavated from sandstone in 1909.” (b) “It weighed about 20 metric tons.” (c) “It lived in the Late Jurassic, 150 million years ago.” (d) “Its hollow neck bones made the neck lighter.”
7. (5 pts) Tell the story of the Carnegie Museum’s Apatosaurus skull in three or four sentences, and state the lesson it teaches about signs and specimens.
8. (5 pts) Potassium-40 has a half-life of about 1.25 billion years. How many half-lives is 150 million years, and roughly what fraction of the potassium-40 would have decayed in that time?
9. (5 pts) List the six rungs of the conversation ladder in order, and write one sentence you could actually say for the “ask” rung at a museum rail.
10. (5 pts) Lord Kelvin’s 1897 upper estimate for the age of the earth was 40 million years; today’s textbooks say about 4.5 billion. By what factor do they differ? Then explain in two sentences how Adam Sedgwick’s 1859 letter to Darwin shows that firm disagreement and friendship can go together.
11. (5 pts) Diagram item. Draw the layout of a museum report page with its nine parts labeled in order. Then, on your diagram, draw a small sketch of any bone with a correctly labeled scale bar, and mark which sections hold evidence and which hold your own reading.
12. (5 pts) Three pacings of a mount gave 8.2, 7.6 and 7.9 m, and the sign says 8.0 m. Report the mean and range in a proper report line, state whether your result agrees with the sign, and name one thing Mary Anning’s 1823 letter did that your report line copies.

UNIT PROJECT: MY MUSEUM REPORT

Visit a natural history museum, in person or through its website and 3D collections, using the field trip guide you built in Lesson 8.1. Bring back a filled observation log of at least ten specimens with measurements, then write the full nine-part report of Lesson 8.4: title, date and place, purpose, methods (your pace length and floor-plan scale), observations with a table and two scale drawings, at least three signs quoted exactly and dated, a three-column box for each sign with the common ground stated first, your own reading with its reasons, questions remaining, and sources.

Finish with a one-page script, in the tone of Lesson 8.3, of a conversation you had or could have with a docent about one sign's date: the mainstream claim stated so fairly that a museum scientist would accept it, the assumption at issue named, and the creation reading given in one clear sentence.

- **Observation**: At least ten specimens logged with measurements in metric units, a method stated for each, and two drawings with scale bars and labels; parts not seen are marked.
- **Reading the signs**: Three or more signs quoted exactly and dated, each sorted into observations, inferences and interpretations, with a three-column box that names the common ground before the disagreement.
- **Fairness and tone**: The mainstream claim is stated accurately and respectfully, the assumption at issue is named, and the creation reading is given clearly without mocking either side.
- **Report craft**: All nine parts in order; numbers carry units, means and ranges; sources are complete; the report reads plainly enough that a parent could follow it and check it.

Answer key

1. (b). The catalog number is a record that can be traced; the others are readings of the evidence.
2. Mean paces = 16; pace length = 10 ÷ 16 = 0.625 m. Length = 36 × 0.625 = 22.5 m.
3. 1 cm = 5 m, so 1 : 500. Hall: 40 m by 30 m.
4. A Philadelphia painter who founded America's first great museum and in 1801 dug up and mounted a mastodon from a marl pit near Newburgh, New York. He labeled it a mammoth; the bones were kept and could be re-examined, and the name was later corrected by comparing the teeth. A label can be wrong while the specimen stays right, which is why specimens are kept and numbered.
5. (c). The years are calculated from the ratio using the decay rate plus assumptions about the starting amount and a sealed crystal.
6. (a) observation; (b) inference, from a bone formula compared with living animals; (c) interpretation; (d) inference.
7. The skeleton was mounted in 1915 without a skull. After the director Holland died in 1932, a boxy Camarasaurus-type skull cast was put on, copying New York's 1905 mount. In 1978 Berman and McIntosh showed from the quarry records that a slender Diplodocus-type skull belonged to it, and the museum switched skulls in 1979. Lesson: signs are readings written by

people and can be revised; the bones with their catalog numbers never changed, so a careful reader quotes and dates the sign and trusts the specimen.

8. 150 ÷ 1,250 = 0.12 half-lives. About 8% would have decayed (about 92% remains).
9. Listen, ask, restate, separate, share, thank. Ask example: “How was the date on this sign measured?”
10. 4,500 ÷ 40 = 112.5, about 110 times. Sedgwick told Darwin plainly that he read the book with more pain than pleasure and named the claims he rejected, yet he signed as Darwin’s old friend and the two stayed friends for life. Honesty about the disagreement and warmth toward the person were in the same letter.
11. A page divided into: title; date and place; purpose; methods; observations (table and sketch with a scale bar, such as a 2 cm line labeled “1 m” at 1 : 50); what the sign says (quoted, dated); how I read it; questions remaining; sources. Observations and the sign’s quoted words are marked as evidence; “how I read it” is marked as the writer’s own reading.
12. Mean = 23.7 ÷ 3 = 7.9 m; range = 8.2 − 7.6 = 0.6 m. “Length by pacing: 7.9 m (7.6 to 8.2, three trials). Sign: 8.0 m. Agreement: yes,” since 8.0 lies inside the range. Anning recorded the specimen carefully enough that another scientist (Cuvier) could check it; giving the method and the spread does the same.

UNIT 9 · OPTIONAL

Bonus: Field Lab

This bonus unit takes the whole year outdoors. Steno's principles, the layers of Unit 2, the sorting power of water from the flume lab, and the "What the sign says / What we observe" habit from Unit 8 all become things you do with a tape measure, a compass, a vinegar bottle and a notebook. Four short field trips are planned: a road cut, a pair of outcrops to map, a creek after a storm, and a museum hall or an online collection. Each trip ends with a page of real field notes.

The people you will meet worked the same way. Highway crews at Sideling Hill, Maryland, opened a mountain for anyone to read in 1985. William Henry Holmes drew the Grand Canyon for the new U.S. Geological Survey so exactly that geologists still trace his lines. USGS scientists read the deposits of the Big Thompson flood of 1976 to tell how fast the water had run. Charles Willson Peale dug up and labeled the first mounted fossil skeleton in America in 1801, and then watched the label change. In every lesson you will keep what you observe in one column and what anyone, including you, concludes in another.

The unit is optional and light. There is one worked example and five practice items per lesson, a six-problem review, and a portfolio that gathers your four field pages into one notebook. The goal is a habit, not a grade: to look at rock, water and museum glass the way the Christian naturalists did, as the ordered and readable handiwork of God, and to write down honestly what you see.

BEFORE YOU BEGIN

- Knows Steno's principles of superposition, original horizontality, lateral continuity and cross-cutting (Unit 1)
- Can read a scale drawing and convert between centimeters on paper and meters in the field
- Can name the three assumptions behind a decay-rate date (Unit 7)
- Has practiced the "What the sign says / What we observe" box from Unit 8

MASTERY CHECKLIST

- I can record a complete field-note page at an outcrop with a header, a scale sketch, measured beds and separate columns for observation and interpretation.
- I can measure my pace, plot outcrops by pacing and bearing on a map with a stated scale, and match a marker bed between two outcrops.
- I can measure a creek's speed with a float, sort a sediment sample into gravel, sand and mud, and explain what the sorting says about the water.
- I can find and sketch a graded bed and tell which way the water flowed from flood evidence.
- I can copy a museum sign exactly, separate its observations from its interpretations, check a measurable claim by pacing, and ask a kind question about an age claim.

- I can state the young-earth reading of a road cut, a creek deposit or a museum exhibit beside the sign’s reading, fairly and without mocking.

OPTIONAL BOOKS AND RESOURCES

- **USGS National Geologic Map Database (NGMDB)** (https://ngmdb.usgs.gov/): Free. Search for your state and county to find the geologic map of the rock under your house for Lesson 9.2. The map viewer lets you click a color and read the legend entry, which you will copy into your notebook.
- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free. If no natural history museum is near you, the Smithsonian’s website offers a virtual tour of its halls and online collection records with label text, which can be journaled for Lesson 9.4 exactly like a glass case.
- **USGS Educational Resources** (https://www.usgs.gov/educational-resources): Free. Short explanations of sediment, streams, geologic maps and rock types from the United States Geological Survey, useful for checking the terms in Lessons 9.1 to 9.3 before a field trip.

9.1 Road-Cut Field Notes

OBJECTIVES

- Choose a safe road cut or outcrop with a parent and record a complete field-note header: place, date, weather, and a photograph with a scale object.
- Sketch an exposed rock face to scale, number the beds from bottom to top, and measure or estimate the thickness of each bed in meters.
- Describe each bed by color, grain size and the vinegar fizz test, and keep observations in a separate column from interpretations.

Warm-up. Cut a slice of layer cake, lasagna or a stacked sandwich straight down and set the cut face toward you. With a ruler, sketch the face and write the thickness of each layer in millimeters. Which layer was put down first? Which is thickest? You have just made your first field note.

Video. Coming soon. How geologists read a road cut and keep field notes: measuring beds, grain size, the vinegar acid test and sketching an outcrop. Search USGS, Smithsonian, state geological survey channels, Moody Science classics and nature footage of Sideling Hill in Maryland.

KEY TERMS

outcrop
Any place where solid rock is exposed at the surface, such as a cliff, a creek bank or a quarry wall.

road cut
An outcrop made by people when a highway is blasted or dug through a hill, leaving a fresh wall of rock on one or both sides.

bed
A single layer of sedimentary rock, also called a stratum. Beds can be thinner than a finger or thicker than a house.

bedding plane
The flat surface between two beds, which marks a pause or a change in what the water was laying down.

scale bar
A line or object of known length in a sketch or photograph, so that anyone can work out the real size of what is shown.

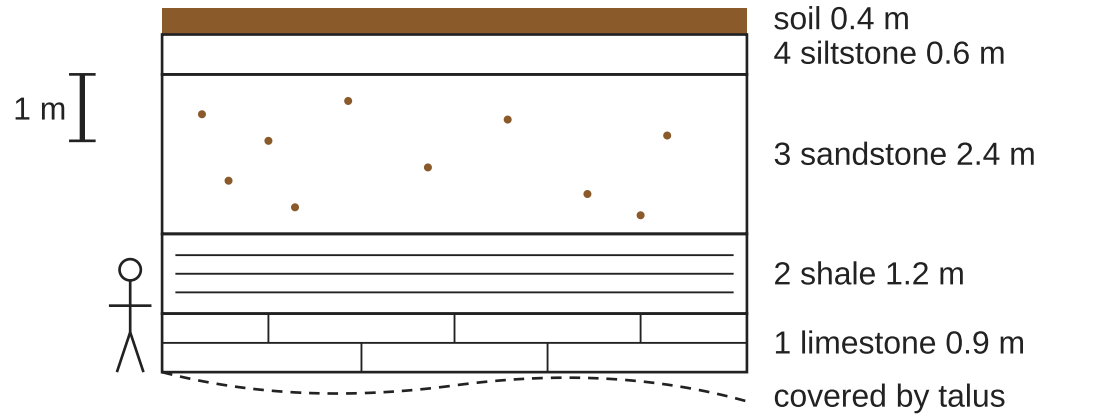
grain size
How big the particles in a rock are: gravel (over 2 mm), sand (gritty, 0.06 to 2 mm), silt (silky) or clay (sticky and smooth).

CORE IDEAS

The story. In August 1985 a new highway opened through Sideling Hill in western Maryland. To get the road over the ridge, crews had blasted a notch about 100 m deep through the mountain, and when the dust cleared they had made one of the finest outcrops in the eastern United States. The rock layers in the cut are not flat. They swing down from both sides and meet in a great U-shaped fold, like a stack of blankets pushed in from the ends. Sandstone, siltstone, shale and thin coal seams can all be seen in the walls. Within a few years a visitor center stood beside the road, and school buses came to see what the highway crews had uncovered. Geologists did not need to travel to a museum. The rock record was open beside the road, and anyone with a notebook could read it.

How they figured it out. A geologist at an outcrop does five things, and you will do the same. First, write a **header**: the place, the date, the weather and the name of your companion. Second, take a photograph with a scale object in it, such as a meter stick, and **sketch** the face, numbering the beds from the bottom up because the bottom bed was laid down first (Steno's superposition). Third, **measure** what you can reach with a tape and estimate the rest from your scale object. Fourth, **describe** each bed: its color on a fresh chip and on the weathered face, its grain size (rub a crumb between your fingers: gritty means sand, silky means silt, sticky means clay), and whether a drop of vinegar makes it fizz, which points to limestone. Fifth, keep two columns. In the first, write only what you *see and measure*. In the second, write what you *think it means*. A tilted bed is an observation. "These beds were flat when they formed and were tilted later" is an interpretation, a good one, resting on Steno's principle of original horizontality.

God's handiwork. A road cut shows what no single hillside can: layers that run for hundreds of meters without a break, with sharp flat contacts between them, and sometimes a whole stack bent into a fold without shattering. The Bible says that in the Flood year "all the fountains of the great deep" were broken up and the windows of heaven opened (Genesis 7:11). Many creation geologists read thick, widespread, sharply bounded beds, folded while still soft enough to bend, as the kind of record a great flood would leave. The roadside sign may tell the story differently, with museum words and a long age, and your notebook has room for both columns. What you can measure stays true whichever interpretation a reader prefers, and that is why a careful field note is worth more than a careless opinion.



A field sketch of a road cut. Beds are numbered from the bottom up, each is measured in meters, and a scale bar and a person give the size.

⏳ Thinking About Time

What the sign says. What the sign says: a roadside marker at a large cut usually gives each layer a museum word and a long age, for example “Mississippian sandstone and shale, about 350 million years old, deposited in slowly changing rivers and seas.”

What we observe. What we observe: the beds themselves. We can measure their thickness, feel their grain size, test them with vinegar, see sharp flat contacts between them, trace them along the wall, and sometimes see the whole stack folded without breaking.

How Christians read it. How Christians read it: Christians who hold the young-earth view read thick, widespread beds with sharp contacts, folded while still soft, as sediment laid down and bent by moving water during the Flood year and the time soon after. The period names are museum words we learn so we can read any sign accurately, not ages we have measured in the rock.

Try it. Copy the marker’s exact words into your “Sign says” column and your own measurements into the “I observe” column, then compare the two.

Genesis 7:11

PICTURE STUDY



Ancient Ruins in the Cañon de Chelle, N.M., Timothy H. O’Sullivan, 1873 · Albumen silver print (photograph made during the Wheeler Survey) · Art Institute of Chicago (this print); other prints in the Library of Congress, Washington, D.C. The canyon is Canyon de Chelly, Arizona

Timothy O’Sullivan had photographed Civil War battlefields before he joined the government surveys of the American West. In 1873, traveling with Lieutenant George Wheeler’s survey, he set up his heavy camera in Canyon de Chelly and photographed the cliff above an ancient stone village. The dwellings sit in a hollow near the base of the wall. Above them the sandstone rises in enormous sweeping curves, the tracks of sand laid down by moving water and wind, bed over bed.

O’Sullivan could not put a meter stick on a cliff this size, so he let the ruins be his scale object. Once you know how tall a doorway is, you can begin to work out how tall the cliff is. That is exactly the trick you will use at a road cut.

Look closely

- Find the dwellings. Use them as a scale: about how many times taller than a doorway is the cliff?
- Follow one of the long curved streaks across the rock. Does it run level, or does it sweep down and across? These are bedding surfaces inside the sandstone.
- Look for places where one set of curved layers is cut off by another set. What does Steno’s cross-cutting principle say about which set came first?
- Notice the dark streaks running down the face. Those are stains left by water trickling over the rock today, not layers inside it. How can you tell the difference?

Talk about it

1. Why does every good field photograph need something of known size in it?
2. What could you measure about this cliff from the photograph, and what would you need to visit it to find out?
3. If a sign at this cliff said the sand was laid down by a slow river over a very long age, what would you write in your “I observe” column and what in your “Sign says” column?

> **Safety first.** Road cuts are beside moving traffic. A parent chooses the site, drives and stays with you. Use only cuts on quiet roads or with a marked pull-off, never on a highway shoulder. Wear a bright vest, stay well back from the pavement, and never cross the road for a better view. Keep away from the base of loose or overhanging rock, because pieces fall, and do not climb the face. If you chip samples, use a proper rock hammer and safety glasses, and never hammer when someone is close. Ask permission before collecting on private land.

EXPERIMENT: A PAGE OF FIELD NOTES AT A ROAD CUT

You will make one complete page of field notes at a real outcrop, the way a survey geologist does. Question: how many beds are exposed here, how thick is each, and what is each one made of? Prediction: before you measure, guess the number of beds and the total height of the face and write the guesses down. What we change: nothing, this is an observation lab. What we keep the same: the same scale object in every photograph and the same vinegar drop size on every bed. What we measure: bed thickness in meters, grain size by touch, and fizz or no fizz.

You will need

- Field notebook with stiff cover, pencil and eraser
- Tape measure (5 m) and a meter stick or walking stick of known length
- Hand lens (a magnifying glass works)
- Small dropper bottle of white vinegar
- Protractor, 30 cm of string and a metal washer, taped together to make a clinometer
- Camera or phone, a bright safety vest, sturdy shoes, and a parent who chooses a safe site

Steps

1. With your parent, choose a road cut or natural outcrop on a quiet road with a safe place to park and stand. Write the header: place (road and nearest town), date, time, weather, and who is with you.
2. Stand your meter stick or walking stick against the base of the face and take one photograph of the whole wall, then close-up photographs of each layer.
3. Sketch the face in your notebook. Draw the bedding planes first, then number the beds from the bottom up: 1 is the lowest. Draw a scale bar in the corner and write what one centimeter in your sketch equals in real meters.

4. Measure the thickness of each bed you can safely reach with the tape, straight across the bed from one bedding plane to the next. For beds above your reach, use the photograph and your scale object to estimate, and mark those numbers with an “e” for estimate.
5. For each bed, record: color of the weathered face, color of a fresh chip if one lies loose at the base, grain size by rubbing a crumb between your fingers, and whether one drop of vinegar fizzes on a fresh surface. Use the same drop size on every bed.
6. If the beds are tilted, hold the protractor edge along a bedding plane with the string hanging straight down and read the angle between the string and the 90° mark. Record the tilt and the direction the beds slope toward, using a compass.
7. Rule two columns at the bottom of the page: “I observe” and “I think it means.” Fill the first with measurements and descriptions only. In the second, write one careful sentence for each bed about the water that laid it down (fast, slow, still) and why you think so.
8. Write one question the outcrop raised that you could not answer today. Good field notes always end with a question.

Tips

- Weathered rock is often orange or gray from rust and lichen. The fresh color inside can be quite different, so always try to find a fresh chip.
- Thin, dark, crumbly layers and thin coal seams are easy to miss. Look for them at the bedding planes.
- If no road cut is near you, a quarry wall, creek bank, old foundation pit or sea cliff works just as well. Any exposed rock is an outcrop.

Check your work

- My page has a header, a photograph with a scale object and a sketch with a scale bar.
- Every bed is numbered from the bottom up and has a thickness in meters, marked “e” if estimated.
- My observations and my interpretations are in separate columns.

FIELD NOTEBOOK

1. Redraw your road-cut sketch neatly at a stated scale (for example 1 cm = 1 m), with every bed numbered, measured and colored to match the real rock.
2. Draw three grain-size swatches side by side, gravel, sand and silt or clay, and under each write how it felt between your fingers and which bed at your outcrop matched it.
3. Make a small table titled “Fizz test” with one row per bed: bed number, fresh or weathered surface tested, fizz (yes, slight, none), and what that suggests about the rock.

> **From history.** Field notebooks became a scientific tradition in the 1700s and 1800s, when surveyors in Britain and the United States began recording every outcrop they passed with sketch, measurement and description. In the early 1970s, two geologists in

> Montana, David Alt and Donald Hyndman, began a series of books called Roadside Geology, written so that ordinary travelers could read the road cuts along the highways of each state. The idea behind them was the same one you are practicing: the rocks beside the road are open to anyone who stops, looks and writes it down.

WORKED EXAMPLES

Example 1. You cannot reach the top of a road cut, so you lean your 1.5 m walking stick against the base and take a photograph. In the print, the stick is 2.0 cm tall and the whole rock face is 12.4 cm tall. The sandstone bed in the middle measures 3.1 cm thick in the print. (a) How tall is the real face? (b) How thick is the real sandstone bed? (c) If your notebook sketch uses the scale 1 cm = 1 m, how tall should you draw the face and the sandstone bed?

(Use the map or drawing “The same kind of scale drawing. The scale bar lets a reader recover the real thi” shown earlier in this lesson.)

1. Find the scale of the photograph from the known object: 1.5 m ÷ 2.0 cm = 0.75 m for every centimeter in the print.
2. (a) Real height of the face: 12.4 cm × 0.75 m/cm = 9.3 m.
3. (b) Real thickness of the sandstone: 3.1 cm × 0.75 m/cm = 2.325 m, which rounds to 2.3 m. Mark it “e” because it was estimated from the photograph, not taped.
4. (c) At 1 cm = 1 m, the face is drawn 9.3 cm tall and the sandstone bed 2.3 cm thick.

Answer: (a) 9.3 m. (b) About 2.3 m (estimated). (c) Draw the face 9.3 cm tall and the sandstone bed 2.3 cm thick.

PRACTICE

1. EASY What is the difference between an outcrop and a road cut? Give one reason geologists like road cuts.
2. EASY In the figure of the road-cut sketch, which bed is the oldest, and which principle of Steno tells you so?
3. MEDIUM A student’s field table for a road cut reads, from the top down: Bed 4, siltstone, silky, no fizz, 0.6 m. Bed 3, coarse sandstone, gritty, no fizz, 2.4 m. Bed 2, shale, sticky and smooth, no fizz, 1.2 m. Bed 1, gray rock, smooth, strong fizz, 0.9 m. (a) What is the total thickness of rock exposed? (b) Which bed is most likely limestone, and why? (c) Which bed was probably laid down by the fastest-moving water, and why?
4. MEDIUM At a road cut the beds all slope at 25° toward the east. Using Steno’s principle of original horizontality, write one sentence of observation and one sentence of interpretation for your notebook.
5. HARD Experiment design. You think Bed 1 at your road cut is limestone because it fizzed, but your sister says the fizz might have come from dirt on the surface. Design a fair

test. Name what you change, what you keep the same, what you measure, and your controls.

COMMON MISTAKES

- Sketching an outcrop without a scale bar or a scale object. Without a known length, no one, including you next year, can tell whether a bed is 20 cm or 2 m thick.
- Writing interpretations in the observation column, such as “laid down by the Flood” or “deposited over millions of years.” Both are interpretations. The column for observations holds only what was seen and measured.
- Judging a rock by its weathered color. Rust, lichen and dust coat the outside of an outcrop, and the fresh color inside is often lighter or quite different.

Make it a game · Outcrop Bingo. Before the trip, each player draws a three-by-three grid and fills it with features to find: a sharp bedding plane, a bed thicker than 1 m, a bed thinner than 10 cm, a layer that fizzes, a tilted bed, a crack cutting across beds, a color change, ripple marks or cross-beds, and a fossil or plant imprint. At the outcrop, you may mark a square only after you show the feature to another player and record it in your notes with a measurement. First to a full row wins, and a full card earns the title Survey Geologist.

Scripture. “In the six hundredth year of Noah’s life, in the second month, the seventeenth day of the month, the same day were all the fountains of the great deep broken up, and the windows of heaven were opened.” (Genesis 7:11, KJV)

The Bible records the Flood with a date, like a field note: the year, the month and the day. Moving water on a vast scale lays down layers, and a road cut lets you measure the layers for yourself.

Practice answers

1. An outcrop is any place where solid rock is exposed at the surface. A road cut is an outcrop made by people when a road is blasted or dug through a hill. Geologists like road cuts because they expose fresh, unweathered rock in a tall straight wall where many beds can be seen and measured at once.
2. Bed 1, the limestone at the bottom, is the oldest. Steno’s principle of superposition says that in an undisturbed stack of layers the lowest bed was laid down first.
3. (a) 0.6 + 2.4 + 1.2 + 0.9 = 5.1 m. (b) Bed 1, because it fizzes strongly with vinegar, which is the test for the calcium carbonate in limestone. (c) Bed 3, the coarse sandstone, because larger grains need faster water to carry them, so a coarse bed records faster flow than silt or clay beds.
4. Observation: the beds are tilted 25° toward the east, measured with the clinometer. Interpretation: because water lays sediment down in nearly flat layers, these beds were probably flat when they formed and were tilted afterward by movement of the earth’s crust.
5. Change: the rock tested (a fresh chip of Bed 1, a fresh chip of each other bed, a known limestone chip from a hardware store or a shell, and a known sandstone or quartz chip). Keep the same: a fresh broken surface on every sample, one drop of the same vinegar from the

same dropper, the same temperature and the same waiting time. Measure: fizz rated none, slight or strong, or the number of seconds bubbles last. Controls: the known limestone should fizz and the known sandstone should not; if Bed 1 fizzes on a fresh chip like the known limestone, the fizz is from the rock, not from dirt. Repeat each test three times.

9.2 Mapping Local Layers

OBJECTIVES

- Measure your own pace length and use pacing and a compass to plot the positions of two or more outcrops on a hand-drawn map with a stated scale.
- Draw a stratigraphic column of the beds at an outcrop and use lateral continuity to match the same bed between outcrops.
- Find your home on a state or USGS geologic map, read the legend, and tell which words name rock types and which are museum words for ages.

Warm-up. Lay a tape measure or a marked string 20 m along a sidewalk or yard. Walk it at a normal pace three times, counting steps each time. Average the three counts, then divide 20 m by the average to find your pace length in meters. Write it inside the front cover of your notebook. You will use it all day.

Video. Coming soon. How a geologic map is made: tracing beds between outcrops, strike and dip, stratigraphic columns, and William Henry Holmes’s drawings of the Grand Canyon for the USGS. Search USGS, Smithsonian, state geological survey channels, Moody Science classics and nature footage of canyon layers.

KEY TERMS

geologic map
A map that colors the land by the kind of rock found just under the soil, with lines where one rock unit meets the next.

stratigraphic column
A drawing of the beds at one place stacked in order from oldest at the bottom to youngest at the top, drawn to a vertical scale.

lateral continuity
Steno’s principle that a bed laid down by water spreads out sideways, so the same bed can be found in outcrops some distance apart.

pace
The length of one of your normal walking steps, measured so that counting steps gives distance.

bearing
The compass direction from one point to another, given in degrees clockwise from north.

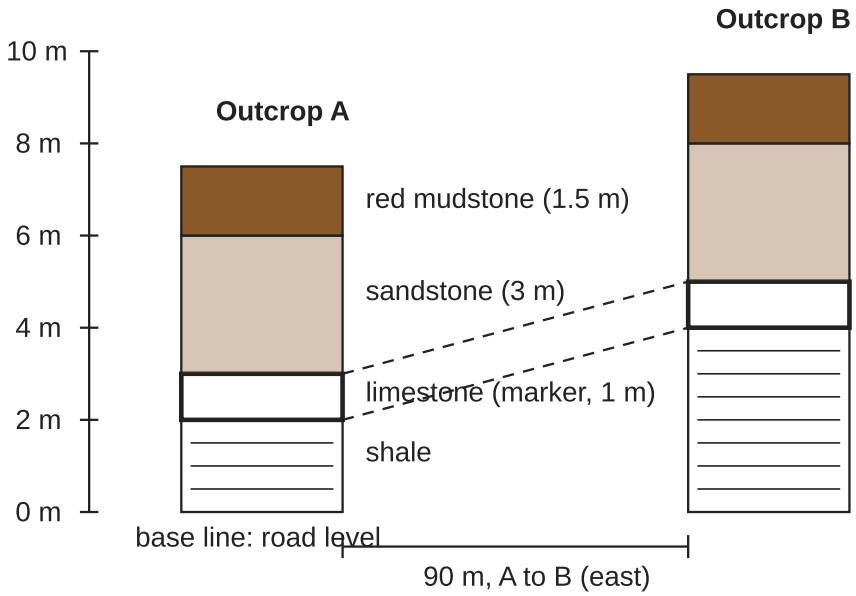
dip
The angle at which a bed slopes down from horizontal, together with the direction it slopes toward.

CORE IDEAS

The story. In the summer of 1880 an artist named William Henry Holmes sat on the North Rim of the Grand Canyon beside the geologist Clarence Dutton. The United States Geological Survey had been founded by Congress only the year before, in 1879, and Dutton had been sent to describe the canyon country. Holmes drew what he saw with such care that every bed in the canyon walls appears in his panoramas in its true place, mile after mile. When Dutton's report and atlas were published in 1882, geologists found they could lay a finger on a limestone ledge on one side of the canyon in Holmes's drawing and follow it, without a break, to the far wall and beyond. That is mapping: not inventing, but tracing what is really there until the pieces connect.

The big idea. A geologic map answers one question: what rock is under the soil at each spot? To make one, a mapper visits outcrops, records the beds at each one in a **stratigraphic column**, and then asks whether the beds at outcrop A are the same beds as at outcrop B. Steno's **lateral continuity** says a water-laid bed spreads sideways, so a distinctive bed, such as a white limestone with a pebble layer on top, is a marker you can follow. If the marker sits at the same height in both outcrops, the beds are flat. If it is higher at B than at A, the beds are tilted, and you can work out the **dip**: rise divided by distance. Mappers show lines they have actually walked as solid lines and lines they infer under cover as dashed lines. That is honesty drawn into the map itself.

Try it and see. Your tools are your own pace, a compass and graph paper. Count paces between outcrops and turn them into meters; take a bearing so you know the direction; plot each outcrop at a stated scale. Then find your home on your state's geologic map (every state has one, and the USGS gathers them online). The legend lists rock types, such as sandstone, shale and limestone, which you can check with your eyes and your vinegar bottle. It also lists museum words such as "Ordovician" and ages in millions of years, which are interpretations added to the rock types. Moses wrote that "in six days the LORD made heaven and earth, the sea, and all that in them is" (Exodus 20:11). The order of the beds, their thickness and their tilt are the Lord's handiwork that anyone can map. How long the beds took is a reading laid over the map, and you will learn to tell the two apart at a glance.



Stratigraphic columns for two outcrops. The white limestone marker bed is the same bed in both, but it sits 2 m higher at B, so the beds dip gently toward A.

⏳ Thinking About Time

What the sign says. What the sign says: the legend of a state geologic map labels each color with a rock type and a museum word for its age, for example “Ordovician limestone and shale, about 450 million years old.”

What we observe. What we observe: the colors on the map stand for rock types that really are found at the surface, and the order and tilt of the beds can be checked at any outcrop. The ages are not printed on the rocks. They are calculated from assumptions about rates that we cannot watch.

How Christians read it. How Christians read it: Christians who hold the young-earth view use the same geologic maps, because where the rocks are and how they stack is observation. They read the great stacks of water-laid beds as mostly the work of the Flood year and its aftermath, and they treat period names as useful labels, not as measured time.

Try it. Find your county on your state geologic map and copy the legend entry for the rock under your house, then underline the words you could check with your own eyes.

Exodus 20:11

PICTURE STUDY



The Grand Cañon at the Foot of the Toroweap, Looking East, William Henry Holmes, 1882 · Lithograph, a plate in the atlas to Clarence Dutton's Tertiary History of the Grand Cañon District, published by the U.S. Geological Survey · U.S. Geological Survey; copies in the Library of Congress and many university libraries

William Henry Holmes was an artist first, then a geologist, and later a museum director at the Smithsonian. His drawings of the Grand Canyon were made for Clarence Dutton's report of 1882, and they are still admired because they are both beautiful and exact. Where a painter might soften the cliffs into mist, Holmes drew every ledge and every bed as a line that can be followed across the whole picture.

Look at this plate the way a mapper would. Each line of cliff is a bed or a group of beds. Follow one as far as you can. If you can follow it across the canyon and up the far wall, you have just used Steno's principle of lateral continuity on a scale of kilometers.

Look closely

- Pick one strong ledge near the top of the canyon wall and trace it with your finger across the whole drawing. Does it stay at the same level, or does it gently rise or fall?
- Count how many major cliff bands Holmes drew between the rim and the river. Each band is a different rock unit.
- Find the flat plateau tops in the distance. What does their flatness tell you about the layers under them?
- Notice how Holmes shows the far wall in lighter, thinner lines. Why would an artist draw distant layers more faintly, and why is it important that he still drew them in their true places?

Talk about it

1. Why is a careful drawing sometimes more useful to a mapper than a photograph?
2. How could a geologist use this plate to make a geologic map of the plateau above the canyon?
3. If the beds in your own creek bank are only a few meters thick, how does seeing them traced for kilometers in a canyon change the way you think about them?

> **Safety first.** Mapping takes you across fields, creek banks and roadsides. Go with a parent, ask permission before crossing private land, and stay off steep or crumbling banks. Watch for traffic on roads, poison ivy along fence lines and ticks in long grass, and check for ticks afterward.

EXPERIMENT: MAP TWO OUTCROPS AND CONNECT THE BEDS

You will make a small geologic map of your own neighborhood or a stretch of creek. Question: are the beds at two nearby outcrops the same beds, and are they flat or tilted? Prediction: write down whether you expect the beds to be flat or to slope, and in which direction. What we change: nothing, this is a mapping lab. What we keep the same: the same pace length, the same compass, the same vertical scale on every column. What we measure: distance by pacing, bearing by compass, bed thickness by tape, and the height of a marker bed above a common level.

You will need

- Graph paper, pencil, ruler and clipboard
- A compass (a phone compass will do)
- Tape measure (5 m) and your pace length from the warm-up
- Vinegar dropper bottle and hand lens
- Colored pencils (brown for sandstone, gray for shale, light blue or white for limestone, red for mudstone)
- Your state geologic map, printed or on a screen (see the kits for this unit)

Steps

1. Choose two outcrops within a few hundred meters of each other: two creek banks, two road cuts, or a bank and a quarry wall. Mark a common level you can see from both, such as the creek surface, a road or a fence line.
2. At outcrop A, draw a stratigraphic column: measure each bed with the tape, draw the column at a scale of 1 cm = 1 m from the bottom up, color each bed by rock type, and note grain size and fizz. Circle any bed that is unusual (a white limestone, a pebble layer, a coal streak). That is your marker bed.
3. Measure how high the top of the marker bed sits above your common level and write it beside the column.
4. Walk from A to B counting paces, and take the bearing from A to B with the compass. Convert paces to meters using your pace length. If the path bends, record each straight leg separately.

5. At outcrop B, draw a second column at the same scale and look for the marker bed. Match it by its color, thickness, grain size, fizz and what lies above and below it. Measure its height above the common level.
6. On graph paper, choose a map scale (for example 1 cm = 10 m). Draw a north arrow, plot A, then plot B at the right distance and bearing. Draw the marker bed as a solid line where you saw it and a dashed line between the outcrops where you infer it.
7. Compare the heights of the marker bed at A and B. If they differ, calculate the dip: rise (the difference in height) divided by the horizontal distance, then find the angle. Write whether the bed dips toward A or toward B.
8. Open your state geologic map, find your spot, and copy the legend entry for the rock unit there. Write two lists: words you could check at the outcrop, and words that are interpretations.

Tips

- If your area has no bare rock, map soil instead: dig small holes with a trowel at three spots, draw a column of the soil layers in each, and match the layers. The method is identical.
- Pace on level ground when you can. Steps shorten going uphill, so note it and add a few percent.
- A marker bed that is the same thickness in both outcrops is strong evidence it is the same bed. A bed that is 1 m at A and 4 m at B may be a different bed.

Check your work

- My map has a north arrow, a stated scale, both outcrops plotted by pacing and bearing, and solid and dashed lines used correctly.
- I drew two stratigraphic columns at the same vertical scale and matched a marker bed between them.
- I calculated whether the beds are flat or dipping, and I separated the legend’s rock words from its museum words.

FIELD NOTEBOOK

1. Copy your best stratigraphic column in ink with a vertical scale bar, a title with the outcrop’s name and date, and a short key for the colors and patterns you used.
2. Draw a plan-view map of your route from outcrop A to outcrop B with each leg labeled by its paces, meters and bearing.
3. Trace or sketch a small piece of your state geologic map around your home and write the legend entry beneath it, underlining the words that name rock types.

> **From history.** The United States Geological Survey was created by an act of Congress on March 3, 1879, with the geologist Clarence King as its first director. One of its first great tasks was to map the plateaus and canyons of the Southwest, and Clarence Dutton’s report on the Grand Canyon, illustrated by William Henry Holmes, came out of that work

in 1882. The USGS still publishes geologic maps of every part of the country, and the National Geologic Map Database lets anyone look up the map for their own county.

WORKED EXAMPLES

Example 1. Your pace length is 0.75 m. From outcrop A you walk 120 paces due east to outcrop B. At A, the top of the white limestone marker bed is 1.0 m above the road; at B, the same bed is 5.5 m above the road, and the road is level. (a) How far apart are A and B? (b) How far apart should they be drawn on a map with the scale 1 cm = 10 m? (c) What is the dip of the beds, as a percent grade and as an angle, and in which direction do they dip?

(Use the map or drawing "In the figure the marker bed rises 2 m over 90 m, a smaller dip than in this exa" shown earlier in this lesson.)

1. (a) Distance = paces × pace length = 120 × 0.75 m = 90 m.
2. (b) At 1 cm = 10 m, the map distance is 90 m ÷ 10 m/cm = 9 cm.
3. (c) Rise of the marker bed from A to B = 5.5 m − 1.0 m = 4.5 m over a horizontal distance of 90 m. Grade = 4.5 ÷ 90 = 0.05, which is 5%.
4. The dip angle has tan θ = 0.05. On a calculator, θ = $\tan^{-1}(0.05) \approx 2.9°$, which rounds to about 3°.
5. The bed is higher at B (east) and lower at A (west), so it slopes down toward the west. The beds dip gently, about 3°, toward the west.

Answer: (a) 90 m. (b) 9 cm on the map. (c) A 5% grade, about 3° of dip, toward the west.

PRACTICE

1. EASY State Steno's principle of lateral continuity in your own words and explain how it lets a mapper connect two outcrops.
2. EASY A student walks a 50 m tape in 64 steps. What is the pace length? How many meters is a walk of 200 steps?
3. MEDIUM Data reading. Three outcrops lie in a straight line along a level road. A coal seam appears at the following heights above the road surface: West outcrop, 6.0 m; Center outcrop (150 m east of West), 3.0 m; East outcrop (300 m east of West), 0 m, right at road level. (a) Which direction does the seam dip? (b) What is the grade? (c) Where would a well east of the East outcrop find the seam, above or below the road?
4. MEDIUM Use the figure of the two stratigraphic columns. (a) What is the total thickness of beds above the base of the limestone in column A? (b) Which bed is thickest? (c) If a third outcrop lay between A and B, at what height above the base line would you predict the top of the limestone?
   (Use the map or drawing "Read the thicknesses from the scale on the left." shown earlier in this lesson.)

5. HARD Two sandstone outcrops lie 300 m apart with fields between them. Describe four kinds of evidence you would gather to decide whether they expose the same bed, and explain what result would make you say they are different beds.

COMMON MISTAKES

- Drawing a solid line on the map between outcrops you never walked. Solid means seen, dashed means inferred, and mixing them up hides what you actually know.
- Matching beds by color alone. Weathering changes color, so match by thickness, grain size, fizz and the beds above and below as well.
- Reading the legend's ages as if they were measured like the thicknesses. Thickness, order and tilt are observed; the ages are interpretations added to the map.

> **Make it a game · Pace Race.** A parent hides three "outcrops" (flags or stones) in a yard or park and gives each player only a list of legs: "From the gate, 40 paces at bearing 90°, then 25 paces at bearing 180°." Players convert the paces to meters using their own pace lengths, follow the bearings with a compass and plot each find on graph paper at 1 cm = 5 m. The player whose map best matches the parent's master map wins. Second round: players write the legs for each other.

> **Scripture.** "For in six days the LORD made heaven and earth, the sea, and all that in them is, and rested the seventh day: wherefore the LORD blessed the sabbath day, and hallowed it." (Exodus 20:11, KJV)

The Lord who made the earth also made it orderly enough to map. Beds keep their order and continue from place to place, so the rocks under your feet can be traced and drawn by anyone willing to walk and look.

Practice answers

1. Water spreads sediment out sideways in sheets, so a bed continues in all directions until it thins out or is cut off. A mapper can therefore expect the same bed to appear in a nearby outcrop and can draw a line connecting the two.
2. 50 m ÷ 64 = 0.78 m per step. 200 steps × 0.78 m = about 156 m.
3. (a) The seam gets lower toward the east, so it dips east. (b) It drops 6.0 m over 300 m: 6 ÷ 300 = 0.02, a 2% grade (about 1.1°). (c) Below the road, because the seam keeps dropping at 2 m for every 100 m east of the East outcrop.
4. (a) Limestone 1 m + sandstone 3 m + red mudstone 1.5 m = 5.5 m. (b) The sandstone, 3 m. (c) About halfway between the two heights: the limestone top is 3 m above the base line at A and 5 m at B, so about 4 m at the midpoint, because the beds dip at a steady angle.
5. Compare (1) thickness, (2) color, grain size and fizz on fresh chips, (3) the beds just above and below, especially any marker such as a pebble layer, coal streak or fossil band, and (4) the height of the bed above a common level, which should fit a steady dip between the two. You could also walk the fields looking for small exposures in ditches. If the thickness differs greatly, the grain size or fizz does not match, the beds above and below are different, or the

heights would need an unreasonable jump in dip, the outcrops are probably different beds, and the connecting line should stay dashed or be left off.

9.3 Flood Deposits in a Creek

OBJECTIVES

- Find and sketch fresh flood deposits along a creek, including a point bar, a sand sheet and a graded bed, and tell which way the water flowed from the evidence.
- Measure the creek's surface speed with a float and a stopwatch and use a grain-size chart to tell which sizes of sediment that speed can move.
- Sort a sediment sample into gravel, sand and mud, record the percentages, and explain what the sorting says about the water that left it.

Warm-up. Fill a clear jar halfway with a mix of garden soil, sand and a few small pebbles, add water nearly to the top, cap it and shake hard for ten seconds. Set it down and watch for five minutes. Write what lands first, what lands last, and what is still clouding the water. Keep the jar for later and look again tomorrow.

Video. Coming soon. How flowing water sorts sediment and leaves graded beds, point bars and imbricated pebbles after a flood: Big Thompson Canyon flood of 1976, stream-table demonstrations, settling-jar experiments. Search USGS, NOAA, Smithsonian, Science Max, Moody Science classics and nature footage of flash floods and creeks.

KEY TERMS

sediment
Loose grains of rock and soil, from clay and silt to sand, pebbles and boulders, that water, wind or ice carry and drop.

sorting
How evenly sized the grains in a deposit are. Water sorts sediment because it drops the heaviest grains first as it slows.

graded bed
A single layer that is coarse at the bottom and fine at the top, left by one pulse of water that slowed and dropped its load biggest first.

point bar
The crescent of sand and gravel that builds on the inside of a creek bend, where the water runs slowest.

floodplain
The flat land beside a creek that is covered only when the creek overflows, and that receives a thin sheet of mud or sand each flood.

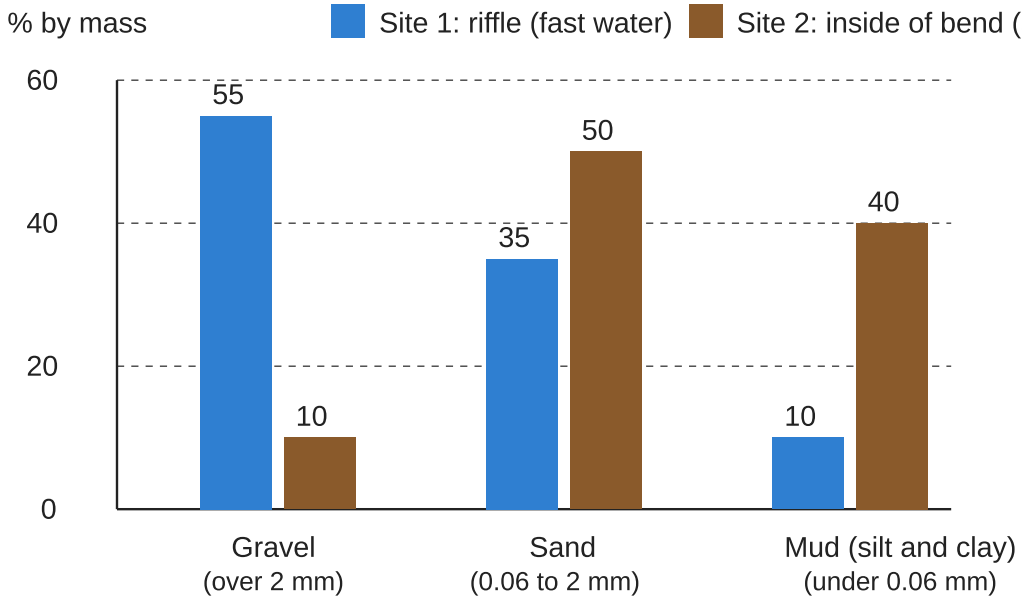
imbrication
Flat pebbles stacked by moving water so that they lean upstream, overlapping like roof shingles.

CORE IDEAS

The story. On the evening of July 31, 1976, a thunderstorm stalled over the Big Thompson Canyon in the Front Range of Colorado. In a few hours it dropped about 30 cm of rain on the upper canyon. The Big Thompson River, normally a pleasant trout stream, rose into a wall of water that tore out the canyon road, carried away cabins and campers, and took more than 140 lives. When geologists from the U.S. Geological Survey walked the canyon afterward, they found that the flood had moved boulders the size of cars and had left behind fresh deposits of gravel, sand and mud. The deposits had patterns. Flat cobbles leaned upstream like shingles. Sand lay in beds that were coarse at the base and fine at the top. From the deposits alone, a geologist could tell which way the water had run and roughly how fast. One night had written a record in stone and sand.

The big idea. Moving water carries grains according to its speed, and when it slows it drops them in order, heaviest first. A creek running at a gentle 0.3 m per second can roll sand; it takes roughly 1 m per second to shift pebbles a centimeter across, and clay settles only when water is nearly still. So one pulse of floodwater that rises and then slows leaves one **graded bed**: gravel, then sand, then silt, then clay on top. A stack of graded beds records a series of pulses. On the inside of a bend the water is slow and builds a **point bar**; on the outside it is fast and cuts the bank. When the creek spills over its banks, the overflow slows at once and lays a thin sheet of mud or sand across the **floodplain**. Every one of these features is something you can find, sketch and measure after the next heavy rain.

God’s handiwork. Genesis says that after the Flood “the waters returned from off the earth continually,” draining over months (Genesis 8:3). Many creation geologists read the thick stacks of graded, sorted, widespread beds in the rock record as the work of water on a continental scale, rising, pulsing and draining in the Flood year, doing in months what a creek does in a night. The textbook reading is slower, and both readings begin with the same observation: moving water sorts and grades what it carries, quickly. The psalmist says of the waters that God “hast set a bound that they may not pass over; that they turn not again to cover the earth” (Psalm 104:9). A creek in its banks is a small daily picture of that promise, and its deposits are a small daily picture of what water can build.



Percent by mass of gravel, sand and mud in two creek samples. Faster water at the riffle left coarser sediment; slow water on the inside of the bend left sand and mud.

⏳ Thinking About Time

What the sign says. What the sign says: textbooks commonly explain that the thick sandstone and shale layers in the rock record were laid down a little at a time, over hundreds of thousands or millions of years, by ordinary rivers and quiet seas.

What we observe. What we observe: after one storm a creek leaves a fresh graded bed several centimeters thick in a few hours, with sorted grains and pebbles leaning upstream. After the 1976 Big Thompson flood, USGS geologists mapped fresh gravel and boulder deposits that had been left in a single night.

How Christians read it. How Christians read it: Christians who hold the young-earth view read the great stacks of graded, sorted beds in the rock record as the work of the Flood year, when water moved sediment on a continental scale and dropped it in pulses as the waters rose and drained. The creek shows the process; the Flood shows the scale.

Try it. After the next heavy rain, find a fresh sand deposit in your creek, scrape a small vertical face and look for a graded bed. Measure its thickness and note how many hours of rain made it.

Genesis 8:3

PICTURE STUDY



View from Mount Holyoke, Northampton, Massachusetts, after a Thunderstorm (The Oxbow), Thomas Cole, 1836 · Oil on canvas · Metropolitan Museum of Art, New York

Thomas Cole painted the Connecticut River from the top of Mount Holyoke in 1836, just as a thunderstorm was passing off to the left. Below lies one of the most famous river bends in America, the Oxbow, where the river swings around in a loop so tight that it nearly meets itself. The flat land inside the loop and along the river is floodplain, built by the river out of the sand and mud it drops every time it overflows.

Cole was a painter, not a geologist, but he painted the shape of the land faithfully. Look at the picture as a map of what moving water does when it slows down.

Look closely

- Find the oxbow loop. On which side of each bend, inside or outside, would you expect the water to run slowest and build a point bar?
- Look at the flat fields inside the loop and along the river. Why is the land there so flat and so good for farming? What has the river been spreading over it?
- Notice the storm on the left and the bright valley on the right. After a storm like that, what would the river be carrying, and what would it leave behind when it slowed?
- Find the tiny figure of the painter with his easel on the rocks in the foreground. Why do you think Cole put himself into the picture?

Talk about it

1. If you could dig a pit in the floodplain inside the Oxbow, what kind of layers would you expect to find, and why?

2. A river that loops this much must be flowing slowly across flat land. What happens to the sediment a slow river carries?
3. Cole painted the storm and the calm side by side. How does a creek show you both its violent side and its calm side in the deposits it leaves?

> **Safety first.** Water is the main danger in this lesson. Never go to a creek during or just after heavy rain, when flash floods can arrive without warning. Go with a parent, wade only where the water is below your knees and slow, and never cross fast water. Wear closed shoes in the creek because of broken glass and sharp stones, keep hands away from your face, and wash your hands well afterward. Stay off undercut banks that could collapse.

EXPERIMENT: READING WHAT THE LAST FLOOD LEFT

You will measure a creek's speed, collect sediment from two places, and sort it to find out what the water can carry and what it has dropped. Question: does sediment on the inside of a bend differ from sediment in a fast riffle, and does the difference match the water speed? Prediction: write which site you expect to have more gravel and which more mud. What we change: the sampling site (fast riffle versus slow inside bend). What we keep the same: the amount of sediment collected, the sieve sizes, and the drying method. What we measure: float speed in meters per second, and the mass or volume of gravel, sand and mud in each sample.

You will need

- Two zip bags or jars for sediment samples, a trowel and a marker
- A kitchen sieve or colander with holes of about 2 mm (gravel from sand) and a piece of fine cloth or coffee filter (sand from mud)
- A kitchen scale or measuring cup, and newspaper or trays for drying
- An orange or a stick to float, a tape measure, a stopwatch and two sticks for marking 10 m along the bank
- Notebook, pencil, hand lens, and a parent to watch the water

Steps

1. Choose a safe, shallow creek on a dry day with a parent. Walk a stretch of it and sketch a plan view showing bends, a riffle (fast, shallow, rippled water), a pool, and any bars of sand or gravel. Draw an arrow for the flow direction.
2. Measure speed: mark 10 m along a straight stretch with the two sticks. Drop the orange upstream of the first stick, start the stopwatch as it passes, and stop as it passes the second. Repeat three times and average. Speed = 10 m ÷ average seconds. Multiply by 0.85 to estimate the average speed of the whole stream, which is slower than the surface.
3. Collect sample 1 from the bed of the riffle and sample 2 from the top of a point bar on the inside of a bend. Scoop the same volume each time (about two cups) and label the

bags.

4. Look for flood evidence: a fresh sand sheet on the floodplain, grass flattened in the flow direction, leaves and sticks caught on the upstream side of trees, and flat pebbles leaning upstream (imbrication). Sketch and measure the height of the highest debris line above the present water surface.
5. With a trowel, cut a small vertical face into a sand bar and look for layers. If you find a bed coarse at the bottom and fine at the top, you have found a graded bed. Measure its thickness and sketch it.
6. At home, spread each sample on newspaper to dry overnight. Then sieve each sample: shake it through the 2 mm sieve to separate gravel, then wash what passed through the fine cloth in a bowl of water, let the sand sink and pour off the muddy water into a second bowl. Dry the sand and the mud and weigh or measure each fraction.
7. Calculate the percent of gravel, sand and mud in each sample and draw a bar graph like the one in this lesson.
8. Compare your float speed with the grain-size chart in the worked example. Could today's creek move the gravel you found? If not, what does that tell you about the water that put it there?

Tips

- Mud is the slowest part to settle. Let the muddy bowl stand for several hours, then pour off the clear water carefully.
- If your creek has no gravel at all, compare a sample from the fast center with one from a slack edge; the sorting difference will still show.
- The height of the debris line tells you how high the last flood rose. Compare it with the creek's present depth to estimate how many times deeper it was.

Check your work

- I measured the creek's speed three times and recorded an average in meters per second.
- I sorted two samples into gravel, sand and mud, calculated percentages and drew a bar graph.
- I found and sketched at least two pieces of flood evidence and used them to tell the flow direction.

FIELD NOTEBOOK

1. Draw a plan view of your creek stretch with the riffle, pool, point bar and cut bank labeled, an arrow for flow direction, and the two sampling sites marked.
2. Sketch the small vertical face you cut into the sand bar, showing any graded bed with its thickness in centimeters and the grain size at the bottom and top.
3. Draw your settling jar from the warm-up after one day, labeling each layer from the bottom up with what it is made of and about how thick it is.

From history. The relation between water speed and the size of grains it can move was measured carefully by the Swedish geographer Filip Hjulström, who studied the Fyris River near Uppsala and published his results in 1935. His diagram, still printed in geology textbooks, shows that fine sand is the easiest sediment to pick up, while clay, once settled, sticks together and needs surprisingly fast water to lift it again. After the Big Thompson flood of 1976, U.S. Geological Survey scientists used the size of the boulders the flood had moved to estimate how fast and deep the water had been, reading the speed from the deposits just as Hjulström's chart allows.

WORKED EXAMPLES

Example 1. You mark 10 m along a creek and float an orange past the marks three times: 12.0 s, 13.0 s and 12.5 s. Use the rough chart below to decide what today's creek can move. After a storm, the same float takes 4.0 s. What can the creek move then?

Rough water speed needed to move grains: clay and silt, about 0.1 m/s or less once stirred up; sand (0.5 mm), about 0.3 m/s; pebbles (10 mm), about 1 m/s; cobbles (100 mm), about 2 to 3 m/s.

1. Average the times: (12.0 + 13.0 + 12.5) ÷ 3 = 12.5 s.
2. Surface speed = distance ÷ time = 10 m ÷ 12.5 s = 0.8 m/s.
3. Average stream speed is lower than the surface speed: 0.8 × 0.85 ≈ 0.68 m/s, about 0.7 m/s.
4. Compare with the chart: 0.7 m/s is above the 0.3 m/s needed for sand but below the 1 m/s for pebbles. Today the creek can carry silt and sand but will leave pebbles where they lie.
5. After the storm: 10 m ÷ 4.0 s = 2.5 m/s at the surface, about 2.5 × 0.85 ≈ 2.1 m/s on average. That is above 1 m/s, so pebbles roll, and it is near the 2 to 3 m/s range where cobbles begin to move.
6. The storm flow is about three times faster than the normal flow (2.1 ÷ 0.7 = 3), yet it moves grains hundreds of times heavier. Speed matters far more than its number suggests.

Answer: Today: about 0.7 m/s average speed, enough to move sand and silt but not pebbles. After the storm: about 2.1 m/s, enough to roll pebbles and start moving cobbles. The gravel on the bar was left by storm flow, not by today's creek.

PRACTICE

1. EASY A pulse of muddy water carrying pebbles, sand and clay slows down and stops. In what order do the grains settle, and what is the resulting layer called?
2. EASY On a creek bend, where does a point bar form, and why does it form there?

3. MEDIUM Data reading. Use the bar graph of the two sediment samples. (a) What percent of Site 1 is gravel, and what percent of Site 2 is mud? (b) Which site had faster water when the sediment was dropped, and what evidence in the graph supports that? (c) A student claims Site 2 must be a riffle because it has the most sand. Explain why the data do not support this.
   (Use the map or drawing "Percent by mass of each grain size at two sites." shown earlier in this lesson.)
4. MEDIUM An orange floats 10 m down a creek in 20 s. (a) What is the surface speed? (b) Estimate the average stream speed using the 0.85 factor. (c) Using the chart in the worked example, can this creek move sand? Pebbles?
5. HARD Experiment design. You want to know whether the amount of mud in a jar of sediment changes how long the water takes to clear after shaking. Describe your experiment: the independent variable, the dependent variable, three things to keep the same, how you would measure clearing, and how many trials you would run.

COMMON MISTAKES

- Thinking slow creeks drop everything. Slow water still carries clay in suspension for hours; it drops only what it can no longer lift, and clay settles last.
- Reading a graded bed upside down. Coarse grains are at the bottom because they settle first; a bed that is fine at the bottom and coarse at the top records water that was speeding up, or several separate pulses.
- Assuming today's creek made the gravel bar you are standing on. Compare the grain size with the speed you measured; gravel usually records the last storm flow, not the normal flow.

> **Make it a game · Which Way Did It Flow?.** At the creek, one player closes their eyes while a parent points to a piece of flood evidence: leaning pebbles, flattened grass, a debris pile against a tree, a point bar, a cut bank or a graded bed. The player must look only at that one feature, say which way the water flowed, and explain why in one sentence. A correct direction scores one point, a correct reason scores two, and measuring the feature in your notebook before answering scores a bonus point. First to ten points wins.

> **Scripture.** "And the waters returned from off the earth continually: and after the end of the hundred and fifty days the waters were abated." (Genesis 8:3, KJV)

The Flood did not end in an instant; the waters drained for months, and draining water sorts and layers what it carries. The patterns you find in a creek after a storm are the same patterns, written small.

Practice answers

1. Pebbles first, then sand, then silt, then clay last. The layer, coarse at the bottom and fine at the top, is a graded bed.

2. On the inside of the bend. Water moves slowest on the inside of a bend, so it can no longer carry its sand and gravel and drops them there, building a crescent-shaped bar.
3. (a) Site 1 is 55% gravel; Site 2 is 40% mud. (b) Site 1, because more than half its sediment is gravel, which only fast water can move, and it has very little mud, which fast water keeps in suspension and carries away. (c) Sand is moved by moderate flow, but the 40% mud at Site 2 shows the water there was slow enough to let mud settle. Riffles are fast and do not collect mud, so Site 2 is better explained as a slow inside bend.
4. (a) 10 ÷ 20 = 0.5 m/s. (b) 0.5 × 0.85 ≈ 0.43 m/s, about 0.4 m/s. (c) Yes to sand, which needs about 0.3 m/s. No to pebbles, which need about 1 m/s.
5. Independent variable: the fraction of mud in the sample (for example 10%, 30% and 50% by volume, with the rest sand). Dependent variable: time for the water to clear. Keep the same: total amount of sediment, amount and temperature of water, jar size and shape, shaking time and strength, and lighting. Measure clearing by placing a printed letter behind the jar and timing until it can be read, or by timing until a flashlight beam passes through without scattering. Run each mud fraction three times and average. Prediction: more mud means longer clearing time, because clay settles far more slowly than sand.

9.4 Museum Sign Journal

OBJECTIVES

- Keep a sign journal at a natural history museum, or an online museum collection, that copies each sign's exact words and separates what the sign claims from what can be seen in the case.
- Check a sign's measurable claims, such as a skeleton's length or the share of real bone in a mount, by pacing and simple arithmetic.
- Write a kind, well-formed question for a museum guide and a short paragraph stating the young-earth reading of one exhibit beside the sign's reading.

Warm-up. Take any labeled thing from the kitchen, such as a cereal box or a jar of honey. Copy one claim from its label word for word. Then write two lists: what you can check right now by looking, weighing or tasting, and what you would have to take on trust. Every museum sign can be sorted the same way.

Video. Coming soon. How museums build and label fossil exhibits: casts versus real bone, how mounts are assembled, Charles Willson Peale's mastodon of 1801, and how exhibit labels have changed over time. Search Smithsonian, American Museum of Natural History, Field Museum, Moody Science classics and museum behind-the-scenes footage.

KEY TERMS

specimen
A real object in a museum, such as a bone, a shell or a rock, that was collected from a particular place.

label
The sign beside a specimen. It usually gives a name, a place found, an age claim and a short story about the specimen.

cast
A copy of a bone or fossil made in plaster or resin from a mold of the original. Many mounted skeletons are partly or wholly casts.

reconstruction
A model, painting or mounted skeleton that fills in missing parts by the best guess of the museum's scientists.

observation
Something anyone can see, count or measure in the case, such as the number of bones, their size or their color.

interpretation
A conclusion drawn from observations plus assumptions, such as an age in years or a story about how the animal lived.

CORE IDEAS

The story. In the summer of 1801 the painter Charles Willson Peale traveled from Philadelphia to a farm near Newburgh, New York, where huge bones had been found in a marl pit. With a great wooden wheel that drove a chain of buckets to drain the pit, Peale and his crew dug out most of a skeleton. By Christmas Eve of that year he had mounted it in his museum in Philadelphia, the first fossil skeleton ever assembled and put on public display in America. Peale called it a "mammoth," and so said his label. A few years later the French anatomist Georges Cuvier showed that the animal's cone-shaped teeth made it something else, and the name became mastodon. The bones had not changed. The label had. Peale's museum, where he painted himself lifting a curtain on rows of labeled specimens in 1822, is the great-grandfather of every natural history hall you will visit, and its first big sign was later rewritten.

The big idea. A museum sign mixes two kinds of statements, and a sign journal pulls them apart. First, copy the sign **word for word**, including every number. Second, write what you can **observe** in the case: how many bones, which are real and which are casts (museums usually tell you, or a darker, heavier look gives the real ones away), how long the mount is when you pace it, what the rock around a fossil looks like. Third, for each number on the sign, write the **assumptions** behind it, which you learned in Unit 7: constant decay rates, known starting amounts, no gain or loss from the rock. Fourth, write **how Christians read it**: the same bones, the same rock, understood as creatures made "after their kind" and buried in the Flood year or soon after. Fifth, write one **question** you would ask a guide, worded so kindly that the guide would enjoy answering it. Job describes behemoth, "which I made with thee; he eateth grass as an ox" (Job 40:15), a reminder that whatever great beasts God made, we now meet most of them only as bones, and bones must be read.

In the world today. Signs change because museums keep learning. The Crystal Palace Iguanodon of 1854 wore its thumb spike as a nose horn; later finds moved it to the hand. Museums have renamed skeletons, re-posed tails from dragging to lifted, and repainted murals as evidence came in. That is not a scandal. It is how honest science works, and it is why your journal keeps the sign's claim and your observation in separate columns, so that when the sign is rewritten, your observations still stand. If no museum is near you, the Smithsonian and other great museums publish their collections and virtual tours online, and a screen label can be journaled exactly like a glass case. Pace what you can, copy what you cannot, and keep asking what was seen and what was supposed.

Museum Sign Journal Date: _____ Museum: _____ Hall: _____ Exhibit: _____
1. The sign says (exact words, every number): “Tyrannosaurus rex. Late Cretaceous, about 66 million years ago. Length 12.3 m
2. I observe (count, measure, look): 17 paces × 0.72 m = 12.2 m. Darker bones (real) in skull and legs; white casts in
3. Numbers and the assumptions behind them: “66 million”: constant decay rate, known starting amount, closed system. “12.3 m
4. How Christians read it: A creature made after its kind, buried quickly in sediment in the Flood year. “Cret
5. My question (asked kindly): “I noticed the sign gives an age. Could you help me understand how that numbe

One page of the sign journal. Copy the sign exactly into the first row and keep your own observations in the second.

⏳ Thinking About Time

What the sign says. What the sign says: a typical dinosaur hall label reads something like “Tyrannosaurus rex, Late Cretaceous, about 66 million years ago,” and a mammoth label often says “Pleistocene, about 12,000 years ago.”

What we observe. What we observe: a mount of real bones and casts of a stated length, the rock the fossil came from, the label’s exact words, and the ages, which are calculated from decay rates and assumptions, not read off the bones.

How Christians read it. How Christians read it: Christians who hold the young-earth view see the same bones as remains of creatures God made, most of them buried quickly in the Flood year, with the mammoths living in the single ice age after it. Cretaceous and Pleistocene are museum words we learn so we can read the label accurately.

Try it. Copy one label’s age claim word for word, then list under it the three assumptions a decay-rate date depends on.

2 Peter 3:5

PICTURE STUDY



The Exhumation of the Mastodon, Charles Willson Peale, 1806–1808 · Oil on canvas · Maryland Center for History and Culture (formerly the Maryland Historical Society), Baltimore

This is the dig itself. Peale painted it a few years after the summer of 1801, when he drained John Masten’s marl pit near Newburgh, New York, and lifted out most of a skeleton. The great wheel at the center was turned by men walking inside it; it drove a chain of buckets that carried the water up and away through a wooden trough, so the diggers could work on the pit floor. A storm is coming in from the left, and the crew is hurrying.

On the right bank Peale gathered his family, and he stands among them pointing to a large drawing of a bone. That drawing is the point of the picture for this lesson: even in the mud, the specimen was being recorded to scale as it came out of the ground. The bones went to Philadelphia, the drawings went with them, and the first label on the finished mount called the animal a mammoth.

Look closely

- Find the wheel and follow the chain of buckets. Where does the water go? Why did the pit have to be drained before anyone could record what was in it?
- Look at the workmen in the pit. What are they holding up, and who on the bank is watching them? Which people in the picture are observing and which are recording?
- Find the large drawing on the right. Why would Peale show a drawing of a bone rather than the bone itself?
- Notice the storm sky and the lightning. How does the weather change the mood of a scene that is really about careful digging?

Talk about it

1. Peale labeled this skeleton a mammoth, and the label was later changed to mastodon after Cuvier studied the teeth. Which parts of this picture, the bones or the words about them, had to change?
2. If you had been standing on the bank with a notebook in 1801, what would you have written in your “I observe” column, and what would have belonged in the “I think it means” column?
3. Peale wanted his museum to be “a world in miniature.” How does a well-kept journal let you carry a museum, or a dig like this one, home with you?

EXPERIMENT: KEEP A SIGN JOURNAL FOR FIVE EXHIBITS

You will journal five signs at a natural history museum, or five labels from an online museum collection if no museum is near you. Question: for each sign, how much of what it says can be checked in the case, and how much rests on assumptions? Prediction: before you start, guess what fraction of the words on a typical sign are observations and what fraction are interpretations. What we change: the exhibit. What we keep the same: the journal page layout, the pace length you use for measuring, and the rule that the sign is copied exactly. What we measure: the length of at least one mount by pacing, and the count of observation sentences versus interpretation sentences on each sign.

You will need

- A small notebook ruled into the five rows of the journal page, one page per exhibit
- Pencil (museums usually forbid pens near the cases)
- Your pace length from Lesson 9.2, written inside the cover
- A phone or camera, if the museum allows photographs, for checking your copied words at home
- Museum admission or a computer with the Smithsonian collections online (see the kits for this unit)

Steps

1. Before the visit, rule five journal pages with the header and the five rows shown in the figure. Decide with your parent which halls to visit, and plan to spend at least ten minutes at each exhibit you journal.
2. At each exhibit, copy the sign word for word into the first row, including every name, place and number. Put museum words such as Cretaceous or Pleistocene in quotation marks so you remember they are the sign’s words.
3. In the second row, record only observations: what is in the case, how many bones you can count, which bones are marked as casts, the color and texture of the fossil, what the surrounding rock looks like, and the length of the mount in paces, converted to meters.
4. In the third row, list every number on the sign and, beside each, the assumptions it depends on. For an age from decay rates, write the three assumptions from Unit 7. For a length or weight, write how the museum likely got it (measured the mount, or estimated from the bones).

5. In the fourth row, write two or three sentences giving the young-earth reading of the same exhibit, using the words of the sign respectfully and stating what you observed that fits that reading.
6. In the fifth row, write one question for a museum guide, beginning with words like “I noticed” or “Could you help me understand,” and if a guide is available, ask it and write down the answer.
7. At home, count the sentences on each sign that are observations and the sentences that are interpretations. Make a small table and compare it with your prediction.
8. Choose your best page and copy it neatly for your portfolio, adding a sketch of the specimen.

Tips

- Pace along the floor beside the mount from the tip of the snout to the end of the tail, keeping your eyes on the skeleton, not your feet, so your pace stays natural.
- If the sign says a mount is, for example, 60% real bone, look for the color difference between the original bones and the casts and see whether your own count agrees.
- Online, use the museum’s own collection pages or virtual tour and copy the label text exactly, including the catalog number if it is shown.

Check your work

- I have five pages with the sign copied exactly and my observations in a separate row.
- I paced at least one mount and compared my length with the sign’s number.
- Each page lists the assumptions behind the sign’s numbers, gives the young-earth reading kindly, and ends with a good question.

FIELD NOTEBOOK

1. Draw one mounted skeleton from the museum with a scale bar, shading the bones the sign or your eyes told you were real and leaving the casts white.
2. Make a two-column chart for your favorite exhibit titled “Sign says / I observe,” with at least four matched pairs of statements.
3. Draw the label itself as a small card and, beneath it, rewrite it in your own words so that every observation comes first and every interpretation is marked “(interpretation).”

> **From history.** Peale’s mastodon had a long journey after Philadelphia. When his museum closed, the skeleton was sold and carried across the Atlantic, and today it stands in the Hessisches Landesmuseum in Darmstadt, Germany. Peale painted the digging itself in a picture called Exhumation of the Mastodon, finished in 1808, showing the great bucket wheel draining the pit while the crew lifts bones from the mud. The mastodon’s name came from Georges Cuvier, who in 1806 argued from the teeth that it was a creature distinct from both living elephants and the mammoth, which is why the sign had to change.

WORKED EXAMPLES

Example 1. A sign says the mounted dinosaur skeleton is 12.3 m long and that the mount has 250 bones, of which 60% are original fossil bone and the rest are casts. You pace the mount at 17 paces, and your pace length is 0.72 m. (a) How long is the mount by your pacing, and by what percent does it differ from the sign? (b) How many of the bones should be real and how many casts? (c) You count 36 cast bones in one hind leg and tail section that holds 90 bones. Is that section mostly real or mostly cast, and does it match the whole-mount percentage?

1. (a) Length by pacing = 17 × 0.72 m = 12.24 m, about 12.2 m. Difference from the sign = 12.3 − 12.2 = 0.1 m. Percent difference = 0.1 ÷ 12.3 × 100 ≈ 0.8%, under 1%. Your pacing agrees with the sign.
2. (b) Real bones = 60% of 250 = 0.60 × 250 = 150. Casts = 250 − 150 = 100.
3. (c) In the section, casts = 36 of 90 = 40%, so real bones = 54 of 90 = 60%. That section is mostly real, and 60% real matches the sign's figure for the whole mount.

Answer: (a) About 12.2 m, within 1% of the sign's 12.3 m. (b) 150 real bones and 100 casts. (c) The section is 60% real, which matches the sign's claim for the mount.

PRACTICE

1. EASY What is the difference between a specimen and a cast, and give one good reason a museum would display a cast instead of the original bone.
2. EASY Sort each sentence from this sign as observation (O) or interpretation (I): (a) "This skull is 1.5 m long." (b) "This animal lived 66 million years ago." (c) "The teeth are up to 30 cm long." (d) "It hunted in packs."
3. MEDIUM Data reading. A student with a pace of 0.70 m paced four mounts. Mount A: sign 9.0 m, 13 paces. Mount B: sign 23.0 m, 31 paces. Mount C: sign 4.5 m, 6 paces. Mount D: sign 12.0 m, 17 paces. (a) Convert each pace count to meters. (b) Which two mounts agree with their signs within 2%? (c) For the mount with the biggest percent difference, suggest one reason pacing might have been off.
4. MEDIUM A sign says a mounted mammoth has 320 bones and is 70% original bone. How many bones are original, and how many are casts? If the sign also says the mammoth is "Pleistocene, about 12,000 years old," which of its numbers did the museum measure and which did it calculate?
5. HARD Peale labeled his skeleton a "mammoth" in 1801, and the label was later changed to "mastodon." In a short paragraph, explain what this teaches about the relationship between specimens and labels, and then write one kind question you could ask a museum guide about an age printed on a sign.

COMMON MISTAKES

- Treating everything on a sign as observed fact. Names, places and lengths are usually measured; ages and behavior stories are interpretations built on assumptions.
- Assuming a complete mounted skeleton means a complete fossil was found. Many mounts are partly casts or are filled in from several individuals, and the sign usually says so in small print.
- Thinking a rewritten label means the museum was dishonest. Labels change as evidence improves; the honest response is to record the sign's date and keep your own observations separate so you can compare later.

Make it a game · Sign or Specimen?. One player reads a sentence from a museum sign, a textbook or a label the family makes up, and the others race to call out "observation" or "interpretation," then say in one sentence how they would check it. A correct call scores one point and a workable way to check it scores two. Bonus round: a player gives a number from a sign, such as "12 m long" or "about 66 million years," and the others must name whether it was measured or calculated and what assumptions it needs. Play to fifteen.

Scripture. "For this they willingly are ignorant of, that by the word of God the heavens were of old, and the earth standing out of the water and in the water: Whereby the world that then was, being overflowed with water, perished:" (2 Peter 3:5–6, KJV)

Peter reminds his readers of two things a person can forget on purpose: that God made the world by His word, and that He once judged it by water. A sign journal is a small way of refusing to forget, by writing down both what the sign says and what the rocks and bones show.

Practice answers

1. A specimen is the real collected object; a cast is a plaster or resin copy made from a mold of it. Museums display casts because original bones are heavy, fragile and rare, may be kept safe in storage for study, or may be in another museum, and casts let a complete skeleton be shown.
2. (a) O, a measurement anyone can repeat. (b) I, an age calculated from assumptions. (c) O, a measurement. (d) I, a conclusion about behavior that no one observed.
3. (a) A: 13 × 0.70 = 9.1 m. B: 31 × 0.70 = 21.7 m. C: 6 × 0.70 = 4.2 m. D: 17 × 0.70 = 11.9 m. (b) A differs by 0.1 m out of 9.0 (1.1%) and D by 0.1 m out of 12.0 (0.8%), so A and D agree within 2%. B differs by 1.3 m (5.7%) and C by 0.3 m (6.7%). (c) C is short, so a single pace of error is a large percent; or the tail curled or the mount stood on a curve so the floor path was shorter than the skeleton; or the student's pace shortened in a crowded hall. Whole-pace rounding also limits precision on a short mount.
4. Original bones = 0.70 × 320 = 224. Casts = 320 − 224 = 96. The bone count and the percent of originals were counted by the museum when it built the mount. The age was calculated from a dating method and its assumptions, not measured by counting or by a tape.

5. Sample answer: The bones did not change between 1801 and the renaming; only the words beside them did, when Cuvier compared the teeth with living elephants and saw they were different. A specimen is a fixed observation; a label is an interpretation that can be improved, corrected or rewritten as people learn. That is why a sign journal keeps what was seen apart from what was claimed. A kind question: “I noticed the sign gives an age of 66 million years. Could you help me understand how that number was measured and what the museum assumed to get it?”

Unit 9 review

Answer each question. Show your arithmetic for calculations and use complete sentences for explanations. Problem 6 asks for a labeled diagram. The review is worth 60 points.

1. (10 pts) Multiple choice. A field photograph of a road cut shows a 1.5 m stick as 2.5 cm tall and the whole face as 15.0 cm tall. The real face is: (a) 6 m, (b) 9 m, (c) 10 m, (d) 22.5 m. Then explain in one sentence why every field sketch needs a scale bar.
2. (10 pts) Short answer. A student wrote in the “I observe” column: “Bed 3 is tilted 20° east, gritty sandstone, 2.4 m thick, laid down by a slow river over a long age.” Which part does not belong in that column, and where should it go? Write one correct observation and one correct interpretation about Bed 3.
3. (10 pts) Calculation. Your pace is 0.8 m. Outcrop B is 150 paces east of outcrop A. A white limestone marker bed is 2.0 m above the road at A and 8.0 m above the road at B; the road is level. Find the distance from A to B in meters, the grade of the beds as a percent, and the direction the beds dip. On a map at 1 cm = 20 m, how far apart are A and B?
4. (10 pts) Data reading. A float travels 10 m in 25 s in a creek. Sediment from the creek bed is 5% gravel, 45% sand and 50% mud. (a) Find the surface speed and estimate the average speed using the 0.85 factor. (b) Using these rough values, sand moves at about 0.3 m/s and pebbles at about 1 m/s, say what the creek can move today. (c) Does the sediment sample fit a fast riffle or a slow pool? Explain.
5. (10 pts) Multiple choice and short answer. A museum sign reads: “Mastodon. Pleistocene, about 13,000 years old. Mount is 2.8 m tall at the shoulder and contains 200 bones, 65% original.” Which of these was measured rather than calculated? (a) the age, (b) the shoulder height, (c) both, (d) neither. Then find how many bones are original and how many are casts, and name the three assumptions behind the age.
6. (10 pts) Diagram. Draw and label a single graded bed as you would see it in a cut face of a sand bar, about 10 cm thick. Label the grain size at the bottom and at the top, draw an arrow showing the order in which the grains settled, and write one sentence explaining what kind of event leaves one graded bed.

Unit project: my field lab notebook

Bind your four field pages into one notebook: the road-cut notes with scale sketch and bed table, the two stratigraphic columns and map from your outcrop survey, the creek page with float speeds, sediment percentages and bar graph, and your best museum sign journal page with a sketch of the specimen. Add a title page with your name, the dates and places of each trip, and your measured pace length.

Finish with a one-page reflection that answers two questions: What did I measure that no sign or textbook could change? and Where did I meet an interpretation, and how did I write the young-earth reading beside it kindly and clearly?

- **Field records**: All four pages have headers with place and date, scale bars or stated scales, and measurements in metric units.
- **Observation and interpretation**: On every page, what was seen and measured is kept apart from what it is taken to mean, and sign words are copied exactly.
- **Calculation**: Pace length, distances, dip, float speed and sediment percentages are worked correctly and shown.
- **Reflection and charity**: The reflection names something firmly observed, states the young-earth reading beside the sign's reading fairly, and ends with a good question.

Answer key

1. (b) 9 m. Scale: 1.5 m ÷ 2.5 cm = 0.6 m per cm, and 15.0 × 0.6 = 9 m. A scale bar lets anyone, including you later, recover the real size of every bed from the sketch.
2. "Laid down by a slow river over a long age" is an interpretation and belongs in the "I think it means" column. Observation: Bed 3 is gritty sandstone, 2.4 m thick, tilted 20° toward the east. Interpretation: because water lays sediment down nearly flat, the bed was probably flat when deposited and tilted later; its coarse grains suggest fast-moving water.
3. Distance = 150 × 0.8 = 120 m. Rise = 8.0 − 2.0 = 6.0 m. Grade = 6 ÷ 120 = 0.05 = 5% (about 3°). The bed is lower at A, so the beds dip toward the west. Map distance = 120 ÷ 20 = 6 cm.
4. (a) 10 ÷ 25 = 0.4 m/s at the surface; 0.4 × 0.85 ≈ 0.34 m/s average. (b) It can just move sand and carries silt and clay, but it cannot move pebbles. (c) A slow pool or inside bend, because half the sample is mud, which settles only in slow water, and there is almost no gravel.
5. (b) the shoulder height. Original bones = 0.65 × 200 = 130; casts = 200 − 130 = 70. The age depends on a constant decay rate, a known starting amount of the parent and daughter material, and a closed system with no gain or loss.
6. The drawing should show one layer with pebbles or coarse sand at the base grading upward to fine sand and then silt or clay at the top, an arrow from bottom to top labeled "settled first" to "settled last," and a sentence such as: "One pulse of fast water that slowed and dropped its load heaviest first leaves one graded bed; a stack of them records a series of pulses."