SCHOOL LAUNCH · EARTH SCIENCE K–8

Grade 3 Earth Science: Rocks, Minerals and Fossils

A year of true stories from under our feet, from Friedrich Mohs ranking minerals by hardness and Michelangelo carving David out of a block of Carrara marble to Cope and Marsh racing to dig dinosaurs in the American West, a fish caught in stone with another fish in its mouth, upright fossil trees in the sea cliffs of Joggins, Nova Scotia, and the twelve stones on the high priest's breastplate, each one looked at closely, scratched, weighed and measured, and then tried at the kitchen table with salt crystals, chocolate, sand jars and plaster.

First edition

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

Course guide

This course follows the ground beneath our feet through one school year: minerals, the three great families of rock (igneous, sedimentary and metamorphic), fossils, dinosaur digs, gems and ores, and at the end a rock collection the student builds, labels and shows. Each unit is built around real people and real places: Friedrich Mohs and his scale of hardness in 1812, the six-sided columns of Devils Tower in Wyoming and the Giant's Causeway in Ireland, the Green River fossil fish of Wyoming, the upright fossil trees of Joggins, Nova Scotia, the Bone Wars of Edward Drinker Cope and Othniel Charles Marsh, Sue Hendrickson's discovery of the *T. rex* called Sue in 1990, and Mary Schweitzer's report of soft tissue inside a dinosaur bone in 2005.

Every lesson follows the same path. First comes **the story**: a real person, a real place, a real find. Then **look closely**: what the rock or fossil looks like, feels like and weighs, and what the people in the story noticed. Then **the big idea** underneath, explained for a third grader: hardness, streak and luster, crystals, cooling, layers, pressure and heat, quick burial. Last, the student **observes and measures** with his or her own hands: scratching with a nail, rubbing a streak on a tile, growing crystals, cooling fudge, settling sand in a jar, pressing a shell into clay, panning for "gold," and writing it all down in a field notebook with a date, a drawing and a number.

The thread of the year is a single question asked again and again: *What happened to this rock?* A student who learns to read a pebble, a road cut or a fossil shell as a small record of what happened to it has learned to think like a geologist. Units 1 through 4 teach the student to name what he or she sees; Units 5 and 6 turn to the living things buried in the rocks; Unit 7 shows the treasures people have dug out of the earth; and Unit 8 gathers the year into a labeled collection. An optional **Field Lab** takes the same skills outdoors.

The course begins where the Bible begins: "In the beginning God created the heaven and the earth." (Genesis 1:1). The granite of a mountain, the quartz in a sandbox, the gold in a stream and the shells pressed into limestone are all part of the world God made and called good. The book of Job asks, "Surely there is a vein for the silver, and a place for gold where they fine it" (Job 28:1), and the student will meet the twelve stones of the high priest's breastplate (Exodus 28) and the jeweled foundations of the heavenly city (Revelation 21). Studying rocks carefully is one way of honoring the Maker who set them in place.

WHO IT IS FOR

Written for students in grade 3 who are beginning to read on their own, can add and subtract within 1,000, and can measure with a ruler to the nearest half inch. The core ideas are written to be read aloud by a parent or teacher, who also handles the hammer, the hot water and the vinegar in the experiments. Nothing needs to be bought beyond ordinary household items: a notebook, a magnifying glass, an old tile, a steel nail, salt, jars, sand, clay and a few rocks gathered from the yard, a creek bed or a gravel drive.

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**, of four outdoor lessons. Each lesson takes two sessions of about 45 minutes. Session 1 is the warm-up, the story and core ideas read aloud, and the picture study. Session 2 is the experiment and the field notebook page. In the last week of each unit, add a third session for the unit review and the unit project. The Field Lab can be used after Unit 8, on spring and summer days, or alongside the year whenever the weather is good.

The ★ quarter path. Ten lessons are marked with ★, at least one in every unit. Together they make a one-quarter version of the course that keeps the core skills: testing minerals, telling the three rock families apart, how fossils form, a real dinosaur dig, gems of the Bible and starting a labeled collection. Families short on time can teach only the ★ lessons and still finish with a rock collection.

The field notebook and experiments. Use one sturdy notebook for the whole year. Every experiment ends with a notebook page: the date, a drawing of what was seen, at least one measurement and one sentence beginning “I noticed….” Measure in inches and pounds first, then in centimeters and grams, so the student learns both. Safety comes first: wear safety glasses whenever a rock is struck or scratched, wrap rocks in an old towel before tapping them with a hammer, let an adult handle hot water and the stove, never taste alum, Epsom salt or plaster, and wash hands after handling rocks and soil. Outdoors, stay well back from roads and cliff edges, and collect only where you have permission; many parks and public lands do not allow collecting.

Worked examples and practice. Each lesson has two worked examples that show, step by step, how to use the idea: ranking minerals by which scratches which, reading the layers in a jar from bottom to top, adding up the weight of a collection, or turning inches into a rough count of centimeters. Six practice problems follow, with numbers a third grader can handle, and the answers are given for the parent. Let the student try first, then check together.

Unit reviews and unit projects. Each unit ends with a short review worth 40 points: ten items asking the student to identify a mineral, rock or fossil from a description or picture and to answer in a sentence or two. The review may be given orally. Each unit also has a unit project that pulls the unit together, such as a mineral test chart, a plaster fossil cast, a rock-cycle board game or a labeled specimen tray. Keep the unit projects in one box or folder for the year; in Unit 8 they become part of the student’s collection display.

A word about time. This course is written from a Christian view of creation (Genesis 1:1) and the Flood (Genesis 6–9). Museum signs, field guides and textbooks often use deep-time names such as “Jurassic” or “Ice Age” and give ages of millions of years. Students learn these names as museum words so they can read any sign or textbook with understanding. Wherever they come up, a ⏳ **Thinking About Time** box sets out three things plainly: what the sign says, what we can actually observe in the rock or fossil, and how Christians read it.

Two lessons, on the upright fossil trees of Joggins and on soft tissue in dinosaur bone, carry a fuller ⏳ note.

SCOPE AND SEQUENCE

Unit 1: Minerals (1–4)

Friedrich Mohs and his scale of hardness; testing minerals by streak, luster and hardness; growing salt and alum crystals; and the four common minerals that make up most rocks.

Unit 2: Igneous Rocks (5–8)

Rocks made from melted rock; granite and basalt; why slow cooling makes big crystals and fast cooling makes small ones; and the columns of Devils Tower and the Giant’s Causeway.

Unit 3: Sedimentary Rocks (9–12)

How layers settle in water; sandstone, shale and limestone; coal made from buried plants; and reading the layers in a road cut.

Unit 4: Metamorphic Rocks (13–16)

Rocks changed by squeezing and heat; marble and Michelangelo’s David; slate for roofs and blackboards; and the rock cycle as a game.

Unit 5: Fossils (17–20)

How quick burial makes a fossil; bones, shells, tracks and molds; the Green River fish caught swallowing another fish; and the upright fossil trees of Joggins, Nova Scotia.

Unit 6: Dinosaur Digs (21–24)

The Bone Wars of Cope and Marsh; Sue the T. rex, found in South Dakota in 1990; how a skeleton is dug, cleaned and mounted; and Mary Schweitzer’s report of soft tissue in dinosaur bone.

Unit 7: Gems and Ores (25–28)

The twelve stones of the high priest’s breastplate; iron, copper and gold and how they are found; panning for “gold”; and why diamonds and coal are both carbon.

Unit 8: My Rock Collection (29–32)

Labeling specimens and keeping a field notebook like a real collector; visiting a rock shop or museum; showing the collection to family and guests; and a review game for the year.

Unit 9: Field Lab (optional) (Optional)

Four outdoor lessons that take the year’s skills outside: hunting for all three rock families, a pocket streak-and-scratch kit, reading a road cut and a fossil hunt where collecting is

allowed.

MATERIALS

- **Field notebook (a sturdy composition book) and colored pencils**: One for the whole year: dated drawings, measurements, test results and “I noticed” sentences.
- **A magnifying glass and a ruler marked in inches and centimeters**: Used in nearly every lesson for looking at grains and crystals and measuring specimens.
- **A testing kit: the unglazed back of a white bathroom tile, a steel nail, a copper penny and a small glass jar or bottle**: For streak and scratch tests. A fingernail, a penny, a nail and glass make a simple hardness scale.
- **Safety glasses, an old towel and a small hammer (adult use)**: Wear the glasses whenever a rock is tapped or scratched; wrap the rock in the towel first.
- **Kitchen supplies: salt, Epsom salt or alum, white vinegar, a dropper, chocolate chips, clear jars with lids, string and pencils**: For growing crystals, the fast-and-slow cooling experiment and the vinegar fizz test for calcite and limestone. An adult handles hot water.
- **Sand, gravel, soil, modeling clay and a small bag of plaster of Paris**: For layers in a jar, the rock-cycle models and fossil molds and casts.
- **A kitchen scale, a pie pan or shallow tray and a few small brass beads or painted pebbles**: For weighing specimens and for panning for “gold” in Unit 7.
- **An egg carton or tackle box, small labels and a few dozen rocks gathered from the yard, a creek bed or a gravel drive**: The beginning of the student’s rock collection, built up all year and displayed in Unit 8.
- **Optional: a rock and mineral starter set, a field guide or one of the books listed in a unit**: Never required. See the list in each unit.

GRADING

Grades come mostly from the experiments and the field notebook, because rocks and fossils are learned by looking, testing and recording. An experiment that did not turn out as expected earns full credit when it is honestly recorded and the student can say what he or she noticed.

- Experiments (careful work, safe habits and a clear observation): 35%
- Field notebook (dated pages, drawings, measurements and “I noticed” sentences): 20%
- Unit reviews (40 points each, 10 items): 25%
- Unit projects: 20%

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

- Grade the process, not just the result. Did the student look closely, test carefully, measure, record honestly and explain what he or she saw?
- A field notebook page earns full marks when it has a date, a title, a labeled drawing, at least one measurement with its unit and one sentence beginning “I noticed….”

- Unit reviews may be given orally for a student who writes slowly; the parent writes down the answers. Each review has ten items worth 4 points each.
- The rock collection in Unit 8 counts as that unit's project. A small, carefully labeled collection is worth more than a large, jumbled one.

A NOTE TO PARENTS

You do not need to be a geologist to teach this course. Read the story aloud together, hand the student a rock and a magnifying glass, and ask three questions: "What do you see?", "How could we test it?" and "What do you think happened to this rock?" Those three questions are most of what a good science teacher does. When you do not know an answer, say so, write the question in the notebook and look it up together.

Rocks and fossils raise questions about the age of the earth, and children notice when the museum sign and the Bible seem to be telling different stories. This course does not hide the museum words. It teaches them plainly, sets out what can actually be seen in the rocks, and shows how Christians who take Genesis seriously read the same evidence. The ⏳ Thinking About Time boxes are written so that you can talk through them together calmly and with confidence.

Most of all, the course hopes to raise a child who looks closely at the world and gives thanks for it. A gravel driveway, a creek bed or a stone wall becomes a place full of stories once a child knows how to read them. As the Psalm says, "The earth is the LORD'S, and the fulness thereof" (Psalm 24:1).

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- 9.1 Rock Cycle Scavenger Hunt
- 9.2 Streak and Scratch Field Kit
- 9.3 Reading a Road Cut
- 9.4 Fossil Hunt

★ quarter path · ⏳ Thinking About Time box

UNIT 1

Minerals

Every rock you pick up is made of **minerals**: natural solids, not alive, with their tiny particles lined up in neat, repeating patterns. God made a great many of them, and each one behaves in its own dependable way. In this unit you will learn to test minerals the way real geologists do, with a fingernail, a copper penny, a steel nail, a piece of glass, a white streak plate and a few drops of vinegar.

You will meet Friedrich Mohs, who lined up ten minerals from soft talc to hard diamond in 1812; Abraham Werner, who taught a whole generation of mineral hunters to read the outside marks of stones; René Just Haüy, who broke a calcite crystal by accident and saw that crystals are built in repeating patterns; and Rasmus Bartholin, who looked through a clear crystal from Iceland and saw every letter twice. You will grow your own salt and alum crystals and learn to recognize quartz, feldspar, mica and calcite, the minerals that build so much of the earth under your feet.

BEFORE YOU BEGIN

- Can add and subtract whole numbers and simple halves (such as 7 − 2½)
- Can measure with a ruler in inches and read centimeters and millimeters
- Can sort objects by color, shape and feel and record observations in a simple table
- Can follow written steps with a grown-up’s help

MASTERY CHECKLIST

- I can name the ten minerals of the Mohs scale in order and use the rule “the harder one scratches the softer one.”
- I can find a mineral’s hardness range using my fingernail, a copper penny, a steel nail and glass.
- I can do a streak test, name a mineral’s luster, and explain why streak is a better clue than color.
- I can explain what a crystal is and grow salt and alum crystals, measuring their growth.
- I can recognize quartz, feldspar, mica and calcite and give two clues for each.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free. The museum’s website has online exhibits and photographs from its Hall of Geology, Gems and Minerals. Look up quartz, calcite and the Hope Diamond together, and visit in person if you are ever in Washington, D.C.
- **Geology.com: Minerals** (https://geology.com/minerals/): Free. Clear photographs and short articles on common minerals, the Mohs scale, streak and luster. Best used by a parent to find pictures to show alongside each lesson.

- **A beginner rock and mineral kit with a streak plate** (https://www.usgs.gov/): Inexpensive kits sold by science stores and rock shops usually include talc, gypsum, calcite, fluorite, quartz, feldspar, mica, hematite and pyrite, plus a streak plate. The USGS website (free) has more information and photographs about minerals and where they are found in the United States.

1.1 Friedrich Mohs' Scale (1812) ★

OBJECTIVES

- Tell how Friedrich Mohs used scratching to line up ten minerals from softest to hardest in 1812.
- Name the ten minerals of the Mohs scale in order and use the rule "the harder one scratches the softer one."
- Use a fingernail, an old copper penny and a steel nail to find the hardness range of an unknown mineral.

Warm-up. Set out a bar of soap, a crayon, a wooden pencil and a coin. Try to scratch each one gently with your fingernail. Which ones got a mark? Which ones did not? Now try to scratch the soap with the coin. Line up the four things from "easiest to scratch" to "hardest to scratch." You have just made your first hardness scale.

Video. Coming soon. The Mohs hardness scale and scratch tests for children: search USGS, the Smithsonian National Museum of Natural History, SciShow Kids, Homeschool Pop (Alternate) and Science Max for real scratch tests on talc, calcite, quartz and diamond.

KEY TERMS

mineral
A natural solid that is not alive, is the same all the way through, and has its tiny particles lined up in a neat, repeating pattern. Quartz, salt and diamond are minerals.

hardness
How well a mineral stands up to being scratched.

scratch test
Rubbing one thing against another to see which one leaves a groove. The harder one scratches the softer one.

Mohs scale
A list of ten minerals from softest (1, talc) to hardest (10, diamond), made by Friedrich Mohs in 1812.

CORE IDEAS

The story. In 1812 a German mineral scientist named Friedrich Mohs had a big job. He was working at a brand-new museum in the city of Graz, in Austria, and there were drawers and drawers of minerals to sort and name. Mohs had studied at a famous mining school in Freiberg, Germany, where his teacher, Abraham Werner, trained students to look closely at every stone. But many minerals look alike. A clear piece of quartz and a clear piece of calcite

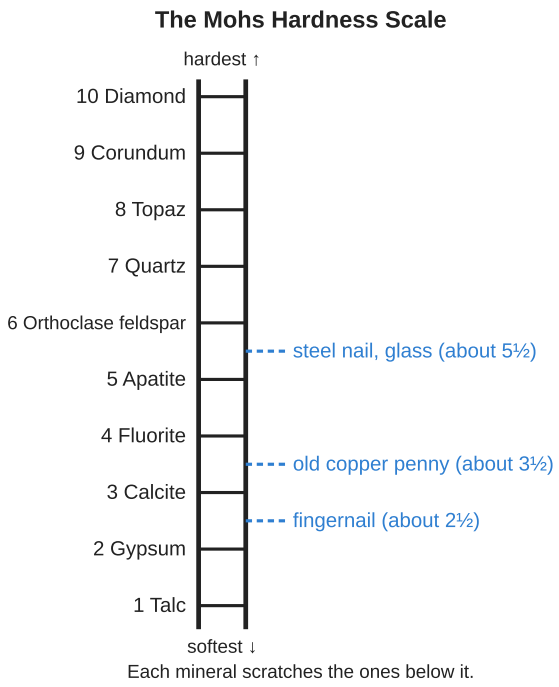
can look like twins. Mohs wanted a simple test that anyone could do, anywhere, without a fancy machine.

How they figured it out. Mohs used a very old trick: scratching. When you rub two minerals together, the harder one scratches the softer one. Mohs chose ten well-known minerals and lined them up from softest to hardest. Soft, slippery talc got the number 1. Diamond, the hardest of all, got the number 10. Each mineral on his list can scratch every mineral with a smaller number, and it can be scratched by every mineral with a bigger number. Now a mineral hunter could hold a strange stone and ask two questions: “Which of the ten can you scratch? Which of the ten can scratch you?”

The big idea. Here is the Mohs scale: 1 talc, 2 gypsum, 3 calcite, 4 fluorite, 5 apatite, 6 orthoclase feldspar, 7 quartz, 8 topaz, 9 corundum, 10 diamond. A silly sentence helps you remember the first letters: *Tall Giraffes Can Find Apples On Quiet Tree-Cutting Days.* The numbers tell the *order*, like first, second and third place in a race. They do not tell *how much* harder one mineral is. Diamond is only one number above corundum, but it is far, far harder. And hard is not the same as strong. Nothing on the scale can scratch a diamond, yet a sharp blow with a hammer can split one.

Try it and see. You do not need all ten minerals to test hardness. You carry a tester on every finger! Your fingernail is about 2½ on the Mohs scale. An old copper penny (made before 1982) is about 3½. A steel nail and a piece of glass are each about 5½. If your fingernail scratches a mineral, its hardness is less than 2½. If a mineral scratches glass, its hardness is more than 5½. After every test, rub the mark with your finger. A line of powder wipes away. A real scratch is a little groove that stays.

God’s handiwork. God made each mineral with its own hardness, and it does not change from place to place. A piece of quartz from Austria and a piece of quartz from your backyard are both 7. That steadiness is what made Mohs’ scale possible, and it is why geologists still carry a nail and a scrap of glass into the field today. When we measure carefully, we find the order God built into His world.



The Mohs scale is a ladder of hardness. Each mineral scratches the ones below it. Household testers fit between the rungs.

PICTURE STUDY



A Goldsmith in His Shop, Petrus Christus, 1449 · Oil on oak panel · The Metropolitan Museum of Art, New York

Petrus Christus was a painter in the busy city of Bruges, in Flanders, who loved to paint tiny details with thin layers of oil paint. In this picture a goldsmith weighs a ring on a little balance while a young couple, perhaps about to be married, waits for it. Some people think the goldsmith is meant to be Saint Eligius, the old patron saint of goldsmiths.

A goldsmith had to know his materials well. Gold is soft and easy to bend and scratch. Rock crystal, which is clear quartz, is hard enough to scratch glass. Long before Mohs gave them numbers, craftsmen knew which stones were hard and which were soft, because they shaped them with their own hands.

Look closely

- Find the small balance in the goldsmith’s hand. What is he weighing?
- Look at the shelves behind him. Can you find pieces of red coral, strings of beads and clear stones?
- Find the round mirror on the counter. What does it show that we could not see otherwise?
- Look at the young woman’s hand. What is she reaching toward?

Talk about it

1. The goldsmith measures with a balance. Mohs measured with scratches. Why do careful workers and scientists both need good ways to measure?
2. Which things on the shelves do you think would be easy to scratch, and which would be hard? Why?
3. If you could ask the goldsmith one question about his stones, what would it be?

> **Safety first.** Use a steel nail with a blunt tip, and only scratch glass that has smooth or taped edges, such as a small glass tile or the flat bottom of a thick jar, laid flat on a towel. A grown-up should hold the glass. Press gently, scratch away from your body, and wash your hands after handling minerals.

EXPERIMENT: MY SCRATCH LADDER

You will act like Friedrich Mohs and line up a set of stones and household things from softest to hardest using only scratch tests. Then you will place each one on the Mohs scale between your fingernail, a penny, a nail and glass.

You will need

- 5 or 6 things to test: a piece of chalk, a pebble from the yard, a piece of brick or tile, a bar of soap, and any minerals you have (an inexpensive beginner mineral kit with talc, gypsum, calcite, fluorite and quartz is ideal)
- Your fingernail
- An old copper penny (from before 1982)
- A blunt steel nail
- A small glass tile or thick glass jar with smooth edges
- A magnifying glass
- Lab notebook, pencil and ruler

Steps

1. **Question:** Write at the top of your page: “Which of my samples is the hardest, and where does each one fit on the Mohs scale?”
2. **Prediction:** Before you test anything, line your samples up in the order you *think* is softest to hardest. Write down your guess.
3. Rule a table with five columns: Sample, Fingernail scratches it?, Penny scratches it?, Nail scratches it?, It scratches glass?
4. **What we keep the same:** Use the same gentle push and make each scratch about ½ inch long (a little more than 1 centimeter). Test on a flat, clean spot each time.
5. Test each sample with your fingernail, then the penny, then the nail. Then try to scratch the glass with the sample. Write yes or no in each box.
6. After each test, rub the mark with your finger and look with the magnifying glass. A powder line that wipes off does not count. Only a groove counts.
7. Use your table to give each sample a hardness range. For example, if the penny scratches it but your fingernail does not, it is between 2½ and 3½.
8. Now line up your samples in the real order. Compare with your prediction. Draw your samples as rungs on a ladder, softest at the bottom.

Tips

- If two samples seem equal, try scratching each one with the other. If neither scratches the other well, they are about the same hardness.
- A soft mineral rubbed on a harder one can leave a line of its own powder, like chalk on a sidewalk. That is why we rub and look before writing “yes.”
- Test on a small corner, not the prettiest face of a mineral.

Check your work

- I made a prediction before testing.
- I filled in every box of my table with yes or no.
- I can tell the hardness range of each sample and explain how I know.

FIELD NOTEBOOK

1. Draw the Mohs scale as a ladder with ten rungs. Write the number and name of each mineral, and add your fingernail, penny, nail and glass beside the right rungs.
2. Draw one sample from your project large, with a small arrow pointing to the scratch you made. Label it with its hardness range.
3. Write the giraffe sentence (or make up your own) and underline the first letter of each word.

> **From history.** Friedrich Mohs later went back to Freiberg to teach in the place of his old teacher, Abraham Werner, and after that he taught in Vienna. He died in 1839 while traveling in Italy. More than two hundred years after he made it, his simple ladder of ten minerals is still printed in nearly every geology book, and field geologists still test rocks with a pocketknife, a nail, a scrap of glass and their own fingernails.

WORKED EXAMPLES

Example 1. A gray mineral can scratch fluorite. But orthoclase feldspar can scratch the gray mineral. What is its hardness on the Mohs scale?

(Use the map or drawing "Find 4 and 6 on the ladder. The answer is the rung between them." shown earlier in this lesson.)

1. Find fluorite on the scale: it is 4. The gray mineral scratches it, so the gray mineral is harder than 4.
2. Find orthoclase feldspar: it is 6. Feldspar scratches the gray mineral, so the gray mineral is softer than 6.
3. The only whole number harder than 4 and softer than 6 is 5.

Answer: Its hardness is about 5, the same as apatite.

Example 2. Sam tests a white mineral. His fingernail cannot scratch it. An old copper penny cannot scratch it. A steel nail does scratch it. What is its hardness range, and which minerals on the Mohs scale could it be?

1. Fingernail (about 2½) cannot scratch it, so it is harder than 2½.
2. Penny (about 3½) cannot scratch it, so it is harder than 3½.
3. Steel nail (about 5½) does scratch it, so it is softer than 5½.
4. Scale minerals between 3½ and 5½ are 4 (fluorite) and 5 (apatite).

Answer: Its hardness is between 3½ and 5½, so it could be like fluorite (4) or apatite (5). Sam needs another test to decide.

PRACTICE

1. EASY Name the softest and the hardest minerals on the Mohs scale, with their numbers.
2. EASY Your fingernail is about 2½. Can it scratch gypsum (2)? Can it scratch calcite (3)?
3. MEDIUM How many numbers up the Mohs scale is quartz from calcite?
4. MEDIUM A quartz crystal is 4 inches long. One inch is about 2½ centimeters. About how many centimeters long is the crystal?
5. HARD A pink mineral scratches glass (about 5½). Quartz (7) scratches the pink mineral. Which whole-number hardness does it have, and which mineral on the scale has that hardness?
6. CHALLENGE Corundum is 9 and diamond is 10, only one number apart. Talc is 1 and gypsum is 2, also one number apart. Does that mean diamond is "a little bit" harder than corundum, the way gypsum is a little harder than talc? Explain.

COMMON MISTAKES

- Thinking a line of powder is a scratch. A soft mineral can leave its own powder on a harder one. Always rub the mark away and look for a real groove.
- Thinking the Mohs numbers are equal steps, like inches on a ruler. They only give the order. The jump from corundum (9) to diamond (10) is much bigger than the jump from talc (1) to gypsum (2).
- Thinking "hard" means "cannot break." Hardness is about scratching. A diamond cannot be scratched by any other mineral on the scale, but it can still crack if it is hit hard in the wrong place.

Make it a game · Who Scratches Whom?. A parent calls out two minerals from the Mohs scale, such as "quartz and calcite." The player answers as fast as possible with the one that scratches the other and both numbers: "Quartz, 7, scratches calcite, 3!" Add the household testers (fingernail, penny, nail, glass) for harder rounds. Score one point for each right answer and play to ten. For a bonus point, say the whole scale from 1 to 10 without looking.

Scripture. "As an adamant harder than flint have I made thy forehead: fear them not, neither be dismayed at their looks, though they be a rebellious house." (Ezekiel 3:9, KJV)

Flint is a kind of quartz, very hard. An "adamant" was the hardest stone people knew. God used hardness as a picture: He would make the prophet Ezekiel firm and steady, so that hard words from others would not scratch his courage.

Practice answers

1. Talc is the softest (1). Diamond is the hardest (10).
2. Yes, it can scratch gypsum, because 2½ is harder than 2. No, it cannot scratch calcite, because calcite (3) is harder than 2½.
3. Quartz is 7 and calcite is 3. $7 - 3 = 4$, so quartz is 4 numbers higher.
4. $4 \times 2½ = 10$. The crystal is about 10 centimeters long.
5. It is harder than 5½ and softer than 7, so its hardness is about 6, the same as orthoclase feldspar.
6. No. The Mohs numbers only tell the order from softest to hardest, like places in a race. They do not tell how much harder one mineral is than another. Diamond is far harder than corundum, even though their numbers are only one apart.

1.2 Streak, Luster and Hardness Tests ★

OBJECTIVES

- Tell how Abraham Werner of Freiberg taught students to name minerals by the marks they can see and feel.
- Do a streak test, name a mineral's luster, and explain why streak is a better clue than color.
- Put streak, luster and hardness clues together in a table to identify a mineral.

Warm-up. Rub a pencil, a piece of chalk and a crayon across the back of a white paper plate or a piece of scrap paper. Look at the lines. Are they the same color as the outside of each thing? Now hold a spoon, a glass and a wooden block under a lamp. Which one shines like metal? Which one shines like glass? Which one hardly shines at all?

Video. Coming soon. Mineral identification with streak, luster and hardness for children: search USGS, the Smithsonian National Museum of Natural History, SciShow Kids, Homeschool Pop (Alternate) and geology teachers' classroom demonstrations of streak plates, pyrite versus gold, and hematite streak.

KEY TERMS

streak
The color of a mineral's powder, made by rubbing the mineral across a rough white tile.

streak plate
A small square of unglazed white porcelain (the rough back of a bathroom tile works too) used for streak tests. It is about 6½ to 7 on the Mohs scale.

luster
The way a mineral's surface shines in the light: metallic (like metal) or nonmetallic (glassy, pearly, silky, greasy or dull).

property
Something about a material that you can observe or measure, such as color, streak, luster or hardness.

pyrite
A brassy, gold-colored mineral called "fool's gold." It leaves a greenish-black streak and is hard enough to scratch glass.

CORE IDEAS

The story. In 1774 a young German mineral scientist named Abraham Gottlob Werner wrote a small book about how to recognize minerals by their outside marks: the things you can see, feel and test with simple tools. The next year he began teaching at the Mining Academy in Freiberg, a mining town in Germany, and students came from all over Europe to hear him.

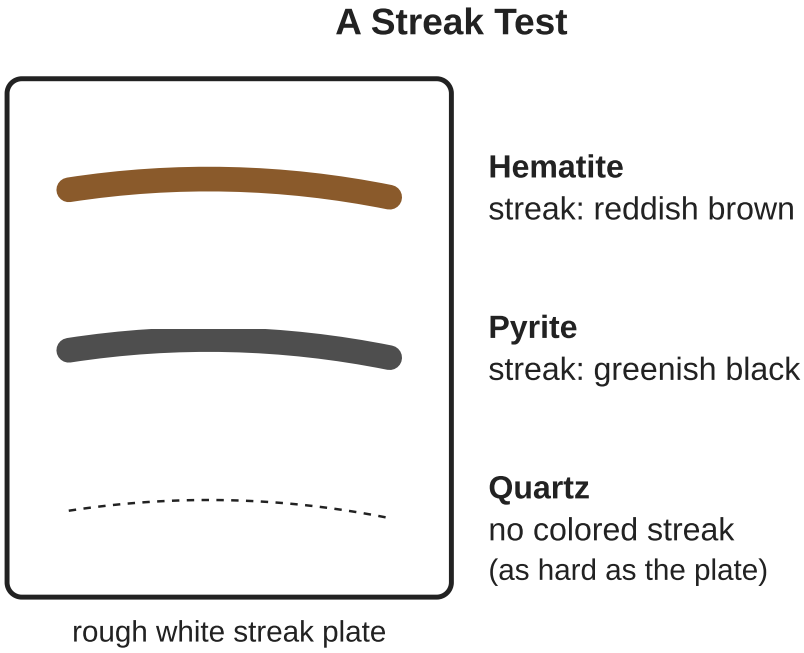
One of them was Friedrich Mohs. In Werner's day, people used the word "fossil" for anything dug out of the ground, because the old Latin word means "dug up." So a book about "fossils" could be all about minerals!

How they figured it out. Werner and his students learned that color can fool you. Pyrite is a brassy yellow mineral that has tricked many hopeful miners into thinking they found gold, which is why it is called "fool's gold." Hematite, an iron mineral, can be black, silvery gray or red on the outside. But when you rub a mineral across a rough white tile, it leaves a line of its own powder, called its **streak**. Hematite's streak is always reddish brown. Pyrite's streak is greenish black. Real gold's streak is yellow. The outside can change, but the powder tells the truth.

The big idea. Mineral scientists use several tests together, like a detective using several clues. **Streak** is the color of the powder. **Luster** is the way the surface shines. A *metallic* luster shines like a spoon or a coin. A *nonmetallic* luster may be *glassy* like a window, *pearly* like the inside of a seashell, *silky* like thread, *greasy* like a buttered plate, or *dull* like dried mud. **Hardness** comes from the scratch tests you learned with the Mohs scale. One clue alone may fit several minerals, but three clues together usually point to just one.

Try it and see. A streak plate is about 6½ to 7 on the Mohs scale. Press a mineral gently and pull it across the plate in one short stroke. Soft minerals leave a clear line. Very hard minerals, like quartz, are as hard as the plate or harder, so they leave no colored streak at all; they may even scratch the plate. Write down the color of the streak, the luster, and whether the mineral scratches glass. Then compare your clues with a mineral chart.

God's handiwork. God made each mineral to behave the same way every time. Hematite dug up in Michigan and hematite dug up in Brazil leave the same reddish-brown streak. Because God's world is orderly and dependable, a careful test done today will give the same answer tomorrow. That is why testing works, and why a good scientist tests before trusting what something only seems to be.



Three minerals on one streak plate. The powder color, not the outside color, is the clue.

PICTURE STUDY



Girl with a Pearl Earring, Johannes Vermeer, about 1665 · Oil on canvas · Mauritshuis, The Hague, Netherlands

Johannes Vermeer lived in the Dutch town of Delft and was a master at painting light. In this small painting a girl turns to look at us, and a large drop-shaped earring catches the light. Up close, the shine on the earring is made with just a few strokes of paint: a bright white spot at the top and a soft glow at the bottom where light bounces up from her white collar.

The word *pearly* luster comes from pearls like this one. A pearl is not a mineral, because an oyster makes it, but its soft, rainbow-like shine gives mineral hunters a word for minerals that glow the same way. Some art experts even wonder whether Vermeer's "pearl" was really a drop of glass or polished metal. Either way, he painted the luster perfectly.

Look closely

- Find the brightest spot on the earring. Where do you think the light is coming from?
- Look at the bottom of the earring. What do you see reflected there?
- Find other places in the painting that shine: her eyes and her lips. Is that shine metallic, glassy or pearly?
- Look at the turban. Does the cloth shine, or is it dull?

Talk about it

1. If you could only use one word to describe the earring's shine, what word would you choose?
2. How did Vermeer make a flat painting look shiny? Why do you think he used so few brushstrokes?
3. Why might a mineral hunter want to have good words for luster?

> **Safety first.** Use a blunt steel nail and only scratch glass that has smooth or taped edges, laid flat on a towel and held by a grown-up. Press gently on the streak plate. Do not taste minerals, and wash your hands after the tests.

EXPERIMENT: THE STREAK AND SHINE LAB

You will test several samples the way Werner's students did: streak, luster and hardness. Your question: *Does a mineral's outside color always match the color of its streak?*

You will need

- A streak plate, or a white bathroom tile turned over to its rough, unglazed back
- 4 to 6 samples: a beginner mineral kit (hematite, pyrite, quartz, calcite, talc) is best; household samples can include a pencil lead, a piece of red brick, a piece of chalk and a pebble
- A blunt steel nail and a small glass tile with smooth edges
- A magnifying glass and a lamp or flashlight
- Lab notebook, pencil and colored pencils

Steps

1. **Question and prediction:** Write the question at the top of your page. For each sample, write the streak color you *predict*.
2. Rule a table with six columns: Sample, Outside color, Predicted streak, Real streak, Luster, Scratches glass?

3. **What we keep the same:** Use the same streak plate for every sample, press gently, and pull each sample in one stroke about 1 inch long (about 2½ centimeters).
4. **What we change:** only the sample being tested.
5. Make a streak for each sample. Color the “Real streak” box with colored pencils so it matches.
6. Hold each sample under the lamp and turn it slowly. Choose a luster word: metallic, glassy, pearly, silky, greasy or dull.
7. With a grown-up holding the glass, try to scratch the glass with each sample. Rub the mark and look closely before writing yes or no.
8. **Record and conclude:** Circle every sample whose streak did not match its outside color. Write one sentence answering the question.

Tips

- Clean the plate with a damp cloth between tests so the colors do not mix.
- If a sample leaves no colored streak, it is probably harder than the plate. Write “none.”
- A broken edge often shows a mineral’s true luster better than a dusty outside.

Check your work

- I made a prediction for each sample before testing.
- My table has a streak, a luster word and a hardness result for each sample.
- I can explain why streak is a better clue than color.

FIELD NOTEBOOK

1. Draw a streak plate and color in the streaks from your lab. Label each one with the mineral’s name.
2. Make a “Luster Words” page: write metallic, glassy, pearly, silky, greasy and dull, and beside each one draw or name something at home that shines that way.
3. Draw pyrite and gold side by side. Under each, write its streak color and whether it scratches glass.

> **From history.** Long before streak plates, goldsmiths and money changers used a *touchstone*: a smooth, dark stone. They rubbed a piece of gold across it and compared the color of the streak with streaks from gold pieces they already trusted. The writers of ancient Greece described this test, and we still use the word “touchstone” today to mean any trusted way of testing whether something is genuine.

WORKED EXAMPLES

Example 1. Lucy finds a shiny, gold-colored mineral. It has a metallic luster. On the streak plate it leaves a greenish-black streak, and it scratches glass. Is it gold or pyrite?

(Use the map or drawing "Pyrite's streak is dark, not gold." shown earlier in this lesson.)

1. Look at the clues for gold: yellow streak, metallic luster, hardness about 2½ to 3, so it cannot scratch glass.
2. Look at the clues for pyrite: greenish-black streak, metallic luster, hardness about 6 to 6½, so it can scratch glass.
3. Lucy's mineral has a greenish-black streak and scratches glass. Both clues match pyrite, and neither matches gold.

Answer: It is pyrite, "fool's gold."

Example 2. Ben has three mystery samples, A, B and C. Sample A scratches sample B. Sample B scratches sample C. Put them in order from softest to hardest.

1. The harder one always scratches the softer one.
2. A scratches B, so A is harder than B.
3. B scratches C, so B is harder than C.
4. So C is the softest, then B, then A.

Answer: Softest to hardest: C, B, A. (A should also be able to scratch C.)

PRACTICE

1. EASY A mineral shines like a new coin. What kind of luster does it have?
2. EASY Hematite can be black, gray or red on the outside. What color is its streak?
3. MEDIUM Why do mineral scientists trust streak more than outside color?
4. MEDIUM A streak plate is 3 inches wide. One inch is about 2½ centimeters. About how many centimeters wide is the plate?
5. HARD Use this key. Galena: lead-gray streak, metallic, hardness about 2½. Hematite: reddish-brown streak, hardness about 6. Pyrite: greenish-black streak, hardness about 6. A heavy, silvery mineral has a metallic luster and a gray streak, and your fingernail can just barely scratch it. Which mineral is it?
6. CHALLENGE Two students test the same mineral. One pulls it across the rough back of a tile and gets a reddish-brown streak. The other rubs it on the smooth, shiny front of the tile and gets almost nothing. Why did they get different results, and what should they keep the same to make it a fair test?

COMMON MISTAKES

- Naming a mineral by its color alone. Many minerals come in several colors, and very different minerals can share a color, like gold and pyrite.
- Using the glazed, shiny side of a tile for a streak test. Only the rough, unglazed side grinds off powder.
- Thinking every mineral must leave a streak. Minerals as hard as the plate or harder, like quartz, leave no colored streak and may scratch the plate instead.

> **Make it a game · Mineral Detective.** A parent secretly chooses one mineral from your key card (gold, pyrite, hematite, galena, quartz, calcite or talc). You may ask only test questions, such as “What color is the streak?” “What is the luster?” or “Does it scratch glass?” Try to name the mineral in three questions or fewer. Score 3 points for one question, 2 for two and 1 for three. Then switch places and let the parent be the detective.

> **Scripture.** “Prove all things; hold fast that which is good.” (1 Thessalonians 5:21, KJV)

In the King James Bible, “prove” means “test.” A good mineral hunter does not trust a stone just because it looks like gold; he tests it. Paul tells Christians to test what they hear in the same careful way, and to hold on to what is true and good.

Practice answers

1. Metallic luster.
2. Reddish brown.
3. The outside color of a mineral can change from one sample to another, but the color of its powder (its streak) stays the same, so streak is a more dependable clue.
4. 3 × 2½ = 7½. The plate is about 7½ centimeters wide.
5. Galena. The gray streak and the softness (about 2½, so a fingernail can barely scratch it) match galena, not hematite or pyrite.
6. The shiny, glazed front of the tile is too smooth to grind off powder, so it leaves little or no streak. For a fair test they should use the same rough, unglazed surface, press with the same gentle force, and make the same length of stroke. Only the mineral should change.

1.3 Crystals: Grow Salt and Alum

OBJECTIVES

- Tell how René Just Haüy's broken calcite crystal led him to the idea that crystals are built of tiny repeating pieces.
- Explain what a crystal is and how crystals grow from a liquid that holds all the dissolved material it can.
- Grow salt and alum crystals, measure their growth, and compare their shapes by counting faces, edges and corners.

Warm-up. Sprinkle a few grains of table salt onto a piece of black paper. Look at them through a magnifying glass. What shape are they? Count the flat sides you can see on one grain. Now sprinkle a few grains of sugar beside them. Do the sugar grains have the same shape?

Video. Coming soon. How crystals grow and how to grow salt and alum crystals at home for children: search the Smithsonian National Museum of Natural History, SciShow Kids, Science Max, Homeschool Pop (Alternate) and time-lapse footage of crystals growing.

KEY TERMS

crystal
A solid whose tiny particles are lined up in a neat, repeating pattern. On the outside it often has flat faces and straight edges.

dissolve
To mix into a liquid so completely that you can no longer see the pieces. Salt dissolves in water; it is still there, but too spread out to see.

saturated
Holding all the dissolved material it can. When water is saturated with salt, extra salt just sits on the bottom.

evaporate
To change slowly from a liquid into a gas that floats away into the air, as a puddle dries up.

seed crystal
A small crystal hung in a saturated liquid so that new layers can grow on it.

CORE IDEAS

The story. About 1781, in Paris, a priest and teacher named René Just Haüy was looking at a friend's mineral collection. Haüy loved God's creation and had already studied plants for fun. That day a cluster of calcite crystals fell and a piece broke off. Most people would have been upset. Haüy picked up the pieces and looked closely. The broken piece had perfectly flat, smooth sides, and its shape was like a box that had been pushed over sideways.

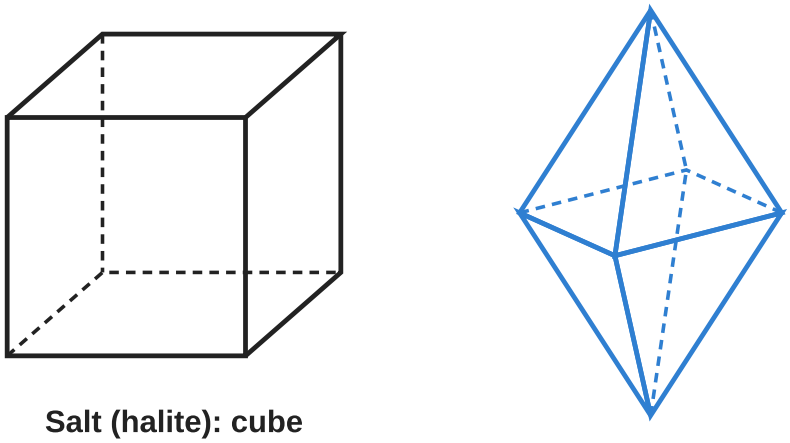
How they figured it out. Haüy went home and carefully broke more calcite. Big piece or small, every piece came apart into the same slanted-box shape. He reasoned that a crystal must be built of tiny pieces of the same shape, stacked together like bricks in a wall. Today we know he was on the right track. A crystal is made of particles far too small to see, even with a microscope, and they are lined up in a pattern that repeats over and over. Haüy is often called the father of crystallography, the study of crystals.

The big idea. A **crystal** is a solid with its tiny particles in a neat, repeating pattern, and you can often see that order on the outside as flat faces and straight edges. Salt (the mineral halite) grows as *cubes*, with 6 square faces. Alum, a powder sold in the spice aisle for making pickles, grows as *octahedrons*, shaped like two pyramids glued bottom to bottom, with 8 triangle faces. Crystals grow from a liquid that is **saturated**: it holds all the dissolved material it can. As the water **evaporates**, or as hot water cools, the extra material has nowhere to go, and it comes out of the water and joins the crystal, layer by layer, always in the same pattern.

Try it and see. Salt dissolves about the same amount in hot or cold water, so salt crystals grow best when the water slowly dries up in a shallow dish. Alum is different: hot water holds much more alum than cool water, so alum crystals start to grow as the hot liquid cools. Look at your crystals each day with a magnifying glass. Sometimes salt makes “hopper” crystals, hollow cubes with stair-step sides, because the edges grow faster than the middle of each face.

God’s handiwork. No one has to carve a salt crystal into a cube. God built the pattern into the salt itself, so every salt crystal on earth, from a sea-salt pan to your kitchen shaker, grows the same way. Snowflakes grow with six sides for the same kind of reason. When you watch a crystal grow in a jar, you are watching God’s orderly laws at work right on your windowsill.

Two Crystal Shapes

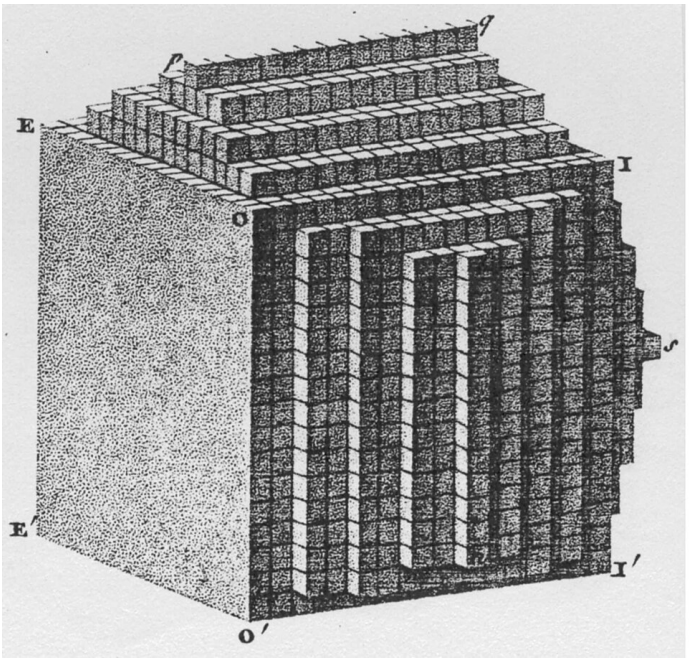


Salt (halite): cube
6 faces, 12 edges,
8 corners

Alum: octahedron
8 faces, 12 edges,
6 corners

Salt grows cubes; alum grows octahedrons. Hidden edges are drawn with dashed lines.

PICTURE STUDY



Tiny Cubes Building a Pyrite Crystal, from Haüy's Traité de minéralogie, René Just Haüy (engraved plate for his book), 1801 · Engraving · Printed in Paris; this copy is in the Science History Institute, Philadelphia

Twenty years after the calcite fell, Haüy published a large book on minerals, the *Traité de minéralogie*, with pages of careful engraved drawings. This drawing shows his big idea at work. Pyrite, the "fool's gold" from Lesson 1.2, often grows as a crystal with twelve five-sided faces. Haüy drew how such a crystal could be built from tiny cubes, stacked in layers

that are set back a little each time, like a staircase. From far away, the tiny steps blur into smooth, slanted faces.

This picture is not a painting. It is a science drawing, made with a ruler and great care, so that a reader anywhere could compare a real crystal with the page and understand how it was built.

Look closely

- Find the tiny cubes. How many can you count along one edge?
- Find the places where the layers step back like a staircase. What does the outside of the stack look like from far away?
- Look at the edges. Are they wavy or straight? Why do you think the engraver used a ruler?
- Find one big flat face of the whole shape. How many sides does it have?

Talk about it

1. Why are careful, exact drawings important in science?
2. How is a stack of tiny blocks like a crystal growing layer by layer in your jar?
3. If you made one page of drawings of your own crystals, what would you label?

> **Safety first.** A grown-up should heat and pour all hot water. Very hot tap water is enough; do not use boiling water near children. Alum is safe to handle but is not a snack: do not eat alum or the crystals, keep them away from little brothers and sisters and pets, and wash your hands after touching them. Label the jars.

EXPERIMENT: SALT CUBES AND ALUM OCTAHEDRONS

Your question: *Do salt and alum grow crystals of the same shape?* You will grow both side by side and measure them each day.

You will need

- Table salt (or rock salt) and a small jar of alum from the spice aisle
- Very hot tap water, a measuring cup and measuring spoons
- Two clean glass jars and a shallow dark saucer or plate
- A pencil, fishing line or thin thread, and a paper towel
- A ruler with inches and centimeters (millimeters too), and a magnifying glass
- Lab notebook, pencil and masking tape for labels

Steps

1. **Prediction:** Write what shape you think each crystal will be.
2. **Salt:** A grown-up pours ½ cup of very hot tap water into a jar. Stir in salt one spoonful at a time until no more will dissolve and a little stays on the bottom. Now the water is saturated. Pour the clear liquid into the dark saucer and set it in a quiet, warm place.

3. **Alum:** A grown-up pours ½ cup of very hot tap water into the second jar. Stir in 2½ tablespoons of alum until it dissolves. Cover loosely with a paper towel and leave it overnight. Small crystals will form on the bottom as it cools.
4. The next day, pour the alum liquid into a clean jar. Pick the best-shaped small alum crystal for your seed crystal. Tie it to fishing line, tie the other end to a pencil, and hang the seed in the liquid so it does not touch the sides or bottom.
5. **What we keep the same:** Both crystals grow in the same room, with the same amount of water, and you measure at the same time each day.
6. **What we measure:** Each day, measure the longest side of your biggest salt crystal and your alum crystal in millimeters. Write the numbers in a table with columns Day, Salt (mm), Alum (mm).
7. Look at each kind with the magnifying glass and draw it. Count the faces you can see.
8. **Conclusion:** After about a week, answer the question: Were the shapes the same or different? Which kind grew bigger?

Tips

- If crystals start growing on your fishing line or the jar walls, pour the liquid into a clean jar and hang the seed again so it gets all the alum.
- Do not jiggle the jars. Crystals grow best when left still.
- Keep the saucer of salt water out of the way of dust; the water must evaporate, so do not seal it.

Check your work

- I wrote a prediction before starting.
- My table has a measurement for each day.
- I can name the shape of a salt crystal and an alum crystal and count their faces.

FIELD NOTEBOOK

1. Draw a salt cube and an alum octahedron. Label the faces, edges and corners on each.
2. Make a bar graph of your alum crystal’s length on each day you measured it.
3. Draw Haüy picking up the broken piece of calcite. Write one sentence about what he noticed.

> **From history.** During the French Revolution, Haüy was arrested in 1792 because he was a priest who would not take an oath the new government demanded. One of his former students, Étienne Geoffroy Saint-Hilaire, worked hard to get him freed, and Haüy was released just days before a terrible attack on the prisons. He went back to his crystals and later became a professor of mineralogy at the great natural history museum in Paris.

WORKED EXAMPLES

Example 1. Count the faces, edges and corners on a salt cube and on an alum octahedron. Which numbers are the same?

(Use the map or drawing "Use the drawing to count." shown earlier in this lesson.)

1. Cube faces: top, bottom, front, back, left and right. That is 6 faces.
2. Cube edges: 4 around the top, 4 around the bottom and 4 standing up the sides. 4 + 4 + 4 = 12 edges.
3. Cube corners: 4 on top and 4 on the bottom. 4 + 4 = 8 corners.
4. Octahedron faces: 4 triangles on the top pyramid and 4 on the bottom pyramid. 4 + 4 = 8 faces.
5. Octahedron edges: 4 from the top point down, 4 around the middle, and 4 from the bottom point up. 4 + 4 + 4 = 12 edges.
6. Octahedron corners: 1 top, 1 bottom and 4 around the middle. 1 + 1 + 4 = 6 corners.

Answer: Cube: 6 faces, 12 edges, 8 corners. Octahedron: 8 faces, 12 edges, 6 corners. Both have 12 edges, and the numbers of faces and corners are swapped.

Example 2. Grace measured her alum crystal every other day. Day 1: 4 mm. Day 3: 8 mm. Day 5: 12 mm. Day 7: 16 mm. How much did it grow every two days? If it keeps growing the same way, how long will it be on Day 9, in millimeters and in centimeters?

1. Find the change: 8 − 4 = 4, 12 − 8 = 4, 16 − 12 = 4. It grew 4 mm every two days.
2. Day 9 is two days after Day 7: 16 + 4 = 20 mm.
3. There are 10 millimeters in 1 centimeter, so 20 mm = 2 cm.

Answer: It grew 4 mm every two days. On Day 9 it would be about 20 mm, which is 2 cm (a little less than 1 inch). Real crystals often slow down as the alum in the jar is used up, so we check by measuring.

PRACTICE

1. EASY What shape do salt crystals grow in?
2. EASY How many faces does an alum octahedron have?
3. MEDIUM The recipe uses 2½ tablespoons of alum for ½ cup of hot water. How much alum do you need for 1 cup of hot water?
4. MEDIUM Your best salt crystal is 1 centimeter long. How many millimeters is that? Is it longer or shorter than 1 inch?
5. HARD Two dishes of the same saturated salt water were set out at the same time. The dish in a warm, sunny window showed crystals after 2 days. The dish in a cool closet

showed crystals after 5 days. How many days longer did the closet dish take? Why do you think it was slower?

6. CHALLENGE You want to find out whether a seed crystal on a string grows a bigger alum crystal than no seed at all. Plan a fair test: what will you change, what will you keep the same, and what will you measure?

COMMON MISTAKES

- Thinking dissolved salt is gone. It is still in the water, just spread out too small to see. When the water evaporates, the salt comes back as crystals.
- Thinking crystals are only fancy gems. Salt, sugar, snowflakes and the quartz in sand are all crystals.
- Thinking hot water always dissolves much more of everything. Hot water dissolves far more alum than cold water, but salt dissolves about the same in both.

> **Make it a game · Crystal Builder.** Use sugar cubes, small blocks or LEGO bricks. A parent calls out a shape: cube, tall box, or step pyramid. Build it as fast as you can, then count its faces, edges and corners aloud. Next, try Haüy's trick: build a big cube out of 8 small cubes (2 across, 2 deep, 2 high), then a bigger one out of 27 (3 by 3 by 3). The outside shape stays a cube no matter how big it grows, just like a salt crystal. Score one point for each correct count.

> **Scripture.** "Ye are the salt of the earth: but if the salt have lost his savour, wherewith shall it be salted? it is thenceforth good for nothing, but to be cast out, and to be trodden under foot of men." (Matthew 5:13, KJV)

In Bible times salt was precious. It kept meat from spoiling and gave food its flavor. Jesus called His followers "the salt of the earth": just as a little salt makes a big difference, Christians are to do good wherever they are.

Practice answers

1. Cubes, with 6 square faces.
2. 8 triangle faces.
3. 1 cup is twice ½ cup, so double the alum: 2½ + 2½ = 5 tablespoons.
4. 1 centimeter = 10 millimeters. It is shorter than 1 inch, because 1 inch is about 2½ centimeters.
5. 5 − 2 = 3 days longer. The water in the cool closet evaporated more slowly, so the salt took longer to come out of the water and form crystals.
6. Change: one jar gets a hanging seed crystal and the other does not. Keep the same: the amount of water, the amount of alum, the water temperature, the jar size, the room and the number of days. Measure: the length of the biggest crystal in each jar, in millimeters, at the end.

1.4 Quartz, Feldspar, Mica, Calcite

OBJECTIVES

- Tell how Rasmus Bartholin of Copenhagen discovered in 1669 that a clear calcite crystal makes everything look double.
- Name four common minerals (quartz, feldspar, mica and calcite) and give two clues for recognizing each one.
- Use a simple identification key with hardness, cleavage and the fizz test to name a mystery mineral.

Warm-up. Look closely at a granite countertop, a granite gravestone or a speckled gray or pink stone step. (If you have none, look at a handful of sand under a magnifying glass.) How many different kinds of grains can you see? Describe each kind with a color word and a shine word.

Video. Coming soon. Common rock-forming minerals quartz, feldspar, mica and calcite for children: search USGS, the Smithsonian National Museum of Natural History, SciShow Kids and Homeschool Pop (Alternate), plus close-up footage of mica splitting into sheets, calcite fizzing in acid and Iceland spar double images.

KEY TERMS

cleavage
The way some minerals break along flat, smooth surfaces, always in the same directions. Mica splits into sheets; calcite breaks into slanted boxes.

fracture
A rough or curved break that does not follow flat surfaces. Quartz breaks with curved, shell-shaped surfaces, like broken glass.

Iceland spar
Very clear calcite, first found in Iceland, that makes anything seen through it look double.

fizz test
Putting a drop of acid, such as vinegar, on a mineral. Calcite fizzes with tiny bubbles; quartz, feldspar and mica do not.

granite
A speckled rock made mostly of quartz and feldspar, often with flakes of mica.

CORE IDEAS

The story. In 1669, in Copenhagen, Denmark, a professor named Rasmus Bartholin was given some unusual crystals brought from Iceland. They were as clear as window glass. When Bartholin set one on a page of writing, every letter showed up twice! He turned the crystal slowly, and one set of letters stayed still while the other set moved around it in a

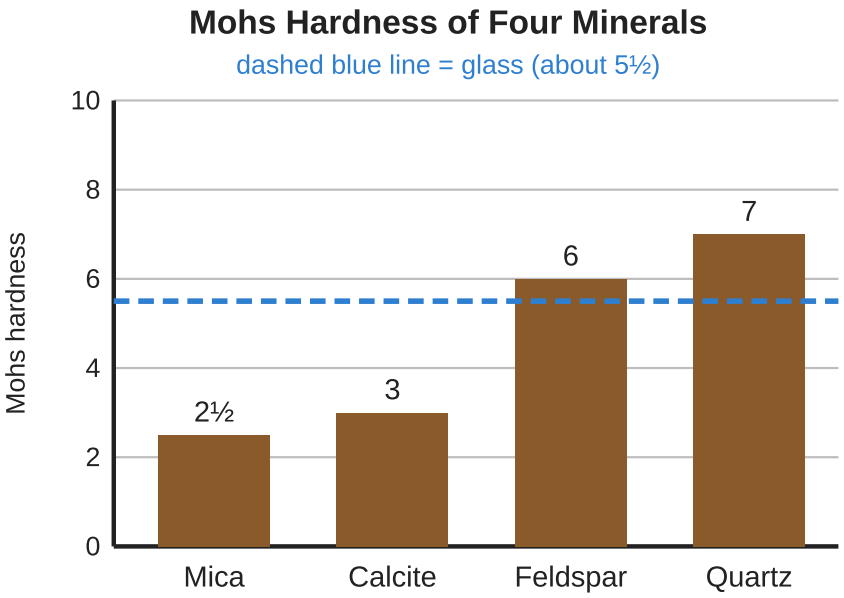
circle. Bartholin wrote a little book that same year describing his careful tests. The crystal was calcite, and clear calcite like this is still called **Iceland spar**.

How they figured it out. Bartholin could not fully explain the double image. That puzzle helped later scientists learn how light travels. But mineral hunters learned something useful right away: a mineral can be known by what it *does*, not just how it looks. In this lesson you will meet four of the most common minerals on earth. Many rocks are made almost entirely of them, so once you know these four, you will see them everywhere.

The big idea. Quartz is hardness 7, so it easily scratches glass. It has a glassy luster, often grows as six-sided crystals with pointed tips, and breaks with curved, shell-shaped surfaces. Much of the sand on beaches is quartz. **Feldspar** is hardness 6, also hard enough to scratch glass. It is often pink, white or gray, and it breaks along flat, shiny faces. The feldspars are the most common group of minerals in the earth's crust. **Mica** is soft, about 2½, and peels apart into thin, bendable sheets like the pages of a book. It may be clear and silvery or black. **Calcite** is hardness 3, so a copper penny scratches it. It breaks into slanted boxes, fizzes in acid, and the clear kind makes double images. Calcite makes up limestone and marble.

Try it and see. Look at a piece of granite. The pink or white blocky grains with flat, shiny faces are feldspar. The gray, glassy grains that look like bits of dirty ice are quartz. Black, shiny flakes that glitter when you tilt the stone are often mica. To test calcite, crush a tiny piece or use a clean seashell or bit of eggshell (both are made mostly of the same material as calcite), and add a few drops of vinegar. Watch with a magnifying glass for tiny bubbles.

God's handiwork. God did not make the earth out of only one plain material. He made minerals that split like paper, minerals that bend light, minerals tough enough to stand up to the pounding of beach waves, and minerals that form the shells of sea creatures. Each one is useful in its own way, and together they build the rocks under our feet. As the psalm says, the earth is full of His riches.



The four minerals on the Mohs scale. Only the bars above the glass line can scratch glass.

PICTURE STUDY



Melencolia I, Albrecht Dürer, 1514 · Engraving on paper · Prints are kept in many museums, including the Metropolitan Museum of Art, New York, and the National Gallery of Art, Washington, D.C.

Albrecht Dürer of Nuremberg, in Germany, was one of the greatest engravers who ever lived. He cut his pictures into copper plates with a sharp tool, so every line is crisp. In this famous print a winged figure sits deep in thought, surrounded by the tools of builders and measurers: a compass, a saw, a plane, a balance and a ruler.

The giant stone block on the left has many flat faces, like a crystal. People still argue about its exact shape, but many describe it as a slanted box with two corners cut off. Its slanted faces look a little like the slanted boxes that calcite breaks into.

Look closely

- Find the big stone block. Count the flat faces you can see.
- Find the square of numbers on the wall. Add the four numbers in the top row: 16, 3, 2 and 13. Then add another row. What do you notice?
- Find the hourglass, the bell and the balance. Which ones are used for measuring?
- Find the sleeping dog and the small winged child. What is each one doing?

Talk about it

1. Every row in Dürer's number square adds up to 34. Why do you think he put a puzzle like that in his picture?
2. How is the stone block like the crystals you studied this week? How is it different?
3. The winged figure looks stuck on a hard problem. What do you do when a science puzzle is hard?

> **Safety first.** Use a grown-up's help when crushing a mineral sample: wrap it in a cloth first and wear safety glasses. Use only household vinegar for the fizz test, and keep it away from your eyes. Use a blunt nail and smooth-edged glass, held by a grown-up, for scratch tests. Mica flakes can be sharp at the edges, so handle them gently.

EXPERIMENT: THE FOUR-MINERAL KEY

You will build and use a simple identification key, a list of yes-or-no questions that leads to the name of a mineral. Your question: *Can four mystery samples be named using only scratch, cleavage and fizz tests?*

You will need

- Samples of quartz, feldspar, mica and calcite (a beginner rock-forming mineral set, a rock shop, or a piece of granite plus a seashell or chalky limestone)
- A small glass tile with smooth edges and a blunt steel nail
- White vinegar and a dropper or spoon
- A magnifying glass and a small dish
- Index cards, masking tape and a marker
- Lab notebook and pencil

Steps

1. Have a parent put tape over the names of the four samples and label them A, B, C and D.
2. **Prediction:** Just by looking, guess which letter is which mineral. Write your guesses.

3. Copy this key into your notebook. Question 1: Does it scratch glass? If yes, go to Question 2. If no, go to Question 3.
4. Question 2: Does it break along flat, shiny faces? Yes means feldspar. No, it has curved, glassy breaks, means quartz.
5. Question 3: Does it peel into thin sheets? Yes means mica. No means go to Question 4.
6. Question 4: Does it fizz with a drop of vinegar (watch closely with the magnifying glass)? Yes means calcite.
7. **What we keep the same:** Use the same glass tile, the same gentle push, and the same 3 drops of vinegar for each sample. Wipe each sample dry after the fizz test.
8. Test each sample and write down every answer. Then peel off the tape. How many did you get right? Compare with your prediction.

Tips

- Vinegar is a weak acid, so calcite fizzes slowly. A tiny scraped pile of powder fizzes better than a big smooth crystal.
- If you have a clear piece of calcite, set it on a page of print and look for the double image, just as Bartholin did.
- Feldspar's flat faces flash in the light when you tilt the sample. Quartz glitters, but it has no flat broken faces.

Check your work

- I wrote predictions before testing.
- I followed the key question by question for each sample.
- I can name all four minerals and give two clues for each.

FIELD NOTEBOOK

1. Draw a piece of granite as large as your page. Color and label the feldspar, quartz and mica grains.
2. Draw a word seen through Iceland spar: write it once, then write it again a little higher and to the side, the way Bartholin saw it.
3. Make a four-box chart, one box for each mineral, with its hardness number, its color, how it breaks and one special trick (sheets, fizz, double image, scratches glass).

> **From history.** Our word "crystal" comes from the Greek word *krystallos*, which means ice. Writers in ancient Greece and Rome thought clear quartz, called rock crystal, was ice that had frozen so hard it could never melt again. Careful testing later showed that quartz is a mineral, not water at all. Thin, clear sheets of mica were once used as little windows in iron stoves and lanterns, because mica lets light through and does not break in the heat. People called it "isinglass."

WORKED EXAMPLES

Example 1. Use the bar graph. Which of the four minerals can scratch glass (about 5½)? How many numbers harder than mica is quartz?

(Use the map or drawing "Read each bar against the numbers on the left." shown earlier in this lesson.)

1. Read each bar: mica about 2½, calcite 3, feldspar 6, quartz 7.
2. Find the dashed glass line at 5½. Only feldspar (6) and quartz (7) rise above it.
3. Subtract: 7 − 2½ = 4½.

Answer: Feldspar and quartz can scratch glass. Quartz is 4½ numbers harder than mica on the Mohs scale.

Example 2. A white mystery mineral does not scratch glass. It does not peel into sheets. When you scrape a little powder from it and add vinegar, tiny bubbles appear. Use the four-mineral key to name it.

1. Question 1: Does it scratch glass? No. That rules out quartz and feldspar. Go to Question 3.
2. Question 3: Does it peel into thin sheets? No. That rules out mica. Go to Question 4.
3. Question 4: Does it fizz in vinegar? Yes.

Answer: The mineral is calcite.

PRACTICE

1. EASY Which of the four minerals peels apart into thin, bendable sheets?
2. EASY Which of the four minerals fizzes when you put vinegar on it?
3. MEDIUM Bartholin set a piece of Iceland spar over a word with 8 letters. Every letter showed up twice. How many letters did he see?
4. MEDIUM A museum quartz crystal is 12 inches (1 foot) long. One inch is about 2½ centimeters. About how many centimeters long is it?
5. HARD Quartz and feldspar both scratch glass and both can be white. Give two ways to tell them apart.
6. CHALLENGE In a granite step you see three kinds of grains: pink, blocky grains with flat, shiny faces; gray, glassy grains with no flat faces; and black flakes that glitter and can be picked apart with a pin. Name each mineral and explain one clue for each.

COMMON MISTAKES

- Thinking every clear, glassy mineral is quartz. Calcite can be just as clear, but it is much softer (3), breaks into slanted boxes and fizzes in acid.

- Thinking the glitter in granite was added by people. The shiny flakes are mica and the flashing faces are feldspar; they grew in the rock.
- Expecting calcite to foam up like baking soda. Vinegar is a weak acid, so calcite gives only slow, tiny bubbles. Use powder and a magnifying glass.

Make it a game · Four-Mineral Clue Cards. Write clues on index cards, one clue per card: “I scratch glass and break with curved surfaces.” “I peel into sheets.” “I fizz in vinegar.” “I make everything look double.” “I am pink with flat, shiny faces.” “Much of the sand on the beach is made of me.” Shuffle the cards. A parent reads one aloud, and the player names the mineral (quartz, feldspar, mica or calcite) and holds up the right sample if you have one. One point for each correct answer; play until the deck is gone.

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)

“Manifold” means many and varied. Quartz, feldspar, mica and calcite are four of God’s many works, each with its own gifts, and they are part of the riches that fill the earth.

Practice answers

1. Mica.
2. Calcite.
3. 8 × 2 = 16 letters.
4. 12 × 2½ = 30. It is about 30 centimeters long.
5. (1) Feldspar breaks along flat, shiny faces, while quartz breaks with curved, shell-shaped surfaces. (2) Quartz (7) is harder, so it can scratch feldspar (6), but feldspar cannot scratch quartz. (Quartz also often grows as six-sided crystals with pointed tips.)
6. The pink blocky grains are feldspar, because they break along flat, shiny faces. The gray glassy grains are quartz, because they are glassy and have curved breaks, not flat faces. The black flakes are mica, because they come apart in thin sheets.

Unit 1 review

Answer each question. Use complete sentences for explanations and show your work for any numbers. Each question is worth 4 points. The quiz is worth 40 points. A parent may read the questions aloud.

1. (4 pts) Who made the scale of mineral hardness in 1812, and what test did he use to put the minerals in order?
2. (4 pts) Name the minerals with these numbers on the Mohs scale: 1, 3, 7 and 10.
3. (4 pts) A mineral scratches calcite (3), but apatite (5) scratches it. What is its hardness, and which mineral on the scale has that hardness?
4. (4 pts) What is a mineral’s streak, and how do you test it?
5. (4 pts) A gold-colored mineral with a metallic luster leaves a greenish-black streak and scratches glass. Is it gold or pyrite? Give one reason.
6. (4 pts) Name two kinds of luster and give an example of something that shines each way.
7. (4 pts) What is a crystal? What did René Just Haüy notice when a piece of calcite broke?
8. (4 pts) What shape do salt crystals grow in, and what shape do alum crystals grow in? How many faces does each shape have?
9. (4 pts) Identify each mineral: (a) peels apart into thin, bendable sheets; (b) fizzes in vinegar and, when clear, makes letters look double.
10. (4 pts) Quartz and feldspar both scratch glass. Give one way to tell them apart, and name the rock that is made mostly of these two minerals.

Unit project: my mineral identification chart

Make a large poster or notebook spread that shows at least five minerals you have tested yourself. For each mineral, glue on a small sample or draw it carefully, and fill in a chart with its color, streak, luster, hardness range (from your fingernail, penny, nail and glass tests) and how it breaks or one special trick (sheets, fizz, double image). Add your salt and alum crystals, or careful drawings of them, with your daily growth measurements in millimeters.

Finish with a short paragraph telling which test was most helpful and why, and a drawing of the Mohs scale ladder with each of your minerals placed on the right rung.

- **Accurate tests**: Each mineral has a streak, luster and hardness result that matches real tests, and the minerals are named correctly.
- **Records and measurements**: The chart is complete, the crystal growth table has a measurement for each day, and units (mm, cm or inches) are written down.
- **Explanation**: The paragraph explains which test helped most and why streak is better than color, using the unit’s key terms.
- **Care and neatness**: Samples are labeled, drawings are careful and colored, and the Mohs ladder is drawn in the correct order.

Answer key

1. Friedrich Mohs. He used a scratch test: the harder mineral scratches the softer one, so he lined up ten minerals from softest to hardest.
2. 1 talc, 3 calcite, 7 quartz, 10 diamond. (1 point each.)
3. It is harder than 3 and softer than 5, so its hardness is 4, the same as fluorite.
4. The streak is the color of the mineral's powder. You test it by rubbing the mineral across the rough, unglazed back of a white tile (a streak plate) and looking at the color of the line.
5. Pyrite (fool's gold). Real gold leaves a yellow streak and is too soft to scratch glass; pyrite leaves a greenish-black streak and is hard enough to scratch glass.
6. Any two, such as: metallic (like a spoon, coin or pyrite), glassy (like a window or quartz), pearly (like the inside of a seashell), silky, greasy or dull (like dried mud).
7. A crystal is a solid whose tiny particles are lined up in a neat, repeating pattern, often showing flat faces and straight edges. Haüy noticed that calcite always broke into pieces with the same slanted-box shape, big or small, so he reasoned that crystals are built of tiny repeating pieces.
8. Salt grows cubes with 6 faces. Alum grows octahedrons (like two pyramids joined at the bottom) with 8 faces.
9. (a) Mica. (b) Calcite (clear calcite is called Iceland spar).
10. Feldspar breaks along flat, shiny faces, while quartz breaks with curved, shell-shaped surfaces (or: quartz, 7, scratches feldspar, 6). The rock is granite.

UNIT 2

Igneous Rocks

Some rocks were once a glowing liquid. Deep underground, God made places hot enough to melt rock into **magma**, and when that melted rock pours out of a volcano we call it **lava**. When magma or lava cools and hardens, it becomes **igneous rock**, “fire rock.” In this unit you will learn how to tell where an igneous rock cooled and how fast, just by looking at its crystals.

You will follow James Hutton up Glen Tilt in Scotland as he finds pink granite veins that prove granite was once melted. You will stand below the granite faces of Mount Rushmore, look at the dark basalt of Hawaii and the ocean floor, and melt rock with Sir James Hall to see why slow cooling grows big crystals and fast cooling makes glass. You will race melted chocolate on cold and warm plates, compare rock candy, fudge and hard candy, and end at two wonders of the world: Devils Tower in Wyoming and the Giant’s Causeway in Ireland, where cooling rock cracked into thousands of tall stone columns.

BEFORE YOU BEGIN

- Can name quartz, feldspar and mica and use a simple scratch and luster test (Unit 1)
- Knows that water can be a liquid or a solid and freezes when it cools
- Can add, subtract and multiply small numbers and read a simple bar graph
- Can measure with a ruler in inches

MASTERY CHECKLIST

- I can explain that igneous rock forms when melted rock cools and hardens, and tell the difference between magma and lava.
- I can tell granite from basalt by color, crystal size and where each one cooled.
- I can explain why slow cooling makes big crystals, fast cooling makes tiny crystals and very fast cooling makes glass like obsidian.
- I can identify pumice and explain what made its holes.
- I can explain how cooling, shrinking rock cracked into the columns of Devils Tower and the Giant’s Causeway.
- I can run a fair test, naming what I changed, what I kept the same and what I measured.

OPTIONAL BOOKS AND RESOURCES

- **USGS Volcano Hazards Program** (https://www.usgs.gov/programs/VHP): Free. Photographs, maps and short articles about volcanoes and lava from the U.S. Geological Survey, including the Hawaiian Volcano Observatory at Kīlauea (Lesson 2.1). A parent can choose pictures to show.
- **Devils Tower National Monument (National Park Service)** (https://www.nps.gov/deto/): Free. Official park pages with photographs of the columns,

the boulder field and the history of the first national monument (Lesson 2.4).

- **Smithsonian Global Volcanism Program** (https://volcano.si.edu/): Free. Photographs and facts about volcanoes around the world, including Kīlauea and Cotopaxi. Best browsed with a parent.

2.1 Rocks from Melted Rock ★

OBJECTIVES

- Explain that igneous rock forms when melted rock cools and hardens.
- Tell the difference between magma and lava, and between melted rock that cools underground and melted rock that cools on the surface.
- Tell how James Hutton found granite veins in Glen Tilt and explain what they showed him.

Warm-up. Put an ice cube on a saucer and a second ice cube in a cup of warm water. Watch for five minutes. Which one turns to liquid first? Now think backward: how could you turn the water back into a solid? Ice is “frozen water.” Today you will learn about rock that is “frozen” too: rock that was once a glowing liquid and hardened as it cooled.

Video. Coming soon. Magma, lava and how igneous rock forms, for kids: search USGS Volcano Hazards Program, Hawaiian Volcano Observatory lava footage, Smithsonian, SciShow Kids, Homeschool Pop (Alternate) and Science Max.

KEY TERMS

igneous rock
Rock that forms when melted rock cools and hardens. The name comes from *ignis*, the Latin word for fire.

magma
Melted rock while it is still underground.

lava
Melted rock after it comes out onto the surface of the earth. Cooled lava is also called lava rock.

volcano
An opening in the earth where lava, ash and gas come out. Often the cooled lava and ash pile up into a mountain.

vein
A long, thin crack in rock that has been filled with a different rock or mineral.

CORE IDEAS

The story. In the autumn of 1785, a Scottish farmer and scientist named James Hutton went walking up a wild valley called Glen Tilt, in the Highlands of Scotland. He was hunting for one special thing: a place where granite met a different kind of rock. Many learned men of his day believed granite had settled out of water at the bottom of a great sea, the way mud settles in a puddle. Hutton believed granite had once been hot and melted. In the bed of the River Tilt he found what he was looking for. Pink granite reached into the darker, layered

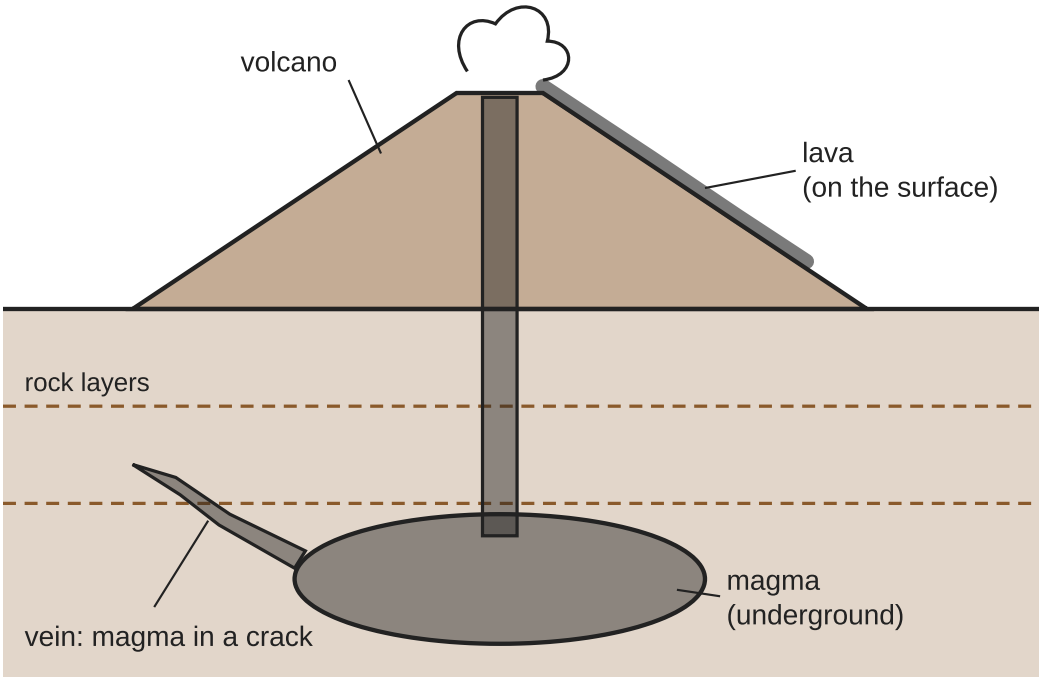
rock around it in long cracks called **veins**, like the fingers of a hand. His friend John Playfair later wrote that Hutton was so delighted that his guides thought he must have found a vein of silver or gold.

How they figured it out. Hutton thought like a detective. Mud and sand cannot squeeze up into the cracks of hard rock and push the rock apart. A hot liquid can. So if granite filled those cracks, the granite must once have been a liquid, and it must have hardened after it flowed in. Hutton also noticed that the rock right next to the granite looked baked and changed, the way bread changes in a hot oven. Clue by clue, he showed that granite is a rock that was once melted.

The big idea. Rock that forms when melted rock cools and hardens is called **igneous rock** (IG-nee-us). Deep underground, some places are so hot that rock melts into a thick, glowing liquid called **magma**. When magma pushes up and pours out of an opening called a **volcano**, we give it a new name: **lava**. It is the same melted rock in two places: magma below the ground, lava above it. Fresh lava in Hawaii is about 2,100 °F (about 1,150 °C), far hotter than any kitchen oven. As the melted rock cools, tiny **crystals** of minerals grow and lock together like puzzle pieces, until the liquid has become solid stone. Some magma cools while it is still hidden underground, as Hutton's granite did. Some cools on the surface as lava. Both make igneous rock.

Try it and see. You already know a liquid can turn into a solid. Water freezes into ice at 32 °F (0 °C). Candle wax drips, cools and hardens. Igneous rock is a kind of "frozen" rock: it freezes from a liquid too, only at a much, much higher temperature. Today, scientists at the Hawaiian Volcano Observatory, begun at Kīlauea volcano in 1912, watch lava flows, measure their heat with special tools and collect pieces of lava rock once they cool.

God's handiwork. The psalmist wrote that God "toucheth the hills, and they smoke" (Psalm 104:32). Volcanoes remind us that the earth is not a dead ball of stone. Under the mud of the ocean floor lies igneous rock, and the islands of Hawaii were built up out of the sea by lava. In November 1963, fishermen near Iceland watched steam and smoke pour from the waves as a brand-new island, later named Surtsey, rose from the sea. God made a world with fire beneath its crust, and when that fire cools, it becomes some of the hardest and most useful rock we have.



Magma is melted rock underground. Lava is melted rock on the surface. Both cool into igneous rock.

PICTURE STUDY



Vesuvius in Eruption, with a View over the Islands in the Bay of Naples, Joseph Wright of Derby, about 1776–1780 · Oil on canvas · Tate Britain, London

Joseph Wright of Derby was an English painter who loved to paint scenes lit by firelight, candlelight and moonlight. In 1774 he traveled to Italy and stayed near Naples, where Mount Vesuvius was smoking and glowing. He was so struck by the volcano that he painted it again and again for the rest of his life.

In this painting he shows Vesuvius at night, with lava spilling down its sides and a great cloud lit from below. Far away, the quiet waters of the Bay of Naples and its islands lie in the moonlight. Wright wanted us to feel both the danger and the wonder of melted rock pouring out of the earth.

Look closely

- Find the brightest part of the painting. What is glowing there?
- Follow the lava with your finger. Which way is it flowing, and why?
- Look at the cloud above the volcano. Why is its underside lit up?
- Find the calm bay and the islands. How do they look different from the volcano?

Talk about it

1. Is the glowing liquid in this painting magma or lava? How do you know?
2. What will happen to the lava when it cools down?
3. Why do you think the painter put a quiet, moonlit bay next to a fiery volcano?

> **Safety first.** Melted crayon wax is hot enough to burn skin. A grown-up melts the wax and does all the pouring, using an oven mitt. Never melt crayons in a pan directly over a flame. Let the wax cool for at least 10 minutes before touching it.

EXPERIMENT: HUTTON'S VEIN IN A CLAY CLIFF

James Hutton knew granite had once been melted because it had flowed into cracks in other rock. You will make a little "cliff" of clay layers, cut cracks in it and pour in melted crayon as your "magma." When it cools, you will cut the clay open and look for your own veins.

You will need

- Two colors of modeling clay or play dough
- Old crayons with the paper peeled off (one bright color works best)
- A clean empty can or a heat-safe measuring cup, set in a pan of hot water (a grown-up's job)
- A butter knife or craft stick
- A ruler with inches and centimeters
- Oven mitt, newspaper, lab notebook and pencil

Steps

1. **Question:** Will melted "magma" flow farther into a wide crack or a narrow crack? Write your **prediction** in your notebook.
2. Build a block of clay about 4 inches long, 2 inches wide and 2 inches tall, pressing thin layers of two colors on top of each other so it looks like layered rock.
3. With the butter knife, cut two cracks down into the top of the block, each about 1 inch deep. Wiggle one crack wide (about as wide as a pencil). Leave the other one narrow

(as thin as a fingernail).

4. **What we change:** only the width of the crack. **What we keep the same:** the same clay, the same crayon wax, the same depth of crack and the same amount of wax poured into each (one spoonful).
5. A grown-up melts the crayon pieces in the can set in hot water, then carefully spoons the same amount of melted wax into each crack.
6. Wait at least 10 minutes for the wax to cool and harden. Feel the top. Is it a liquid or a solid now?
7. **What we measure:** Slice the block in half across both cracks. Use the ruler to measure how far down the wax went in each crack, in inches and in centimeters.
8. **Record:** Make a table with two rows (wide crack, narrow crack) and columns for “How deep the wax went” and “What it looks like.” Draw the cut face of your clay cliff and label the layers, the vein and the “magma.”

Tips

- Wax that cools too quickly will stop at the top of a narrow crack. That is a real clue: hot magma flows farther than cooling magma.
- If you have no crayons, a grown-up can use candle stubs. Never use a microwave to melt wax.

Check your work

- I can explain how my wax vein is like Hutton’s granite vein.
- I can name what I changed, what I kept the same and what I measured.
- I can say whether my prediction was right.

FIELD NOTEBOOK

1. Draw a volcano cut in half like a cake. Color and label the magma underground and the lava on the surface.
2. Draw Hutton’s granite veins reaching into the dark layered rock, like fingers of a hand. Write one sentence telling what the veins proved.
3. Make a two-column chart titled “Liquid to Solid.” List three things in your home that start as a liquid and harden (ice, wax, glue) and, at the bottom, igneous rock.

> **From history.** In Hutton’s day, a famous German teacher named Abraham Gottlob Werner taught that granite and even the dark rock basalt had settled out of a great ocean. His followers were nicknamed Neptunists, after the Roman god of the sea. Those who said these rocks were made by heat were nicknamed Plutonists, after the Roman god of the underworld. In the 1760s, a French scientist named Nicolas Desmarest walked the hills of Auvergne in central France and traced sheets of basalt back to old, worn-down volcanoes. Field work like Desmarest’s and Hutton’s slowly convinced scientists that igneous rocks came from melted rock.

WORKED EXAMPLES

Example 1. Fresh lava in Hawaii is about 2,100 °F. A kitchen oven baking bread is set to 400 °F. How many degrees hotter is the lava than the oven?

1. We want the difference between two temperatures, so we subtract the smaller from the larger.
2. 2,100 − 400 = 1,700.
3. Check by adding back: 1,700 + 400 = 2,100. It matches.

Answer: The lava is about 1,700 °F hotter than the oven. (In metric, lava is about 1,150 °C and the oven is about 200 °C.)

Example 2. Sort these four kinds of melted rock into “magma” or “lava”: (a) a pool of melted rock deep under a volcano; (b) a glowing river of melted rock running down a hillside; (c) melted rock squeezing into a crack far below the ground, like Hutton’s granite before it hardened; (d) a fountain of melted rock spraying into the air at Kīlauea.

(Use the map or drawing “Same melted rock, two names: magma below, lava above.” shown earlier in this lesson.)

1. Ask one question about each: is it under the ground or on top of it?
2. (a) is deep under the volcano: underground. (c) is in a crack far below the ground: underground.
3. (b) runs down a hillside and (d) sprays into the air: both are on the surface.
4. Underground melted rock is magma. Melted rock on the surface is lava.

Answer: Magma: (a) and (c). Lava: (b) and (d).

PRACTICE

1. EASY The word igneous comes from the Latin word *ignis*. What does *ignis* mean?
2. EASY What is the difference between magma and lava?
3. MEDIUM A slow lava flow creeps forward 3 feet every minute. How far will it move in 10 minutes?
4. MEDIUM Hutton found pink granite filling cracks in darker rock. Explain how this showed that the granite had once been melted.
5. HARD A student measured melted crayon wax as it cooled. Start: 150 °F. After 5 minutes: 120 °F. After 10 minutes: 100 °F. After 15 minutes: 90 °F. How many degrees did it cool in the first 5 minutes? In the last 5 minutes? When did it cool faster?
6. CHALLENGE You want to test whether the color of crayon changes how far melted wax flows into a crack. Name what you would change, two things you would keep the same and what you would measure.

COMMON MISTAKES

- Thinking magma and lava are two different materials. They are the same melted rock; the name changes when it reaches the surface.
- Thinking all igneous rock comes out of volcanoes. Much igneous rock, like granite, cooled underground and never came out at all.
- Thinking the inside of the earth is one big ocean of liquid magma. Most of the rock deep inside the earth is solid; magma forms only in certain hot places.

> **Make it a game · Magma or Lava?.** A parent calls out a place: “in a crack deep underground,” “pouring down a mountain,” “in a pool under a volcano,” “spraying into the sky.” If the melted rock is underground, crouch down low and say “Magma!” If it is on the surface, jump up and say “Lava!” Score a point for each right answer. Bonus point: tell what kind of rock it will become when it cools (igneous rock).

> **Scripture.** “He looketh on the earth, and it trembleth: he toucheth the hills, and they smoke.” (Psalm 104:32, KJV)

Psalm 104 praises God for the whole created world, from springs and trees to the sea. Even smoking mountains are under His hand. When we study volcanoes, we are studying part of the world He made and rules.

Practice answers

1. Fire.
2. They are the same melted rock. Magma is underground; lava has come out onto the surface.
3. 3 × 10 = 30 feet (about 9 meters).
4. Only a liquid could flow into the cracks and fill them. So the granite must have been a hot liquid (magma) that flowed in and then cooled and hardened.
5. First 5 minutes: 150 − 120 = 30 degrees. Last 5 minutes: 100 − 90 = 10 degrees. It cooled faster at the beginning, when it was hottest.
6. Change: only the crayon color. Keep the same: crack width and depth, amount of wax, the clay, how hot the wax is (any two). Measure: how far the wax went into each crack, with a ruler.

2.2 Granite and Basalt

OBJECTIVES

- Identify granite and basalt by their color, crystal size and minerals.
- Explain that granite cooled slowly underground and basalt cooled quickly from lava on the surface.
- Tell how granite was used to carve Mount Rushmore and name places where basalt is found, such as Hawaii and the ocean floor.

Warm-up. Hunt around your home and neighborhood for speckled stone: a kitchen counter, a gravestone in a churchyard, a curb, a stone step or a building front. Look closely. Can you see separate specks of color, pink or white, gray and black? Count how many colors you see. Then look for a plain dark gray or black stone, such as gravel along a road or railroad track. Can you see any specks in it at all?

Video. Coming soon. Granite and basalt for kids, comparing the two igneous rocks, how Mount Rushmore was carved and Hawaiian lava rock: search USGS, National Park Service (Mount Rushmore, Hawaii Volcanoes), Smithsonian, SciShow Kids, Homeschool Pop (Alternate) and Science Max.

KEY TERMS

granite
A light-colored, speckled igneous rock with crystals big enough to see. It cooled slowly deep underground.

basalt
A dark gray or black igneous rock with crystals too small to see. It cooled quickly from lava on or near the surface.

grain
One small piece or crystal in a rock. Big grains make a rock look speckled; tiny grains make it look smooth.

texture
How a rock looks and feels because of the size and shape of its grains: coarse (big grains) or fine (tiny grains).

thin section
A slice of rock ground so thin that light shines through it, so its tiny crystals can be studied under a microscope.

CORE IDEAS

The story. In 1927, a sculptor named Gutzon Borglum and a crew of workers climbed onto a granite mountain in the Black Hills of South Dakota. Their plan was enormous: to carve the

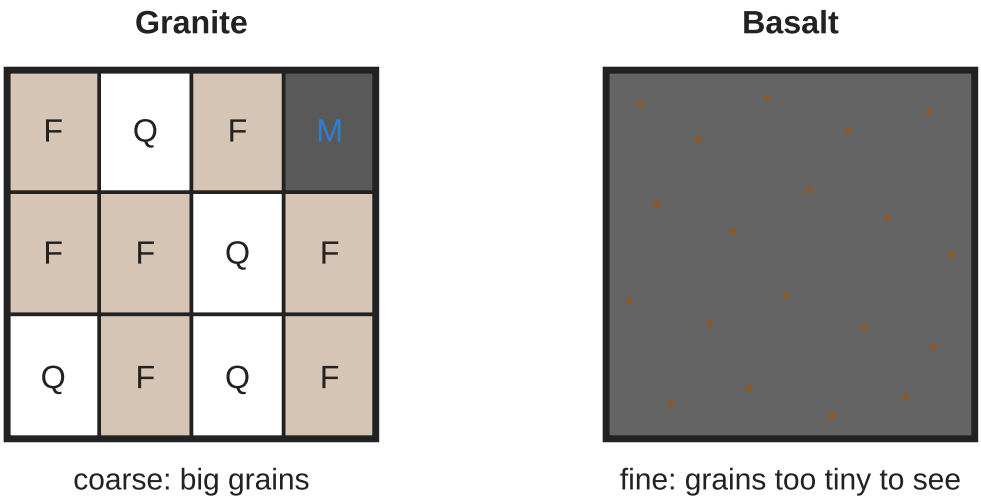
faces of four presidents, George Washington, Thomas Jefferson, Theodore Roosevelt and Abraham Lincoln, into the mountain itself. Each face would be about 60 feet tall. Nearly 400 men worked on Mount Rushmore over the next fourteen years. They blasted away most of the rock with dynamite, then used jackhammers and hand tools to shape eyes, noses and lips. Borglum chose granite because it is hard, strong and wears away very slowly, so the faces would last.

How they figured it out. If you look closely at granite, you can see that it is made of separate crystals packed together. Using the mineral tests from Unit 1, you can name them. The glassy gray grains are **quartz**, hard enough to scratch glass. The pink or white blocky grains are **feldspar**. The shiny black flakes that peel into thin sheets are **mica**. Basalt is harder to read, because its grains are too tiny to see. In the 1850s, an English scientist named Henry Clifton Sorby showed a new way. He ground slices of rock so thin that light could shine through them, then looked at these **thin sections** under a microscope. Under the microscope, a thin section of dark basalt shows a crowd of tiny crystals, all locked together.

The big idea. Granite and basalt are both igneous rocks, but they are opposites in almost every way. **Granite** is light-colored and speckled, with big crystals you can see. It cooled slowly, deep underground, so its crystals had plenty of time to grow. **Basalt** is dark and plain, with crystals too small to see. It cooled quickly from lava at or near the surface, so its crystals had no time to grow large. Basalt is also a little heavier than a piece of granite the same size, because it is rich in dark minerals that contain iron. Scientists call a rock with big grains **coarse** and a rock with tiny grains **fine**. That is the rock's **texture**.

In the world today. Granite is found under much of the land of the continents. People use it for countertops, gravestones, curbs, bridges and buildings because it is tough and takes a beautiful polish. The great cliffs of Yosemite Valley in California are made of granite and rocks very much like it. Basalt is the most common rock under the oceans. The islands of Hawaii are built almost entirely of basalt lava. Crushed basalt is used for gravel on roads and railroad tracks. The dark patches you see on the face of the moon are basalt too, and astronauts brought pieces of it home.

God's handiwork. Jesus said that a wise man builds his house upon a rock (Matthew 7:24). Builders have trusted granite for thousands of buildings because it stands firm in wind, rain and frost. God made the land we stand on and the floor beneath the sea out of strong igneous rock, and He gave people the wisdom to find it, test it and build with it.



Granite (left) has big grains you can count. Basalt (right) has grains too tiny to see without a microscope.

PICTURE STUDY



Looking Down Yosemite Valley, California, Albert Bierstadt, 1865 · Oil on canvas · Birmingham Museum of Art, Birmingham, Alabama

Albert Bierstadt was born in Germany and grew up in Massachusetts. In 1863 he traveled west and spent weeks sketching in Yosemite Valley in California. Back in his studio, he turned his sketches into huge paintings that showed people in the East a place most of them had never seen.

The giant cliffs in this painting are made of granite and rocks very much like it. They cooled slowly deep underground and were later uncovered and carved into the steep walls of the valley. Bierstadt painted them glowing in warm light, as if the whole valley were a cathedral of stone.

Look closely

- Find the river. Follow it with your eyes as far into the distance as you can.
- Look at the cliffs on each side. What colors did Bierstadt use for the granite?
- Find the trees at the bottom of the cliffs. How do they help you guess how tall the cliffs are?
- Where is the light coming from? What time of day do you think it is?

Talk about it

1. Why do you think granite cliffs like these can stand so tall and steep?
2. If you could climb down into this valley and pick up a piece of the cliff, what would you expect to see in it?
3. How does this painting make you feel about the world God made?

EXPERIMENT: GRANITE AND BASALT DETECTIVE

You will study a piece of granite and a piece of basalt like a real rock scientist. You will look through a magnifying glass, count grains inside a 1-inch window and measure the biggest crystal in each rock.

You will need

- A piece of granite and a piece of basalt (from a rock kit, a rock shop, or a granite sample tile from a home store; dark landscaping gravel is often basalt)
- A magnifying glass
- An index card with a 1-inch square hole cut in the middle (your “window”)
- A ruler with inches and millimeters
- Colored pencils, lab notebook and pencil

Steps

1. **Question:** Which rock has bigger crystals, granite or basalt? Write your **prediction**.
2. **What we change:** the kind of rock. **What we keep the same:** the same window, the same magnifying glass, the same ruler and the same bright light.
3. Lay the window card on the granite. With the magnifying glass, count the grains you can see inside the square. Make tally marks for each color: pink or white (feldspar), gray and glassy (quartz), black and shiny (mica).
4. Measure the biggest crystal you can find in the granite, in millimeters.
5. Do the same with the basalt. Can you count any grains at all? Measure the biggest grain you can see.

6. **Record:** Make a table with two rows (granite, basalt) and columns for Color, Grains counted in the window, Biggest crystal (mm) and Texture (coarse or fine).
7. Draw what you see through each window with colored pencils, as large as you can.

Tips

- Wet the rock with a damp cloth. Water makes the colors of the crystals easier to see.
- Some stone sold as “granite” for countertops is really a different rock. Ask the store for true granite if you can.

Check your work

- I can tell granite from basalt by color and grain size.
- I can name the three minerals I see in granite.
- I can explain why one rock has bigger crystals than the other.

FIELD NOTEBOOK

1. Draw a magnified circle of granite and label quartz, feldspar and mica. Next to it, draw a magnified circle of basalt and write “grains too tiny to see.”
2. Draw Mount Rushmore and write the names of the four presidents under their faces. Add a label: “carved in granite.”
3. Make a T-chart titled “Granite and Basalt” with rows for color, crystal size, where it cooled, fast or slow and one place it is found.

> **From history.** Gutzon Borglum did not live to see Mount Rushmore finished. He died in March 1941, and his son Lincoln Borglum led the last months of work. The workers removed about 450,000 tons of granite from the mountain. Even with dynamite, jackhammers and dangerous work hanging in harnesses from the cliff, not one worker died during the carving.

WORKED EXAMPLES

Example 1. Each face on Mount Rushmore is about 60 feet tall. A third grader is about 4 feet tall. How many third graders, standing on each other’s heads, would it take to reach from chin to forehead?

1. We want to know how many 4-foot children fit into 60 feet, so we divide: 60 ÷ 4.
2. Count by fours: 4, 8, 12, 16, 20, 24, 28, 32, 36, 40, 44, 48, 52, 56, 60. That is 15 fours.
3. Check: 15 × 4 = 60.

Answer: 15 third graders. (60 feet is about 18 meters.)

Example 2. Mia laid a 1-inch window on a piece of granite and counted the grains inside it: 7 pink feldspar grains, 4 gray quartz grains and 1 black mica grain. How many grains did she count in all? Which mineral was most common? Was it more than half of the grains?

(Use the map or drawing "Mia's granite window (left) and a basalt window (right)." shown earlier in this lesson.)

1. Add the grains: 7 + 4 + 1 = 12 grains.
2. Compare the numbers: 7 is more than 4 and more than 1, so feldspar was most common.
3. Half of 12 is 6. Feldspar had 7 grains, and 7 is more than 6.

Answer: 12 grains in all. Feldspar was most common, and yes, it was more than half of the grains (7 out of 12).

PRACTICE

1. EASY A rock is light-colored and speckled with pink, gray and black crystals big enough to see. Is it granite or basalt?
2. EASY Where did basalt cool, and did it cool fast or slow?
3. MEDIUM The biggest crystal in a piece of granite is 8 millimeters long. The biggest grain you can find in a piece of basalt is 1 millimeter. How many times longer is the granite crystal?
4. MEDIUM Work on Mount Rushmore began in 1927 and ended in 1941. How many years did the carving go on?
5. HARD Two blocks are exactly the same size. The granite block weighs 27 ounces. The basalt block weighs 30 ounces. Which is heavier, and by how much? What makes it heavier?
6. CHALLENGE In two or three sentences, explain why granite has big crystals but basalt has tiny ones.

COMMON MISTAKES

- Thinking granite came out of a volcano. Granite cooled underground from magma that never reached the surface.
- Thinking every dark rock is basalt. Color is only one clue; also check grain size, weight and whether the rock is glassy or has holes.
- Thinking every countertop sold as "granite" is true granite. Stores often use the name for many hard, polished stones.

Make it a game · Granite or Basalt?. A parent reads one clue at a time: "I am dark." "I cooled slowly." "You can see my crystals." "Hawaii is made of me." "Mount Rushmore is carved in me." "I cooled from lava." "I am speckled pink and gray." "I am a little heavier."

Point to the left for granite or to the right for basalt. Score a point for each right answer, and a bonus point if you can give the reason.

Scripture. “Therefore whosoever heareth these sayings of mine, and doeth them, I will liken him unto a wise man, which built his house upon a rock:” (Matthew 7:24, KJV)

A rock foundation does not wash away when the storms come. Jesus says that the person who hears His words and does them is like that wise builder.

Practice answers

1. Granite.
2. It cooled from lava at or near the surface, and it cooled fast.
3. $8 \div 1 = 8$ times longer.
4. $1941 - 1927 = 14$ years.
5. The basalt block is heavier by $30 - 27 = 3$ ounces. Basalt is rich in dark minerals that contain iron, which makes it heavier for its size.
6. Granite cooled slowly deep underground, where the rock around it kept it warm, so its crystals had a long time to grow big. Basalt cooled quickly from lava at the surface, so its crystals had only a short time to grow and stayed tiny.

2.3 Fast and Slow Cooling: Chocolate and Fudge

OBJECTIVES

- Explain that slow cooling makes big crystals, fast cooling makes tiny crystals and very fast cooling makes glass with no crystals.
- Identify obsidian and pumice and explain how each one formed.
- Carry out a fair test with melted chocolate, record the times in a table and read the results from a bar graph.

Warm-up. Look at three treats with a magnifying glass, if you have them: a piece of rock candy or a few grains of table sugar, a piece of fudge, and a clear hard candy such as a lemon drop. Which one has crystals you can see? Which one is smooth? Which one is clear like glass? Guess: how might the way each candy cooled have made it look so different?

Video. Coming soon. How cooling speed changes crystal size in igneous rock (granite, basalt, obsidian, pumice), with kitchen crystal and candy demonstrations: search USGS, Smithsonian, SciShow Kids, Science Max, Homeschool Pop (Alternate) and Moody Science classics.

KEY TERMS

crystal
A solid whose tiny particles are lined up in a neat, repeating pattern. Crystals grow as melted rock cools.

cooling rate
How fast something cools down. Slow cooling makes big crystals; fast cooling makes small ones.

obsidian
Natural volcanic glass. It cooled so fast that no crystals could grow, so it is shiny and breaks with very sharp edges.

pumice
A light, frothy igneous rock full of holes left by gas bubbles. Many pieces are light enough to float on water.

vesicle
A small hole in lava rock left by a gas bubble that was trapped as the lava hardened.

CORE IDEAS

The story. In the late 1790s, a Scottish gentleman named Sir James Hall set out to answer a hard question about his friend James Hutton’s ideas. Hutton said that the dark rock the Scots called whinstone, which is much like basalt, had once been melted. His critics

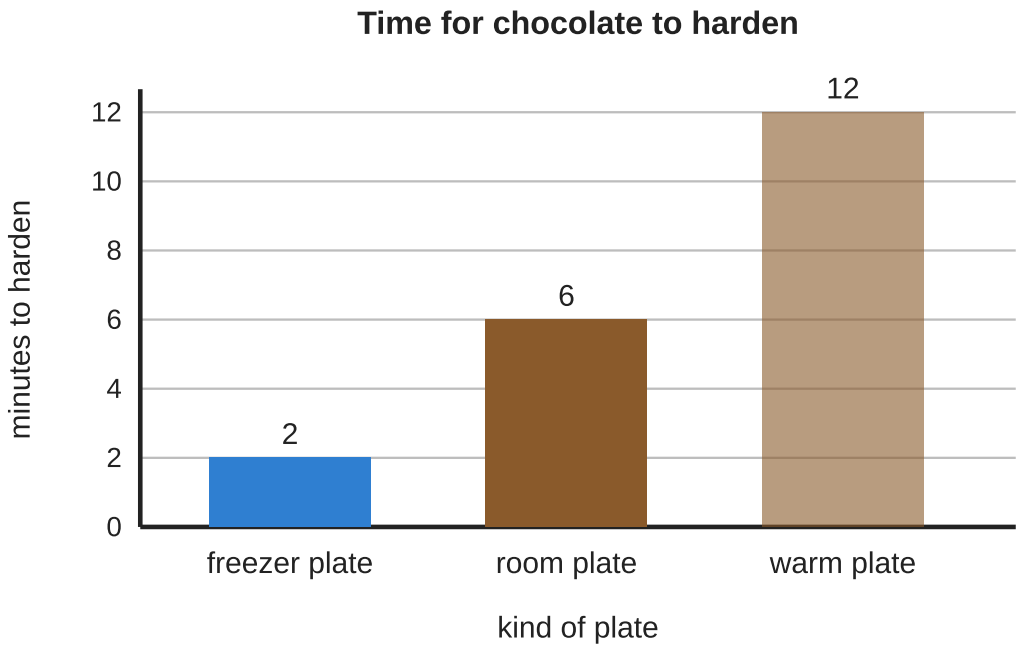
answered: if that were true, it would have cooled into glass, the way melted rock in a glassmaker's furnace cools into black, shiny glass. Whinstone is stony and full of crystals, not glassy. So how could it once have been melted? Hall decided to stop arguing and test it. He gathered lumps of whinstone near Edinburgh and melted them in a furnace used for melting iron.

How they figured it out. When Hall let the melted rock cool quickly, it turned into black glass, just as the critics said. Then he tried something new. He melted the rock again and let it cool *slowly*, keeping it hot in the furnace for a long time. This time it did not turn to glass. It became stony, crystal-filled rock very much like the whinstone he started with. Hutton and his critics had each been partly right. Melted rock can become glass or stone. The difference is how fast it cools.

The big idea. When melted rock cools, **crystals** begin to grow, the way frost crystals grow on a cold window. If the rock cools **slowly**, the crystals have a long time to grow, and they grow big. Granite cooled deep underground with warm rock wrapped around it like a blanket, so it has big crystals. If the rock cools **fast**, many crystals start at once but have little time to grow, so they stay tiny. That is basalt. If some thick lavas cool **very fast**, there is no time to make crystals at all. They become natural glass called **obsidian**, shiny and black, with edges sharper than a knife. And if lava is full of gas bubbles when it hardens, the bubbles are frozen into the rock as holes. Frothy **pumice** has so many holes that it can float on water.

Try it and see. Candy makers know this secret too. Rock candy is made by letting sugar crystals grow slowly in a jar for about a week, so the crystals grow big, like granite. Good fudge is beaten hard as it cools so that a great many tiny sugar crystals form at once, making it smooth, like basalt. Hard candy is boiled sugar that cools too fast to make crystals, so it is clear and glassy, like obsidian. In this lesson you will pour melted chocolate onto a cold plate, a room-temperature plate and a warm plate, and time how fast it hardens.

God's handiwork. Solomon wrote that God "hath made every thing beautiful in his time" (Ecclesiastes 3:11). Some of the most beautiful crystals in the earth grew slowly, a little at a time. Yet God made the fast-cooled rocks useful too. Long ago, people across North America chipped obsidian into arrowheads and knives with edges sharper than steel, and they traded it over great distances. Fast or slow, every igneous rock tells the story of how it cooled.



The colder the plate, the faster the melted chocolate hardened.

PICTURE STUDY



Cotopaxi, Frederic Edwin Church, 1862 · Oil on canvas · Detroit Institute of Arts, Detroit, Michigan

Frederic Edwin Church was an American painter who traveled to Ecuador, in South America, in 1853 and again in 1857 to sketch its mountains and volcanoes. Cotopaxi is one of the tallest active volcanoes in the world, with a nearly perfect cone shape.

In this painting, Cotopaxi sends a long trail of ash across the sky, and the sun glows red through the haze. In front, water tumbles over dark rock into a deep gorge. Church shows us

a land shaped by fire and by water.

Look closely

- Find the volcano's cone. What shape is it?
- Follow the cloud of ash with your finger. Which way is the wind blowing it?
- Find the sun. Why does it look red instead of yellow?
- Look at the dark rocks around the waterfall. Could they have once been lava?

Talk about it

1. If you could climb Cotopaxi, what igneous rocks might you find on its slopes: glassy ones, rocks with holes, or rocks with big crystals? Why?
2. Why would lava on the surface of a volcano cool faster than magma deep inside the mountain?
3. Which part of the painting do you think Church wanted you to look at first?

> **Safety first.** Melted chocolate and the bowl it is melted in can be hot. A grown-up melts the chocolate in short bursts in the microwave or over a pan of hot water on the stove, and does the pouring. Use an oven mitt for anything that has been heated. Do not use plates warmed in an oven; warm water is enough. If anyone makes fudge or candy, a grown-up handles all the boiling sugar, which is much hotter than boiling water.

EXPERIMENT: CHOCOLATE LAVA COOLING RACE

You will play the part of Sir James Hall. Your melted chocolate is the "lava," and your plates are the places where it cools. You will find out whether the temperature of the plate changes how fast the chocolate hardens.

You will need

- 1/2 cup of chocolate chips
- A microwave-safe bowl and a spoon (for a grown-up)
- Three small plates of the same kind: one chilled in the freezer for 20 minutes, one at room temperature, one warmed in hot tap water and dried
- A teaspoon for measuring
- Toothpicks
- A clock or timer
- A magnifying glass, lab notebook and pencil

Steps

1. **Question:** Does melted chocolate harden faster on a cold plate or a warm plate? Write your **prediction**.
2. **What we change:** only the temperature of the plate. **What we keep the same:** the same chocolate, the same size spoonful (1 teaspoon), the same kind of plate and the

same room.
3. A grown-up melts the chocolate chips and stirs them smooth.
4. Start the timer. Quickly drop 1 teaspoon of melted chocolate in the middle of each plate.
5. **What we measure:** Every minute, gently touch each puddle with a fresh toothpick. Write down the minute when the toothpick no longer leaves a mark. That is when the chocolate has hardened.
6. **Record:** Make a table with three rows (freezer plate, room plate, warm plate) and a column for "Minutes to harden." Then draw a bar graph of your results.
7. When all three have hardened, look at each one with the magnifying glass. Is one shinier or smoother than the others? Break each in half. Does one snap more sharply?

Tips

- Work quickly: a freezer plate starts warming up as soon as you take it out.
- On a warm day, the warm-plate chocolate may take a long time. Stop after 20 minutes and write "more than 20."
- For a candy model of the three igneous textures, compare rock candy (big crystals, like granite), fudge (tiny crystals, like basalt) and a clear hard candy (glass, like obsidian).

Check your work

- I can name what I changed, what I kept the same and what I measured.
- I can read my bar graph and tell which plate cooled the chocolate fastest.
- I can explain how my chocolate test is like lava cooling fast and magma cooling slowly.

FIELD NOTEBOOK

1. Draw three boxes. In the first, draw big crystals and label it "slow cooling: granite." In the second, draw tiny crystals and label it "fast cooling: basalt." In the third, draw smooth glass and label it "very fast cooling: obsidian."
2. Draw a piece of pumice floating in a glass of water. Label the holes "gas bubbles."
3. Draw Sir James Hall's two results side by side: "cooled fast: glass" and "cooled slowly: stony rock with crystals."

> **From history.** Sir James Hall kept experimenting. He sealed crushed chalk tightly inside iron gun barrels and heated it in a furnace. Out in the open air, hot chalk crumbles, but squeezed tight inside the barrel, it turned into a hard, crystal-filled stone much like marble. Hall's furnace tests helped begin a new kind of science: testing ideas about rocks with real experiments in the laboratory. You will meet marble again in Unit 4.

WORKED EXAMPLES

Example 1. Sam did the chocolate test. The bar graph shows his results: freezer plate 2 minutes, room plate 6 minutes, warm plate 12 minutes. How many more minutes did the warm plate take than the freezer plate? How many times as long did it take?

(Use the map or drawing "Sam's chocolate test." shown earlier in this lesson.)

1. Read each bar: freezer plate 2, room plate 6, warm plate 12.
2. How many more minutes: $12 - 2 = 10$ minutes.
3. How many times as long: $12 \div 2 = 6$. Check: $2 \times 6 = 12$.

Answer: The warm plate took 10 more minutes, which is 6 times as long as the freezer plate.

Example 2. Four igneous rocks are on the table. A has crystals about 5 millimeters long. B has grains too tiny to see. C is shiny black glass with no crystals at all. D is light and full of holes. Put A, B and C in order from fastest cooling to slowest cooling, and tell what made the holes in D.

1. No crystals means there was no time for crystals to grow, so C cooled fastest.
2. Tiny grains mean crystals started but had only a little time to grow, so B cooled next fastest.
3. Big crystals mean a long time to grow, so A cooled slowest.
4. Holes in lava rock are left by gas bubbles that were trapped as the lava hardened.

Answer: Fastest to slowest: C (obsidian), B (basalt), A (granite). D is pumice; its holes were made by gas bubbles.

PRACTICE

1. EASY Fill in the blanks: Slow cooling makes _____ crystals. Fast cooling makes _____ crystals.
2. EASY Which igneous rock is natural glass?
3. MEDIUM Chocolate on a cold plate hardened in 3 minutes. Chocolate on a warm plate hardened in 9 minutes. How many times as long did the warm plate take?
4. MEDIUM Match each candy to the igneous rock it is most like: rock candy, smooth fudge, clear hard candy. Rocks: basalt, granite, obsidian.
5. HARD A piece of pumice floats in a bowl of water, but a piece of basalt the same size sinks. Explain why.
6. CHALLENGE Jake put 1 teaspoon of melted chocolate on a cold plate and 3 teaspoons on a warm plate. The cold plate's chocolate hardened first. Can he say the cold plate was the reason? What should he change to make it a fair test?

COMMON MISTAKES

- Thinking big crystals mean the rock cooled fast. It is the opposite: big crystals need a long, slow cooling to grow.
- Thinking obsidian is not a real rock because it is glass. Obsidian is an igneous rock; it simply cooled too fast to grow crystals.
- Thinking the holes in pumice or lava rock were drilled or made by bugs. They were made by gas bubbles trapped as the lava hardened.

Make it a game · Fast or Slow Freeze. Everyone moves around the room as "melted rock." When the parent calls "Slow cooling!" everyone walks slowly together and joins hands in one big circle: one big crystal. When the parent calls "Fast cooling!" everyone freezes at once in tiny groups of one or two: many tiny crystals. When the parent calls "Very fast cooling!" everyone freezes instantly wherever they are, with no groups at all: glass! Then name the rock: granite, basalt or obsidian.

Scripture. "He hath made every thing beautiful in his time: also he hath set the world in their heart, so that no man can find out the work that God maketh from the beginning to the end." (Ecclesiastes 3:11, KJV)

Big, beautiful crystals take patience to grow. God works on His own timetable, and He makes every thing beautiful in its proper time, in rocks and in our lives.

Practice answers

1. Big; small (tiny).
2. Obsidian.
3. 9 ÷ 3 = 3 times as long.
4. Rock candy: granite (big crystals, slow). Smooth fudge: basalt (tiny crystals). Clear hard candy: obsidian (glass, no crystals).
5. Pumice is full of holes left by gas bubbles, so much of it is air. That makes it lighter than the same amount of water, so it floats. Basalt is solid, with no air spaces, so it is heavier than the same amount of water and sinks.
6. No. He changed two things at once (the plate temperature and the amount of chocolate), so he cannot tell which one made the difference. He should use the same amount, 1 teaspoon, on both plates and change only the plate temperature.

2.4 Devils Tower and the Giant's Causeway

OBJECTIVES

- Locate Devils Tower in Wyoming and the Giant's Causeway in Northern Ireland and tell one true fact about each.
- Explain how cooling, shrinking igneous rock cracks into tall columns with many sides.
- Count and graph the number of sides on a set of columns and find the most common shape.

Warm-up. Look at a honeycomb, a picture of one, or the cells on a soccer ball. How many sides does each shape have? Now think of a dried-up mud puddle you have seen. What shapes did the cracks make? Draw one quick sketch of each. Today you will see whole cliffs of stone that cracked into shapes like these.

Video. Coming soon. Devils Tower and the Giant's Causeway, how columnar basalt forms as lava cools and shrinks: search National Park Service (Devils Tower), USGS, National Trust (Giant's Causeway), Smithsonian, SciShow Kids and nature footage of basalt columns.

KEY TERMS

column
A tall, straight post of rock with flat sides, formed when a thick body of igneous rock cracked as it cooled.

joint
A crack that splits a rock into pieces without the pieces sliding past each other. The cracks between columns are joints.

contract
To shrink and take up less room. Hot rock contracts as it cools.

phonolite
A gray-green igneous rock with small crystals. Devils Tower is made of phonolite.

causeway
A raised road or path across water or wet ground.

CORE IDEAS

The story. On September 24, 1906, President Theodore Roosevelt made a great stone tower in northeastern Wyoming the very first national monument in the United States. Devils Tower rises 867 feet above the pine forests around its base, like a giant tree stump made of stone. Its sides are not smooth. They are made of tall, straight stone **columns** standing side by side, like a bundle of pencils. Long before the monument was named, Plains Indian

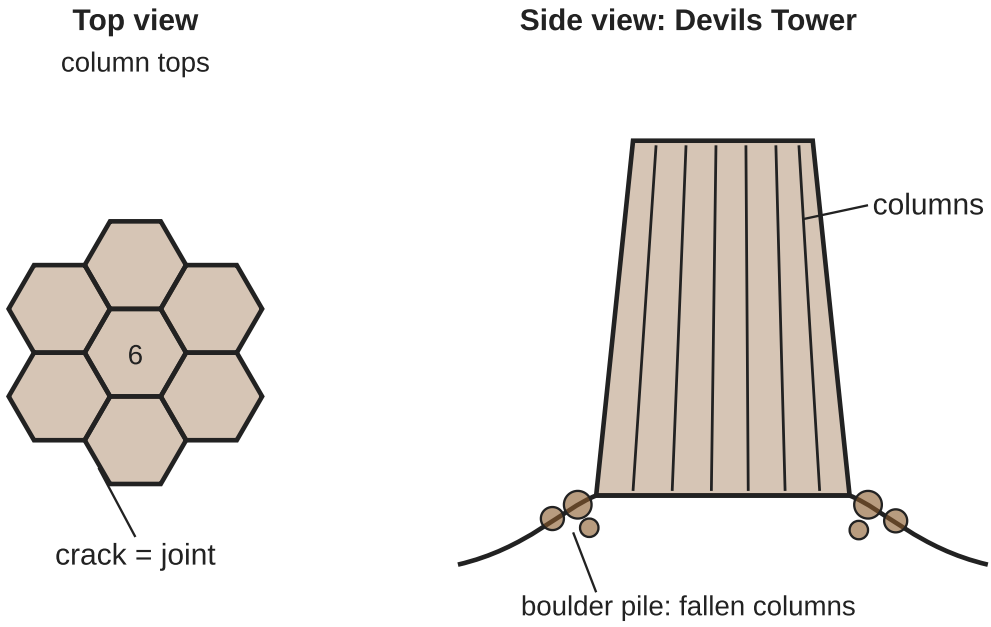
nations such as the Lakota and the Kiowa knew the tower well and told stories about it. Many of them call it Bear Lodge.

How they figured it out. Far across the Atlantic Ocean, on the north coast of Ireland, lies a place that looks as if someone built a stone road into the sea. It is called the Giant's Causeway. About 40,000 stone columns, most of them with six sides, fit together like the cells of a honeycomb. An old Irish legend says a giant named Finn McCool built it as a road to Scotland. In 1693, a report about the Causeway was sent to the Royal Society in London, and learned men began to wonder: were the columns giant crystals? Had people carved them? Careful study showed the truth. The Causeway is made of basalt, and its columns were made by cracks that formed as a thick sheet of lava cooled.

The big idea. Hot rock takes up a little more room than cold rock. As a thick layer of lava or magma cools, it **contracts**, or shrinks, just a tiny bit. Shrinking rock pulls on itself until it cracks. The cracks start where the rock is coolest, at its outside edges, and meet in a pattern of shapes, mostly with five, six or seven sides. As the cooling moves deeper, the cracks grow deeper too, until the rock is split into long columns. The cracks are called **joints**. You can see the same pattern in a dried mud puddle. The Giant's Causeway is basalt. Devils Tower is a different igneous rock called **phonolite** (FOE-nuh-lite). Both cracked into columns the same way.

In the world today. Climbers from around the world climb the cracks between the columns of Devils Tower, and broken columns that have fallen from its sides lie in a great pile of boulders around its base. At the Giant's Causeway, visitors hop from column to column along the shore. Across the sea in Scotland, the little island of Staffa has the same kind of basalt columns, and its Fingal's Cave so stirred the composer Felix Mendelssohn, who visited in 1829, that he wrote music about it.

God's handiwork. No stonemason cut these columns. God made melted rock so that, as it cools, it cracks into orderly shapes as neat as a honeycomb. Devils Tower stands tall because the softer rock that once surrounded it was worn away. Many creation geologists think the rushing waters of the Flood, draining off the land, carved much of that rock away. The tower is a good picture of Psalm 18:2, which calls the Lord "my rock" and "my high tower."



Cooling rock shrinks and cracks into columns. Seen from above, the column tops fit together like a honeycomb.

PICTURE STUDY

A View of the Giant's Causeway: East Prospect (engraving after Susanna Drury), Engraved after a painting by Susanna Drury, printed 1768, after a painting of about 1739 · Engraving on paper · This print: Linda Hall Library, Kansas City, Missouri. Drury's original painting: Ulster Museum, Belfast, Northern Ireland

Susanna Drury was an Irish artist from Dublin. Around 1739 she traveled to the north coast of Ireland and painted two careful views of the Giant's Causeway, one looking east and one looking west. In 1740 her paintings won a prize from the Dublin Society.

Soon afterward, engravers copied her paintings so that prints could be sold, and the picture shown here is one of those engraved prints. The prints traveled all over Europe, and for the first time many scientists could study the columns without making the long journey to see them. Drury painted the rocks so faithfully that her pictures helped people argue about how the columns were formed.

Look closely

- Find the columns. Do they stand straight up, lean, or both?
- Look at the cliffs. Can you see columns in them too, stacked in layers?
- Find the people. How do they help you tell how big the columns are?
- Look at where the columns meet the sea. Does the causeway look like a road?

Talk about it

1. Why would a careful picture like this be useful to a scientist far away?

2. If you could stand on the Causeway, how would you test whether the columns were carved by people or cracked by cooling?
3. Why do you think the old legend said a giant built it?

> **Safety first.** A desk lamp bulb can get very hot. Keep the lamp at least 12 inches from the cup, never touch the bulb, keep paper and cloth away from it, and turn it off whenever no grown-up is home.

EXPERIMENT: COLUMNS IN A CUP

Scientists have found that a paste of cornstarch and water, dried slowly from the top, shrinks and cracks into tiny columns like those at the Giant's Causeway. Drying works like cooling: the paste shrinks as it loses water, the way lava shrinks as it loses heat. You will test whether the thickness of the layer changes the size of the pieces.

You will need

- 1 cup of cornstarch and 1 cup of water, mixed well
- A shallow jar lid and a clear plastic cup
- A desk lamp
- A ruler with inches and centimeters
- A magnifying glass and a butter knife
- Lab notebook and pencil

Steps

1. **Question:** Does a thick layer crack into bigger pieces or smaller pieces than a thin layer? Write your **prediction**.
2. Stir the cornstarch and water into a smooth paste. Pour a thin layer, about 1/4 inch deep, into the jar lid. Pour a thick layer, about 2 inches deep, into the plastic cup.
3. **What we change:** only the thickness of the layer. **What we keep the same:** the same paste, the same lamp, the same distance from the lamp (about 12 inches) and the same room.
4. Set both under the lamp. Each day, look at the tops with the magnifying glass and draw the cracks you see.
5. **What we measure:** When the tops are cracked all over (after several days), count how many pieces you see across the top of each one, and count the sides on 10 pieces.
6. **Record:** Make a table with columns for Day, Thin layer and Thick layer. Write your counts and make a tally of how many pieces had 4, 5, 6 or 7 sides.
7. When the thick layer is completely dry (about a week), ask a grown-up to cut the cup away. Gently break the dried cornstarch apart with the butter knife. Look at the side. Can you see tiny columns? Measure the longest one.

Tips

- Stir the paste again right before pouring; cornstarch settles quickly.

- If you have no lamp, a sunny windowsill works, but the drying takes longer.
- Your columns will be small, perhaps the width of a pencil lead. Use the magnifying glass.

Check your work

- I can explain how my drying cornstarch is like cooling lava.
- I can name what I changed, what I kept the same and what I measured.
- I can tell which shape was most common in my tally.

FIELD NOTEBOOK

1. Draw Devils Tower standing over the pine trees, with lines for its columns and a pile of fallen boulders at its base. Label it “phonolite.”
2. Draw the tops of seven columns fitted together like a honeycomb. Count and write the number of sides on each one.
3. Draw a map of the Atlantic Ocean. Put a star on Wyoming in the United States and a star on the north coast of Ireland. Label Devils Tower and the Giant’s Causeway.

> **From history.** On July 4, 1893, two local ranchers, William Rogers and Willard Ripley, made the first known climb to the top of Devils Tower. They pounded wooden pegs into a long crack between two columns, tied them together into a ladder and climbed up while a large crowd watched from below. At the top they raised an American flag. Some of their old pegs can still be seen on the side of the tower today.

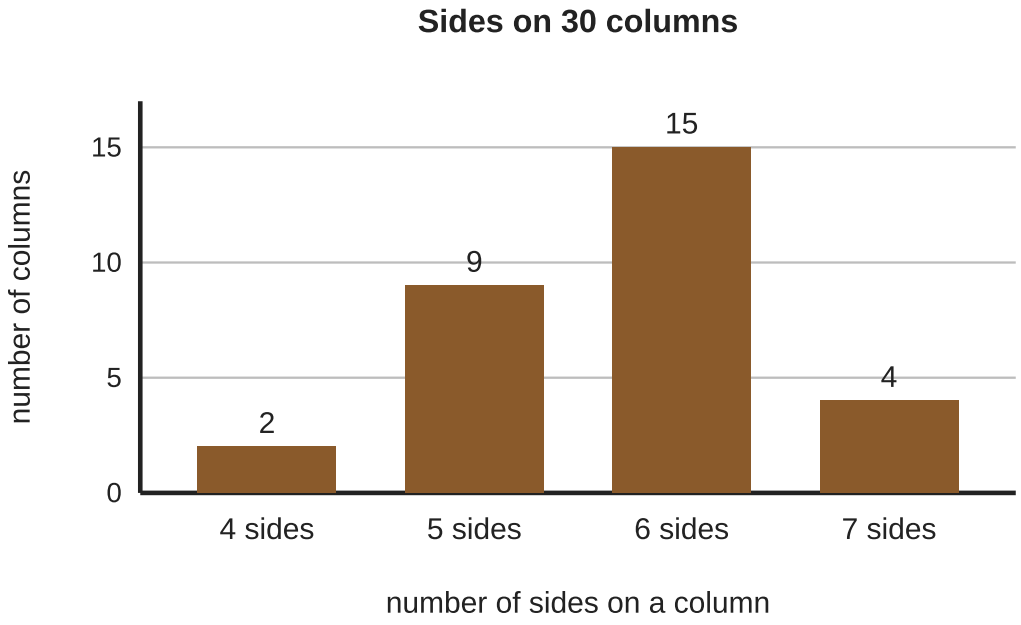
WORKED EXAMPLES

Example 1. Devils Tower rises 867 feet above its base. An American football field is 300 feet long from one goal line to the other. About how many football fields, stood on end, would it take to reach the top of the tower?

1. Count up by 300s: 1 field is 300 feet, 2 fields are 600 feet, 3 fields are 900 feet.
2. 867 is more than 600 but less than 900.
3. 867 is much closer to 900 (only 33 feet short), so it is almost 3 fields.

Answer: Almost 3 football fields standing on end. (867 feet is about 265 meters.)

Example 2. Ella studied a photograph of the Giant's Causeway and counted the sides of 30 columns. Her bar graph shows: 4 sides: 2 columns; 5 sides: 9 columns; 6 sides: 15 columns; 7 sides: 4 columns. Check that she counted 30 columns. Which shape was most common? What part of the columns had that shape?



Ella's count of column sides at the Giant's Causeway.

1. Add the bars: 2 + 9 + 15 + 4. First 2 + 9 = 11. Then 11 + 15 = 26. Then 26 + 4 = 30. She counted 30 columns.
2. The tallest bar is 6 sides, with 15 columns.
3. Half of 30 is 15. So exactly half of the columns had six sides.

Answer: Yes, 30 columns. Six-sided columns were most common: 15 out of 30, which is exactly half.

PRACTICE

1. EASY What igneous rock is the Giant's Causeway made of?
2. EASY Which president made Devils Tower a national monument, and what was special about it?
3. MEDIUM A visitor hops across 6 columns in a straight line. Each column is about 1 foot (30 centimeters) across. About how far did the visitor travel, in feet and in centimeters?
4. MEDIUM Explain in two sentences how a thick layer of lava turns into columns.
5. HARD A visitor counted the sides of 4 columns: 6, 6, 5 and 7. How many sides is that in all? If all 4 columns had been six-sided, how many sides would there be? Are the two

totals the same?

6. CHALLENGE In the cornstarch test, the thin layer in the lid cracked into 40 small pieces. The thick layer in the cup cracked into 12 bigger pieces across a top of the same size. What pattern do you see? Name one thing that had to stay the same to make this a fair test.

COMMON MISTAKES

- Thinking the columns were carved by people (or built by a giant). They formed by themselves when cooling rock shrank and cracked.
- Thinking each column is one giant crystal. Each column is made of many tiny crystals; the flat sides are cracks, not crystal faces.
- Thinking Devils Tower is a volcano with a crater on top. Its top is flat, rocky and grassy; the tower is a mass of igneous rock that was uncovered when the softer rock around it was worn away.

Make it a game · Causeway Hop. With chalk outdoors or tape indoors, draw a path of about ten six-sided "columns" that leads from the "shore" to the "sea." To hop to the next column, answer a question from the parent: "What rock is the Causeway?" "Why does cooling rock crack?" "Who climbed Devils Tower first?" "How many sides does a hexagon have?" A wrong answer means you stay put for a turn. Reach the sea to win, then tell the legend of Finn McCool and the true story of how the columns really formed.

Scripture. "The LORD is my rock, and my fortress, and my deliverer; my God, my strength, in whom I will trust; my buckler, and the horn of my salvation, and my high tower." (Psalm 18:2, KJV)

David had hidden from his enemies among rocks and high places. He knew that even the strongest tower of stone is only a picture of the true safety we have in the Lord.

Practice answers

1. Basalt.
2. Theodore Roosevelt, in 1906. It was the first national monument in the United States.
3. 6 × 1 = 6 feet, and 6 × 30 = 180 centimeters.
4. As the lava cools, it shrinks (contracts) and pulls on itself until it cracks. The cracks meet in five-, six- and seven-sided shapes and grow deeper as the rock cools, splitting it into long columns.
5. 6 + 6 + 5 + 7 = 24 sides. Four six-sided columns: 4 × 6 = 24 sides. Yes, both totals are 24.
6. The thicker layer cracked into fewer, bigger pieces; the thinner layer cracked into more, smaller pieces. Things to keep the same: the same paste, the same lamp and distance, the same room, the same size of top (any one).

Unit 2 review

Answer each question. Use complete sentences for explanations and show your work for any math. Each question is worth 4 points. The quiz is worth 40 points.

1. (4 pts) What is igneous rock? What does the word igneous come from?
2. (4 pts) Label each one magma or lava: (a) melted rock in a pool under a volcano; (b) a glowing river of melted rock running down a hill.
3. (4 pts) James Hutton found pink granite filling cracks (veins) in darker rock at Glen Tilt. What did this show him about granite, and why?
4. (4 pts) Identify the rock: light-colored and speckled, with pink, gray and black crystals big enough to see. Name the three minerals that make the pink, gray and black specks.
5. (4 pts) Identify the rock: dark gray or black, with crystals too small to see. Name one place where this rock is found.
6. (4 pts) Each face on Mount Rushmore is about 60 feet tall. A grown man is about 6 feet tall. How many men, standing on each other’s shoulders, would it take to reach the height of one face?
7. (4 pts) Granite has big crystals and basalt has tiny ones. Explain why.
8. (4 pts) Identify each rock: (a) shiny black natural glass with very sharp edges; (b) a light, frothy rock full of holes that floats on water. What made the holes in rock (b)?
9. (4 pts) In a chocolate test, chocolate on a freezer plate hardened in 2 minutes and chocolate on a warm plate hardened in 10 minutes. How many more minutes did the warm plate take? Which plate is more like lava pouring out into cold air, and which is more like magma cooling deep underground?
10. (4 pts) Devils Tower and the Giant’s Causeway are both made of tall stone columns. Explain how the columns formed, and tell one way the two places are different.

Unit project: my igneous rock museum

Build a small museum display about igneous rocks in an egg carton, shoebox lid or tray. Include at least four igneous rocks if you can collect or buy them (granite, basalt, obsidian, pumice), or careful colored drawings of any you do not have. Give each one a label card with its name, its color, its crystal size (big, tiny or none), where it cooled (underground or on the surface) and whether it cooled slowly, fast or very fast.

Add your chocolate cooling bar graph, a drawing of a volcano with magma and lava labeled, and a dried cornstarch column or a drawing of the Giant’s Causeway. Finish with a short paragraph, read aloud to your family, that explains how one melted rock can become granite, basalt or obsidian depending on how fast it cools.

- **Accuracy**: Each rock is named correctly, and its crystal size, cooling place and cooling speed are right.
- **Records**: The bar graph and experiment notes are complete, labeled and show what was changed, kept the same and measured.

- **Explanation**: The paragraph clearly explains magma and lava and how cooling speed changes crystal size.
- **Care**: The display is neat, the labels are easy to read and the drawings are careful and colored.

Answer key

1. Igneous rock is rock that forms when melted rock (magma or lava) cools and hardens. The word comes from *ignis*, the Latin word for fire.
2. (a) magma, because it is underground; (b) lava, because it is on the surface.
3. It showed that granite had once been melted. Only a liquid could flow into the cracks and fill them, so the granite must have been hot magma that later cooled and hardened.
4. Granite. Pink: feldspar. Gray and glassy: quartz. Black and shiny: mica.
5. Basalt. It is found in Hawaii, under the ocean floor, at the Giant’s Causeway, or on the dark patches of the moon (any one).
6. 60 ÷ 6 = 10 men.
7. Granite cooled slowly deep underground, so its crystals had a long time to grow big. Basalt cooled quickly from lava at the surface, so its crystals had little time to grow and stayed tiny.
8. (a) obsidian; (b) pumice. The holes were made by gas bubbles trapped as the lava hardened.
9. 10 − 2 = 8 more minutes. The freezer plate is like lava cooling fast at the surface; the warm plate is like magma cooling slowly underground.
10. As a thick body of melted rock cooled, it shrank (contracted) and cracked. The cracks met in five-, six- and seven-sided shapes and grew deeper as the rock cooled, splitting it into columns. Differences (any one): Devils Tower is in Wyoming and the Causeway is in Northern Ireland; Devils Tower is phonolite and the Causeway is basalt; Devils Tower is a tall tower and the Causeway steps down into the sea.

UNIT 3

Sedimentary Rocks

Sedimentary rocks are the rocks of layers. They are made from **sediment**: sand, mud, shells and even plants that water carries along and then drops, one layer on top of another. Buried, squeezed and glued together by minerals, those loose bits become solid rock. Most of the rock you see in cliffs, canyons and road cuts is sedimentary, and nearly all fossils are found in it.

In this unit you will shake up a jar of gravel, sand and soil and watch it settle into layers, just as Nicolas Steno saw layers in the hills of Tuscany in 1669. You will look through Robert Hooke's microscope at a limestone made of tiny grains, test rocks for calcite with vinegar and make your own sandstone. You will follow Judge Jesse Fell as he lights hard coal in an open iron grate in his home, and squeeze a pile of wet leaves to see how plants shrink on their way to becoming coal. Last, you will learn to read the giant folded layers of the Sideling Hill road cut in Maryland and Thomas Moran's painted cliffs of Wyoming.

In every lesson you will ask the same questions a field geologist asks: **What is this rock made of? How was it laid down? Which layer came first?** You will also learn to tell the difference between what we can see and measure in the rocks and the stories people tell about how long they took.

BEFORE YOU BEGIN

- Can measure with a ruler to the nearest inch and read the centimeter side
- Can add and subtract numbers to 100
- Knows that rocks are made of minerals (Unit 1)
- Knows that igneous rocks form from melted rock (Unit 2)

MASTERY CHECKLIST

- I can explain how moving water carries sediment and lays it down in layers, biggest pieces first.
- I can use Steno's rule to tell which layer in a stack was laid down first.
- I can identify sandstone, shale and limestone, and use the vinegar fizz test to find calcite.
- I can explain how compaction and cementation turn sediment into rock.
- I can explain that coal is made from buried plants and put peat, lignite, bituminous coal and anthracite in order.
- I can draw and read a cross-section of a road cut, including bent layers and cracks.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free. Browse the museum's online geology and mineral collections for clear

photographs of sandstone, shale, limestone and coal to compare with your own samples.

- **U.S. Geological Survey (USGS)** (https://www.usgs.gov/): Free. Search the site for “sedimentary rocks” and “coal” for photographs and short articles, and for Mount St. Helens to see pictures of the layers laid down after the 1980 eruption. Best read with a parent.
- **Institute for Creation Research** (https://www.icr.org/): Free articles. Search for “Mount St. Helens,” “coal” and “rock layers” to read how creation geologists understand the layers you study in this unit. A parent may choose the articles.

3.1 Layers in a Jar ★

OBJECTIVES

- Explain what sediment is and how moving water carries it and then lets it settle into layers.
- Predict and observe the order in which gravel, sand, silt and clay settle in water, and measure each layer in inches and centimeters.
- Tell how Nicolas Steno learned to read rock layers and use his rule that the bottom layer was laid down first.

Warm-up. Fill a clear glass with water. Drop in one spoonful of garden dirt and stir it hard. Now watch for five quiet minutes without touching the glass. What sinks first? What is still floating or swirling at the end? Tell a parent three things you saw.

Video. Coming soon. Sediment settling in a jar and how sedimentary rock layers form; search USGS, Smithsonian, SciShow Kids, Homeschool Pop (Alternate), Science Max and classroom soil-shake-test demonstrations.

KEY TERMS

sediment
Loose bits of rock, sand, mud, shells or plants that can be carried by water or wind and then settle down.

deposit
To drop and leave sediment in a new place. Water deposits sediment when it slows down.

stratum (plural strata)
One layer of rock or sediment. Many layers together are called strata.

superposition
Steno’s rule: in a stack of layers that has not been turned over, the bottom layer was laid down first and the top layer last.

sedimentary rock
Rock made when layers of sediment are buried, pressed together and glued by minerals.

CORE IDEAS

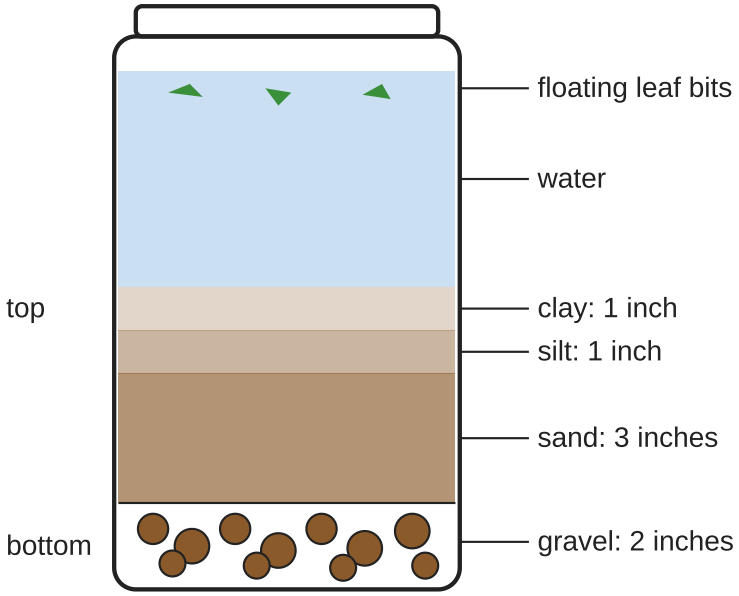
The story. In the year 1669, in the city of Florence, Italy, a Danish scientist named Nicolas Steno published a small book about rocks. Steno had walked the hills of Tuscany and looked closely at the layers of rock in cliffs, quarries and riverbanks. He noticed that many layers were flat, like the pages of a closed book. Some of them held seashells, far away from the sea. Steno asked a simple question: how did these layers get here? His answer was that each layer had once been loose sand or mud that settled out of water, one layer on top of another.

How they figured it out. Steno wrote down rules that geologists still use today. First, when sand and mud settle out of water, they spread out **flat**, because gravity pulls them down evenly. Second, in a stack of layers, **the bottom layer was laid down first** and each layer above it came later. This is called **superposition**. You can see it in a pile of mail on a table: the letter on the bottom was put there first. Third, a layer keeps spreading sideways until it thins out or bumps into something. So if you find a layer that is tilted or broken, something must have happened to it *after* it was laid down.

The big idea. Bits of broken rock, sand, mud, shells and plants are called **sediment**. Fast water can pick up sediment and carry it along. When the water slows down, it **deposits** the sediment. The biggest, heaviest pieces drop first: pebbles and gravel, then sand, then fine silt that feels like flour. The tiny clay bits drop last, and they can stay floating for many hours. Each time sediment settles, it makes a layer. One layer is a **stratum**, and many layers are **strata**. When layers of sediment are buried, pressed tight and glued together by minerals, they become **sedimentary rock**.

Try it and see. You can watch this happen in a jar. Put in gravel, sand, garden soil and water, close the lid tight and shake. In a few seconds the gravel lands on the bottom with a clatter. The sand piles on top of it. The water stays cloudy with silt and clay for a long time, and bits of leaves and twigs float to the top. By the next day you have a neat little stack of layers, sorted by size, and you made it with one shake. That teaches us something important: layers do not always need a long time. Fast-moving water carrying lots of sediment can lay down several layers at once.

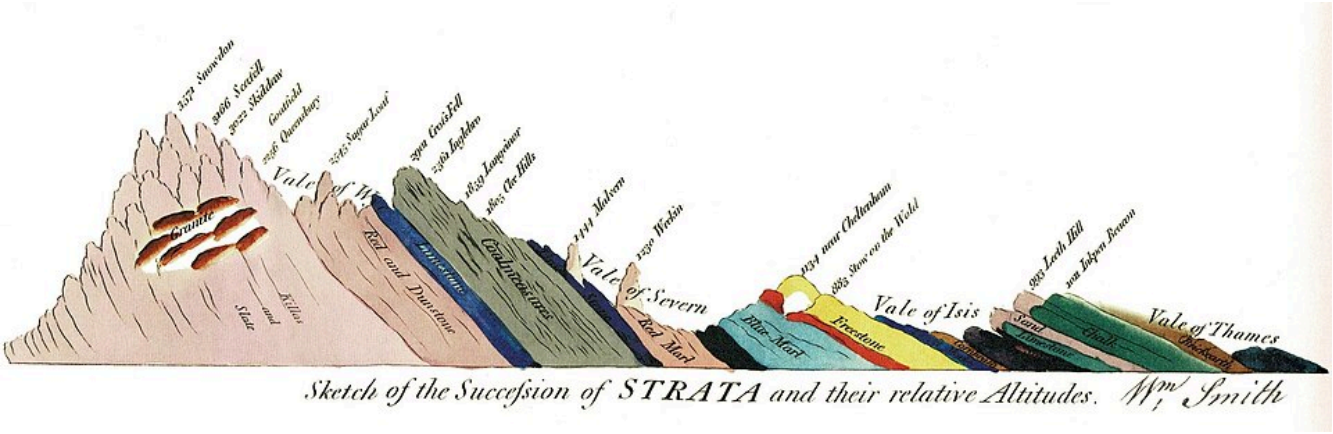
God’s handiwork. Steno was a careful scientist and a devoted Christian. He believed that the God who gave us the Bible also made the rocks, so both would tell the truth when they were read rightly. He thought that some of the layers he studied in Tuscany had been laid down by the waters of Noah’s Flood. When you read the layers in your jar or in a cliff, you are learning to read pages that God wrote into the earth itself.



Bottom layer settled first; top layer settled last.

After one shake and a day of waiting, the sediment sorts itself by size: heaviest on the bottom, finest on top.

PICTURE STUDY



Sketch of the Succession of Strata and Their Relative Altitudes, William Smith, 1815 · Engraving colored by hand, printed with Smith's great geological map · Printed in London on Smith's map of the strata of England and Wales; copies are kept in libraries and geological collections

William Smith was an English surveyor who spent years digging canals and walking through quarries and mines. Like Steno before him, he learned to read rock layers in order, bottom to top. In 1815 he published a giant colored map of the rocks of England and Wales, and along its edge he printed this long, narrow picture: a slice through the land showing which layer lies on top of which.

This kind of drawing is called a cross-section. It is just what you will draw of your jar: the layers stacked in order, each with its own color and name. Geologists today still draw cross-sections in almost the same way.

Look closely

- Find the bands of color. Does each layer have its own color?
- Find the layer on the very bottom. By Steno's rule, was it laid down first or last?
- Are the layers flat, or do they tilt? What does that tell you happened after they were laid down?
- Read a few of the layer names. Do you see any rocks you know, such as chalk, clay or sand?

Talk about it

1. How is Smith's picture like the layers in your jar? How is it different?
2. If you drew a cross-section of your jar after one day, what colors and names would you give each layer?

> **Safety first.** Use a plastic jar if you can, because glass can break when it is shaken or dropped. Screw the lid on tight before shaking. Wipe up spilled water right away so no one slips, and wash your hands after handling soil.

EXPERIMENT: THE SHAKE-AND-SETTLE JAR

You will make layers of sediment in a jar, just as moving water makes them in a river or a flood. Like a real scientist, you will predict, watch, measure and record.

You will need

- A clear jar with a tight lid, about 1 quart (a large peanut-butter or pickle jar works well)
- About ½ cup of small gravel or aquarium pebbles
- About ½ cup of sand
- About ½ cup of garden soil (not potting soil)
- A few dry leaves or twigs broken into small bits
- Water
- A ruler with inches and centimeters
- Lab notebook, pencil and colored pencils
- A clock or timer

Steps

1. **Question.** Write at the top of your page: In what order will gravel, sand and soil settle out of water, and how thick will each layer be?
2. **Prediction.** Draw an empty jar and color in the layers you think you will see. Write which you think will land first.
3. Put the gravel, sand, soil and leaf bits into the jar. Fill it with water until it is about 1 inch from the top. Screw the lid on tight.
4. Shake the jar hard for 30 seconds, then set it on a flat table where no one will bump it.

5. Watch closely for the first minute. Write down what lands first, second and third.
6. **What we change and what we measure.** The only thing we change is how long we wait. Measure the thickness of each layer with your ruler after 1 minute, after 1 hour and after 1 day. Measure in inches and in centimeters.
7. **What we keep the same.** Do not move, tilt or shake the jar while you are waiting, and measure from the same side every time.
8. Record your measurements in a table with columns for Layer, 1 minute, 1 hour and 1 day. Also write whether the water is cloudy or clear each time.
9. After one day, slowly pour in one more spoonful of sand and one of soil without shaking. Watch a new, thinner set of layers form on top of the old ones. Which set is older?
10. Draw and color your finished jar and label every layer.

Tips

- Hold the ruler flat against the outside of the jar and read where each layer starts and stops.
- Clay is so fine that it may only look like a thin, smooth skin on top of the silt. That still counts as a layer.
- If your soil is very sandy, you may see little silt and clay. Try soil from a different part of the yard and compare.

Check your work

- I made a prediction before I shook the jar.
- I measured each layer at three times and recorded the numbers in inches and centimeters.
- I can explain why the gravel landed first and the clay last.
- I can point to the oldest layer in my jar and explain how I know.

FIELD NOTEBOOK

1. Draw your jar at 1 minute, 1 hour and 1 day, side by side. Label the gravel, sand, silt, clay and floating bits in each picture.
2. Find layers somewhere outside or at home (a stack of pancakes, a layered dessert, a pile of folded towels or a cliff). Draw them and write which layer was put down first.
3. Write Steno’s rule of superposition in your own words and draw a small picture that shows it.

> **From history.** Nicolas Steno was born in Copenhagen, Denmark, and his Danish name was Niels Stensen. Before he studied rocks he studied the human body, and a small tube that carries saliva into your mouth is still called Stensen’s duct after him. Later Steno gave up science to serve the church. He became a priest and then a bishop, and he lived so simply that he gave away most of what he had to the poor.

WORKED EXAMPLES

Example 1. After one day, a jar shows these layers from the bottom up: gravel 2 inches, sand 3 inches, silt 1 inch and clay 1 inch. How thick is all the sediment together? Which layer is the thickest?

(Use the map or drawing “Read each layer’s thickness from the labels, then add.” shown earlier in this lesson.)

1. Add the four layers: 2 + 3 + 1 + 1.
2. 2 + 3 = 5. Then 5 + 1 = 6. Then 6 + 1 = 7.
3. Compare the layers: 3 inches is more than 2 inches and more than 1 inch, so the sand layer is the thickest.

Answer: The sediment is 7 inches thick in all. The sand layer, at 3 inches, is the thickest.

Example 2. Scientists all over the world measure in centimeters. One inch is about 2½ centimeters. About how many centimeters thick is the 2-inch gravel layer? About how many centimeters is the 3-inch sand layer?

1. Each inch is about 2½ cm, so 2 inches is 2½ + 2½.
2. 2½ + 2½ = 5. The gravel layer is about 5 cm.
3. For the sand: 2½ + 2½ + 2½. Two of them make 5, and one more 2½ makes 7½.
4. Check with your ruler: find the 3-inch mark and look at the centimeter side. It sits between 7 and 8 cm.

Answer: The gravel layer is about 5 centimeters thick, and the sand layer is about 7½ centimeters thick.

PRACTICE

1. EASY What is sediment? Name three things that can be sediment.
2. EASY You shake a jar of water with gravel, sand and clay. Put them in the order they settle, first to last.
3. MEDIUM Read this table from a jar experiment. Layer: gravel, 1 inch. Layer: sand, 4 inches. Layer: silt, 2 inches. How thick is the sediment in all, and which layer is the thinnest?
4. MEDIUM A sand layer is 4 inches thick. One inch is about 2½ centimeters. About how many centimeters thick is the sand layer?
5. HARD A cliff has three flat layers: red sandstone on the bottom, gray shale in the middle and white limestone on top. Which layer was laid down first? Explain using Steno’s rule.

6. CHALLENGE You want to find out whether muddy water clears faster in a jar with a little soil or a jar with a lot of soil. Plan the experiment: What will you change? What will you keep the same? What will you measure?

COMMON MISTAKES

- Thinking the top layer is the oldest. In layers that have not been turned over, the bottom layer was laid down first, so it is the oldest.
- Thinking every layer must take a very long time to form. The jar made several neat layers in minutes; fast water carrying lots of sediment can lay down layers quickly.
- Thinking sediment is only sand. Pebbles, mud, shells and bits of plants are all sediment too.

Make it a game · Sink Race. Fill a tall clear glass or vase with water. Line up five small things: a pebble, a dry bean, a pinch of rice, a pinch of flour and a small piece of leaf. Each player writes down the order they think the things will reach the bottom, first to last. Drop them in all at once and watch. Score one point for each thing you placed in the right spot. Then play again with new objects, such as a button, a paper clip or a pinch of sand.

Scripture. “And God said, Let the waters under the heaven be gathered together unto one place, and let the dry land appear: and it was so.” (Genesis 1:9, KJV)

From the very beginning, God set the waters and the land in their places. When water moves and then grows still, it sorts the sediment it carries into layers, just as you saw in your jar.

Practice answers

1. Sediment is loose bits of material that water or wind can carry and then drop. Examples: gravel, sand, mud (silt and clay), shells, and bits of leaves or wood.
2. Gravel first, then sand, then clay last. The biggest, heaviest pieces settle first.
3. 1 + 4 + 2 = 7 inches in all. The gravel layer (1 inch) is the thinnest.
4. 2½ + 2½ + 2½ + 2½ = 10. The layer is about 10 centimeters thick.
5. The red sandstone on the bottom was laid down first. Steno’s rule of superposition says that in layers that have not been turned over, the bottom layer was deposited first and each layer above it came later.
6. Change: the amount of soil (for example, 2 spoonfuls in one jar and 8 in the other). Keep the same: the size of the jars, the amount of water, the kind of soil, and how long and hard you shake. Measure: how long it takes until you can see clearly through each jar (or how cloudy each jar is after 1 hour and after 1 day).

3.2 Sandstone, Shale and Limestone ★

OBJECTIVES

- Identify sandstone, shale and limestone by grain size, feel, layering and the vinegar fizz test.
- Explain how loose sediment becomes rock through compaction and cementation.
- Tell how Robert Hooke looked at a limestone through his microscope and describe what he saw.

Warm-up. Put three small piles on a plate: a spoonful of sand, a spoonful of flour and a crushed eggshell. Rub a pinch of each between your finger and thumb. Which feels gritty? Which feels smooth and silky? Which has sharp little flakes? Now look at each one with a magnifying glass and describe what you see.

Video. Coming soon. Identifying sandstone, shale and limestone and the vinegar fizz test for calcite; search USGS, Smithsonian National Museum of Natural History, SciShow Kids, Homeschool Pop (Alternate) and rock-collecting channels for kids.

KEY TERMS

sandstone
A sedimentary rock made of sand grains glued together. You can see and feel the grains, and it feels like sandpaper.

shale
A sedimentary rock made of hardened mud (silt and clay). Its grains are too small to see, and it splits into thin, flat sheets.

limestone
A sedimentary rock made mostly of the mineral calcite, often from shells and the skeletons of sea creatures. It fizzes in acid such as vinegar.

compaction
The squeezing of buried sediment by the weight of the layers above it, which presses the grains close together and pushes out water.

cementation
The gluing of sediment grains together by minerals that come out of the water between the grains and harden.

CORE IDEAS

The story. In the year 1665, an English scientist named Robert Hooke published a famous book called *Micrographia*, which means “small drawings.” Hooke had built a fine microscope, and he looked through it at everything he could find: a flea, a fly’s eye, the point of a needle and a thin slice of cork. One day he looked at a chip of Kettering stone, a pale

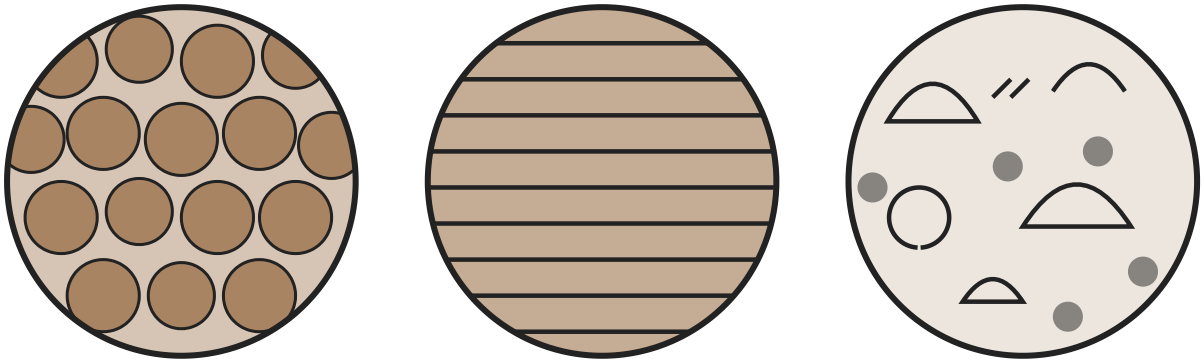
building stone from the town of Kettering in England. To his surprise, the stone was made of tiny round balls packed together, with little holes between them. Hooke said the little balls looked like the eggs of a fish. Today we call this kind of rock *oolite*, from Greek words that mean “egg stone.” It is a kind of **limestone**.

How they figured it out. Hooke saw what geologists still look for: what a rock is made of. Sedimentary rocks are sorted by their grains. If you can see the grains and the rock feels like sandpaper, it is **sandstone**, made of sand. If the grains are too small to see, the rock feels smooth, and it splits into thin, flat sheets, it is **shale**, made of hardened mud. If the rock is made of the mineral calcite, it is **limestone**. Many limestones are full of broken shells, corals and tiny sea creatures. Geologists test for calcite with a drop of acid. Calcite fizzes and makes bubbles of gas. At home, vinegar works too, though the bubbles may be small and slow.

The big idea. How does a pile of loose sand turn into solid rock? It takes two steps. First comes **compaction**. As more and more layers pile on top, their weight squeezes the sediment below. The grains are pressed tight together, and water is pushed out. Mud gets squeezed so much that its tiny flat flakes lie down in thin sheets, which is why shale splits so easily. Second comes **cementation**. Water moving between the grains carries minerals dissolved in it, like sugar dissolved in tea. Those minerals harden in the spaces and glue the grains together. Calcite, quartz and iron minerals are nature’s glues. Iron cement often colors sandstone red, orange or yellow.

In the world today. People have built with these three rocks for thousands of years. The Great Pyramid of Egypt is made mostly of limestone blocks. The Empire State Building in New York City is covered with limestone from Indiana. Many old houses in New York are called brownstones because their fronts are made of brown sandstone. Shale is ground up and baked to make bricks. Limestone is crushed to make cement, and farmers spread ground limestone on fields to help their crops grow.

God’s handiwork. Loose sand runs through your fingers, but sand that is pressed and cemented becomes a rock strong enough to build on. Jesus told of a wise man who built his house on a rock and a foolish man who built on the sand. When the storm came, the house on the rock stood firm. God made the earth so that even tiny grains, pressed and joined together, can become something strong and lasting.



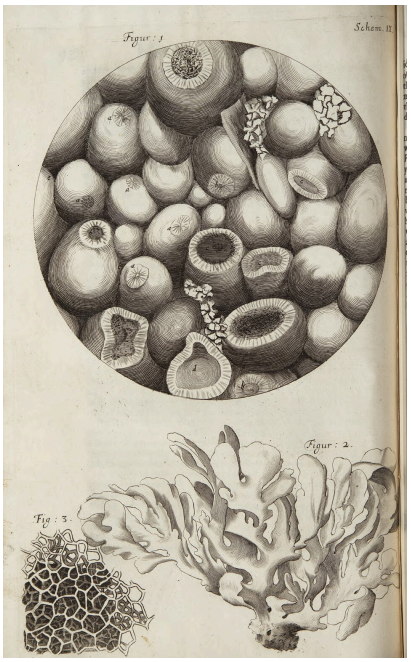
Sandstone
sand grains you can see and feel

Shale
hardened mud in thin, flat sheets

Limestone
calcite and shell bits; fizzes

What you would see with a strong magnifying glass: sand grains in sandstone, thin flat sheets in shale, and shell bits in limestone.

PICTURE STUDY



Kettering-stone, from Micrographia, Robert Hooke, 1665 · Engraving printed in a book · Published in London for the Royal Society; copies are kept in many libraries, and the whole book can be read free online

Robert Hooke made most of the drawings in *Micrographia* himself, by looking through his microscope again and again and drawing a little at a time. His picture of Kettering-stone shows a tiny chip of rock made huge, so that each grain looks like a ball. Hooke used the

picture to explain something he had noticed: water and even air could pass through this stone, because there were little open spaces between the grains.

Hooke was one of the first people to show the hidden world inside a rock. When you use a magnifying glass on a rock, you are doing just what he did.

Look closely

- Find the drawing of Kettering-stone on the page, then find its round grains. Are they all the same size, or are some bigger than others?
- Find the dark spaces between the grains. What could fill those spaces in the ground: water, air or mineral glue?
- Look at how the grains touch each other. How is this like a jar full of marbles or a bowl of tapioca pudding?
- Compare the picture with a piece of sandpaper or a rock seen through your magnifying glass. What is the same? What is different?

Talk about it

1. Why do you think Hooke said the grains looked like fish eggs?
2. If water can soak through a rock, what might the water leave behind between the grains as it dries? How does that help turn sediment into rock?

> **Safety first.** Vinegar stings if it gets in your eyes, so keep it away from your face and wash your hands after the fizz test. Do not taste any of the samples. Work on a tray and wipe up spills.

EXPERIMENT: ROCK DETECTIVE LAB: FIZZ TEST AND HOMEMADE SANDSTONE

In Part A you will test samples with vinegar, the way geologists test for calcite. In Part B you will try to turn loose sand into rock by adding a cement, and you will compare it with sand that has no cement.

You will need

- White vinegar in a small cup and a medicine dropper or spoon
- Samples to test: a seashell, a piece of eggshell, a small piece of limestone if you have one, a spoonful of sand, a piece of sandstone or shale if you have them, and an ordinary pebble
- A magnifying glass
- Two paper cups
- 1 cup of sand
- White school glue and water
- A spoon, a ruler and a tray
- Lab notebook and pencil

Steps

1. **Part A question.** Which samples have calcite in them? Write your prediction for each sample: fizz or no fizz.
2. Look at each sample with the magnifying glass. Write whether you can see grains, and whether it feels gritty or smooth.
3. Put each sample on the tray. Drip a few drops of vinegar on each one. Put your ear close (but not your eyes) and listen, and watch for tiny bubbles for one minute.
4. Record a table with columns for Sample, Grains I can see?, Feel and Fizz?.
5. **Part B question.** Does sand need a cement to become rock? Write your prediction.
6. **What we change.** Cup 1 gets ½ cup of sand mixed with 2 tablespoons of glue and 1 tablespoon of water. Cup 2 gets ½ cup of sand mixed with 3 tablespoons of plain water and no glue.
7. **What we keep the same.** Use the same amount of sand, the same kind of cup, press each one down with the spoon the same way, and let both dry in the same place for 3 days.
8. After 3 days, peel the paper cups away. **What we measure.** Measure the height of each one in inches and centimeters, and see whether it holds together when you gently pick it up and rub it with your thumb.
9. Write a sentence about what the glue did. In real sandstone, what does the job of the glue?

Tips

- Some chalk sold today is made of gypsum, not calcite, so it may not fizz. A seashell or eggshell is a sure test.
- Bubbles from vinegar are slow and small. Be patient, and use the magnifying glass.
- Cup 2 is your control. It shows what happens with no cement, so you can be sure it was the glue that made the difference.

Check your work

- I tested at least five samples and recorded which ones fizzed.
- I can explain why limestone and shells fizz in vinegar.
- I can explain what compaction and cementation do and why Cup 2 was my control.

FIELD NOTEBOOK

1. Draw what sand looks like through your magnifying glass. Then draw what you imagine sandstone looks like up close, with cement between the grains.
2. Make a three-column chart titled Sandstone, Shale, Limestone. Under each, write what it is made of, how it feels and one way people use it.
3. Draw Hooke’s microscope and write one thing you would like to look at with it.

From history. The Great Pyramid of Egypt was built mostly of limestone blocks, and it was once covered with smooth, gleaming white limestone casing stones. Over the centuries, most of those casing stones were carried away to build other buildings, so the pyramid we see today has a rough, stepped surface. Many limestones, including the stone of the pyramids, contain tiny fossil shells you can see with a magnifying glass.

WORKED EXAMPLES

Example 1. A family finds three rocks. Rock A has grains you can see and feels like sandpaper, and it does not fizz. Rock B is dark gray, smooth, breaks into thin flat sheets and does not fizz. Rock C has bits of shells in it and fizzes in vinegar. Name each rock.

(Use the map or drawing "Match each clue to one of the three close-up views." shown earlier in this lesson.)

1. Rock A: grains you can see and a sandpaper feel mean it is made of sand. No fizz means it is not limestone. It is sandstone.
2. Rock B: grains too small to see and thin flat sheets mean hardened mud. It is shale.
3. Rock C: shell bits and fizzing mean it has calcite. It is limestone.

Answer: Rock A is sandstone, Rock B is shale and Rock C is limestone.

Example 2. To model compaction, a student stacks wet sponges 6 inches high and sets heavy books on top. The stack is squeezed to 2 inches. How many inches thinner did it get? How many times taller was it before?

1. Subtract to find how much thinner: $6 - 2 = 4$.
2. To find how many times taller, ask how many 2s make 6: $2 + 2 + 2 = 6$, so three 2s.
3. The water squeezed out of the sponges is like the water pushed out of buried mud.

Answer: The stack got 4 inches thinner. Before squeezing it was 3 times as tall.

PRACTICE

1. EASY Which rock is made of sand grains glued together: shale, sandstone or limestone?
2. EASY Why does limestone fizz when vinegar touches it?
3. MEDIUM What are the two steps that turn loose sediment into rock? Tell what happens in each one.
4. MEDIUM A fizz test table shows: seashell, fizz; eggshell, fizz; pebble, no fizz; sandstone, no fizz; limestone, fizz; shale, no fizz. How many samples fizzed? How many did not?
5. HARD Your glued sand rock is 2 inches tall. One inch is about 2½ centimeters. About how tall is it in centimeters? Why did you also make a cup of sand with no glue?

6. CHALLENGE Explain in two or three sentences why shale splits into thin, flat sheets but sandstone does not.

COMMON MISTAKES

- Thinking every white, chalky rock is limestone. Test it: real limestone fizzes in acid, but some white rocks, like gypsum, do not.
- Thinking wet sand just dries into sandstone. Loose sand needs compaction and a natural cement to become rock.
- Thinking shale and slate are the same rock. Slate is what shale becomes after it is squeezed and heated; you will meet it in Unit 4.

Make it a game · Grain, Sheet or Shell?. A parent gives a clue about a rock, such as “I feel like sandpaper,” “I split into thin flat pages,” “I fizz in vinegar,” “I am hardened mud” or “I was made from shells.” The first player to call out the right rock (sandstone, shale or limestone) scores a point. Then trade places and let the child give the clues. Play to ten points.

Scripture. “Therefore whosoever heareth these sayings of mine, and doeth them, I will liken him unto a wise man, which built his house upon a rock: And the rain descended, and the floods came, and the winds blew, and beat upon that house; and it fell not: for it was founded upon a rock.” (Matthew 7:24–25, KJV)

Loose sand shifts and washes away, but rock stands firm. Jesus says that the person who hears His words and does them is like the builder who chose solid rock.

Practice answers

1. Sandstone.
2. Limestone is made mostly of the mineral calcite. The acid in vinegar reacts with calcite and makes bubbles of gas.
3. Compaction: the weight of layers above squeezes the sediment, pressing grains together and pushing out water. Cementation: minerals in the water between the grains harden and glue the grains together.
4. 3 samples fizzed (seashell, eggshell and limestone). 3 did not fizz (pebble, sandstone and shale).
5. About 5 centimeters (2½ + 2½ = 5). The cup with no glue is the control. It shows what happens without cement, so we know the glue is what held the sand together.
6. Shale is made of mud with tiny flat clay flakes. When the mud is buried and squeezed, the flakes lie down flat in thin layers, so the rock splits easily along them. Sandstone is made of rounder sand grains cemented together in all directions, so it has no thin sheets to split along.

3.3 Coal from Plants

OBJECTIVES

- Explain that coal is a sedimentary rock made from buried plants and describe the clues that show it.
- Put peat, lignite, bituminous coal and anthracite in order from least to most squeezed, and use a simple rule to compare plant thickness with coal thickness.
- Tell the story of Jesse Fell's coal grate and how hard coal came to warm American homes.

Warm-up. Gather a big double handful of fresh grass clippings or leaves and pile them loosely on a plate. Measure how tall the pile is with a ruler. Now press down on it as hard as you can with both hands and measure again. How much thinner did it get? Did any water come out?

Video. Coming soon. How coal forms from buried plants, peat to anthracite, and coal-mining history; search USGS, Smithsonian, Institute for Creation Research, SciShow Kids and historic coal-mine museum footage.

KEY TERMS

peat
A soft, brown, spongy mass of partly decayed plants that has been soaked in water. Buried and squeezed, it can become coal.

coal
A black or brown sedimentary rock made mostly of carbon from plants that were buried, squeezed and warmed. It burns.

carbon
The main building material of living things. Coal, charcoal and pencil lead are mostly carbon.

anthracite
The hardest, shiniest kind of coal. It has the most carbon and burns hot with little smoke.

fossil fuel
A fuel such as coal, oil or natural gas that comes from the buried remains of things that once lived.

CORE IDEAS

The story. On February 11, 1808, in Wilkes-Barre, Pennsylvania, a judge named Jesse Fell tried an experiment by his fireplace. The hills around his town were full of hard, shiny black coal called anthracite. It burned very hot, but it was hard to light, and many people said it would never work in a home fireplace. Fell built a grate out of iron bars that held the coal up

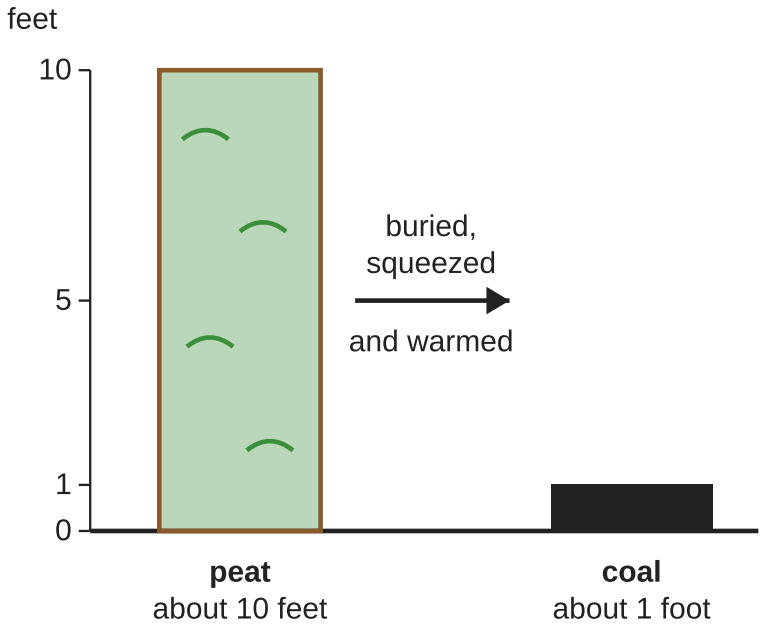
off the hearth so that air could flow underneath it. He lit a fire, and the coal caught and burned with a bright, steady heat. Soon his neighbors were building grates of their own, and before long hard coal was warming homes all over the eastern United States.

How they figured it out. Coal is not like the other rocks in this unit. It is not made of sand or mud or shells. It is made of **plants**. Miners found the clues every day. The shale just above a coal seam is often full of fossil fern leaves, flattened stems and pieces of bark. Some bark has a diamond pattern, like the scales on a fish, from a kind of plant called a scale tree. Scientists sliced coal so thin that light could shine through it, then looked through a microscope. They saw woody bits, plant cells and tiny spores. Coal burns because, like wood, it is made mostly of **carbon**.

The big idea. To make coal, a great mass of plants must be **buried quickly**. If plants lie on the ground, they rot away or are eaten. Under water and mud, they are kept from rotting. A soaked mass of plants is called **peat**. When peat is buried deeper, the weight above squeezes out water and gas, and the warmth of the earth helps change it. First it becomes soft brown **lignite**, then black **bituminous** coal, and with more squeezing and heat, hard, shiny **anthracite**. Plants shrink a great deal on the way. One rule of thumb is that about 10 feet of peat makes about 1 foot of coal.

In the world today. Coal is called a **fossil fuel** because it comes from things that once lived. It is mined in many states, with Wyoming, West Virginia and Pennsylvania among the best known. Power plants burn coal to make electricity. Steel mills bake coal into a hard fuel called coke, which is used to make iron and steel for bridges, ships and cars. Every lump of coal is a lump of plants that God made, stored up underground.

God’s handiwork. On the third day of creation, God made grass, plants and trees. Long after, great masses of plants were buried and turned to rock, and today that rock gives light and heat to millions of people. Job, speaking of the treasures hidden in the earth, said that under the ground “is turned up as it were fire.” When you hold a piece of coal, you are holding a store of energy that began as green leaves in sunlight.



A rule of thumb: about 10 feet of peat squeezes down to about 1 foot of coal.

⏳ Thinking About Time

What the sign says. Museum signs often say coal formed in great swamp forests during the "Carboniferous Period," a museum word that means "coal-bearing." They say the plants piled up slowly and took an extremely long time to turn into coal.

What we observe. We find coal in layers, some many feet thick, full of flattened bark, leaves, stems and spores. In a laboratory, scientists have heated plant material together with clay and made something like coal in only a few months. After the 1980 eruption of Mount St. Helens, a huge mat of floating logs covered Spirit Lake; creation geologists who studied the lake report that bark rubbed off the logs sank and built up a peat-like layer on the bottom.

How Christians read it. Many creation scientists think that much of the world's coal comes from enormous masses of plants that were torn up, carried and buried quickly during Noah's Flood. Quick, deep burial would keep the plants from rotting and help turn them into coal without needing long ages.

Try it. Look at a piece of charcoal from the grill (unused). It was made from wood in a short time with heat. Compare its color and weight with a piece of wood.

Genesis 7:11

PICTURE STUDY



Breaker Boys Working in Ewen Breaker, South Pittston, Pennsylvania, Lewis Hine, January 1911 · Black-and-white photograph · Library of Congress, Washington, D.C. (National Child Labor Committee Collection)

Lewis Hine was a teacher who became a photographer. He traveled across America taking pictures of children at work in mills, fields and mines. This photograph was taken in the hard-coal country of Pennsylvania, not far from where Jesse Fell first burned anthracite in his grate. After coal was dug, it was crushed in a tall building called a breaker. Boys sat over the chutes as the coal slid by and picked out the pieces of rock by hand. Miners called that rock “slate,” though most of it was really shale.

Hine’s photographs helped many Americans see how hard and dangerous this work was, and they helped convince the country to pass laws that kept young children out of the mines and in school.

Look closely

- Find the chutes. Which way is the coal sliding?
- Look at the boys’ hands and faces. What does the coal dust do to them?
- Count the boys in one row. How many children do you think worked in this one room?
- Look at the air in the picture. What would it be like to breathe here all day?

Talk about it

1. Why did the breaker boys need to pick the rock out of the coal? (Think about what happens when rock is in a fire.)
2. How can a photograph change what people think and do?

> **Safety first.** Never try to burn coal, leaves or charcoal yourself; fire is for grown-ups only. Stack weights low and steady so they cannot fall on hands or feet. Wipe up any water that squeezes out, and wash your hands after handling leaves and soil.

EXPERIMENT: THE SQUEEZE TEST: HOW MUCH THINNER DO PLANTS GET?

Coal forms when piles of plants are buried and squeezed. You cannot squeeze as hard as the earth can, but you can measure how much a pile of wet plants shrinks when you press it. This is a small model of the first step from plants to peat.

You will need

- A clear, straight-sided plastic container, such as a tall food tub (about 4 inches wide)
- Fresh grass clippings or torn green leaves, enough to fill the container loosely
- Water in a cup
- A smaller flat-bottomed container or a plastic lid that fits inside the first one, to press with
- Three heavy books of about the same size, or three full food cans
- A ruler with inches and centimeters
- Lab notebook and pencil

Steps

1. **Question.** Write: When I press wet plants with more and more weight, how much thinner does the pile get?
2. **Prediction.** Write how tall you think the pile will be with 1 book, 2 books and 3 books on top.
3. Fill the clear container loosely with plants. Sprinkle on water until the plants are damp all through.
4. Measure the height of the loose pile from the outside of the container. Record it in inches and centimeters.
5. **What we change.** Set the small press container on top and add 1 book. Wait 1 minute and measure the pile again. Then add a second book, wait 1 minute and measure. Then add the third book, wait 1 minute and measure.
6. **What we keep the same.** Use the same plants, the same container and the same waiting time for each measurement, and always measure from the same side.
7. Leave all three books on for 3 days and measure once a day. Pour off any water that collects and note how much there is.
8. Make a table with the columns Weight and Height of pile. Then make a simple bar graph with one bar for each row.
9. Write two sentences: What happened as you added weight? What do you think would happen with the weight of a whole hill of rock on top?

Tips

- Use a marker to make a small line on the outside of the container at each height so you can see the change.
- When you take the books off at the end, the pile may spring back a little. Real buried peat cannot spring back, because the rock above never goes away.
- Do not let the wet plants sit for more than a few days, or they will start to smell. Put them in the compost when you finish.

Check your work

- I measured the loose pile and the pressed pile in inches and centimeters.
- I made a table and a bar graph of my results.
- I can explain why plants must be buried quickly to become coal.

FIELD NOTEBOOK

1. Draw the four steps from plants to coal in a row: peat, lignite, bituminous coal and anthracite. Color each one and write one word that describes it.
2. Draw a fern leaf from life or from a picture, and next to it draw what it might look like flattened as a fossil in the shale above a coal seam.
3. Draw Jesse Fell’s iron grate with coal on top and arrows showing the air flowing underneath.

> **From history.** Coal was burned long before Jesse Fell’s grate. Marco Polo, the Venetian traveler, described in his famous book of travels how people in China dug black stones out of the mountains and burned them like logs, and how these stones kept a fire going all night better than wood. To people in Europe who had never seen coal burned this way, it seemed like a marvel.

WORKED EXAMPLES

Example 1. A miner finds a coal seam 3 feet thick. Using the rule of thumb that about 10 feet of peat makes about 1 foot of coal, about how thick was the peat before it was squeezed?

(Use the map or drawing “Each foot of coal stands for about 10 feet of peat.” shown earlier in this lesson.)

1. Each 1 foot of coal came from about 10 feet of peat.
2. The seam has 3 feet of coal, so add 10 three times: 10 + 10 + 10.
3. 10 + 10 + 10 = 30.

Answer: The peat was about 30 feet thick, about as tall as a three-story building.

Example 2. A student pressed wet leaves and recorded this table. No books: 8 inches. 1 book: 5 inches. 2 books: 4 inches. 3 books: 3 inches. How much thinner was the pile with 3 books than with no books? What pattern do you see?

1. Subtract the last height from the first: $8 - 3 = 5$.
2. Read down the table: 8, then 5, then 4, then 3. Each time a book is added, the pile gets thinner.
3. Notice that the first book squeezed the most ($8 - 5 = 3$ inches), and later books squeezed less (1 inch each), because the leaves were already packed tight.

Answer: The pile was 5 inches thinner with 3 books. The more weight, the thinner the pile, but each added book squeezed it a little less.

PRACTICE

1. EASY What is coal made from?
2. EASY Put these in order from least squeezed to most squeezed: anthracite, peat, bituminous coal, lignite.
3. MEDIUM A coal seam is 2 feet thick. Using the rule that about 10 feet of peat makes about 1 foot of coal, about how thick was the peat?
4. MEDIUM One foot is about 30 centimeters. About how many centimeters thick is a coal seam that is 2 feet thick? How many inches is it?
5. HARD Why must plants be buried quickly if they are going to become coal?
6. CHALLENGE A miner finds fossil fern leaves and pieces of scale-tree bark in the shale just above a coal seam. What do these fossils tell us about the coal? Write two sentences.

COMMON MISTAKES

- Thinking coal is made from dinosaurs. Coal is made from plants; you can find fossil leaves, bark and spores in it, not bones.
- Thinking any pile of dead leaves will turn into coal. Leaves left in the open rot away; plants must be buried quickly and deeply.
- Thinking coal is a mineral like quartz. Coal is a rock made from the remains of plants, so it has no crystal shape of its own.

Make it a game · Plant to Anthracite Line-Up. Write PLANTS, PEAT, LIGNITE, BITUMINOUS and ANTHRACITE on five cards, mix them up and set a timer. Race to lay them in order from first to last. Then play “Squeeze”: each player stands tall as a plant, and as a parent calls out each stage, everyone crouches a little lower and makes themselves smaller, until at ANTHRACITE you are a tight, hard little ball. Last one to get the order right does five jumping jacks.

> **Scripture.** “As for the earth, out of it cometh bread: and under it is turned up as it were fire.” (Job 28:5, KJV)

Job wondered at the treasures God hid in the earth. On top, the ground grows grain for bread; underneath, miners dig up coal that burns with fire.

Practice answers

1. Coal is made from plants that were buried, squeezed and warmed until they turned into rock.
2. Peat, lignite, bituminous coal, anthracite.
3. About 20 feet (10 + 10 = 20).
4. About 60 centimeters (30 + 30 = 60). It is 24 inches (12 + 12 = 24).
5. Plants left lying in the open rot away or are eaten by animals, insects and tiny living things. Quick burial under water and mud keeps them from rotting, so they can be squeezed and changed into coal.
6. The fossils show that plants were buried in that place, so the coal below was made from plants too. The leaves are flattened, which shows that the plant layer was buried and squeezed under mud that became shale.

3.4 Rock Layers in a Road Cut

OBJECTIVES

- Read the layers in a road cut or cliff from oldest to youngest and name the kind of rock in each layer.
- Explain what bent layers and cracks that cut across layers tell us about what happened after the layers were laid down.
- Draw and measure a cross-section of rock layers, adding thicknesses in feet and inches.

Warm-up. Make a quick “layer sandwich” with whatever you have: a slice of bread, a layer of peanut butter or cheese, a second slice, a layer of jam, a third slice. Before you eat it, cut it in half and look at the cut side. Which layer went down first? Which went on last? Now gently bend the sandwich. Did the order change?

Video. Coming soon. Reading rock layers in road cuts and cliffs, folded rock layers, and the Sideling Hill road cut in Maryland; search USGS, state geological surveys, Smithsonian, Institute for Creation Research and family geology field-trip channels.

KEY TERMS

road cut
A place where builders have cut or blasted through a hill to make room for a road, showing the rock layers inside.

outcrop
A place where bare rock shows at the surface, such as a cliff, a riverbank or a road cut.

cross-section
A drawing of what you would see if you sliced straight down through the ground and looked at the cut side.

fold
A bend in rock layers. Layers are laid down flat, so a fold shows that they were pushed and bent afterward.

ripple marks
Small wavy ridges in sand made by moving water or wind. Found in rock, they show that the sand was laid down by moving water.

CORE IDEAS

The story. In the 1980s, road builders in western Maryland blasted a deep notch through a long ridge called Sideling Hill to make way for the highway that is now Interstate 68. When the rock was cleared away, travelers saw something wonderful. On both sides of the road, layers of gray and tan sandstone and dark shale were bent into a giant U shape, like a stack of blankets sagging in the middle. The cut is more than 300 feet deep. Families and school

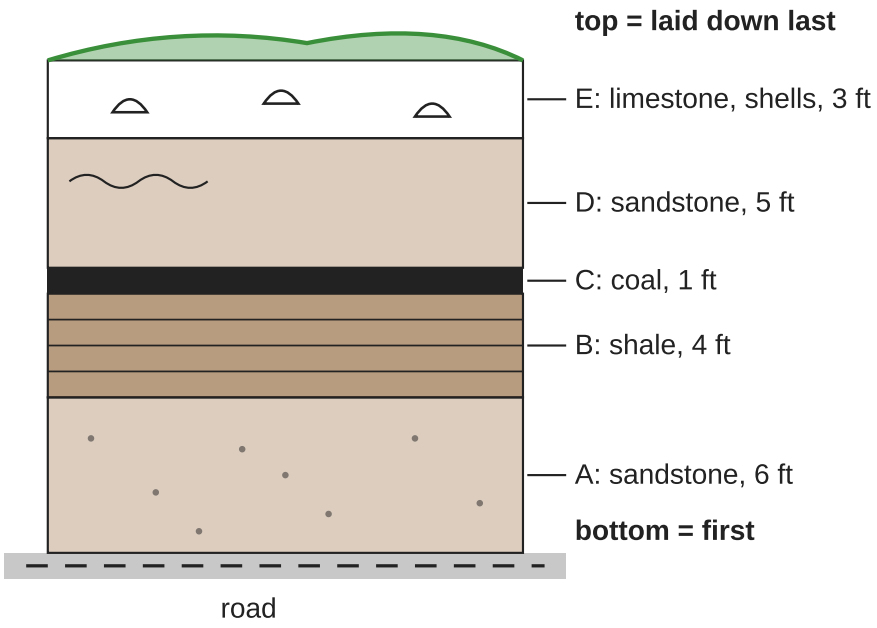
groups began stopping to look, and geologists called it one of the best road cuts in the eastern United States.

How they figured it out. A road cut is a window into the hill. To read it, geologists use the rules you learned from Steno. First, the bottom layer was laid down first and the top layer last. Second, layers are laid down flat, so if they are tilted or bent, they were moved *after* they formed. The Sideling Hill layers were laid down flat and then squeezed into a U-shaped **fold**. Third, anything that cuts across the layers, like a crack, is younger than the layers it cuts. Geologists also match layers from one side of the road to the other, like matching the stripes on a torn piece of cloth.

The big idea. Each layer tells a story about how it was laid down. Sandstone tells of moving water carrying sand. Shale tells of quieter water where fine mud could settle. Limestone with shells tells of sea creatures and limy water. A coal seam tells of a great mass of buried plants. Little wavy **ripple marks** show that water was flowing over the sand. Fossils show what living things were buried in each layer. When you draw what you see in a **cross-section**, you can read the whole story from bottom to top, like reading a book from the first page to the last.

Try it and see. The next time you ride through hilly country, watch for road cuts and other **outcrops**. Are the layers flat, tilted or bent? Are they all the same color, or striped? Are some thick and some thin? Never walk along the edge of a highway to look. With a grown-up, find a safe place such as a scenic overlook, a park trail or a rest area, and look from there. Take a notebook and draw what you see, with the bottom layer labeled “first.”

God’s handiwork. Job tells us to “speak to the earth, and it shall teach thee.” A road cut is the earth speaking. The flat layers, the bends and the fossils are real clues that God has left for us to read. A careful scientist looks closely, writes down only what is truly there, and then thinks hard about what story the clues tell.



A model road cut. Layer A on the bottom was laid down first; layer E on top was laid down last.

⏳ Thinking About Time

What the sign says. Signs at road cuts, parks and museums often say that each layer took a very long time to form and that the whole stack of layers took ages too long to imagine. They may use museum words such as “Devonian” or “Mississippian” for the layers.

What we observe. In many places we see flat layers with sharp, smooth boundaries that stretch for miles, often with little sign of soil, roots or wearing away between them. At Sideling Hill, thick layers are bent into a smooth U shape. After the 1980 eruption of Mount St. Helens, flows of ash and mud laid down layered deposits many feet thick in hours, and a mudflow later cut a canyon more than 100 feet deep.

How Christians read it. Many creation geologists read most of these layers as laid down quickly, one after another, during the year of Noah’s Flood. Layers that bent without shattering may have still been soft and wet when they were folded. Then the draining Flood waters could carve valleys and hills through them.

Try it. Bend a stack of soft play dough layers and then bend a stack of dry crackers. Which one folds smoothly, and which one cracks?

Genesis 7:20

PICTURE STUDY



Green River Cliffs, Wyoming, Thomas Moran, 1881 · Oil on canvas · National Gallery of Art, Washington, D.C.

Thomas Moran was an American painter who first traveled west in 1871. On his way to the land that became Yellowstone National Park, he stepped off the train at Green River, Wyoming, and saw these great striped cliffs. He painted them again and again for the rest of his life.

Moran was an artist, not a geologist, but he looked so carefully that you can read the rock layers in his painting almost as well as in a photograph. The cliffs are a natural road cut, carved by water instead of by road builders.

Look closely

- Find the stripes in the cliffs. Are the layers flat, tilted or bent?
- Count how many different colored bands you can see from the bottom of the cliff to the top.
- Find the river. What do you think cut these cliffs?
- Find the people on horseback. How do they help you tell how big the cliffs are?

Talk about it

1. Which layer in the cliffs was laid down first? How do you know?
2. If you could walk up to these cliffs with a magnifying glass and a bottle of vinegar, what tests would you do to find out what kind of rock each layer is?

> **Safety first.** Never walk or stand along a highway road cut. Look only from a safe pull-off, overlook, trail or parking area with a grown-up, and never climb a road cut or cliff, because rocks can fall. For the project, use dental floss or a plastic knife, not a sharp knife.

EXPERIMENT: BUILD AND READ A PLAY-DOUGH ROAD CUT

You will build your own rock layers, fold them like the layers at Sideling Hill and then cut a "road" through them. Then you will measure and draw them like a field geologist.

You will need

- Play dough or modeling clay in at least four colors
- A rolling pin or a smooth round jar
- A ruler with inches and centimeters
- Dental floss or a plastic knife
- A few grains of rice or tiny beads to be "fossil shells"
- A can or a rolled-up towel to bend the layers over
- Lab notebook, pencil and colored pencils

Steps

1. **Question.** Write: If rock layers are bent, does the order of the layers change?
2. **Prediction.** Write what you think, yes or no, and why.
3. Roll each color into a flat sheet about ½ inch thick and about 6 inches long. Measure to check.
4. Stack the sheets one at a time. Write down the order: Layer A (first, on the bottom), Layer B, Layer C and so on. Press a few rice grains into one layer as fossils, and write which layer.
5. Slice the flat stack in half with dental floss. Draw the cut side in your notebook as a cross-section and label each layer.
6. **What we change.** Take the other half of the stack and gently press it down over the can or towel so it bends into a U shape, like Sideling Hill. (Turn it over so the U opens upward.)
7. **What we keep the same.** The same layers, in the same order, with the same fossils.
8. Cut straight through the bent stack with dental floss to make your "road cut." Draw the cut side.
9. **What we measure.** Measure the thickness of each layer at the bottom of the U and up on one side, in inches and centimeters. Record your numbers in a table.
10. Compare your two drawings. Did the order of the layers change? Which layer is still the oldest? Write your answer in a sentence.

Tips

- Cold play dough cracks when bent. Warm it in your hands first, just as soft, wet sediment bends more easily than hard rock.
- Pull the floss down through the clay in one smooth motion for a clean cut.
- Show your road cut to someone and see whether they can tell which layer was laid down first.

Check your work

- I built at least four layers and recorded their order.
- I drew a cross-section of the flat stack and of the folded stack.
- I measured the layers in inches and centimeters.
- I can explain that bending changes the shape of layers but not their order.

FIELD NOTEBOOK

1. Draw a road cut, outcrop or cliff that you have seen in real life or in a photograph. Label the bottom layer “first” and the top layer “last.”
2. Copy the model road cut from the lesson and color each layer: sandstone tan, shale gray, coal black and limestone white with little shells.
3. Draw ripple marks in sand (at a beach, a sandbox or the bottom of a creek if you can) and write how they were made.

> **From history.** In the 1790s, an English surveyor named William Smith was planning a canal to carry coal in Somerset, England. As the workmen dug, Smith noticed that the rock layers always came in the same order, and that each layer held its own kinds of fossil shells. He traveled all over the country studying layers in quarries, mines and cuttings, and in 1815 he published the first geological map of a whole country, a giant hand-colored map of England and Wales. People nicknamed him “Strata Smith.”

WORKED EXAMPLES

Example 1. Look at the model road cut. Which layer was laid down first? Which was laid down last? How thick are all five layers together?

(Use the map or drawing “Read from the bottom up: A, B, C, D, E.” shown earlier in this lesson.)

1. By Steno’s rule of superposition, the bottom layer came first. Layer A, sandstone, is on the bottom.
2. The top layer came last. Layer E, limestone with shells, is on top.
3. Add the thicknesses: 6 + 4 + 1 + 5 + 3.
4. 6 + 4 = 10. 10 + 1 = 11. 11 + 5 = 16. 16 + 3 = 19.

Answer: Layer A (sandstone) was laid down first, and Layer E (limestone) was laid down last. All five layers together are 19 feet thick.

Example 2. The Sideling Hill road cut is about 300 feet deep. A two-story house is about 30 feet tall. About how many two-story houses would you have to stack to reach the top of the cut?

1. Count by 30s until you reach 300: 30, 60, 90, 120, 150, 180, 210, 240, 270, 300.
2. Count how many 30s you said: 10.
3. Check: 10 houses × 30 feet = 300 feet.

Answer: About 10 two-story houses stacked on top of each other.

PRACTICE

1. EASY What is a road cut?
2. EASY In the model road cut, which layer is coal, and what was it made from?
3. MEDIUM In the model road cut, how much thicker is Layer A (6 feet) than Layer B (4 feet)? How thick are A and B together?
4. MEDIUM The coal layer in the model road cut is 1 foot thick. How many inches is that? About how many centimeters? (1 foot is about 30 centimeters.)
5. HARD A crack cuts straight through Layers A, B, C and D, but Layer E lies across the top of the crack without being broken. Put these in order from first to last: Layer A, the crack, Layer E. Explain.
6. CHALLENGE At a road cut, the layers are bent into a U shape. A friend says the layers must have been laid down that way. Do you agree? Explain using what you know about how sediment settles.

COMMON MISTAKES

- Thinking bent or tilted layers were laid down that way. Sediment settles flat; bends and tilts happened later.
- Thinking a crack or a layer that cuts across others is older than the layers it cuts. Something that cuts through layers must be younger than they are.
- Thinking it is safe to climb or walk along a road cut. Loose rocks can fall and traffic is dangerous; look from a safe place with a grown-up.

Make it a game · Layer Detective. While one player hides their eyes, another stacks five different books or colored sheets of paper in a secret order, one at a time, and writes the order on a slip of paper. The detective opens their eyes and, looking only at the stack, says which item was put down first and which last, and lists the full order from oldest to youngest. Score one point for each item in the right place. For a harder round, slide a ruler “crack” partway into the stack and ask: was the crack made before or after the top book was added?

> **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)

God made the earth so that we can learn from it. Every road cut and cliff is a page we can read, if we look carefully and think honestly about what we see.

Practice answers

1. A place where builders cut or blasted through a hill to make a road, so that the rock layers inside the hill can be seen.
2. Layer C is coal. It was made from buried plants.
3. Layer A is 2 feet thicker (6 − 4 = 2). Together they are 10 feet thick (6 + 4 = 10).
4. 12 inches, which is about 30 centimeters.
5. Layer A first, then the crack, then Layer E. The crack cuts through Layers A to D, so it came after them. Layer E covers the crack without being broken, so Layer E was laid down after the crack formed.
6. No. Sediment settles out of water in flat layers because gravity pulls it down evenly, as we saw in the jar. So the layers were laid down flat and were pushed and bent into a U shape afterward. Smooth bends without many cracks suggest the layers may still have been soft when they were bent.

Unit 3 review

Answer each question. Name the rock or idea for the identification questions, and use complete sentences for the explanations. Show your work for any adding or measuring. Each question is worth 4 points. The quiz is worth 40 points.

1. (4 pts) You shake a jar of water with gravel, sand and clay and let it sit for a day. Which material will be on the bottom, and which will be on top? Why?
2. (4 pts) Who wrote the rule that the bottom layer in a stack was laid down first? What is that rule called?
3. (4 pts) Identify the rock: it has grains you can see, feels like sandpaper and does not fizz in vinegar.
4. (4 pts) Identify the rock: it is full of shell bits and fizzes in vinegar. What mineral makes it fizz?
5. (4 pts) Name the two steps that turn loose sand into sandstone and tell what happens in each.
6. (4 pts) What is coal made from? What is the soft, soaked mass called that comes before coal?
7. (4 pts) Using the rule of thumb that about 10 feet of peat makes about 1 foot of coal, about how thick was the peat that made a coal seam 4 feet thick?
8. (4 pts) Why must plants be buried quickly to become coal? Name one clue that shows coal came from plants.
9. (4 pts) A road cut has these flat layers from bottom to top: shale 3 feet, sandstone 5 feet, limestone 2 feet. Which layer is the oldest? How thick are the three layers together?
10. (4 pts) At Sideling Hill, the rock layers are bent into a U shape. Were they laid down bent? Explain.

Unit project: my sedimentary rock layer book

Make a small book or poster that shows everything you learned about the rocks of layers. Include a drawing or photograph of your shake-and-settle jar with each layer measured and labeled; a chart of your fizz-test results; your homemade sandstone and the cup with no glue, or drawings of them; your leaf-squeeze table and bar graph; and a colored cross-section of your play-dough road cut or of a real outcrop you visited, with the layers labeled from first to last.

If you can, collect at least three real sedimentary rocks or samples (a piece of sandstone, shale or limestone, a seashell, a lump of coal from a rock shop or a cup of beach sand). Label each one with its name, where you found it and one clue that helped you name it. Finish with a short paragraph telling how sediment becomes rock and how a road cut tells the story of its layers.

- **Accuracy**: Rocks and layers are named correctly, and the oldest and youngest layers are labeled correctly.

- **Records**: Measurements are recorded in inches and centimeters, tables are complete, and the bar graph matches the data.
- **Explanation**: The paragraph explains settling, compaction and cementation, and how to read layers using Steno's rules.
- **Care**: The book or poster is neat, colorful and clearly labeled, and samples are carefully stored.

Answer key

1. Gravel will be on the bottom and clay on top (with sand in between). The biggest, heaviest pieces settle first, and the tiniest clay bits settle last.
2. Nicolas Steno. It is called the rule (or law) of superposition.
3. Sandstone.
4. Limestone. The mineral calcite makes it fizz.
5. Compaction: the weight of the layers above squeezes the sand grains together and pushes out water. Cementation: minerals in the water harden between the grains and glue them together.
6. Coal is made from buried plants. The soaked mass of plants that comes before coal is called peat.
7. About 40 feet (10 + 10 + 10 + 10 = 40).
8. Plants left in the open rot or are eaten, so they must be buried quickly to be kept. Clues: fossil leaves, bark and stems in or just above the coal, or plant cells and spores seen in thin slices of coal under a microscope.
9. The shale on the bottom is the oldest. Together the layers are 10 feet thick (3 + 5 + 2 = 10).
10. No. Sediment settles out of water in flat layers, so the layers were laid down flat and were pushed and folded into a U shape afterward.

UNIT 4

Metamorphic Rocks

Some rocks are made over. Deep underground, where the weight of the earth presses down and the stone grows hot, a soft mudstone can become hard, ringing slate, plain limestone can become shining marble, and granite can become striped gneiss. These are **metamorphic rocks**, rocks changed by heat and pressure without melting. In this unit you will learn how they form, why their grains line up, and how to tell a metamorphic rock from its **parent rock**.

You will sit beside John Ruskin as he draws a rock of gneiss by a Scottish stream, and watch Sir James Hall bake chalk in sealed gun barrels to see what heat and pressure can do. You will stand before Michelangelo's *David*, carved from a single block of marble, and visit the great slate quarries of Wales, whose sheets of stone roofed houses around the world and filled American schoolrooms with blackboards. Last, you will put all three rock families together and play the rock-cycle game, rolling a die to follow a grain of rock from mountain to river to deep underground and back again.

Along the way you will squeeze a model rock, test samples with vinegar and a steel nail, find out which material keeps water out best, and graph your rock's journey. In every lesson you will remember that "in his hand are the deep places of the earth" (Psalm 95:4).

BEFORE YOU BEGIN

- Knows the Mohs hardness scale and can do a simple scratch test (Unit 1)
- Can tell how igneous rock forms from melted rock (Unit 2)
- Can tell how sedimentary rock forms from layers of sediment, and can name sandstone, shale and limestone (Unit 3)
- Can add and subtract within 1,000, multiply small numbers and measure with a ruler in inches

MASTERY CHECKLIST

- I can explain that a metamorphic rock is a rock changed by heat and pressure without melting.
- I can match parent rocks to metamorphic rocks: shale to slate, limestone to marble, sandstone to quartzite and granite to gneiss.
- I can test a rock for calcite with vinegar and a scratch test, and explain why marble is good for carving.
- I can explain why slate splits into thin sheets and why it makes good roofs and blackboards.
- I can draw the rock cycle and trace a rock's path through it using the words weathering, erosion, pressing and cementing, heat and pressure, melting and cooling.
- I can record results in a table and make a bar graph from my data.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free. Look for the Geology, Gems and Minerals hall and its online exhibits to see photographs of marble, slate, gneiss and quartzite and the rocks they came from.
- **U.S. Geological Survey (USGS)** (https://www.usgs.gov/): Free. Search the site for “metamorphic rocks” and “Mount St. Helens” to find photographs and plain explanations a parent can read aloud.

4.1 Squeezed and Heated ★

OBJECTIVES

- Explain that a metamorphic rock is a rock that was changed by heat and pressure without melting.
- Name the parent rocks of slate, marble, quartzite and gneiss.
- Squeeze a model rock, measure it before and after, and describe how its grains lined up.

Warm-up. Take a slice of soft bread and look closely at its holes. Now lay it on a plate and press down hard with your flat hand for ten seconds. Look again. Is the bread thinner? Did the holes get smaller? Did the bread melt or fall apart, or did it simply change its shape? Tell someone what the squeeze did. Rocks deep underground can be squeezed and changed too.

Video. Coming soon. Metamorphic rocks for kids (heat and pressure, parent rocks, gneiss, slate, marble, quartzite); search USGS, Smithsonian National Museum of Natural History, SciShow Kids, Homeschool Pop (Alternate) and close-up footage of banded gneiss outcrops.

KEY TERMS

metamorphic rock
A rock that was changed into a new kind of rock by heat and pressure, without melting. The name comes from Greek words meaning “change of form.”

pressure
A strong push or squeeze. Deep underground, the weight of rock above presses down with great pressure.

heat
Warmth. Rock deep underground and rock near melted rock is very hot, and heat helps rock change.

parent rock
The rock that a metamorphic rock was before it changed. Shale is the parent rock of slate.

gneiss
A hard metamorphic rock (say “nice”) with light and dark stripes, or bands, of minerals. Granite can become gneiss.

CORE IDEAS

The story. In the summer of 1853, the English writer and artist John Ruskin sat beside a rushing stream in Glenfinlas, a valley in the Highlands of Scotland. Day after day he bent over his paper and drew one rock, line by careful line. It was not a plain gray stone. It had

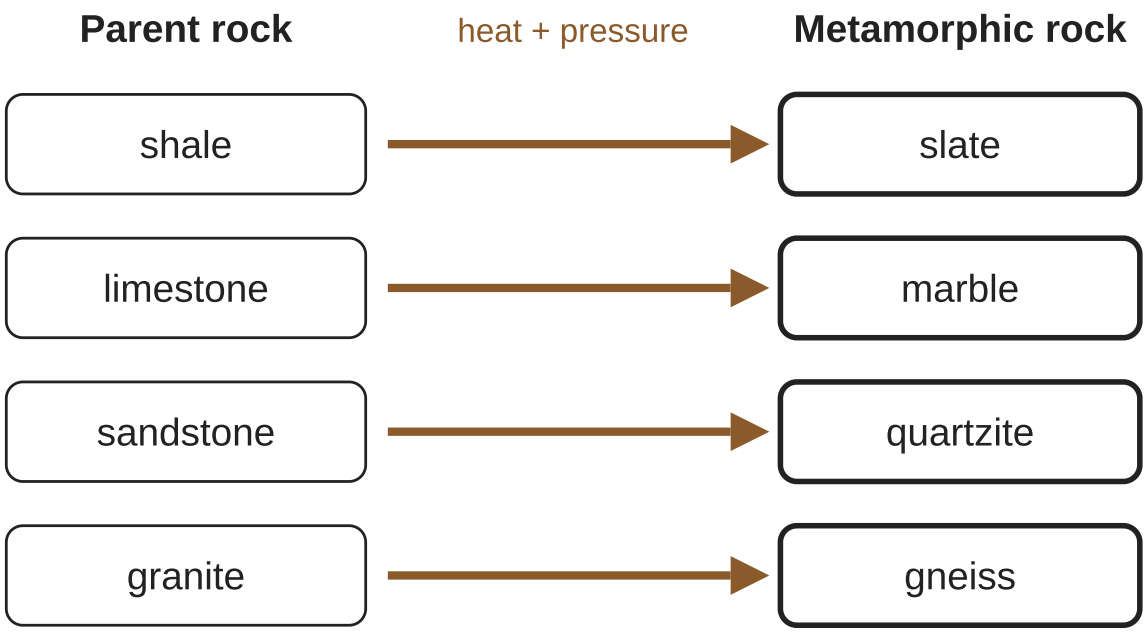
wavy stripes of light and dark, like ribbons pressed together, and the water had worn it smooth. Ruskin believed that drawing a thing slowly was the best way to truly see it. The rock he drew is called **gneiss** (say “nice”), and it is one of the most beautiful kinds of **metamorphic rock**.

How they figured it out. Years before Ruskin, a Scottish scientist named Sir James Hall wondered how rocks like marble were made. In Edinburgh, in the late 1790s and early 1800s, he packed powdered chalk tightly into thick iron gun barrels, sealed them shut and heated them red-hot in a furnace. Chalk heated in the open air turns into crumbly white lime. But Hall’s chalk was trapped and squeezed, and some of it came out as a hard, crystal stone much like marble. Heat plus pressure had changed it! In 1833 the geologist Charles Lyell gave rocks like this their name: *metamorphic*, from Greek words that mean “change of form.”

The big idea. A metamorphic rock started out as another kind of rock, called its **parent rock**. Deep underground, great **heat** and **pressure** changed it into something new, and it did all this without melting. Shale, a soft rock made of hardened mud, becomes slate. Limestone becomes marble. Sandstone becomes quartzite, a rock so hard it can scratch glass. Granite can become striped gneiss. When rock is squeezed very hard, its flat mineral grains turn and line up in the same direction, the way a messy pile of playing cards lines up when you press down on it. That is why many metamorphic rocks have stripes, bands or thin layers. Where does such squeezing happen? Deep inside mountains, where huge masses of rock push against each other, and next to hot melted rock, which bakes the stone around it like an oven.

Try it and see. You can’t visit the deep inside of a mountain, but you can squeeze a model rock. In this lesson you will mix bits of dry spaghetti into a ball of clay every which way, then press it flat under a stack of books. When you cut it open, you will see whether the bits lie flatter and more lined up, like the grains in gneiss and slate. You will measure the ball before and after, in inches and in centimeters, just as a real scientist would. Real rocks are squeezed far harder than you could ever squeeze anything, but the idea is the same.

God’s handiwork. The psalm says, “In his hand are the deep places of the earth: the strength of the hills is his also” (Psalm 95:4). The places too deep and too hot for us to visit are not hidden from God. When you pick up a striped piece of gneiss or a shining chunk of marble, you are holding a rock that was changed in those deep places. We can thank the One who made stone that can be changed into something new and beautiful.



Four parent rocks and the metamorphic rocks they can become.

PICTURE STUDY



Study of Gneiss Rock, Glenfinlas, John Ruskin, 1853 · Pen, ink and wash on paper · Ashmolean Museum, Oxford, England

John Ruskin was an English writer who taught that artists, and everyone else, should look at God’s creation slowly and honestly. In 1853, on a trip to the Scottish Highlands, he spent many days drawing a single rock of gneiss beside a stream. He tried to draw every crack, curve and stripe exactly as he saw it, almost the way a geologist would record it in a field notebook.

Look closely

- Find the lines that curve across the face of the rock. Do they all run in about the same direction?
- Look for the cracks in the stone. How are they different from the curving stripes?
- Find where the rock meets the water or the plants. How did Ruskin show the difference between hard stone and soft leaves?
- Look at how much tiny detail there is. How long do you think this drawing took?

Talk about it

1. Why might drawing a rock slowly help you notice things you would miss with a quick look?
2. The stripes in gneiss were made when the rock was squeezed and heated. What do the curving lines in the drawing make you think of?
3. If you drew a rock from your yard as carefully as Ruskin did, what details would you want to show?

EXPERIMENT: SQUEEZE A MODEL ROCK

Geologists can’t watch rocks being squeezed deep inside a mountain, so they make models. In this small experiment you will find out whether squeezing makes scattered grains line up, the way the grains line up in gneiss and slate.

Question: Will squeezing a clay “rock” make the spaghetti “grains” inside it lie flatter and line up? **What we change:** whether the ball is squeezed. **What we keep the same:** the amount of clay, the number of spaghetti bits and the way we mix them. **What we measure:** the height of each ball and how many bits lie flat.

You will need

- Modeling clay or play dough, enough for two balls the size of a lemon
- Uncooked spaghetti, broken into 20 pieces about ½ inch long
- Ruler marked in inches and centimeters
- Wax paper and a small cutting board or a stiff piece of cardboard
- Six heavy books
- Dental floss or a plastic knife for cutting
- Magnifying glass (if you have one)
- Science notebook and pencil

Steps

1. Write the question in your notebook. Then write your prediction: Do you think the bits will line up when you squeeze the clay?
2. Make two clay balls of the same size. Push 10 spaghetti bits into each ball every which way: some standing up, some lying down, some tilted. Roll each ball smooth again.

3. Label one ball A (not squeezed) and the other ball B (squeezed). Ball A is your *control*: it shows what happens with no squeezing.
4. Measure the height of each ball with your ruler, in inches and in centimeters. Record both.
5. Set ball B on wax paper, lay a second piece of wax paper on top, then the cutting board. Stack six books on the board and leave it for 10 minutes.
6. Take off the books and measure the height of ball B again. Record it.
7. Use dental floss to slice both balls in half from top to bottom. Look at each cut face with the magnifying glass.
8. For each ball, count the spaghetti bits you can see. Sort them into “lying flat” (sideways, like the table top) and “tilted or standing up.” Record the numbers in a table with the columns: Ball, Height before, Height after, Bits lying flat, Bits tilted or standing.
9. Write your conclusion: Did squeezing make more bits lie flat? Was your prediction right?

Tips

- Warm the clay in your hands before you start. Warm clay squeezes more easily, just as hot rock changes more easily deep underground.
- “Lying flat” means the bit lies the same way as the table top.
- Notice that the clay changed shape but never melted. That is the key to metamorphic rock: changed, not melted.

Check your work

- I measured both balls in inches and centimeters and recorded the numbers.
- I counted the bits lying flat in the squeezed ball and the control ball.
- I can explain how my model is like the way grains line up in gneiss and slate.

FIELD NOTEBOOK

1. Draw your two clay balls cut in half, side by side. Draw the spaghetti bits where you saw them, and label the drawings “not squeezed” and “squeezed.”
2. Copy the parent-rock chart from this lesson into your notebook: shale to slate, limestone to marble, sandstone to quartzite, granite to gneiss. Draw a small picture of each rock.
3. Find a rock with stripes or bands (in your yard, a garden border or a stone wall). Draw it slowly and carefully, like Ruskin, and write where you found it and the date.

> **From history.** Sir James Hall was a friend of James Hutton, the Scottish scientist who taught that heat deep in the earth can change rocks. People who disagreed with Hutton said that heated limestone would only burn into lime, as it does in a lime kiln. After Hutton died, Hall set out to test the idea himself. His sealed gun-barrel experiments showed that chalk, heated while it was trapped and squeezed, could become hard and

crystal-like instead. It was one of the first times anyone made a “rock” in a laboratory to learn how real rocks form.

WORKED EXAMPLES

Example 1. Before squeezing, Sam’s clay ball was 3 inches tall. After a stack of books pressed on it, it was 1 inch tall. How many inches shorter did it get? About how many centimeters tall is it now? (1 inch is about 2½ centimeters.)

1. Start with the height before: 3 inches.
2. Subtract the height after: 3 inches − 1 inch = 2 inches.
3. So the ball got 2 inches shorter.
4. The new height is 1 inch, and 1 inch is about 2½ centimeters.

Answer: The ball got 2 inches shorter. It is now about 2½ centimeters tall.

Example 2. Use the parent-rock chart. A rock collector finds a piece of marble. What was its parent rock? Another collector finds sandstone that was baked and squeezed beside hot melted rock. What rock will it most likely become?

(Use the map or drawing “Follow the arrows from parent rock to metamorphic rock.” shown earlier in this lesson.)

1. Find marble on the right side of the chart. Follow its arrow back to the left: limestone.
2. Find sandstone on the left side of the chart. Follow its arrow to the right: quartzite.
3. Both changes needed heat and pressure, and neither rock melted.

Answer: Marble’s parent rock is limestone. The sandstone will most likely become quartzite.

PRACTICE

1. EASY What two things change a rock into a metamorphic rock?
2. EASY Fill in the blanks: Shale becomes _____. Limestone becomes _____. Granite can become _____.
3. MEDIUM In the control ball, 2 of the 10 spaghetti bits were lying flat. In the squeezed ball, 8 of the 10 bits were lying flat. How many more bits were lying flat in the squeezed ball?
4. MEDIUM Each of the 6 books in your stack weighs about 2 pounds. About how many pounds are pressing on the clay? (A kilogram is a little more than 2 pounds. About how many kilograms is that?)

5. HARD Why did Sir James Hall seal the chalk inside an iron gun barrel instead of just heating it in an open fire?
6. CHALLENGE You want to find out whether more squeezing makes more spaghetti bits line up. Plan the experiment: What will you change? What will you keep the same? What will you measure?

COMMON MISTAKES

- Thinking metamorphic rock is melted rock. Rock that melts and cools becomes igneous rock. Metamorphic rock is changed while it stays solid.
- Thinking rocks change into metamorphic rock at the surface, lying in the sun. The heat and pressure needed are found deep underground or right beside hot melted rock.
- Thinking the stripes in gneiss are layers of sand and mud like the layers in sandstone. The bands in gneiss are minerals that were sorted and lined up by squeezing and heating.

Make it a game · Squeeze or Melt?. A parent describes what happens to a rock, such as “Limestone is buried deep under a mountain and squeezed” or “Granite melts and flows up as lava.” If the rock is changed without melting, squeeze your hands together and shout “Metamorphic!” If it melts, wiggle your fingers like flowing lava and shout “Melted!” Score one point for the right action and a bonus point if you can name the new rock (marble, slate, quartzite or gneiss). Play to ten points.

Scripture. “In his hand are the deep places of the earth: the strength of the hills is his also.” (Psalm 95:4, KJV)

Metamorphic rocks are made in the deep places of the earth, where no person can go. God holds those places in His hand, and He knows every stone there.

Practice answers

1. Heat and pressure. The rock changes without melting.
2. Slate; marble; gneiss.
3. $8 - 2 = 6$ more bits were lying flat in the squeezed ball.
4. $6 \times 2 = 12$ pounds. Since 2 pounds is about 1 kilogram, 12 pounds is about 6 kilograms (a little less).
5. Chalk heated in the open air turns into crumbly lime. Sealing it in the gun barrel trapped it and kept it under pressure, so the heat and pressure together could change it into a hard, marble-like rock.
6. Change: the number of books on each ball (for example 0, 2, 4 and 6 books). Keep the same: the size of the clay balls, the number of spaghetti bits, how the bits are mixed and how long the books press. Measure: the number of bits lying flat in each ball (and the height of each ball).

4.2 Marble and Michelangelo's David

OBJECTIVES

- Explain that marble is a metamorphic rock made mostly of calcite and that its parent rock is limestone.
- Tell the story of how Michelangelo carved *David* from a single block of marble.
- Test rock samples for calcite with a vinegar fizz test and a scratch test, and record the results in a table.

Warm-up. Look at a sugar cube with a magnifying glass, then at a spoonful of loose sugar. How are they the same? How are they different? The cube is made of many tiny crystals pressed and stuck tightly together. A freshly broken piece of white marble sparkles in much the same way, because it is made of many small crystals that fit tightly together.

Video. Coming soon. Marble and Michelangelo's David for kids (Carrara marble quarries, how marble is carved, marble fizzing with acid); search Smithsonian, USGS, art museum channels, SciShow Kids, Homeschool Pop (Alternate) and footage of stone carvers at work.

KEY TERMS

marble
A metamorphic rock made mostly of the mineral calcite. Its parent rock is limestone.

calcite
A soft mineral (3 on the Mohs scale) that fizzes when a drop of acid, such as vinegar, touches it.

quarry
A place where stone is cut or dug out of the ground.

sculptor
An artist who makes statues by carving, shaping or building them.

vein
A streak or line of a different color running through a rock, made by other minerals mixed in.

CORE IDEAS

The story. In the summer of 1501, the men in charge of the great cathedral of Florence, Italy, had a problem in their workshop yard. A huge, tall block of white marble had been lying there for many years. Other sculptors had started to carve it long before and then stopped, and people thought the block was spoiled. A young sculptor named Michelangelo Buonarroti said he could still make something grand from it. For about three years he

chipped, carved and polished. In 1504 the finished statue was moved slowly through the streets to the main square of the city. It was *David*, the shepherd who faced Goliath, standing with his sling over his shoulder and his eyes fixed on the giant. The statue is about 17 feet tall, which is about 5 meters.

How they figured it out. Sculptors had learned long before Michelangelo why marble is such a good stone for statues. Marble is made almost entirely of the mineral **calcite**, which is only a 3 on the Mohs hardness scale. That means a steel chisel, which is harder, can carve it. Yet marble is solid and even all the way through, with no layers to split apart, so a carver can make curly hair and a wrinkled brow without the stone breaking off in sheets. A **sculptor** starts with a pointed chisel and a hammer to knock away big chunks, then uses a chisel with teeth, then flat chisels and files, and last of all polishes the stone smooth. Light shines a tiny way into white marble, which makes a statue seem to glow.

The big idea. Marble is a metamorphic rock. Its parent rock is limestone, a sedimentary rock made of calcite, often from tiny shells. Deep underground, heat and pressure changed the limestone. Its small grains grew into larger calcite crystals that fit tightly together like the pieces of a puzzle, which is why broken marble sparkles a little, like a sugar cube. Pure marble is snowy white, like the marble from the **quarries** near Carrara, in the mountains of Tuscany, where Michelangelo's block was cut. Other minerals mixed in make streaks of gray, green, pink or black called **veins**. And because marble is calcite, it fizzes when a drop of acid touches it. Calcite is one of the minerals you met in Unit 1.

In the world today. You can find marble all over the United States. The great seated statue of Abraham Lincoln in the Lincoln Memorial in Washington, D.C., was carved from white marble from Georgia. Marble covers floors, walls and steps in banks, churches and state capitols, and many old gravestones are marble too. Rain, wind and dust slowly roughen marble that stands outdoors, which is one reason *David* was moved indoors in 1873. Today he stands in the Galleria dell'Accademia, a museum in Florence, and a copy stands in his old place in the square.

God's handiwork. Long before Michelangelo, the real King David gathered stone for the temple his son Solomon would build. The Bible says he prepared "marble stones in abundance" (1 Chronicles 29:2). God made limestone that heat and pressure could change into a strong, glowing stone, and He gave people the skill to shape it into beautiful things.

PICTURE STUDY



Bringing Down Marble from the Quarries to Carrara, John Singer Sargent, 1911 · Oil on canvas · Metropolitan Museum of Art, New York

John Singer Sargent was a famous American painter who was born in Florence, Italy, the same city where *David* stands. In 1911 he spent time at the marble quarries near Carrara, in the mountains of Tuscany, and painted the men who cut the stone and brought it down the mountain. Marble has been quarried in these mountains since the days of ancient Rome, and Michelangelo himself traveled to Carrara to choose blocks for his statues.

Bringing a block down was slow, dangerous work. The heavy stone was set on a wooden sled and let down the steep slope little by little, held back by thick ropes wound around strong posts.

Look closely

- Find the great block of marble. How big is it compared with the men?
- Follow the ropes. What are they holding back?
- Look at the color of the mountainside. Why do you think it is so pale?
- Find the workers. What is each one doing to help?

Talk about it

1. Why must a block of marble be brought down the mountain slowly and carefully?
2. The marble in these mountains was once limestone. What changed it into marble?
3. Michelangelo's *David* is about 17 feet tall. What would it take to move a block of stone big enough to carve him?

> **Safety first.** Have an adult help with the steel nail. Scratch away from your body and keep your fingers clear of the point. Keep vinegar away from your eyes, never taste rock samples, and wash your hands when you finish.

EXPERIMENT: THE FIZZ AND SCRATCH TEST

A sculptor must know his stone. In this experiment you will test four samples to find out which ones act like marble and contain calcite.

Question: Which samples fizz in vinegar and can be scratched by a steel nail but not by a fingernail? **What we change:** the kind of sample. **What we keep the same:** the amount of vinegar, the size of the samples and how long we watch. **What we measure:** how many bubbles we see (none, a few or many) and which tools leave a scratch.

You will need

- A small piece of white marble (marble chips from a garden center, or a scrap of real marble tile)
- A piece of seashell
- A gray pebble of granite or quartz
- A piece of sandstone or a chip of brick
- White vinegar and a measuring spoon
- Four small clear cups or a white plate
- Magnifying glass
- A steel nail
- Timer, science notebook and pencil

Steps

1. Write the question in your notebook. For each sample, predict whether it will fizz.
2. Rule a table with five columns: Sample, Prediction, Bubbles (none, a few, many), Fingernail scratch? (yes or no), Nail scratch? (yes or no).
3. Put each sample in its own cup. Pour 1 tablespoon of vinegar over each one.
4. Watch each sample for 1 minute with the magnifying glass. Record what you see.
5. Rinse and dry the samples. Press your fingernail hard across each one. Does it leave a groove? Record.
6. With an adult, drag the point of the steel nail across a corner of each sample. Rub the mark with your finger to see whether it is a real scratch or just a line of metal. Record.
7. Look over your table. Which samples fizzed and were scratched by the nail but not by your fingernail? Those samples behave like calcite.
8. Write your conclusion. Was your prediction right? Which sample is most like the stone of *David*?

Tips

- Marble fizzes slowly in kitchen vinegar. Look for tiny bubbles on the surface. Scraping a fresh spot or using vinegar warmed with hot tap water makes the bubbles easier to see.
- A seashell is made of calcium carbonate, the same stuff as calcite, so it is a good sample to compare. (Some school chalk is made of gypsum and won't fizz much, so a seashell is better.)
- Hard rocks like quartz may wear a little metal off the nail and leave a gray line. If it rubs off, it was not a scratch.

Check your work

- I tested all four samples the same way and recorded my results in a table.
- I can name which samples contain calcite and explain how I know.
- I can explain why a steel chisel can carve marble.

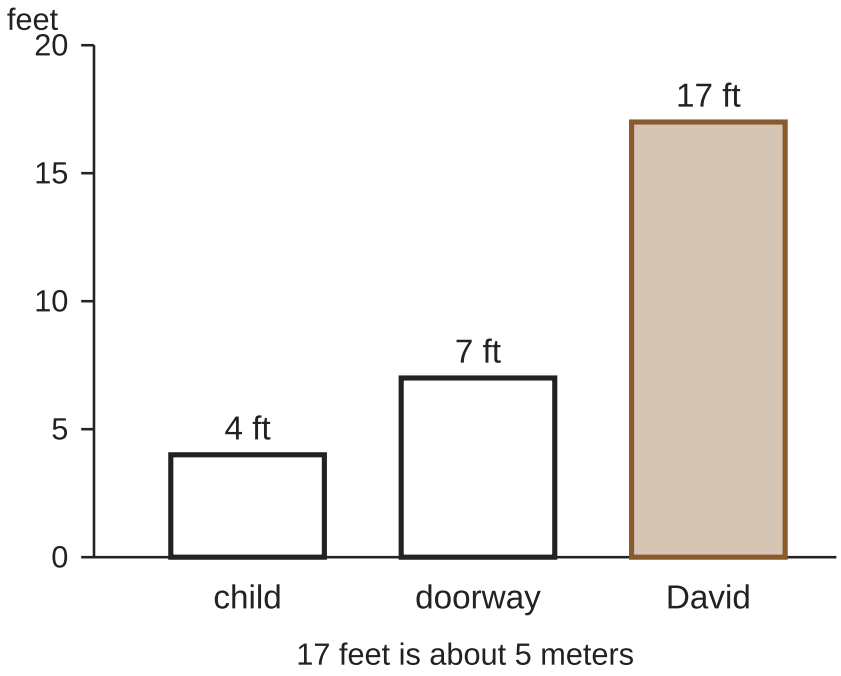
FIELD NOTEBOOK

1. Draw a tall block of marble. Inside it, draw in light pencil the shape of a statue you would carve. Label the parts you would carve away first.
2. Draw and label a sculptor's tools: hammer, pointed chisel, toothed chisel, flat chisel and file.
3. Copy your fizz-test table into your notebook neatly and draw a tiny picture of each sample beside its row.

> **From history.** The statue of Abraham Lincoln inside the Lincoln Memorial in Washington, D.C., was designed by the American sculptor Daniel Chester French. A family of Italian-born carvers in New York, the Piccirilli brothers, carved it from 28 blocks of white Georgia marble, fitted together so well that it looks like one stone. The memorial was dedicated in 1922, and visitors still climb its marble steps to see the statue today.

WORKED EXAMPLES

Example 1. Michelangelo's *David* is about 17 feet tall. A child is about 4 feet tall. How much taller is the statue than the child? About how tall is the statue in meters? (1 meter is a little more than 3 feet.)



Comparing the height of David with a child and a doorway.

1. Start with the statue's height: 17 feet.
2. Subtract the child's height: 17 feet − 4 feet = 13 feet.
3. To change feet to meters, think: about 3 feet make 1 meter. 5 × 3 = 15, and 6 × 3 = 18. So 17 feet is between 5 and 6 meters.
4. Because a meter is a little more than 3 feet, 17 feet is about 5 meters.

Answer: The statue is about 13 feet taller than the child. It is about 5 meters tall.

Example 2. On the Mohs scale, calcite (the mineral in marble) is 3. A fingernail is about 2½, and a steel nail is about 5½. Which one can scratch marble?

1. A tool can scratch a mineral only if the tool is harder than the mineral.
2. Fingernail: 2½ is less than 3, so the fingernail is softer than calcite. It cannot scratch marble.
3. Steel nail: 5½ is more than 3, so the nail is harder than calcite. It can scratch marble.

Answer: The steel nail can scratch marble. The fingernail cannot. That is why Michelangelo used steel chisels.

PRACTICE

1. EASY What is the parent rock of marble?
2. EASY Name the mineral that makes up almost all of marble.
3. MEDIUM Read the results table. Seashell: many bubbles. Marble: a few bubbles. Sandstone: no bubbles. Granite: no bubbles. Which samples contain calcite, according to this test?
4. MEDIUM Michelangelo began carving *David* in 1501 and finished in 1504. About how many years did he work on it?
5. HARD *David* was set up outdoors in 1504 and moved indoors in 1873. How many years did the statue stand outside?
6. CHALLENGE Quartzite is made of quartz, which is a 7 on the Mohs scale. Explain why a sculptor would rather carve a statue from marble than from quartzite.

COMMON MISTAKES

- Thinking marble was made from melted rock. Marble is metamorphic: it is limestone that was changed by heat and pressure without melting.
- Thinking marble statues were poured into a mold. Some statues are cast in bronze, but marble statues are carved by chipping stone away. *David* was carved from one block.
- Thinking all marble is white. Pure marble is white, but other minerals mixed in give marble veins and colors of gray, green, pink and black.

Make it a game · Sculptor and Statue. One player is the “block of marble” and stands very still. The sculptor gently moves the marble’s arms, head and hands into the pose of a Bible hero, such as David with his sling, Moses holding up his staff or Noah holding out his hand for the dove. The other players guess who the statue is. The guesser who is right must also say one fact about marble (its parent rock, its mineral or how to test it) to score a point. Then trade places.

> **Scripture.** “Now I have prepared with all my might for the house of my God the gold for things to be made of gold, and the silver for things of silver, and the brass for things of brass, the iron for things of iron, and wood for things of wood; onyx stones, and stones to be set, glistering stones, and of divers colours, and all manner of precious stones, and marble stones in abundance.” (1 Chronicles 29:2, KJV)

King David said he worked “with all my might” to gather the best materials, marble among them, for the house of God. Our best work, like Michelangelo’s careful carving, can be given to the Lord too.

Practice answers

1. Limestone.
2. Calcite.
3. The seashell and the marble, because they fizzed in vinegar.
4. 1504 − 1501 = 3. He worked on it for about 3 years.
5. 1873 − 1504 = 369 years.
6. Marble is made of calcite, which is only a 3, so a steel chisel (about 5½) can carve it. Quartzite is a 7, harder than steel, so a steel chisel could not carve it well. Marble is also even all the way through and takes a smooth, glowing polish.

4.3 Slate Roofs and Blackboards

OBJECTIVES

- Explain how shale is changed into slate and why slate splits into thin, flat sheets.
- Tell how slate was quarried in Wales and used for roofs, school slates and blackboards.
- Test slate and other materials for soaking up water and for holding chalk, and record the results in a table.

Warm-up. Hold a deck of playing cards. Slide your thumbnail into the side of the deck. How easily does it split into thin layers? Now take a lump of play dough and try to split it the same way. What happens? Slate is a rock that splits like the deck of cards, into thin, flat sheets.

Video. Coming soon. Slate for kids (how slate is quarried and split by hand, Welsh slate quarries, slate roofs and old school slates); search Smithsonian, USGS, National Museum Wales / National Slate Museum, Homeschool Pop (Alternate) and footage of slate splitters at work.

KEY TERMS

slate
A hard, fine-grained metamorphic rock that splits into thin, smooth, flat sheets. Its parent rock is shale.

shale
A soft sedimentary rock made of hardened mud. It crumbles easily and is the parent rock of slate.

cleavage
The way a rock or mineral splits along flat surfaces. Slate splits into sheets along its lined-up flakes.

absorb
To soak up, the way a sponge soaks up water. Slate absorbs very little water.

splitter
A skilled quarry worker who splits blocks of slate into thin sheets with a chisel and mallet.

CORE IDEAS

The story. In the late 1700s, in the green hills of North Wales, a landowner named Richard Pennant began to dig a great quarry into a mountainside. The rock there was dark blue-gray **slate**. Over the next hundred years the Penrhyn Quarry grew into one of the largest slate quarries in the world, cut into the mountain like a giant staircase of ledges. Thousands of quarrymen worked there, and a town grew up nearby that took the name Bethesda from its

chapel. Ships carried Welsh slate across the oceans, and roofs in Britain, America and many other lands were covered with it.

How they figured it out. The quarrymen learned to read the slate. The most skilled workers, called **splitters**, sat in small sheds with a block of fresh, damp slate resting against their knees. A splitter set a broad, thin chisel against the edge of the block and tapped it with a wooden mallet. The block opened like the pages of a book into thin, smooth sheets, each one flat. Other men trimmed the sheets into neat rectangles, and the sizes were given names such as Duchess, Countess and Lady. Before a roofer nailed a slate in place, he tapped it. A good slate rings like a bell. A cracked one sounds dull.

The big idea. Slate is a metamorphic rock. Its parent rock is **shale**, a soft sedimentary rock made of hardened mud. When shale is squeezed hard and warmed deep underground, its tiny flat flakes of clay change into tiny flakes of mica, and they all turn to lie the same way, like the cards in a deck. The rock becomes much harder, and it splits along those lined-up flakes into sheets. This way of splitting is called **cleavage**. Shale crumbles and soaks up water, but slate is tough and **absorbs** very little water. It does not burn or rot. That is why a well-made slate roof can keep a house dry for a hundred years or more.

In the world today. Slate also went to school. In the 1800s, children wrote their lessons on small slates set in wooden frames, using a slate pencil, and wiped them clean to use again. Teachers wrote on large slate blackboards fixed to the classroom wall. Many blackboards for American schools came from the slate quarries of eastern Pennsylvania, near towns with Welsh names such as Bangor and Pen Argyl. Slate is smooth, but it has just enough grip to catch the chalk dust. Today many boards are made of other materials, but slate is still used for roofs, floor tiles, garden stepping stones and the flat bed under the cloth of a pool table.

God’s handiwork. Long before children wrote on slates, God Himself wrote on stone. The Bible says He gave Moses “two tables of testimony, tables of stone, written with the finger of God” (Exodus 31:18). The Bible does not tell us what kind of stone it was. But each time you write on a slate or a chalkboard, you can remember that God speaks clearly to His people, and that He made the very stones that can hold our words.

PICTURE STUDY



Blackboard, Winslow Homer, 1877 · Watercolor on paper · National Gallery of Art, Washington, D.C.

Winslow Homer was one of America’s greatest painters. In the 1870s he painted many pictures of country schools and schoolchildren. In this watercolor, a young teacher stands beside her blackboard, where chalk lines and shapes are drawn for a lesson. In schools like hers, the blackboard was often made of real slate.

Look closely

- Look at the chalk marks on the board. What shapes or lines can you find?
- Look at the color of the board. Is it pure black, or can you see gray and dusty places where chalk was wiped away?
- Look at the teacher. How is she standing? What do you think she is about to teach?
- Find the edges of the blackboard. How big is it compared with the teacher?

Talk about it

1. Why was slate a good rock for a blackboard?
2. What would be hard about a school where every child had to share one board?
3. If you could draw a lesson on this blackboard, what would you draw?

> **Safety first.** Slate tiles can have sharp edges and corners. Carry them with care, don’t try to break or split slate yourself, and wipe up spilled water so no one slips.

EXPERIMENT: THE ROOF AND CHALKBOARD TEST

Quarrymen and roofers trusted slate to keep out the rain, and teachers trusted it to hold chalk. In this experiment you will find out whether slate really is better than other materials

at both jobs.

Question: Which material soaks up the least water, and which one holds chalk and wipes clean best? **What we change:** the material. **What we keep the same:** the number of water drops, the waiting time, the chalk letter and the wiping cloth. **What we measure:** whether the water soaks in, and how many wipes it takes to erase the chalk.

You will need

- A piece of slate (a slate floor tile, slate coaster or garden slate from a home or craft store)
- A piece of plain cardboard
- A piece of an unglazed clay flowerpot or a brick
- A kitchen sponge
- A small piece of plain wood
- Eyedropper or teaspoon, and a cup of water
- Chalk and a dry cloth
- Timer, ruler, science notebook and pencil

Steps

1. Write the question in your notebook and predict which material will be best for a roof and which will be best for a chalkboard.
2. Rule a table with four columns: Material, Prediction, Water after 5 minutes (beaded up or soaked in), Wipes to erase.
3. Lay all five materials flat on a tray. Put 10 drops of water in the middle of each one.
4. Wait 5 minutes. Look closely. Is the water still sitting in a drop on top, or has it soaked in and left a dark, wet spot? Record.
5. Dry everything. Then write a capital letter A about 2 inches tall on each material with the same piece of chalk.
6. Wipe each letter with the dry cloth, one stroke at a time, and count the wipes until the letter is gone. If it is still there after 10 wipes, write “more than 10.”
7. Look at your table. Which material would make the best roof? Which would make the best chalkboard?
8. Write your conclusion. Was your prediction right?

Tips

- Measure the chalk letter with your ruler so each one is about the same size: 2 inches is about 5 centimeters.
- Look at the slate from the side. Can you see thin layers along its edge? That is its cleavage.
- Gently tap your slate with a pencil and listen. A sound slate rings.

Check your work

- I tested every material the same way and recorded my results in a table.
- I can tell which material absorbed the least water and why that matters for a roof.
- I can explain why slate splits into thin, flat sheets.

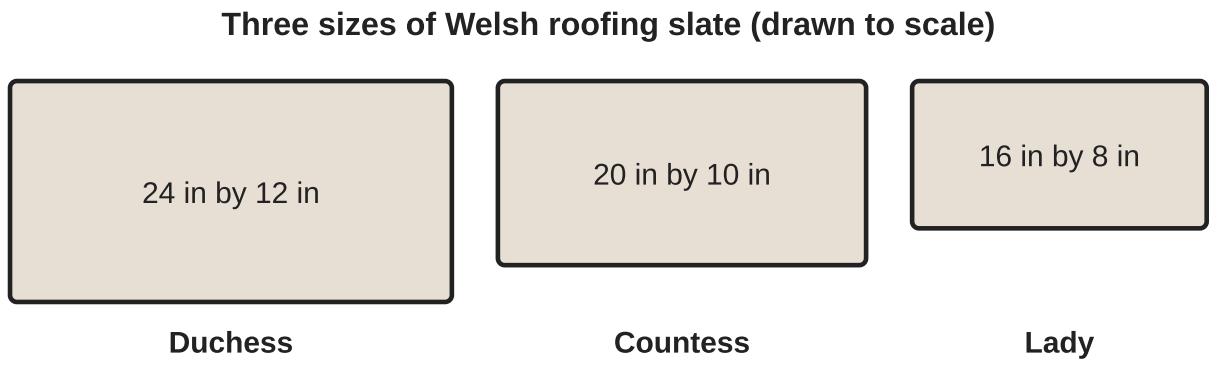
FIELD NOTEBOOK

1. Draw a slate roof seen from the street. Show how each row of slates overlaps the row below it so the rain runs off.
2. Draw a block of slate opening into thin sheets like the pages of a book. Label the chisel, the mallet and the sheets.
3. Draw a school slate in its wooden frame, as children used them in the 1800s, and write a short spelling list on it.

> **From history.** In Wales, the standard sizes of roofing slate were named after noble ladies. For example, a Duchess was 24 inches by 12 inches, a Countess 20 inches by 10 inches and a Lady 16 inches by 8 inches. The names made it easy for builders far away to order exactly the size they needed. In 2021 the slate quarries and villages of North Wales, including Penrhyn, were named a World Heritage Site because of how much they shaped the roofs of the world.

WORKED EXAMPLES

Example 1. A roofing slate called a “Lady” is 16 inches long and 8 inches wide. What is its perimeter (the distance all the way around)? Give your answer in inches and in feet. About how many centimeters is that? (1 foot is about 30 centimeters.)



Three traditional sizes of Welsh roofing slate, drawn to scale.

1. A rectangle has two long sides and two short sides. Add all four: 16 + 8 + 16 + 8.
2. 16 + 16 = 32, and 8 + 8 = 16. Then 32 + 16 = 48 inches.
3. There are 12 inches in 1 foot. 12 + 12 + 12 + 12 = 48, so 48 inches is 4 feet.
4. Each foot is about 30 centimeters, so 4 feet is about 4 × 30 = 120 centimeters.

Answer: The perimeter is 48 inches, which is 4 feet, or about 120 centimeters.

Example 2. A small shed roof is covered with 6 rows of slates. Each row has 8 slates. How many slates are on the roof?

1. There are 6 equal rows with 8 slates in each, so multiply: 6 × 8.
2. Count by eights: 8, 16, 24, 32, 40, 48.
3. 6 × 8 = 48.

Answer: There are 48 slates on the roof.

PRACTICE

1. EASY What is the parent rock of slate?
2. EASY What do we call the way slate splits into thin, flat sheets?
3. MEDIUM Look at the slate-size drawing. A “Duchess” slate is 24 inches long and 12 inches wide. How many feet long is it? How many feet wide?
   (Use the map or drawing “Three traditional sizes of Welsh roofing slate.” shown earlier in this lesson.)
4. MEDIUM Read the water-test results. Slate: water beaded up. Cardboard: soaked in. Clay pot: soaked in. Sponge: soaked in. Wood: partly soaked in. Which material would make the best roof? Why?
5. HARD A “Countess” slate is 20 inches long and 10 inches wide. What is its perimeter in inches? How many feet is that?
6. CHALLENGE Slate splits easily into thin sheets, but granite does not. Explain why, using what you learned about how slate forms.

COMMON MISTAKES

- Thinking slate and shale are the same rock. Shale is soft, crumbly hardened mud. Slate is shale that heat and pressure changed into a hard, ringing rock that splits into smooth sheets.
- Thinking slate only comes in black or gray. Slate can also be green, purple or red, depending on the minerals in it.
- Thinking every chalkboard is made of slate. Old blackboards often were, but many boards today are painted wood, steel or other materials.

Make it a game · Chalkboard Clues. Use a chalkboard, a slate or a piece of paper. A parent reads a clue, such as “I am the parent rock of slate” or “I am the way slate splits.” Write the answer as fast as you can (shale, cleavage, splitter, absorb, Wales). A correct answer stays on the board for a point. A wrong one gets wiped clean, and you try again. Fill the board with ten right answers to win.

Scripture. “And he gave unto Moses, when he had made an end of communing with him upon mount Sinai, two tables of testimony, tables of stone, written with the finger of God.” (Exodus 31:18, KJV)

God wrote His law on stone so that it would last. Every slate and chalkboard can remind us that God speaks plainly and that His words endure.

Practice answers

1. Shale.
2. Cleavage.
3. 24 inches = 2 feet long. 12 inches = 1 foot wide.
4. Slate, because it absorbed almost no water. A roof must keep water out, not soak it up.
5. 20 + 10 + 20 + 10 = 60 inches. 60 inches = 5 feet (12 × 5 = 60).
6. When shale was squeezed and heated into slate, its tiny flat flakes all turned to lie the same way, so the rock splits along them like the pages of a book. Granite’s crystals are jumbled and locked together every which way, so it has no flat direction to split along.

4.4 The Rock-Cycle Game

OBJECTIVES

- Name the three families of rock (igneous, sedimentary and metamorphic) and tell how each one forms.
- Trace a path through the rock cycle using the words weathering, erosion, pressing and cementing, heat and pressure, melting and cooling.
- Play the rock-cycle game, record a rock's journey in a tally table and make a bar graph of the results.

Warm-up. Take a graham cracker and crumble it onto a plate with your fingers. That is weathering: rock breaking into bits. Brush the crumbs into a pile at one side of the plate. That is erosion: the bits being carried away. Now press the crumbs together hard into a little cake. You have made a "sedimentary rock"! What could you do to it next?

Video. Coming soon. The rock cycle for kids (igneous, sedimentary and metamorphic rocks; weathering, erosion, melting and cooling); search USGS, Smithsonian, SciShow Kids, Homeschool Pop (Alternate), Science Max and footage of Mount St. Helens and its new rock layers.

KEY TERMS

rock cycle
The ways rocks change from one kind into another: igneous, sedimentary and metamorphic, over and over.

magma
Melted rock underground. When it flows out onto the surface it is called lava.

sediment
Bits of rock, sand, mud and shell that are carried by water, wind or ice and settle in layers.

weathering
The breaking of rock into smaller pieces by water, ice, wind, roots and other forces.

erosion
The carrying away of broken bits of rock by water, wind or ice.

CORE IDEAS

The story. On the morning of May 18, 1980, Mount St. Helens in Washington State blew apart. Hot ash and broken rock blasted across the forests, and thick flows of ash, rock and mud raced down the valleys. Some of those flows piled up new layers within just hours. Over the next few years, lava oozed up inside the crater and cooled into a new dome of rock. In 1982 a rushing mudflow from the mountain cut a canyon through the soft new layers in

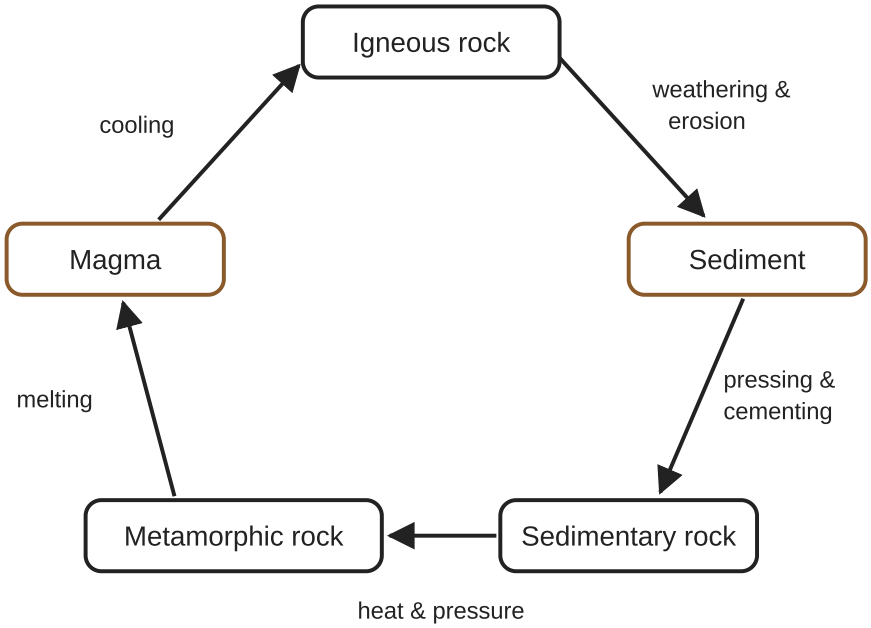
about a day. In a short time, people saw melted rock, broken rock and layered rock all being made and moved. They were watching parts of the **rock cycle** happen.

How they figured it out. Back in the 1780s, a Scottish farmer and scientist named James Hutton spent years studying rocks along streams and sea cliffs. He saw that mountains wear down into sand and mud, that rivers carry the bits away and lay them down in layers, and that buried layers can be pressed, heated and pushed back up into new land. He described it as a great circle of change. Hutton believed it all happened very slowly, and many Christians read the rocks differently. But his idea that rocks change from one kind into another, again and again, is the rock cycle that geologists use today.

The big idea. Every rock belongs to one of three families. *Igneous* rock forms when melted rock, called **magma** underground or lava above ground, cools and hardens. *Sedimentary* rock forms when bits of rock called **sediment** settle in layers and are pressed and cemented together. *Metamorphic* rock forms when any rock is changed by heat and pressure without melting. The rock cycle shows how each kind can become another. **Weathering** breaks rock into pieces, and **erosion** carries the pieces away. Pressing and cementing turn sediment into sedimentary rock. Heat and pressure make metamorphic rock. Melting turns any rock back into magma, and cooling makes it igneous rock again. There is no single road: a rock can skip a step, go back the way it came or take a shortcut.

Try it and see. In this lesson you will play the rock-cycle game. You become a single grain of rock. At each station you roll a die to find out what happens next: melted, squeezed, broken, carried or cemented. You will record every stop of your journey in a tally table and make a bar graph of the stations you visited. Then you can tell the story of your own trip, the way a geologist reads the story written in a real rock.

God’s handiwork. After the Flood, God promised Noah, “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). God built steady cycles into His world: the seasons, the water cycle and the cycle of rocks. They show that He is a God of order who keeps His promises.



The rock cycle. Any rock can also be weathered, squeezed or melted, so there are many shortcuts.

⏳ Thinking About Time

What the sign says. What the sign says: Many textbooks and museum signs say the rock cycle is extremely slow, and that one trip around it takes far longer than people have lived on the earth.

What we observe. What we observe: We can watch some parts of the cycle happen quickly. Lava hardens into rock in days. At Mount St. Helens, new layers piled up within hours, and a mudflow cut a canyon through them in about a day. Other parts, like rock being squeezed deep inside a mountain, cannot be watched at all.

How Christians read it. How Christians read it: Many creation geologists think that much of the rock record, including thick layers of sedimentary rock and the mountain-building that squeezed rock into metamorphic rock, formed quickly during the worldwide Flood of Noah’s day and in the years just after it, not slowly over vast ages.

Try it. Watch a cup of warm gelatin cool and set. How long did it take to “harden”? Some changes are fast and some are slow.

Genesis 7:11

PICTURE STUDY



Among the Sierra Nevada, California, Albert Bierstadt, 1868 · Oil on canvas · Smithsonian American Art Museum, Washington, D.C.

Albert Bierstadt was born in Germany and grew up in Massachusetts. He traveled west to paint the great mountains of America and made enormous paintings, some taller than a grown man. In this picture he shows the granite mountains of the Sierra Nevada in California, with a waterfall, a still lake and light shining through the clouds. Many parts of the rock cycle are hiding in this scene.

Look closely

- Find the high, rocky peaks. Granite is an igneous rock. Where might the rock be cracking and breaking (weathering)?
- Follow the waterfall down. What might the water be carrying with it (erosion)?
- Look at the calm lake. Where would sand and mud settle in layers (sediment)?
- Find the deer and the trees. How does the painter make the mountains look huge?

Talk about it

1. If a grain of sand broke off one of these peaks, what journey might it take through the rock cycle?
2. Why do you think Bierstadt painted sunlight breaking through the storm clouds?
3. What does this painting make you want to say to God about the world He made?

EXPERIMENT: ROCK-CYCLE DICE JOURNEY

You are a grain of rock! In this game-experiment you will roll a die to travel through the rock cycle, record every stop and graph your results.

Question: In 10 rolls, which station will a rock visit most often? **What we change:** the player (each person takes a turn). **What we keep the same:** the rules at each station, the starting station (Igneous Rock) and the number of rolls (10). **What we measure:** how many times each station is visited.

You will need

- One die
- Five sheets of paper or index cards and markers for station signs
- A small token for each player (a dried bean, button or pebble)
- Science notebook, pencil and graph paper

Steps

1. Make five station signs and set them in different spots around the room: Igneous Rock, Sediment, Sedimentary Rock, Metamorphic Rock and Magma. Copy the rules for each station onto its sign.
2. **Igneous Rock:** roll 1 or 2, weathering and erosion: go to Sediment. Roll 3, heat and pressure: go to Metamorphic Rock. Roll 4, melting: go to Magma. Roll 5 or 6: stay (you are still part of a mountain).
3. **Sediment:** roll 1, 2 or 3, pressing and cementing: go to Sedimentary Rock. Roll 4, 5 or 6: stay (you are still tumbling down a river).
4. **Sedimentary Rock:** roll 1 or 2, weathering and erosion: go to Sediment. Roll 3 or 4, heat and pressure: go to Metamorphic Rock. Roll 5 or 6: stay (you are buried in a layer).
5. **Metamorphic Rock:** roll 1 or 2, weathering and erosion: go to Sediment. Roll 3, melting: go to Magma. Roll 4, 5 or 6: stay (you are deep inside a mountain).
6. **Magma:** roll 1, 2 or 3, cooling: go to Igneous Rock. Roll 4, 5 or 6: stay (you are still melted and hot).
7. Write the question and your prediction in your notebook. Start at Igneous Rock. Roll the die 10 times. After each roll, move your token and write down the station where you end up.
8. Make a tally table with the five stations and count how many times you ended up at each. Check that your tallies add up to 10.
9. Draw a bar graph of your tallies. Then combine everyone’s tallies in the family and draw a second bar graph.
10. Write your conclusion: Which station was visited most? Was your prediction right? Write two or three sentences telling the story of your rock’s journey.

Tips

- When you “stay,” you still write down the station for that roll.
- The more rolls you put together, the more you can trust your results. One player’s 10 rolls can come out very differently from the family’s total.

- Act it out: crouch small as Sediment, stand stiff as Sedimentary Rock, squeeze your arms tight as Metamorphic Rock and wiggle like hot liquid as Magma.

Check your work

- I followed the station rules and recorded all 10 stops.
- My tally table adds up to 10, and I made a bar graph from it.
- I can tell my rock's journey using the words weathering, erosion, pressing and cementing, heat and pressure, melting and cooling.

FIELD NOTEBOOK

1. Copy the rock-cycle diagram into your notebook. Color the three rock families in three different colors and draw a small picture of a real rock beside each one (granite, sandstone, marble).
2. Write and illustrate "The Travels of a Grain of Sand," a short story of a grain that starts in a granite mountain and ends up in a piece of quartzite.
3. Look around your house or neighborhood for one igneous, one sedimentary and one metamorphic rock (a granite countertop, a sandstone step, a slate path or a marble windowsill). Draw each and write where you found it.

> **From history.** In 1788 James Hutton went out in a small boat along the coast of southeast Scotland with two friends, the teacher John Playfair and Sir James Hall, the same James Hall who later baked chalk into a marble-like rock in sealed gun barrels. At a rocky point called Siccar Point they saw layers of rock standing almost straight up, with flat layers resting on top of them. Hutton read it as a sign of a great cycle of rocks being laid down, tilted, worn away and laid down again. Creation geologists study the same kind of rocks and read them as the work of the Flood.

WORKED EXAMPLES

Example 1. A grain of quartz starts in a granite mountain. The granite breaks apart and the grain washes down a river as sand. The sand is pressed and cemented into sandstone. Then the sandstone is squeezed and heated into quartzite. Name the rock family or station at each step.

(Use the map or drawing "Follow the arrows to trace the grain's journey." shown earlier in this lesson.)

1. Granite forms from cooled melted rock, so it is an igneous rock.
2. Weathering and erosion break the granite and carry the grain away as sand, so it becomes sediment.
3. Pressing and cementing turn the sand into sandstone, a sedimentary rock.
4. Heat and pressure change the sandstone into quartzite, a metamorphic rock.

Answer: Igneous rock (granite) → sediment (sand) → sedimentary rock (sandstone) → metamorphic rock (quartzite).

Example 2. Ben played the rock-cycle game. After each of his 10 rolls he ended up at: Igneous, Igneous, Sediment, Sediment, Sedimentary, Metamorphic, Metamorphic, Metamorphic, Magma, Igneous. Make a tally table. Which station did he visit most?

1. Count each station. Igneous: 3. Sediment: 2. Sedimentary: 1. Metamorphic: 3. Magma: 1.
2. Check the total: 3 + 2 + 1 + 3 + 1 = 10. It matches his 10 rolls.
3. The biggest numbers are Igneous (3) and Metamorphic (3). They are tied.

Answer: Igneous 3, Sediment 2, Sedimentary 1, Metamorphic 3, Magma 1. Igneous and Metamorphic tied for most, with 3 visits each.

PRACTICE

1. EASY Name the three families of rock.
2. EASY What must happen to magma for it to become igneous rock?
3. MEDIUM A river carries sand from the mountains down to the sea. Is that weathering or erosion? Explain the difference.
4. MEDIUM In the game, which rolls move a rock from Sediment to Sedimentary Rock? How many of the 6 numbers on the die is that?
5. HARD A family put all their tallies together. Igneous: 12. Sediment: 9. Sedimentary: 8. Metamorphic: 14. Magma: 7. How many stops did they record in all? Which station had the most? How many more visits did it have than Magma?
6. CHALLENGE Can a piece of marble someday become part of a sedimentary rock? Explain the path it would take.

COMMON MISTAKES

- Thinking the rock cycle always goes in one fixed order, like a clock. A rock can skip steps or go back the way it came; for example, sedimentary rock can be weathered back into sediment.
- Thinking weathering and erosion are the same thing. Weathering breaks rock apart; erosion carries the pieces away.
- Thinking metamorphic rock forms by melting. Melting makes magma. Metamorphic rock is changed by heat and pressure while it stays solid.

Make it a game · Rock Cycle Callout. Tape the five station signs (Igneous Rock, Sediment, Sedimentary Rock, Metamorphic Rock and Magma) on the walls of a room or on trees in the yard. A parent calls out a change, such as “Cooling!”, “Heat and pressure!”, “Weathering and erosion!”, “Melting!” or “Pressing and cementing!” Everyone runs to the station that change makes. The first one there scores a point if they can name a real rock from that station (granite, sand, sandstone, marble or lava). Play to ten points.

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 gave this promise right after the Flood. The steady cycles of the earth, from the seasons to the rocks under our feet, show His faithfulness.

Practice answers

1. Igneous, sedimentary and metamorphic.
2. It must cool and harden.
3. Erosion. Weathering breaks rock into pieces; erosion carries the pieces away.
4. Rolls of 1, 2 or 3. That is 3 of the 6 numbers, or half of them.
5. 12 + 9 + 8 + 14 + 7 = 50 stops. Metamorphic had the most. 14 − 7 = 7 more visits than Magma.
6. Yes. Weathering could break the marble into small bits, erosion could carry the bits away as sediment, and the sediment could settle in layers and be pressed and cemented into a sedimentary rock.

Unit 4 review

Read each question aloud with your parent, then answer it. Use complete sentences for explanations. The whole quiz is worth 40 points (4 points for each question).

1. (4 pts) What is a metamorphic rock? Name the two things that make one.
2. (4 pts) Name the metamorphic rock each parent rock becomes: shale, limestone, sandstone, granite.
3. (4 pts) Why do many metamorphic rocks, like gneiss and slate, have stripes, bands or thin layers?
4. (4 pts) Identify this rock: it is metamorphic, made mostly of calcite, often white, and it fizzes in vinegar. What is its parent rock?
5. (4 pts) Who carved the statue *David*, what rock is it made of, and in what city can you see it today?
6. (4 pts) Calcite is 3 on the Mohs scale. A fingernail is about 2½ and a steel nail is about 5½. Which can scratch marble? Explain.
7. (4 pts) Identify this rock: it is dark gray, fine-grained, splits into thin, smooth, flat sheets and was used for roofs and blackboards. What is its parent rock?
8. (4 pts) Give two reasons slate is a good rock for roofs.
9. (4 pts) Fill in the blanks. Magma that cools becomes _____ rock. Sediment that is pressed and cemented becomes _____ rock. Any rock changed by heat and pressure becomes _____ rock. Breaking rock into bits is called _____.
10. (4 pts) Describe a path a grain of sand could take through the rock cycle from a granite mountain to a piece of quartzite.

Unit project: my metamorphic rock museum

Set up a small museum display on a tray, shelf or poster board. Show at least three pairs of parent rocks and metamorphic rocks (real samples, tiles, or careful drawings), such as shale and slate, limestone and marble, sandstone and quartzite, or granite and gneiss. Give each one a museum label with its name, its rock family, where you found it and one fact about it.

Beside the display, add your hand-drawn rock-cycle diagram, your fizz-test and roof-test tables, and the bar graph from your rock-cycle game. Then give a short tour of your museum to your family, explaining how heat and pressure change rocks without melting them.

- **Accuracy**: Each parent rock is correctly matched with its metamorphic rock, and every label names the right rock family.
- **Observation and records**: Test tables and the bar graph are complete, neatly labeled and show real results.
- **Explanation**: The tour clearly explains heat and pressure, why grains line up, and how a rock moves through the rock cycle.
- **Care**: The display is neat, well arranged and easy for a visitor to read.

Answer key

1. A metamorphic rock is a rock that was changed into a new kind of rock without melting. Heat and pressure make it.
2. Shale → slate; limestone → marble; sandstone → quartzite; granite → gneiss. (1 point each.)
3. When the rock is squeezed very hard, its flat mineral grains turn and line up in the same direction, making bands or layers.
4. Marble. Its parent rock is limestone.
5. Michelangelo carved it from a single block of white marble (from Carrara). It stands in Florence, Italy, in the Galleria dell'Accademia.
6. The steel nail. A tool can scratch only a mineral that is softer than it, and 5½ is more than 3. The fingernail (2½) is softer than calcite, so it cannot.
7. Slate. Its parent rock is shale.
8. Any two: it splits into thin, flat sheets; it absorbs very little water; it does not burn or rot; it lasts a hundred years or more.
9. Igneous; sedimentary; metamorphic; weathering. (1 point each.)
10. The granite (igneous) is broken by weathering, and erosion carries the grain away as sand (sediment). The sand is pressed and cemented into sandstone (sedimentary). Heat and pressure change the sandstone into quartzite (metamorphic).

UNIT 5

Fossils

A **fossil** is the remains or a trace of a living thing preserved in rock. Fossils are where the rocks speak most plainly: a skeleton with every bone in place, a fish with its last meal still inside, a footprint pressed into mud, a tree trunk standing straight up through layer after layer. In this unit you will learn the one rule behind almost every fossil, **no quick burial, no fossil**, and practice telling the difference between what we observe in the rocks and how people interpret it.

You will walk the stormy beach at Lyme Regis with Mary Anning and her dog Tray, follow farm boy Pliny Moody's plow to a slab of three-toed footprints, watch Nicolas Steno match "tongue stones" to a shark's teeth, dig a fish-within-a-fish out of the Kansas chalk with George F. Sternberg, and stand with Charles Lyell under the giant tides of the Bay of Fundy, looking up at stone trees. Along the way you will make molds and casts, bury toys in a jar flood, build a scale model of a giant fish and test whether logs sink upright.

BEFORE YOU BEGIN

- Knows that sedimentary rocks form in layers from sand, mud and shells (Unit 3)
- Can measure with a ruler in inches and feet and read centimeters
- Can add, subtract and multiply small whole numbers (such as 4×12 and $14 - 6$)
- Can record results in a simple table and tally chart

MASTERY CHECKLIST

- I can explain the four steps of how a fossil forms and why quick burial is the step that cannot be skipped.
- I can sort fossils into body fossils and trace fossils and explain the difference between a mold and a cast.
- I can use a footprint's length to estimate how tall an animal's hips were.
- I can explain why a fish caught swallowing another fish shows very quick burial.
- I can explain what a polystrate fossil is and why it shows the layers around it formed quickly.
- I can tell the difference between what we observe in a fossil and how people interpret it.

OPTIONAL BOOKS AND RESOURCES

- **National Park Service: Fossils and Paleontology** (https://www.nps.gov/subjects/fossils/): Free. Photographs and short articles on fossils found in America's national parks, including fossil tracks, petrified wood and fossil fish. A parent can find pictures to show alongside each lesson.
- **Fossil Butte National Monument (National Park Service)** (https://www.nps.gov/fobu/): Free. The park website shows the fossil fish of Wyoming's

Green River rocks, including fish found swallowing other fish (Lesson 5.3). Visit in person if you travel through southwestern Wyoming.

- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free. The museum's online exhibits include its fossil hall. Use it to practice reading museum signs: find the observations, then find the interpretations.

5.1 How Fossils Form: Quick Burial ★

OBJECTIVES

- Tell the story of Joseph and Mary Anning's sea-reptile skeleton and explain what a whole skeleton tells us about how it was buried.
- Explain the four steps of how most fossils form and why quick burial is the most important step.
- Test, measure and record how quickly sandy mud can bury an object in water.

Warm-up. Look out a window or think about a park. Have you ever seen a dead bird, mouse or fish lying on the ground for weeks? Probably not. Make a quick list of everything that might happen to a dead fish lying on a beach: who might eat it, and what might the sun, rain and waves do to it? Keep your list for the lesson.

Video. Coming soon. How fossils form by quick burial in mud and sand, and Mary Anning's fossil discoveries at Lyme Regis; search Smithsonian, Natural History Museum London, SciShow Kids, Homeschool Pop (Alternate), Institute for Creation Research kids channels.

KEY TERMS

fossil
The remains or a trace of a living thing that has been preserved in rock.

sediment
Loose bits of rock, sand and mud that water, wind or ice carry and drop in layers.

scavenger
An animal that eats dead things, such as a gull, crab, beetle or vulture.

quick burial
Being covered by thick sediment fast, before scavengers, air and rot can destroy a dead plant or animal.

petrified
Turned to stone: minerals carried by water have filled and replaced the bone, shell or wood.

CORE IDEAS

The story. In 1811, on the stormy seashore at Lyme Regis in southern England, a boy named Joseph Anning spotted a strange skull poking out of the crumbling cliff. It was long and narrow, with a huge eye socket and rows of sharp teeth. About a year later his younger sister, Mary Anning, found the rest of the animal in the same cliff. With hammers, chisels and help from neighbors, the Annings dug out a whole skeleton, its backbone still in a neat row and its paddles still beside its body. Scientists named this kind of creature *Ichthyosaurus*,

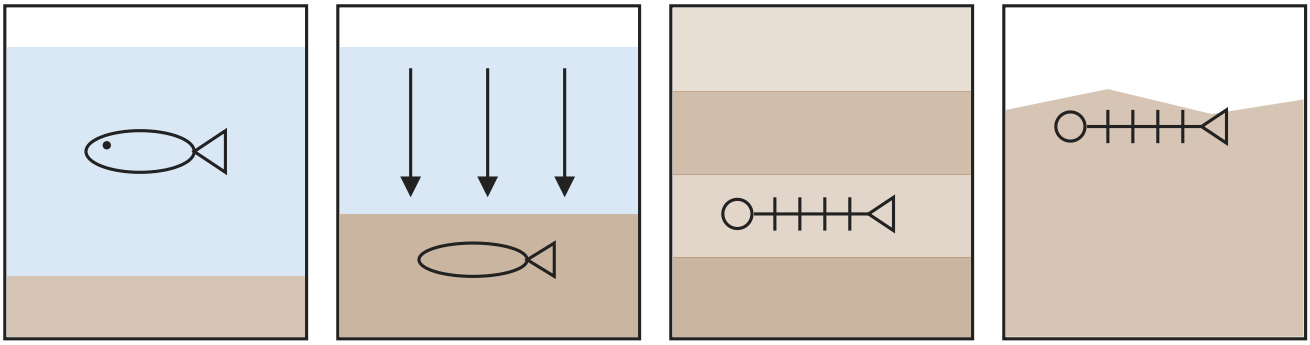
which means “fish lizard.” It was a sea reptile shaped a little like a dolphin. Mary grew up to be one of the most famous fossil hunters in the world.

How they figured it out. Think about what happens when an animal dies in an ordinary place. Gulls, crabs, flies and beetles come to eat. Sun and rain break down what is left. Bones are pulled apart, chewed and scattered, and soon there is almost nothing to find. Fossil hunters like Mary noticed that the skeletons they dug up were often whole, with every bone in its place, and some fossil fish even show their fins and scales. That told them something important: these animals were covered up **fast**, before scavengers and rot could tear them apart.

The big idea. A **fossil** is the remains or a trace of a living thing preserved in rock. Most fossils form in four steps (look at the diagram). First, a plant or animal is buried quickly under thick mud or sand, called **sediment**. Second, the sediment shuts out air and hungry **scavengers**. Third, water carrying dissolved minerals soaks through, and the minerals fill the tiny spaces in bone, shell or wood. Fourth, the mud hardens into rock, and the bone becomes a stone copy of itself. When minerals fill and replace bone or wood like this, we say it is **petrified**, which means “turned to stone.” Remember the rule: no quick burial, no fossil.

Try it and see. In this lesson’s experiment you will drop a small toy into a jar of water and pour in sandy mud, counting the seconds until the toy disappears. A gentle dusting of silt on a pond bottom would take so long to bury a fish that it would be eaten first. A rushing, muddy flood can bury it in moments.

God’s handiwork. Fossil beds full of whole animals are found on every continent, often in thick, wide layers of mud and sand that stretch across huge areas. Many creation geologists read many of these layers as the work of the great Flood in Noah’s day, when “all the fountains of the great deep” were broken up and the waters covered even the high hills (Genesis 7:11, 19). A flood that big could bury countless creatures quickly. Each fossil is a small, silent witness, and when we study it carefully, we are reading a page of history written in the rocks of the world God made.



The four steps of making a fossil. Step 2, quick burial, is the one that cannot be skipped.

PICTURE STUDY



Mary Anning with Her Dog Tray, Unknown artist, before 1842 · Oil on canvas · Natural History Museum, London

This is the best-known portrait of Mary Anning, painted while she was still alive. She is standing on the shore near Lyme Regis where she searched for fossils almost every day of her life, often right after winter storms had washed fresh pieces out of the cliffs. Her little dog Tray went with her on her hunts.

Mary had very little schooling, but she taught herself to read scientific books, copied out drawings and studied the anatomy of living fish and animals so that she could understand the bones she found. The greatest scientists in England came to visit her and learn from her.

Look closely

- Find Tray, the dog. Where is Tray, and what is the dog doing?
- Find Mary’s fossil-hunting tools. What would she use each one for?
- Look at the cliffs behind her. Why would a cliff by the sea be a good place to find fossils?
- Look at the ground near Mary’s feet. What might she be pointing to or looking for?

Talk about it

1. Why do you think Mary went hunting most often right after storms?
2. If you were painting a portrait of yourself as a scientist, what tools and helpers would you put in the picture?

> **Safety first.** Use a clear plastic jar or bottle if you can; glass can break. Wipe up spills right away so no one slips. Pour the muddy water out in the yard or garden, not down the

> sink, where sand can clog the pipes. Wash your hands after handling soil.

EXPERIMENT: BURY IT FAST! A FLOOD IN A JAR

Question: **Does a big pour of sandy mud bury a toy faster than a slow trickle?** You will be a sediment scientist. You will copy a slow, gentle settling and a fast, muddy flood, time each one, and measure how deep the toy is buried.

You will need

- Two clear jars or plastic bottles with wide mouths, the same size
- Water
- Two small plastic toy fish or animals (or two shells) about the same size
- About 2 cups of sandy garden soil mixed with a little water to make thick mud
- A spoon and a measuring cup
- A timer or stopwatch
- A ruler with inches and centimeters
- Lab notebook and pencil

Steps

1. Fill both jars halfway with water. Drop one toy into each jar so it rests on the bottom.
2. Prediction: write which jar you think will hide its toy first, the slow jar or the fast jar, and why.
3. Slow jar: add one spoonful of mud every 10 seconds. Start the timer and count spoonfuls. Stop when you can no longer see any part of the toy, and write down the time.
4. Fast jar: pour 1 cup of mud in all at once. Start the timer as you pour and stop it when the toy is hidden. Write down the time.
5. Let both jars sit until the water clears a little. Hold the ruler against the outside of each jar and measure how deep the mud is above each toy, in inches and in centimeters.
6. Record your results in a table with three columns: Jar, Seconds to hide the toy, Mud above the toy.
7. Write a sentence: Which jar was more like a flood? Which toy would be safer from a hungry crab?

Tips

- What we change: how fast the mud goes in. What we keep the same: the jars, the water, the toys and the kind of mud. What we measure: seconds to hide the toy and depth of mud above it.
- Look closely at the side of the fast jar after it settles. Heavier sand usually sinks first and finer mud lands on top, making layers.

Check your work

- I can name what I changed, what I kept the same and what I measured.
- I can read my table and say which jar buried its toy faster.
- I can explain why quick burial protects a dead animal from scavengers.

FIELD NOTEBOOK

1. Draw the four steps of fossil making in four boxes, just like the diagram, and write one short sentence under each.
2. Draw Mary Anning’s fish lizard skeleton lying in a cliff. Label the skull, the backbone and the paddles.
3. Draw your two jars after the experiment. Label the toy, the mud and any layers you see, and write how many inches of mud covered each toy.

> **From history.** Mary Anning kept hunting the cliffs at Lyme Regis all her life. In 1823 she found the first nearly complete skeleton of a *plesiosaur*, a sea reptile with a small head, four flippers and a very long neck. Some scientists at first thought it might be a fake, because no one had ever seen an animal shaped like that, but when the bones were studied carefully, they agreed it was real. Learned men such as William Buckland walked the beach with her and asked her advice.

WORKED EXAMPLES

Example 1. A toy fish lying in a jar is 5 centimeters tall. Each pour of mud adds a layer 2 centimeters deep. How many pours does it take to cover the fish completely? How much mud is above the fish then?

1. After 1 pour the mud is 2 cm deep. That is less than 5 cm, so the fish still shows.
2. After 2 pours: $2 + 2 = 4$ cm. Still less than 5 cm, so the top of the fish still shows.
3. After 3 pours: $4 + 2 = 6$ cm. Now the mud is deeper than the fish.
4. Mud above the fish: $6 - 5 = 1$ cm.

Answer: 3 pours. The fish is covered by 1 centimeter of mud.

Example 2. A family tested scavengers in the backyard. They set 10 fish crackers on an open plate and buried 10 more under 1 inch of sand in a pan. After 2 hours they counted what was left.
Open plate: 3 crackers left.
Buried in sand: 10 crackers left.
How many crackers did scavengers take from the open plate? What does this test show?

1. The open plate started with 10 and ended with 3: $10 - 3 = 7$ crackers taken.
2. The buried pan started with 10 and ended with 10: $10 - 10 = 0$ crackers taken.
3. The ants and birds found the crackers they could see and smell, but not the buried ones.

Answer: 7 crackers were taken from the open plate and none from the sand. Burial protects food, and dead animals, from scavengers.

PRACTICE

1. EASY What is a fossil?
2. EASY Name two scavengers that might eat a dead fish lying on a beach.
3. MEDIUM A flood leaves a layer of mud 6 inches deep over a bone that is 2 inches thick. How many inches of mud are above the bone? One inch is about 2½ centimeters. About how many centimeters is that?
4. MEDIUM Put these steps in order: (A) The mud hardens into rock. (B) An animal is buried quickly by thick mud. (C) Minerals in water fill the tiny spaces in the bones. (D) The mud shuts out air and scavengers.
5. HARD In a jar test, Pour A hid a toy in 4 seconds. Pour B hid the same toy in 40 seconds. Which pour was faster, and by how many seconds? Which pour is more like a flood?
6. CHALLENGE Mary Anning’s fish lizard was found with its backbone in a neat row and its paddles beside its body. In two or three sentences, explain what this tells us about how it was buried.

COMMON MISTAKES

- Thinking any dead plant or animal will become a fossil if you wait. Almost all are eaten or rot away; only quick burial gives a fossil a chance to form.
- Thinking a fossil bone is just an old bone. Most fossil bones have been filled and replaced with minerals, so they are heavy and hard like stone.
- Thinking fossils are only dinosaurs. Most fossils are shells, fish, plants and small sea creatures.

Make it a game · Scavenger or Sediment?. One player is the “fish” and lies still on the floor with a few paper bones (strips of paper) beside them. The “scavengers” (other players or a parent) tiptoe in and try to carry off bones one at a time. The “flood” player

tries to cover the fish with a blanket of sediment (a real blanket) before all the bones are gone. Count how many bones were left under the blanket. Then switch jobs. Talk about it: what happened when the flood came quickly, and what happened when it came slowly?

Scripture. “And the waters prevailed exceedingly upon the earth; and all the high hills, that were under the whole heaven, were covered. Fifteen cubits upward did the waters prevail; and the mountains were covered.” (Genesis 7:19–20, KJV)

The Flood in Noah’s day was a real event in history. Water that covered the whole earth would carry and drop enormous amounts of mud and sand, just the kind of quick burial that turns living things into fossils.

Practice answers

1. The remains or a trace of a living thing that has been preserved in rock.
2. Any two, such as gulls, crabs, flies, beetles or raccoons.
3. $6 - 2 = 4$ inches of mud above the bone. $4 \times 2½ = 10$, so about 10 centimeters.
4. B, D, C, A.
5. Pour A was faster by $40 - 4 = 36$ seconds. Pour A is more like a flood.
6. It was buried quickly. If it had lain on the sea floor for a long time, scavengers would have pulled the bones apart and scattered them, and the body would have rotted away. Because the bones are still in place, mud must have covered it soon after it died.

5.2 Kinds of Fossils: Bones, Shells, Tracks and Molds

OBJECTIVES

- Sort fossils into body fossils (bones, teeth, shells, wood) and trace fossils (tracks, burrows and other signs of life).
- Explain the difference between a mold and a cast and make both with clay and plaster.
- Use a footprint's length to estimate the hip height of the animal that made it.

Warm-up. Press your thumb firmly into a ball of clay or play dough, then lift it away. What is left behind? Now press a coin, a shell or a toy's foot into the clay. Could someone who never saw the object tell what made each print? Which details show up best?

Video. Coming soon. Kinds of fossils for kids: body fossils, trace fossils, dinosaur footprints, molds and casts, petrified wood; search Smithsonian, National Park Service paleontology, Natural History Museum London, SciShow Kids, Homeschool Pop (Alternate) .

KEY TERMS

body fossil
A fossil of part of the living thing itself, such as a bone, tooth, shell or piece of wood.

trace fossil
A fossil of something a living thing did or left behind, such as a footprint, a burrow or a nibble mark.

mold
A hollow print left in rock after a shell, bone or plant was pressed in or dissolved away.

cast
A solid copy made when a mold is filled in with minerals or sediment that harden.

trackway
A line of footprints made by one animal as it walked.

CORE IDEAS

The story. In 1802 a farm boy named Pliny Moody was plowing his family's field in South Hadley, Massachusetts, when his plow turned up a slab of reddish sandstone. On it were footprints with three long toes, like the tracks of a huge bird. Neighbors were amazed. Some joked that they must be the tracks of Noah's raven, the bird Noah sent out from the ark. No one in the town had ever seen footprints like these in solid rock.

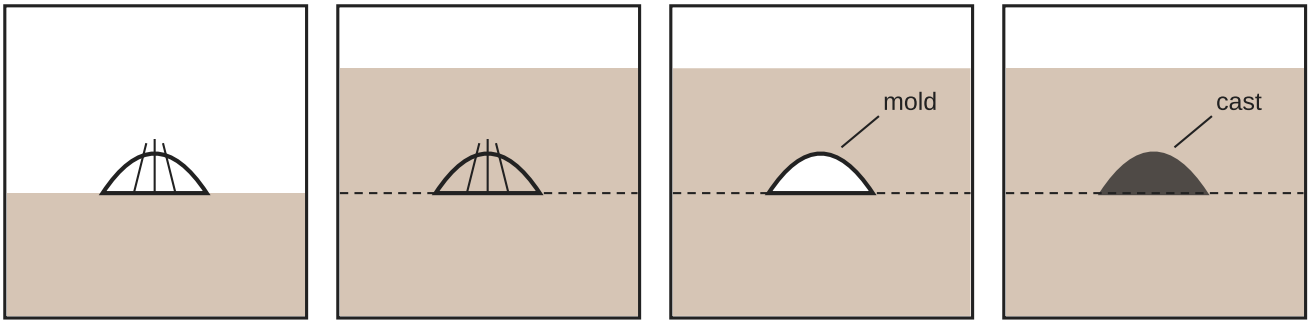
How they figured it out. Years later Edward Hitchcock, a minister and a professor at Amherst College, began collecting stone slabs with tracks from all along the Connecticut River valley. He measured thousands of footprints, drew them carefully, and gave each kind a name. He thought giant birds had made them. Today most museum signs say the three-toed

tracks were made by dinosaurs walking on two legs. Long before Hitchcock, a scientist named Nicolas Steno had solved a different puzzle. People in Europe found pointed “tongue stones” in rocks. In 1666 Steno studied the head of a great shark and saw that its teeth matched the tongue stones exactly. They were fossil shark teeth!

The big idea. Fossils come in two big families. **Body fossils** are parts of the living thing itself: bones, teeth, shells, wood and leaves. **Trace fossils** are signs that something was alive and busy: footprints, **trackways**, burrows, egg nests, bite marks, even fossil droppings. Some fossils are **molds** and **casts**. When a shell is buried in mud and then dissolves away, it leaves a hollow print called a mold. If minerals or sand later fill the hollow and harden, they make a solid copy called a cast (look at the diagram). A footprint is a natural mold; the sand that fills it can harden into a cast. Petrified wood is a body fossil where minerals have replaced the wood so well that you can still count the tree rings.

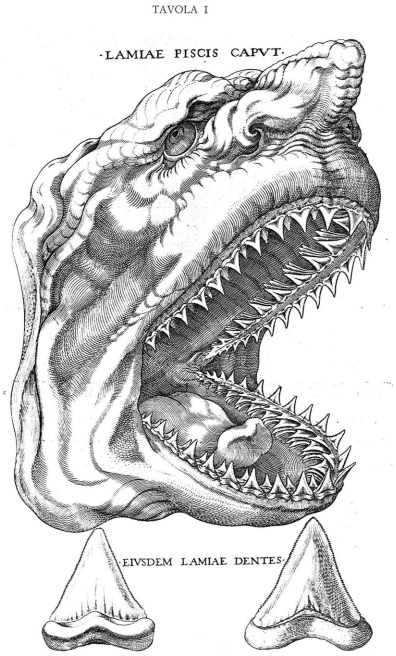
Try it and see. A body fossil tells you what an animal looked like. A trace fossil tells you what it was doing. A trackway can show which way an animal walked, whether it was walking or running, and whether several animals traveled together. Track scientists also use a rough rule: an animal’s hip height is about 4 times the length of its footprint. A 10-inch footprint means hips about 40 inches off the ground, a little higher than a kitchen counter.

God’s handiwork. Footprints are delicate. Rain, wind or the next wave can wipe a print away in minutes. For a track to become a fossil, it must be covered gently but quickly by fresh sediment soon after it was made. Every fossil footprint is a moment kept safe. When we study tracks, bones and shells, we are doing what Psalm 111:2 describes: seeking out the works of the Lord with delight.



How a mold and a cast form. The mold is the hollow; the cast is the solid copy that fills it.

PICTURE STUDY



The Head of a Shark and Its Teeth, from Steno's Book on the Shark, Nicolas Steno (engraved for his book), 1667 · Copper engraving printed in a book · From Steno's *Elementorum myologiae specimen*, printed in Florence; copies in many rare-book libraries

In 1666 fishermen near the Italian coast caught a huge shark. Its head was sent to Florence, where the young Danish scientist Nicolas Steno studied it. He compared the shark's teeth with the "tongue stones" people dug out of hillsides and found they were the same shape. He decided the stones were teeth from sharks that had once lived where the rocks now lie.

Steno had this picture engraved for the little book he wrote about the shark in 1667. You met Steno before, when you learned about rock layers. Later in life he became a bishop, but he never lost his love of studying God's works closely.

Look closely

- Find the shark's open jaws. How many rows of teeth can you see?
- Find the teeth drawn by themselves. What shape are they?
- Look at the edges of the teeth. Are they smooth or jagged?
- Where is the shark's eye? How big is it compared with the head?

Talk about it

1. Why was it a good idea for Steno to compare the tongue stones with a real, living animal?
2. Is a fossil shark tooth a body fossil or a trace fossil? How do you know?

> **Safety first.** A grown-up should mix the plaster of Paris. Do not breathe the dry powder, and keep it away from eyes. Plaster gets warm as it hardens: never put a hand or any

> body part into wet plaster to make a cast. Throw leftover plaster in the trash, never down a sink or drain, because it hardens in pipes.

EXPERIMENT: MAKE MOLDS AND CASTS

Question: **Does pressing an object harder into clay make a deeper, clearer mold?** You will press shells and a toy dinosaur foot into clay to make molds, measure how deep they are, and then fill them with plaster to make casts, just as nature does.

You will need

- Modeling clay or play dough, rolled into three flat pancakes about 1 inch thick
- Three of the same kind of object: shells, leaves or toy dinosaur feet
- A toothpick and a ruler with millimeters
- Petroleum jelly or cooking oil (a thin coat helps the cast come out)
- Plaster of Paris, water, a paper cup and a craft stick for stirring
- Strips of cardboard and tape to make a wall around each mold
- Lab notebook and pencil

Steps

1. Prediction: write whether you think a hard press, a medium press or a light press will make the clearest mold.
2. Press one object lightly into the first clay pancake, one medium into the second, and one as hard as you can into the third. Lift each object out carefully.
3. Measure the depth of each mold: stand the toothpick in the deepest spot, pinch it at the clay surface, and hold it against the ruler. Record the depth in millimeters.
4. Look closely and give each mold a score for clearness: 1 (blurry), 2 (some details) or 3 (sharp details).
5. Wrap a cardboard strip around each mold and tape it to make a little wall. Brush a thin coat of oil inside each mold.
6. With a grown-up, mix plaster and water in the cup until it is like thick pancake batter. Pour it into each mold until it is about half an inch deep.
7. Wait about an hour, then peel away the clay. You now have a cast. Compare each cast with its mold and record which press made the best cast.

Tips

- What we change: how hard we press. What we keep the same: the clay, the kind of object and the plaster. What we measure: the depth of each mold and its clearness score.
- Label each cast on the back with a pencil, such as “light press, shell.”
- Make one set of dinosaur tracks in a row, a trackway, and cast them too.

Check your work

- I can show which of my fossils is a mold and which is a cast.
- I can read my table and tell which press made the deepest and clearest mold.
- I can explain how nature makes a mold and a cast.

FIELD NOTEBOOK

1. Fold a page in half. Title one side “Body Fossils” and the other “Trace Fossils.” Draw and label at least three examples on each side.
2. Draw Pliny Moody’s slab with its three-toed footprints. Measure a three-toed track you made in clay and write its length in inches and centimeters.
3. Draw your shell mold and your shell cast side by side. Label which is hollow and which is solid.

> **From history.** Edward Hitchcock gathered one of the largest collections of fossil footprints in the world, and in 1858 he published a big book about them called *Ichnology of New England*. (Ichnology means “the study of tracks.”) Hitchcock was a Christian minister as well as a scientist and later served as president of Amherst College. Many of his stone slabs are still kept at Amherst College in Massachusetts, where visitors can see them today.

WORKED EXAMPLES

Example 1. Sort these six fossils into body fossils and trace fossils: a leg bone, a footprint, a clam shell, a worm burrow, a shark tooth, a petrified log. How many are in each group?

1. Ask of each one: is it part of the living thing, or a sign of what it did?
2. Parts of the living thing: leg bone, clam shell, shark tooth, petrified log. These are body fossils.
3. Signs of what it did: footprint (walking) and worm burrow (digging). These are trace fossils.

Answer: Body fossils: leg bone, clam shell, shark tooth, petrified log (4). Trace fossils: footprint, worm burrow (2).

Example 2. A three-toed fossil footprint is 10 inches long. Use the track scientists' rule (hip height is about 4 times the footprint length) to estimate how high the animal's hips were. One inch is about 2½ centimeters. Give both answers in centimeters too.

1. Hip height ≈ 4 × footprint length = 4 × 10 inches = 40 inches.
2. Footprint in centimeters: 10 × 2½ = 25 cm.
3. Hip height in centimeters: 40 × 2½ = 100 cm, which is 1 meter.
4. Compare: 40 inches is a little higher than a kitchen counter.

Answer: The hips were about 40 inches high. The footprint is about 25 cm long and the hips about 100 cm (1 meter) high.

PRACTICE

1. EASY Is a dinosaur footprint a body fossil or a trace fossil?
2. EASY Which is hollow, a mold or a cast?
3. MEDIUM A footprint is 12 inches long. Using the rule "hip height is about 4 times the footprint length," how many inches high were the animal's hips? How many feet is that?
4. MEDIUM A trackway has 6 footprints in a straight line. Each footprint is 3 feet from the next one. How far is it from the first footprint to the last?
5. HARD On a fossil hunt a family found: 8 shells, 3 shark teeth, 1 footprint and 2 pieces of petrified wood. (a) How many fossils did they find in all? (b) How many were body fossils? (c) Which kind did they find most?
6. CHALLENGE Write two or three sentences: What can a trackway tell us that a skeleton cannot?

COMMON MISTAKES

- Thinking only bones count as fossils. Footprints, burrows, molds and even fossil droppings are fossils too.
- Mixing up a mold and a cast. The mold is the hollow print; the cast is the solid copy that fills it.
- Thinking petrified wood is still wood. Minerals have filled and replaced it, so it is heavy stone that only keeps the wood's shape and rings.

Make it a game · Body or Trace?. A parent calls out a fossil: "shark tooth," "burrow," "seashell," "nest of eggs," "bite mark," "leaf," "footprint," "petrified log." If it is a body fossil, stand up tall like a skeleton. If it is a trace fossil, stomp your feet like a walking dinosaur. Score a point for each right answer. For a bonus point, say whether it could be a mold or a cast. Play to ten points.

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

Steno with his shark and Hitchcock with his footprints both took delight in seeking out God’s works. A fossil hunter is someone who enjoys searching carefully.

Practice answers

1. A trace fossil, because it shows what the animal did (walked), not a part of its body.
2. A mold is hollow. A cast is the solid copy that fills it.
3. 4 × 12 = 48 inches. Since 12 inches make 1 foot, 48 inches = 4 feet.
4. There are 5 spaces between 6 footprints. 5 × 3 = 15 feet.
5. (a) 8 + 3 + 1 + 2 = 14 fossils. (b) Body fossils: 8 + 3 + 2 = 13 (only the footprint is a trace fossil). (c) Shells.
6. A trackway shows the animal alive and moving. It can tell which way it walked, whether it walked or ran, how long its steps were, and whether several animals traveled together. A skeleton shows the body’s shape but not what the animal was doing.

5.3 Fossil Fish Caught Swallowing Fish

OBJECTIVES

- Tell the story of George F. Sternberg's "fish-within-a-fish" and explain why fossils caught in the middle of an action point to very quick burial.
- Use the words predator, prey and stomach contents to describe a fossil.
- Build a scale model of the two fish (1 inch for every foot) and compare their lengths in feet, inches and meters.

Warm-up. Take a photo, or just freeze like a statue, in the middle of an action: reaching for a cookie, jumping, or throwing a ball. A snapshot catches one moment. If someone found only that snapshot, what could they figure out about what you were doing? What would they not know?

Video. Coming soon. The Xiphactinus "fish within a fish" fossil at the Sternberg Museum and Green River fossil fish swallowing smaller fish at Fossil Butte; search National Park Service, Sternberg Museum of Natural History, Smithsonian, SciShow Kids, Homeschool Pop (Alternate) and Institute for Creation Research kids.

KEY TERMS

predator
An animal that hunts and eats other animals.

prey
An animal that is hunted and eaten by another animal.

stomach contents
Food found inside the belly of a fossil animal, showing what it ate last.

preserved
Kept safe from rotting or breaking apart, so that its shape lasts.

scale model
A copy of something made larger or smaller, with every part shrunk or grown by the same amount, such as 1 inch for every foot.

CORE IDEAS

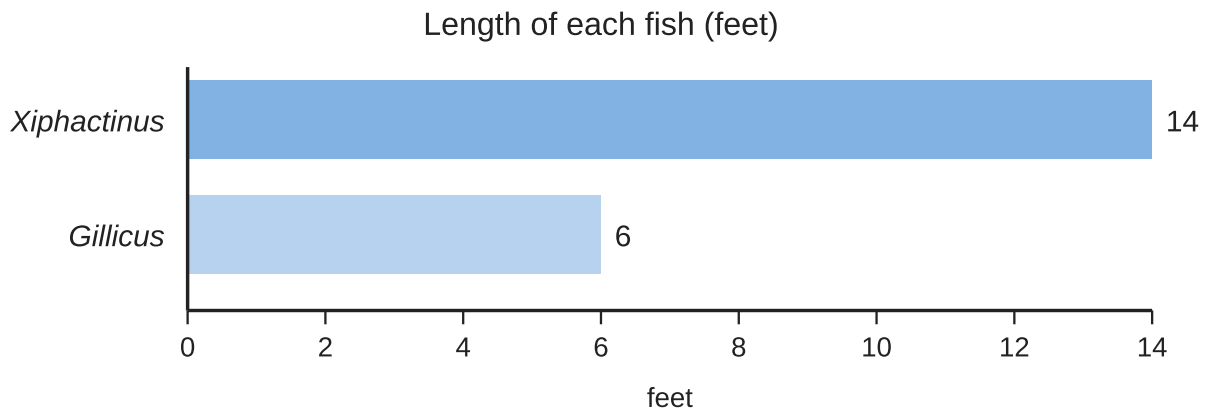
The story. In 1952 a fossil hunter named George F. Sternberg was digging in the chalk hills of western Kansas, far from any ocean. Out of the white rock came a giant fish called *Xiphactinus* (zy-FAK-tih-nus), about 14 feet long, with a bulldog face and fangs. But that was not the surprise. Inside its belly lay another whole fish, a *Gillicus* about 6 feet long. The big fish had swallowed it whole! Today this "fish-within-a-fish" hangs on the wall of the Sternberg Museum of Natural History in Hays, Kansas, and visitors still gasp when they see it.

How they figured it out. Look closely and you can tell how fast things happened. The bones of the swallowed fish are still in place, not digested or broken up. A fish's stomach starts digesting its meal right away, so the big fish must have died very soon after eating, perhaps because its prey was too big and hurt it from the inside. Then both fish were buried before they could rot or be torn apart by other fish. Fossils like this are found in other places too. In the rock layers of Fossil Butte, Wyoming (part of the same Green River rocks you saw in Thomas Moran's cliffs), small fish have been found with even smaller fish stuck halfway down their throats.

The big idea. A fossil caught in the middle of an action is like a snapshot. A fish does not stay half-swallowed for long. It either finishes its meal or spits it out in seconds. For the fossil to show the **predator** with its **prey** still in its mouth or belly, the animal had to be killed and buried almost at once. These fossils of **stomach contents** also tell us what ancient animals ate, which no bone by itself could prove.

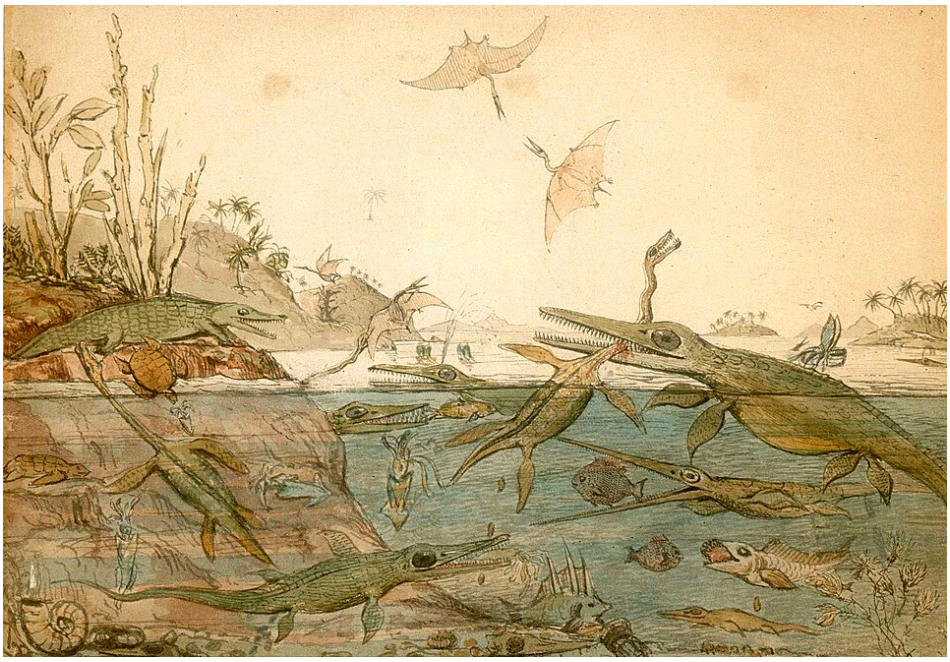
Try it and see. How big was this meal? Make a **scale model**, letting 1 inch stand for 1 foot. Cut a paper fish 14 inches long and another 6 inches long, then lay the small one inside the big one. In meters, the big fish was a little more than 4 meters long and the small one almost 2 meters, longer than most grown men are tall!

God's handiwork. The psalmist marveled at the sea, full of creatures "both small and great" (Psalm 104:25). Fish like these were wonderfully made swimmers. Their fossils also remind us that creatures die and eat one another, part of a world spoiled by sin (Romans 5:12) and waiting for the day God makes all things new. Many creation geologists read these sudden burials as part of the Flood, when great masses of mud could catch even a fish at its dinner.



The predator and its prey, side by side. The big fish was more than twice as long as the fish it swallowed.

PICTURE STUDY



Duria Antiquior (A More Ancient Dorset), Henry De la Beche, 1830 · Watercolor (later printed as a lithograph) · National Museum Cardiff, Wales

Henry De la Beche was an English geologist who grew up near Lyme Regis and hunted fossils there with Mary Anning. In 1830 he painted this imaginary scene of the sea creatures whose bones Mary had found. Prints were sold to raise money to help her.

This is one of the very first pictures ever made to show fossil animals as living creatures. Almost every animal in it is eating or being eaten, because De la Beche wanted to show what the fossils told him about how these creatures hunted.

Look closely

- Find a long-necked sea reptile being bitten. Who is biting it?
- Find the flying creatures in the sky. What are they doing?
- Count how many animals you can find that are attacking or being attacked.
- Find something in the picture that De la Beche could have seen in a real fossil, and something he had to imagine.

Talk about it

1. Which parts of a picture like this come from observation (real bones), and which come from the painter’s imagination?
2. If you painted the Kansas “fish-within-a-fish” as a living scene, what would you show happening just before it was buried?

EXPERIMENT: A FISH-WITHIN-A-FISH SCALE MODEL

Question: **Could a 14-foot fish fit a 6-foot fish inside its body?** You will make a scale model where 1 inch stands for 1 foot, measure carefully, and test whether the small fish fits inside the big one. Then you will press your model into clay to make a fossil mold.

You will need

- Two sheets of paper taped end to end (or a paper grocery bag cut open)
- Ruler or yardstick with inches and centimeters
- Pencil, crayons and scissors
- A flat slab of modeling clay or play dough about 15 inches long (or a smaller slab for a half-size model)
- Lab notebook

Steps

1. Prediction: write whether you think the 6-foot fish will fit inside the 14-foot fish with room to spare.
2. Draw a straight line 14 inches long. Around it, draw a big, deep-bodied fish with a large mouth, so that it is 14 inches from nose to tail. This is *Xiphactinus*.
3. Draw a slimmer fish 6 inches long. This is *Gillicus*. Cut out both fish.
4. Lay *Gillicus* on top of *Xiphactinus*, inside the belly area. Measure how many inches of the big fish are left over in front of and behind the small fish.
5. Record in a table: Fish, Real length (feet), Model length (inches), Model length (centimeters). Use 1 inch ≈ 2½ cm.
6. Press both paper fish gently onto the clay slab, the small one inside the big one, and trace around them with a toothpick or pencil tip to make a “fossil” outline.
7. Write a sentence answering the question: did the small fish fit, and what does that tell you about how big a meal it was?

Tips

- What we change: nothing; this is a measuring test. What we keep the same: the scale, 1 inch for every foot. What we measure: the length of each model fish and the space left over.
- A real *Xiphactinus* was not much wider at the belly than its prey, which is one reason scientists think the meal was too big for it.

Check your work

- I can explain what “1 inch stands for 1 foot” means.
- I can measure my model fish in inches and change the lengths to centimeters.
- I can explain why a fish caught with its prey inside tells us it was buried quickly.

FIELD NOTEBOOK

1. Draw the “fish-within-a-fish” as it looks in the rock. Label the predator, the prey and the stomach contents.
2. Draw a three-box comic strip: the big fish swallows, the big fish dies, mud buries both. Write a caption under each box.
3. Make a list of three things a predator-and-prey fossil can tell a scientist that a single bone cannot.

> **From history.** George F. Sternberg came from a famous fossil-hunting family. His father, Charles H. Sternberg, spent his whole life digging fossils in Kansas, Wyoming and Canada with his three sons, and he wrote a book about his adventures called *The Life of a Fossil Hunter* (1909). The Sternbergs found and prepared fossils for museums all over the world, and today a museum in Hays, Kansas, carries the family’s name.

WORKED EXAMPLES

Example 1. *Xiphactinus* was about 14 feet long and the *Gillicus* inside it was about 6 feet long. In a scale model where 1 inch stands for 1 foot, how long is each model fish? How much longer is the big model than the small one?

(Use the map or drawing “Read each bar against the scale of feet.” shown earlier in this lesson.)

1. 1 inch stands for 1 foot, so 14 feet becomes 14 inches.
2. 6 feet becomes 6 inches.
3. Difference: $14 - 6 = 8$ inches.

Answer: The big model is 14 inches long, the small model is 6 inches long, and the big one is 8 inches longer.

Example 2. How many 6-foot *Gillicus* fish, laid nose to tail, would be as long as one 14-foot *Xiphactinus*?

1. One fish: 6 feet. That is less than 14.
2. Two fish: $6 + 6 = 12$ feet. Still less than 14.
3. Three fish: $12 + 6 = 18$ feet. That is more than 14.
4. So two whole fish fit, with $14 - 12 = 2$ feet left over.

Answer: A little more than 2 of them: two *Gillicus* make 12 feet, 2 feet short of the big fish.

PRACTICE

1. EASY In the Kansas fossil, which fish was the predator and which was the prey?

2. EASY What are stomach contents, and what do they tell scientists?
3. MEDIUM A Wyoming fossil shows a fish 10 inches long with a smaller fish 4 inches long stuck in its mouth. How much longer is the big fish? Is the small fish more or less than half as long as the big one?
4. MEDIUM One foot is about 30 centimeters. About how many centimeters long was the 6-foot *Gillicus*?
5. HARD Use this table of lengths: *Xiphactinus* 14 feet; *Gillicus* 6 feet; a third grader 4 feet; a family car 15 feet. (a) Which is closest in length to *Xiphactinus*? (b) How many third graders lying head to toe make 12 feet? (c) Which two lengths add up to 10 feet?
6. CHALLENGE In two or three sentences, explain what the “fish-within-a-fish” tells us about how quickly the big fish was buried.

COMMON MISTAKES

- Thinking fish fossils in Kansas or Wyoming mean those places are near the sea today. The fish lived in water that once covered the land where their fossils are now found.
- Thinking a painting of fossil animals is a photograph. Bones are observations; colors, skin and the action around them are the artist’s best guess.
- Thinking a fossil predator swallowing prey could lie on the sea floor for a long time. The meal would be digested and the bodies would rot or be eaten; only fast burial keeps the scene.

Make it a game · Freeze-Frame Fossils. Play music or have a parent clap. Everyone moves like a sea creature: swimming, chasing, gulping or hiding. When the music stops, the parent shouts “Mudslide!” and everyone freezes in place. The parent walks around as the museum scientist and guesses what each frozen “fossil” was doing. If the guess is right, the scientist scores a point; if wrong, the fossil scores a point. Talk about it: why is a fossil frozen in the middle of an action a clue that burial was sudden?

Scripture. “So is this great and wide sea, wherein are things creeping innumerable, both small and great beasts.” (Psalm 104:25, KJV)

The sea God made is full of creatures too many to count, from tiny fish to fourteen-foot giants. Their fossils let us see some of them, even catching them at dinner.

Practice answers

1. *Xiphactinus*, the big fish, was the predator. *Gillicus*, the fish it swallowed, was the prey.
2. Stomach contents are food found inside a fossil animal’s belly. They show what the animal ate last.
3. 10 − 4 = 6 inches longer. Half of 10 is 5, so the 4-inch fish is less than half as long.
4. 6 × 30 = 180 centimeters (almost 2 meters).
5. (a) The family car (15 feet, only 1 foot longer). (b) 12 ÷ 4 = 3 third graders. (c) *Gillicus* and the third grader: 6 + 4 = 10 feet.

6. The swallowed fish was still whole and not digested, so the big fish died very soon after eating. Both fish are complete, so they were buried before they could rot or be eaten by scavengers. That means burial happened very quickly, soon after the meal.

5.4 Polystrate Tree Fossils at Joggins, Nova Scotia

OBJECTIVES

- Tell how Charles Lyell and William Dawson studied the upright fossil trees in the sea cliffs at Joggins, Nova Scotia.
- Explain what a polystrate fossil is and why a trunk standing through several layers shows those layers were laid down before the tree could rot.
- Read the “Thinking About Time” box and tell the difference between what we observe at Joggins and how people interpret it.

Warm-up. Stand a pencil upright in an empty cup. Now pour in a spoonful of rice, then a spoonful of dried beans, then more rice, until the pencil is half buried. How many layers does your pencil pass through? What would happen to the pencil if you waited a very long time between spoonfuls, and it were a real tree trunk out in the rain?

Video. Coming soon. Joggins Fossil Cliffs upright fossil trees, Bay of Fundy tides, and polystrate fossils and the Spirit Lake upright logs at Mount St. Helens; search UNESCO World Heritage, Joggins Fossil Cliffs, Nova Scotia museums, Institute for Creation Research, Creation Ministries International.

KEY TERMS

polystrate fossil
A fossil, often an upright tree trunk, that passes through two or more rock layers. “Poly” means many and “strate” means layers.

stratum
One layer of rock. More than one layer are called strata.

scale tree
A tall tree with bark covered in diamond-shaped scars like scales, often found as fossils in coal-bearing rocks. No trees quite like them grow today.

coal seam
A layer of coal in the rock, made from squeezed and buried plants.

tide
The daily rise and fall of the sea along the shore.

CORE IDEAS

The story. In 1842 the famous British geologist Charles Lyell sailed to Nova Scotia, Canada, to see the sea cliffs at a place called Joggins on the Bay of Fundy. The tides in this bay are among the highest in the world, rising more than 40 feet. Twice a day the sea crashes against the cliffs, and as the soft rock wears away, new fossils come into view. Lyell saw something wonderful: stone tree trunks standing straight up in the cliff, some taller than a

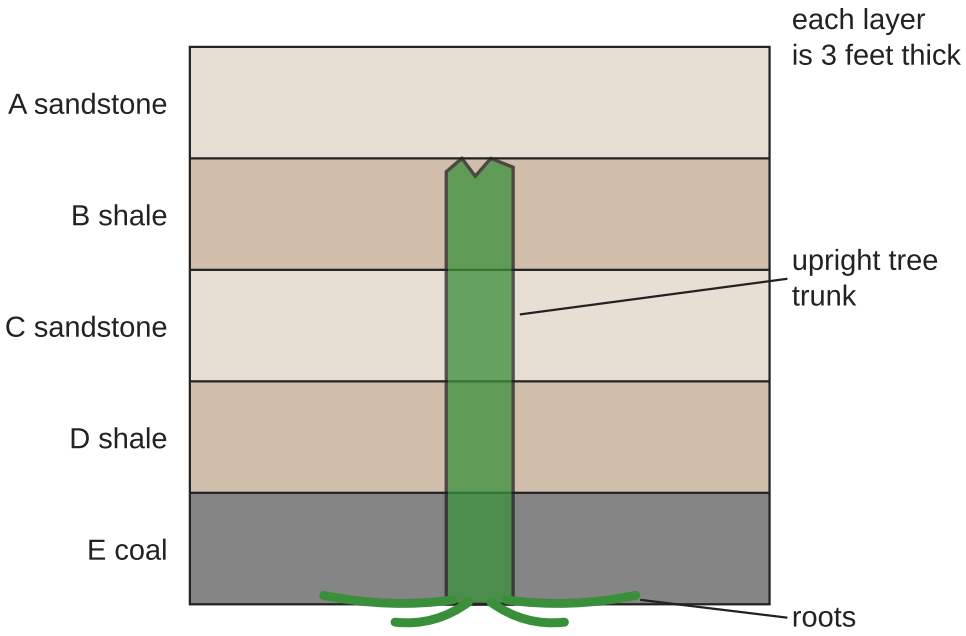
man. Ten years later he came back with a Nova Scotia scientist, John William Dawson. Inside one hollow fossil stump they found the tiny bones of small animals that had fallen in or crawled in.

How they figured it out. The trunks at Joggins are not lying down. They stand upright and pass right through several layers of sandstone, shale and coal. A fossil that crosses many layers is called a **polystrate fossil**. Many of the trees are **scale trees**, with bark marked by rows of diamond-shaped scars. Some still have their roots spreading out at the bottom. The wood itself is gone; the hollow trunks were filled with sand and mud that hardened into stone casts. Upright trees appear at many different levels in the cliff, one above another.

The big idea. A dead tree standing in a swamp or forest does not last long. Fungi, insects and weather rot it and knock it down. So a trunk that stands through four layers tells us something everyone can agree on: all four layers must have piled up around it **before** the top of the tree could rot away. Those layers were laid down quickly. Look at the diagram and count how many strata one trunk crosses.

Try it and see. In 1980 Mount St. Helens erupted in Washington State. The blast knocked down whole forests, and a giant wave in Spirit Lake washed thousands of trees into the water, where they floated as a great mat of logs. Creation geologists who studied the lake with divers saw that many waterlogged logs sank root end first and settled upright on the lake bottom, where mud began to bury them. In this lesson’s experiment you will test whether a stick with a heavy “root ball” sinks upright.

God’s handiwork. Joggins is now a World Heritage Site, protected so that visitors can walk the beach at low tide and see the stone trees for themselves. The trees that once grew there were made by the same Creator who “planted” the cedars of Lebanon (Psalm 104:16). Read the “Thinking About Time” box to see how different people explain these upright trees.



A polystrate tree trunk stands through four layers, B, C, D and E. All four had to pile up before the trunk could rot.

⏳ Thinking About Time

What the sign says. What the sign says: Museum signs call the Joggins rocks part of the "Coal Age," or the *Carboniferous* period. They say forests grew here again and again over an extremely long time. Each time, a river flood buried a forest quickly, and then a new forest grew on top of the mud.

What we observe. What we observe: Upright stone trunks pass through several layers of rock. They appear at many levels in the cliff. Some have roots, and some hollow stumps were filled with sand and hold the bones of small animals. A standing dead tree rots and falls in a short time, so each trunk was buried quickly.

How Christians read it. How Christians read it: Many creation geologists read Joggins as a Flood deposit. They think uprooted trees floated in huge log mats and sank upright, as logs did in Spirit Lake after Mount St. Helens, and were buried layer upon layer within a short time. Some creation scientists think a few trees may have grown in place before rising waters buried them. Either way, the upright trees show quick burial.

Try it. Look at the diagram and ask: if each layer took a very long time to form, what would have happened to the top of the trunk?

Genesis 7:11

PICTURE STUDY



An Upright Fossil Tree in the Cliffs at Joggins, Nova Scotia, Engraving made for John William Dawson's book *Acadian Geology*, 1868 · Engraving printed in a book · From the second edition of Dawson's *Acadian Geology* (London, 1868); copies in many libraries

John William Dawson walked the Joggins shore many times, first with Charles Lyell in 1852 and then on his own. In his book *Acadian Geology*, about the rocks of Nova Scotia and its neighbors, he printed careful pictures of what he saw, including this upright fossil tree standing in the cliff.

A drawing like this is not a work of fine art. It is a careful scientific record, made so that readers far away could see what the scientist saw and check it for themselves.

Look closely

- Find the tree trunk. Is it standing up or lying down?
- Count how many layers of rock the trunk passes through.
- Look at the bottom of the trunk. Can you see anything like roots?
- Look at the top of the trunk. Is it whole, or broken off?

Talk about it

1. Why is a careful drawing useful to scientists who cannot travel to the place themselves?
2. What is one thing you observe in the picture, and one question you would want to ask Dawson about it?

> **Safety first.** Work with water on a towel or outdoors and wipe up spills right away so no one slips. Use a plastic tub or tall plastic container rather than glass. Wash your hands

> after handling the sand or soil.

EXPERIMENT: DO LOGS SINK UPRIGHT? A SPIRIT LAKE TEST

Question: **Does a log with a heavy root end sink upright more often than a log without one?** You will make model logs, drop them into deep water, and count how many land standing up. Then you will bury the upright ones in layers of sand and soil to make your own polystrate “fossil.”

You will need

- Six straight sticks or unsharpened pencils of the same length (about 6 inches)
- Modeling clay (a ball about the size of a grape for each of three sticks)
- A tall clear plastic container or tub at least 8 inches deep, filled with water
- A cup of sand and a cup of garden soil
- A ruler with inches and centimeters
- Lab notebook and pencil

Steps

1. Press a grape-sized ball of clay onto one end of three sticks. These are the “root ball” logs. Leave the other three sticks plain.
2. Prediction: write which kind of log you think will land upright more often.
3. Hold a plain stick lying flat just above the water and let it go. If it floats, gently push it down and let go under the water. Record whether it ends upright, leaning or lying flat. Do this 5 times.
4. Do the same thing 5 times with a root-ball log.
5. Make a tally table: Kind of log, Upright, Leaning, Lying flat.
6. Stand one root-ball log upright on the bottom. Gently pour in a layer of sand, then a layer of soil, then sand again. Measure each layer’s thickness against the side of the container.
7. Count how many layers your log passes through, and write a sentence about what your test shows.

Tips

- What we change: whether the log has a heavy root end. What we keep the same: the sticks, the water depth and the way we let go. What we measure: how many logs land upright out of 5.
- Real waterlogged logs at Spirit Lake took time to soak up water before they sank. Your clay does the same job by making one end heavy.

Check your work

- I can name what I changed, what I kept the same and what I measured.
- I can read my tally table and say which kind of log landed upright more often.

- I can count the layers my model trunk passes through and explain what a polystrate fossil is.

FIELD NOTEBOOK

1. Draw a cliff with five layers and one upright tree trunk passing through three of them. Label the strata and the trunk, and write “polystrate fossil” as the title.
2. Draw a piece of scale-tree bark with its diamond-shaped scars. Look at a pinecone or pineapple skin and compare the pattern.
3. Make a two-column page titled “Observe” and “Interpret.” Write two things we can see at Joggins on one side and two explanations people give on the other.

> **From history.** John William Dawson, Lyell’s guide at Joggins, grew up in Pictou, Nova Scotia, and became one of Canada’s leading scientists and the head of McGill University in Montreal. In 1860 he named one of the little animals from the hollow stumps *Hylonomus lyelli*, after his friend Lyell. Dawson was a devoted Christian who wrote many books about how the study of nature points to God the Creator.

WORKED EXAMPLES

Example 1. Look at the diagram. Through how many layers does the upright trunk pass? In which layer are its roots?

(Use the map or drawing “Count the layers the trunk crosses.” shown earlier in this lesson.)

1. Start at the bottom of the trunk. The roots spread out at the bottom of layer E (coal).
2. Move up the trunk: it passes through E, then D, then C, then B.
3. The trunk is broken off at the top of layer B and does not reach layer A.
4. Count the layers: E, D, C, B make 4.

Answer: The trunk passes through 4 layers (B, C, D and E). Its roots are in layer E.

Example 2. In the diagram, each layer is 3 feet thick and the trunk fills 4 whole layers. How tall is the fossil trunk? One foot is about 30 centimeters. About how many centimeters is that?

1. The trunk crosses 4 layers, each 3 feet thick: $4 \times 3 = 12$ feet.
2. Change to centimeters: $12 \times 30 = 360$ centimeters.
3. Since 100 centimeters make 1 meter, 360 cm is a little more than 3½ meters.

Answer: The trunk is about 12 feet tall, about 360 centimeters (a little more than 3½ meters).

PRACTICE

1. EASY What does “polystrate” mean?
2. EASY Where are the Joggins Fossil Cliffs, and what washes against them twice a day?
3. MEDIUM The tide at Joggins can rise 40 feet. If a third grader is 4 feet tall, how many third graders standing on each other’s heads would reach as high as the tide?
4. MEDIUM An upright fossil trunk is 15 feet tall. It passes through layers that are each 5 feet thick. How many layers does it cross? About how many centimeters tall is it (1 foot is about 30 cm)?
5. HARD A class did the sinking-log test. Plain sticks: 1 upright out of 5. Root-ball sticks: 4 upright out of 5. (a) How many more root-ball sticks landed upright? (b) How many plain sticks did not land upright? (c) What does the test suggest?
6. CHALLENGE Explain in two or three sentences why an upright fossil tree that passes through four layers tells us those four layers were laid down quickly.

COMMON MISTAKES

- Thinking every rock layer took a very long time to form. An upright trunk through several layers shows those layers piled up quickly.
- Thinking the stone trunks are still wood. At Joggins the wood is gone, and most trunks are casts of sand and mud that filled the hollow tree.
- Mixing up what we observe with how we interpret it. Upright trunks, roots and layers are observations; how and when they got there is an interpretation.

> **Make it a game · Observe or Interpret?.** A parent reads a sentence about Joggins, such as “The trunk passes through four layers,” “The trees floated in from far away,” “The stump has roots,” or “A flood buried the trees.” If the sentence is something you can see or measure, shout “Observe!” If it is an explanation of how it happened, shout “Interpret!” Score a point for each right answer. Then switch and make up sentences for your parent.

> **Scripture.** “The trees of the LORD are full of sap; the cedars of Lebanon, which he hath planted;” (Psalm 104:16, KJV)

Every tree, living or turned to stone, was first planted by God. The fossil trees at Joggins were once full of sap and growing, before water and mud buried them standing up.

Practice answers

1. Many layers. A polystrate fossil passes through two or more rock layers.
2. In Nova Scotia, Canada, on the Bay of Fundy. The very high tides wash against them.
3. 40 ÷ 4 = 10 third graders.
4. 15 ÷ 5 = 3 layers. 15 × 30 = 450 centimeters.
5. (a) 4 − 1 = 3 more. (b) 5 − 1 = 4 plain sticks did not land upright. (c) A log with a heavy root end is much more likely to sink and settle upright.

6. A dead tree left standing rots and falls down fairly soon. For the trunk to be buried standing up through all four layers, the layers had to pile up around it before the top could rot away. So the layers must have formed quickly.

Unit 5 review

Answer each question. Show your work for any measuring or arithmetic, and use complete sentences for explanations. Each question is worth 4 points, and the quiz is worth 40 points.

1. (4 pts) What is a fossil? Name the one step that must happen for almost every fossil to form.
2. (4 pts) Mary Anning's fish lizard skeleton was found with its backbone in a neat row. What does this tell us, and why?
3. (4 pts) A toy fish 5 centimeters tall sits in a jar. Each pour of mud adds 2 centimeters. How many pours are needed to cover it completely?
4. (4 pts) Identify each as a body fossil or a trace fossil: (a) shark tooth, (b) dinosaur footprint, (c) worm burrow, (d) petrified log.
5. (4 pts) What is the difference between a mold and a cast?
6. (4 pts) A fossil footprint is 9 inches long. Track scientists say hip height is about 4 times the footprint length. About how high were the animal's hips? What did Nicolas Steno discover "tongue stones" really were?
7. (4 pts) In the Kansas "fish-within-a-fish," the big *Xiphactinus* was about 14 feet long and the *Gillicus* inside was about 6 feet long. Which was the predator? How much longer was it than its prey?
8. (4 pts) Why does a fossil fish with an undigested fish inside show that it was buried very quickly?
9. (4 pts) What is a polystrate fossil? Where are the famous upright fossil trees that Charles Lyell visited?
10. (4 pts) An upright fossil trunk passes through 4 layers that are each 3 feet thick. How tall is it? Is "the trunk passes through 4 layers" an observation or an interpretation?

Unit project: my fossil museum drawer

Make a small fossil museum in a shoebox lid or an egg carton. Include at least four fossils or models you made in this unit: a mold, a cast, a footprint trackway and your fish-within-a-fish or polystrate-tree model. You may add real fossils you have found or collected. Give each one a museum label card with its name, whether it is a body fossil or a trace fossil, and how it formed.

Add one large "museum sign" card for your favorite fossil with two sections: **What we observe** (things anyone can see or measure) and **What it tells us** (how quick burial explains it). Present your museum to your family and answer their questions like a real museum guide.

- **Accuracy**: Each fossil is correctly named and labeled as a body or trace fossil, mold or cast.
- **Observation and measurement**: Labels include at least two real measurements (in inches and centimeters) and careful descriptions of what can be seen.

- **Explanation**: The museum sign clearly separates observations from interpretations and explains why quick burial was needed.
- **Care**: The display is neat, the labels are easy to read, and the presentation is clear and confident.

Answer key

1. A fossil is the remains or a trace of a living thing preserved in rock. The plant or animal must be buried quickly by sediment such as mud or sand.
2. It was buried quickly. Otherwise scavengers and rot would have pulled the bones apart and scattered them.
3. 3 pours (2, 4, then 6 cm, which is more than 5 cm).
4. (a) body, (b) trace, (c) trace, (d) body. One point each.
5. A mold is the hollow print left in rock. A cast is the solid copy made when minerals or sediment fill the mold and harden.
6. $4 \times 9 = 36$ inches (3 feet). Tongue stones were fossil shark teeth.
7. *Xiphactinus* was the predator. $14 - 6 = 8$ feet longer.
8. The prey would have been digested, and both bodies would have rotted or been eaten, if they were not buried soon after the meal. The whole prey shows the big fish died and was buried very quickly.
9. A fossil, often an upright tree trunk, that passes through two or more rock layers. They are at Joggins, Nova Scotia, Canada, on the Bay of Fundy.
10. $4 \times 3 = 12$ feet tall. It is an observation, because we can see and count it.

UNIT 6

Dinosaur Digs

In Unit 5 you learned how fossils form. Now you will follow the people who dig them up. You will meet Edward Drinker Cope and Othniel Charles Marsh, two scientists whose race for bones in the American West was called the **Bone Wars**. You will stand at the foot of a South Dakota cliff with Sue Hendrickson on the day in 1990 when she looked up and saw the bones of the T. rex now called Sue. Then you will go behind the scenes of a museum to see how a skeleton is cleaned, copied and stood up on a steel frame.

Last of all, you will look inside a dinosaur bone with Mary Schweitzer, who announced in 2005 that she had found soft, stretchy tissue in a T. rex leg bone. Along the way you will dig chocolate chips out of cookies, map a dig in a tub of sand, balance a model skeleton and turn a chicken bone to rubber with vinegar. You will also practice reading a museum sign about time carefully: what the sign says, what scientists actually observe, and how many Christians read it.

Through it all, remember that the great beasts are part of God's creation (Genesis 1:24–25). Digging, measuring and drawing them carefully and honestly is a way to marvel at His works.

BEFORE YOU BEGIN

- Can explain how a fossil forms by quick burial (Unit 5)
- Can measure length with a ruler in inches and feet
- Can add and subtract numbers to 100 and count by 2s, 4s, 5s and 10s
- Can find a square on a simple grid using a letter and a number

MASTERY CHECKLIST

- I can tell the story of Cope and Marsh and explain why careful digging matters.
- I can tell how Sue the T. rex was found and why paleontologists map bones with a grid.
- I can name the steps of mounting a skeleton and explain what an armature, a mold and a cast are.
- I can explain what Mary Schweitzer found and show the two parts of bone with a vinegar experiment.
- I can compare dinosaur sizes using feet and meters and read a simple bar graph.
- I can read a museum sign about time and tell what the sign says, what we observe and how Christians read it.

OPTIONAL BOOKS AND RESOURCES

- **Field Museum, Chicago (home of Sue the T. rex)** (https://www.fieldmuseum.org/): Free to browse. Search the site for "SUE" to find photos and facts about the skeleton you study in Lessons 6.2 and 6.3.

- **Yale Peabody Museum** (https://peabody.yale.edu/): Free to browse. The museum that holds much of O. C. Marsh's collection from the Bone Wars (Lesson 6.1).
- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free online. Look for photos of fossil preparation and mounted dinosaur skeletons. Signs use museum time words; use the ⏳ box from Lesson 6.4 to read them carefully.

6.1 The Bone Wars: Cope and Marsh ★

OBJECTIVES

- Tell the true story of Edward Drinker Cope and Othniel Charles Marsh and explain what the Bone Wars were.
- Name at least three dinosaurs that Cope or Marsh dug up and named, and read a bar graph of their lengths.
- Test whether slow, careful digging saves more “fossils” than fast digging, and explain why careful work matters in science.

Warm-up. Scatter a small handful of dry spaghetti broken into finger-length pieces on a towel. Give yourself 10 seconds to scoop up as many as you can into a bowl. Count how many pieces snapped into smaller bits. Now put them back and pick them up one at a time with care for 10 seconds. Which way broke fewer pieces? Which way was faster?

Video. Coming soon. The Bone Wars of Edward Drinker Cope and Othniel Charles Marsh, told for children; search the Yale Peabody Museum, American Museum of Natural History, Smithsonian National Museum of Natural History, Academy of Natural Sciences of Drexel University, Homeschool Pop (Alternate) and short museum history clips.

KEY TERMS

paleontologist
A scientist who digs up and studies fossils to learn about plants and animals that lived long ago.

fossil
The remains or traces of a living thing preserved in rock, such as a bone, shell, tooth or footprint.

excavate
To dig something out of the ground slowly and carefully so it is not broken.

quarry
A place where people dig rock out of the ground. A bone quarry is a spot full of fossil bones.

rival
A person who is trying to beat you at the same thing.

CORE IDEAS

The story. In 1868 a scientist named Othniel Charles Marsh came to visit his friend Edward Drinker Cope in New Jersey. Cope lived near Philadelphia, and Marsh worked at Yale College in Connecticut. Cope proudly showed his friend the marl pits, where workers dug a crumbly greenish earth and sometimes found big fossil bones. Soon after, Marsh quietly paid the pit

workers to send any new bones to *him* instead of to Cope. Then Cope made an embarrassing mistake. He rebuilt a long-necked sea reptile called *Elasmosaurus* and put its head on the end of its tail! Marsh and other scientists noticed, and Cope never forgot it. The two friends became **rivals**.

How they figured it out. In the 1870s, railroads were reaching across the American West, and digging crews found huge bones in places like Como Bluff in Wyoming and the hills of Colorado. Cope and Marsh each hired teams of diggers. They raced to **excavate** each **quarry**, packed the bones in wooden crates, and shipped them east by train. Each man tried to be the first to describe a new animal in print. Their crews spied on each other, and some were even said to smash leftover bones so the other side could not have them. People came to call this race the “Bone Wars.”

The big idea. A **paleontologist** is a scientist who studies **fossils**. Cope and Marsh were two of the most famous paleontologists in America, and together they named well over a hundred new kinds of animals. Marsh named *Stegosaurus*, *Triceratops*, *Allosaurus* and *Apatosaurus*. Cope named *Camarasaurus* and *Coelophysis*. But hurry caused mistakes. Marsh gave two names, *Apatosaurus* and *Brontosaurus*, to bones that later scientists decided came from the same kind of animal. (Some scientists today think they may be different after all, so the bones are still being studied.) Rushing gave America many new dinosaurs, but it also broke bones and mixed up names.

Try it and see. In this lesson you will dig “fossils” out of a cookie. Chocolate chips will be your bones. One cookie you will dig fast with a fork, like a crew in a hurry. The other you will dig slowly with a toothpick, like a careful scientist. Then you will count the whole chips and the broken chips. Real paleontologists today use brushes, dental picks and patience, and they sometimes spend weeks freeing a single bone.

God’s handiwork. The bones Cope and Marsh found are part of God’s creation, and studying them is good work. Sadly, pride turned two friends into enemies, and their fighting wasted time, money and fossils. The Bible says, “Only by pride cometh contention.” Good scientists work carefully, tell the truth about what they find and are glad when someone else discovers something wonderful too.

PICTURE STUDY



Leaping Laelaps, Charles R. Knight, 1897 · Watercolor · American Museum of Natural History, New York

Charles R. Knight was one of the first artists to paint dinosaurs as lively, moving animals instead of slow, lumpy lizards. In 1897 he visited Edward Drinker Cope in Philadelphia and talked with him about how this dinosaur might have moved. Cope had named it *Laelaps* from bones found in New Jersey.

Here is a Bone Wars surprise: Marsh pointed out that the name *Laelaps* had already been given to a tiny mite, so he gave the dinosaur a new name, *Dryptosaurus*. That is the name scientists use today, but Knight's painting still carries Cope's old name.

Look closely

- Find the dinosaur in the air. What are its feet and claws doing?
- Find the dinosaur on the ground. How is it trying to fight back?
- Look at the background. Is this a dry desert, or a place near water?
- Look at how the dinosaurs' tails and bodies are held. Do they look slow or quick?

Talk about it

1. Knight worked from bones and from talking with a scientist. Which parts of the picture could he learn from bones, and which parts did he have to imagine?
2. Why do you think this painting made people excited about dinosaurs?
3. If you could paint a dinosaur from Cope or Marsh, which would you choose, and what would it be doing?

> **Safety first.** Toothpicks and forks have sharp points; dig on a plate, point them away from your body and keep them away from eyes. Ask before eating any cookie pieces, and

> wash hands first if you plan to eat them.

EXPERIMENT: THE GREAT COOKIE DIG: FAST OR CAREFUL?

Cope's and Marsh's crews often dug in a hurry. Does digging fast break more fossils than digging slowly? You will find out like a real scientist, with a question, a prediction, a fair test and a record of what you measure.

You will need

- 2 chocolate chip cookies of the same kind and size (crunchy ones work best)
- A fork and a toothpick
- 2 paper plates labeled "Fast" and "Careful"
- A small paintbrush or clean makeup brush
- A timer or clock
- Notebook and pencil

Steps

1. **Question:** Write: "Does digging slowly with a small tool save more whole chips than digging fast with a big tool?"
2. **Prediction:** Write which cookie you think will have more whole chips, and why.
3. **Keep the same:** Use the same kind of cookie, the same size, and the same amount of time for each dig (3 minutes).
4. **What we change:** The digging style. Fast dig: use the fork and work quickly. Careful dig: use the toothpick and brush and work slowly.
5. Set the timer for 3 minutes and do the fast dig on the "Fast" plate. Put every chip you free beside the cookie.
6. Set the timer again and do the careful dig on the "Careful" plate.
7. **What we measure:** Count the whole chips and the broken chips (any chip in two or more pieces) on each plate.
8. **Record:** Make a table with three columns: Dig style, Whole chips, Broken chips. Fill it in.
9. Write one sentence telling whether your prediction was right, and one sentence about what this teaches about the Bone Wars.

Tips

- If chips are still stuck in the cookie when time runs out, count them as "not yet dug."
- Brush away crumbs the way a paleontologist brushes away sand, so you can see what you are doing.
- If two people do the test, each can do both digs and you can compare results.

Check your work

- I wrote a question and a prediction before I started.

- I kept the cookie, the size and the time the same.
- I counted whole and broken chips and recorded them in a table.
- I can explain why careful digging matters.

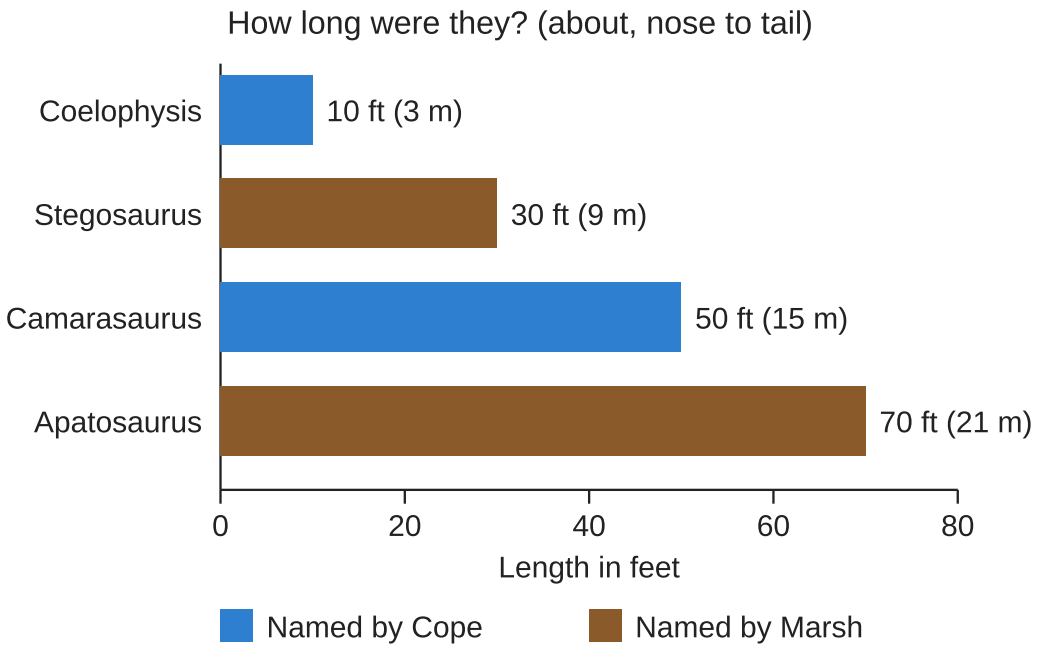
FIELD NOTEBOOK

1. Draw your two cookie plates after the dig. Label the whole chips and the broken chips.
2. Make a T-chart titled “Cope and Marsh” with two columns. Write each man’s name, where he worked and two dinosaurs he named.
3. Draw one of the dinosaurs from the bar graph and write its length in feet and in meters beside it.

> **From history.** The Bone Wars became front-page news in January 1890, when the *New York Herald* newspaper printed the two men’s angry charges against each other for everyone to read. Many of the bones they fought over are still studied today. Much of Marsh’s collection is at Yale’s Peabody Museum in New Haven, Connecticut, and much of Cope’s collection went to the American Museum of Natural History in New York.

WORKED EXAMPLES

Example 1. Look at the bar graph of dinosaur lengths. How much longer was *Apatosaurus* than *Stegosaurus*? Give the answer in feet and in meters.



Four dinosaurs named during the Bone Wars. Blue bars were named by Cope, brown bars by Marsh. Lengths are about, nose to tail.

1. Read the bar for *Apatosaurus*: about 70 feet (21 meters).
2. Read the bar for *Stegosaurus*: about 30 feet (9 meters).
3. Subtract the feet: 70 − 30 = 40 feet.
4. Subtract the meters: 21 − 9 = 12 meters.

Answer: *Apatosaurus* was about 40 feet (about 12 meters) longer than *Stegosaurus*.

Example 2. Historians often count about 80 new kinds of dinosaurs named by Marsh and about 56 named by Cope. Who named more, and how many more? How many did they name together?

1. Compare: 80 is more than 56, so Marsh named more.
2. Find the difference: 80 − 56. Take away 50 to get 30, then take away 6 more to get 24.
3. Find the total: 80 + 56. Add 80 + 50 = 130, then 130 + 6 = 136.

Answer: Marsh named about 24 more kinds than Cope. Together they named about 136 kinds of dinosaurs (and many other animals besides).

PRACTICE

1. EASY Which scientist worked at Yale College, Cope or Marsh? Which one lived near Philadelphia?
2. EASY Look at the bar graph. Which dinosaur was the shortest? About how long was it in feet and in meters?
3. MEDIUM How many *Coelophysis* lined up nose to tail would be as long as one *Apatosaurus*? (Use 10 feet and 70 feet.)
4. MEDIUM How much longer was *Camarasaurus* (50 feet, 15 meters) than *Stegosaurus* (30 feet, 9 meters)? Answer in feet and in meters.
5. HARD Ben did the cookie dig. Fast dig with a fork: 3 whole chips, 7 broken chips. Careful dig with a toothpick: 8 whole chips, 2 broken chips. Which dig saved more whole chips, and how many more? Name one thing Ben had to keep the same for a fair test.
6. CHALLENGE In two or three sentences, tell one way the Bone Wars helped science and one way they hurt it.

COMMON MISTAKES

- Thinking Cope and Marsh were always enemies. They began as friends who traded letters and visited each other before pride drove them apart.
- Thinking faster digging finds more fossils. Rushing breaks bones and loses clues; careful work saves more of what is there.
- Thinking every dinosaur name from long ago is still used. Some names, like *Laelaps*, were changed when scientists found mistakes or learned more.

> **Make it a game · Cope or Marsh?.** A parent reads a clue, such as “I named Stegosaurus,” “I put the head on the wrong end of Elasmosaurus,” “I worked at Yale,” or “I named Coelophysis.” Shout “Cope!” or “Marsh!” to score a point. For a bonus point, give the dinosaur’s length in feet from the bar graph. First to ten points wins, and the winner must shake hands and say “Well dug!” to the other player.

> **Scripture.** “Only by pride cometh contention: but with the well advised is wisdom.” (Proverbs 13:10, KJV)

Cope and Marsh were brilliant, but pride turned friends into rivals and caused fights that hurt their work. Wise people listen to good advice, admit their mistakes and share the joy of discovery.

Practice answers

1. Marsh worked at Yale College. Cope lived near Philadelphia.
2. *Coelophysis*, about 10 feet (3 meters) long.
3. 7, because 10 + 10 + 10 + 10 + 10 + 10 + 10 = 70 (or 70 ÷ 10 = 7).
4. 20 feet longer (50 − 30 = 20), or 6 meters longer (15 − 9 = 6).

5. The careful dig saved 5 more whole chips ($8 - 3 = 5$). Ben had to keep the same kind and size of cookie and the same digging time (any one of these).
6. Sample answer: The Bone Wars helped science because Cope and Marsh found and named many new dinosaurs, like *Stegosaurus* and *Triceratops*, and filled museums with bones. They hurt science because the men rushed, broke or wasted fossils, and made mistakes such as giving two names to the same kind of animal.

6.2 Sue the T. rex (found 1990)

OBJECTIVES

- Tell how Sue Hendrickson found the T. rex skeleton named Sue in South Dakota in 1990 and how it came to the Field Museum in Chicago.
- Explain how paleontologists use a grid map and plaster jackets to dig up a skeleton without losing clues.
- Compare Sue's size to familiar things using feet and meters.

Warm-up. Lie down on the floor and have someone put a piece of tape at your head and at your feet. Measure the distance with a tape measure in feet and inches. Sue the T. rex was about 40 feet long. Guess how many of you, lying head to toe, it would take to stretch the length of Sue. Write your guess and check it in the worked examples.

Video. Coming soon. Sue the T. rex at the Field Museum: discovery in South Dakota, digging and mounting the skeleton; search the Field Museum, Smithsonian National Museum of Natural History, Homeschool Pop (Alternate), SciShow Kids and museum behind-the-scenes clips.

KEY TERMS

Tyrannosaurus rex
A huge meat-eating dinosaur that walked on two strong legs and had a giant head, sharp teeth and small arms. Its name means "tyrant lizard king."

skeleton
All the bones of an animal's body, fitted together.

grid
A pattern of equal squares marked with string over a dig site, so every bone's place can be written down and mapped.

plaster jacket
A hard shell of cloth soaked in wet plaster, wrapped around a fossil and the rock around it to protect it on the trip to the museum.

complete
Having all or nearly all of its parts. Sue is one of the most complete T. rex skeletons ever found.

CORE IDEAS

The story. On August 12, 1990, a team of fossil hunters was working near the small town of Faith, South Dakota. That morning their truck had a flat tire. Most of the team drove to town to fix it, but Sue Hendrickson stayed behind with her dog. She walked over to a tall, crumbly cliff she had been wanting to explore. At the bottom she found small pieces of bone. She

looked up, and sticking out of the cliff were huge bones. They belonged to a ***Tyrannosaurus rex***! The team named the dinosaur Sue, after the woman who found it.

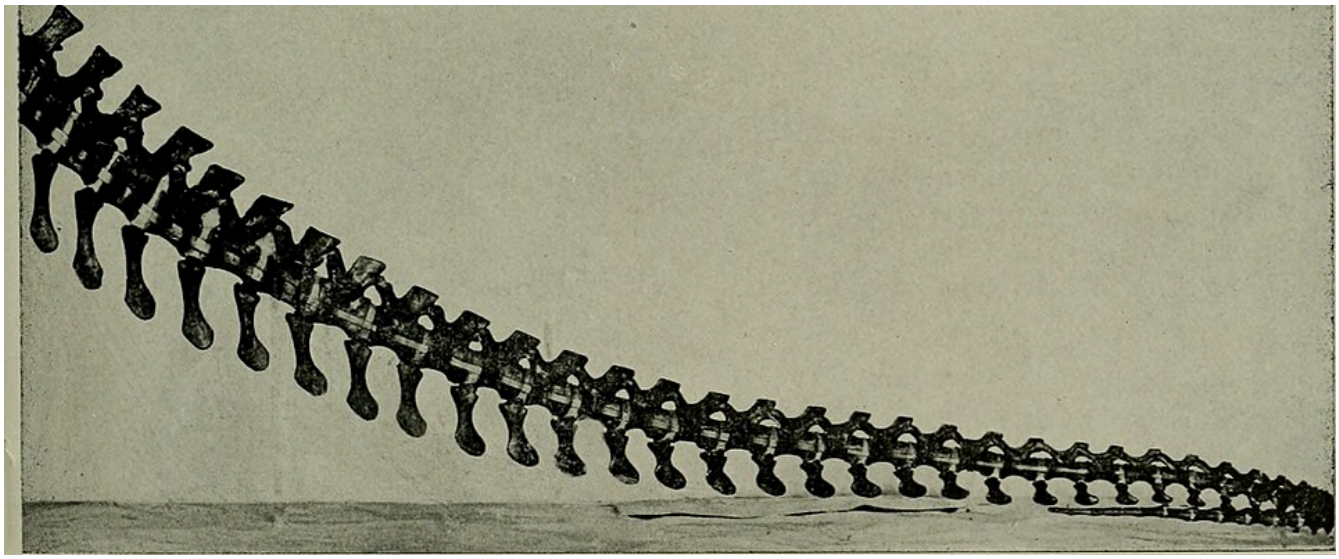
How they figured it out. Digging up a giant **skeleton** takes care and teamwork. The team cleared away the rock above the bones. They marked the ground into a **grid** of squares and drew a map showing where each bone lay, because the way bones lie can tell how the animal died and was buried. They wrapped big blocks of bone and rock in **plaster jackets**, like a cast on a broken arm. Then a long argument in court about who owned the bones began. In the end the skeleton was sold at an auction in 1997, and the Field Museum in Chicago bought it with help from companies and many supporters. Workers spent years cleaning the bones, and Sue was set up for visitors in 2000.

The big idea. Sue is one of the largest and most **complete** T. rex skeletons ever found. Scientists say about nine out of every ten parts of the skeleton were found. Sue is about 40 feet (12 meters) long and stands about 13 feet (4 meters) tall at the hips. The skull alone is about 5 feet long and weighs about 600 pounds, so heavy that the real skull sits in its own case, and a lighter copy is on the skeleton. Sue's bones also tell a life story. Some ribs had been broken and healed, and there are holes in the jaw that may have come from a sickness. Nobody knows if Sue was male or female.

Try it and see. In this lesson you will bury "bones" in a tub of sand, lay a string grid over it and dig the way Sue's team did. You will draw a map of each square before lifting anything out. Then you will test whether a partner can put the skeleton back together better with your map or without it.

God's handiwork. God made the great beasts as well as the small ones, and He gave people curious minds to dig, measure and learn. The book of Job says, "Speak to the earth, and it shall teach thee." A cliff in South Dakota held a giant skeleton until a careful observer stopped to look. Many discoveries come to people who are patient, notice small things and keep exploring.

PICTURE STUDY



The First Mounted Tyrannosaurus rex Skeleton, American Museum of Natural History, Photographer of the American Museum of Natural History, 1915 · Black-and-white photograph printed in *The American Museum Journal* · American Museum of Natural History, New York

Long before Sue was found, the American Museum of Natural History in New York put up the first T. rex skeleton ever mounted for visitors, in 1915. The bones had been dug up in Montana by the fossil hunter Barnum Brown. The scientists of that time stood the dinosaur tall and straight, like a kangaroo, with its tail dragging on the ground. This photograph was printed in the museum's own magazine the year the skeleton was mounted.

Today scientists think T. rex held its body level, with its head forward and its tail up in the air to balance. That is how Sue stands in Chicago, and the New York skeleton was later rebuilt in the new pose too.

Look closely

- Find the head. Is it held high or stretched forward?
- Find the tail. Where does it end?
- Look at the small arms. How big are they compared with the legs?
- Look for anything near the skeleton that helps you guess how big it is.

Talk about it

1. How is this pose different from the way Sue stands today?
2. Why do you think scientists changed their minds about how T. rex stood?
3. If you were planning a T. rex skeleton for a museum, what pose would you choose, and why?

EXPERIMENT: GRID DIG IN A TUB

Sue’s team mapped every bone before lifting it out. Does a grid map really help? You will dig a “skeleton,” map it, and test whether a partner can rebuild it better with your map than without it.

You will need

- A shallow plastic tub or baking pan, at least 12 inches long
- Play sand or dry rice to fill it about 3 inches deep
- 6 to 9 “bones”: dry pasta of different shapes (shells, tubes, bow ties, macaroni) or paper bones you cut out of cardstock
- String and masking tape
- A ruler, a spoon and a soft paintbrush
- Graph paper or paper with a 3 by 3 grid drawn on it, and a pencil

Steps

1. Ask a parent to lay the “bones” in the tub in the shape of a skeleton (skull at one end, ribs in the middle, tail at the other end) and cover them with sand while you are out of the room.
2. Measure the tub. Use string and tape to make a grid of 9 equal squares. Label the columns A, B, C across the top and the rows 1, 2, 3 down the side, like the dig map in this lesson.
3. **Question:** Write: “Can a partner rebuild the skeleton better with my map than without it?” **Prediction:** Write what you think.
4. Dig one square at a time with the spoon and brush. Brush sand away gently instead of scooping.
5. When you uncover a bone, do not lift it yet. Draw it on your paper map in the right square, the right way around.
6. When every square is mapped, lift the bones out and mix them up in a bowl.
7. **Test 1 (no map):** A partner tries to lay the bones back in the tub where they were. Count how many land in the right square.
8. **Test 2 (with map):** Mix the bones again. The partner uses your map. Count how many land in the right square.
9. **Record:** Write both numbers in a table and circle the bigger one. Was your prediction right?

Tips

- Keep the same bones and the same tub for both tests; only the map changes.
- Real paleontologists also write the date, the square and a number for each bone in a field notebook.
- Work over a towel or outdoors to catch spilled sand.

Check your work

- I made a grid of equal squares and labeled it with letters and numbers.
- I drew each bone in its square before lifting it out.
- I recorded how many bones my partner placed correctly with and without the map.
- I can explain why mapping matters at a dig.

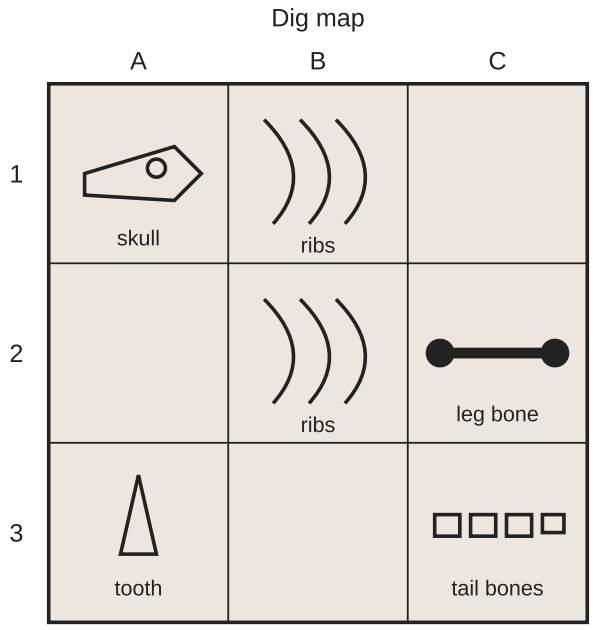
FIELD NOTEBOOK

1. Draw your finished dig map. Give it a title, the date and a note saying how big each square is.
2. Draw a life-size outline of one of Sue’s teeth: a cone 12 inches (about 30 centimeters) long. Write a label beside it.
3. Draw Sue Hendrickson at the cliff the moment she looked up. Add a speech bubble with what you think she said.

> **From history.** *Tyrannosaurus rex* was first named in 1905 by Henry Fairfield Osborn of the American Museum of Natural History in New York. He named it from bones that the fossil hunter Barnum Brown had dug up in Montana a few years before. Brown spent his life searching for fossils, and he found the very first T. rex skeletons ever known.

WORKED EXAMPLES

Example 1. Look at the dig map. Each square is 1 meter (a little more than 3 feet) on a side. In which square is the skull? Which squares have ribs? How many squares have bones, and how many are empty?



A dig map. Each square is 1 meter (about 3 feet) on a side.

1. Find the skull. Go across to its column letter (A) and down to its row number (1). The skull is in square A1.
2. Find the ribs. They are in column B, rows 1 and 2: squares B1 and B2.
3. Count every square that has a bone: A1 (skull), B1 (ribs), B2 (ribs), C2 (leg bone), A3 (tooth), C3 (tail bones). That is 6 squares.
4. The grid has 3 rows of 3 squares, and $3 \times 3 = 9$ squares in all. Empty squares: $9 - 6 = 3$ (A2, B3 and C1).

Answer: The skull is in A1. The ribs are in B1 and B2. Six squares have bones and three squares are empty.

Example 2. Sue is about 40 feet long. A third grader lying down is about 4 feet long. How many third graders lying head to toe would stretch as long as Sue? Check it in meters too: Sue is about 12 meters and the child is about 1.2 meters.

1. Count by 4s until you reach 40: 4, 8, 12, 16, 20, 24, 28, 32, 36, 40. That is 10 fours.
2. So $40 \div 4 = 10$.
3. Check in meters: 1.2 meters ten times is 12 meters, the same as Sue.

Answer: About 10 third graders lying head to toe would be as long as Sue.

PRACTICE

1. EASY Who found the T. rex named Sue? In what state, and in what year?
2. EASY Look at the dig map. What was found in square C3? What was found in square C2?
3. MEDIUM Sue’s skull is about 5 feet long. How many 1-foot rulers laid end to end would match it? About how many meters is that, if 1 foot is about 30 centimeters?
4. MEDIUM Sue’s biggest tooth, root and all, is about 12 inches long. Your hand is about 6 inches long. How many of your hands would match the tooth?
5. HARD Sue’s real skull weighs about 600 pounds. If a third grader weighs about 60 pounds, how many third graders would weigh as much as the skull? Why is the real skull not on the skeleton?
6. CHALLENGE Maria’s grid dig test: without a map, her partner put 3 of 9 bones in the right squares. With the map, her partner put 8 of 9 bones in the right squares. What do these results show? Write two sentences explaining why real paleontologists map bones before lifting them.

COMMON MISTAKES

- Thinking a skeleton is found lying neatly in one piece. Bones are often scattered, broken or mixed, so mapping where each one lies is important.
- Thinking everything you see on a museum skeleton is real bone. Sue’s head on the skeleton is a lighter copy, and many museum skeletons use copies for missing or heavy parts.
- Thinking paleontologists know a dinosaur’s name, color and whether it was male or female from its bones. The name Sue honors the finder; nobody knows whether Sue was male or female, and bones do not show color.

Make it a game · Battleship Bones. Each player draws a secret 3 by 3 grid (A, B, C across and 1, 2, 3 down) and hides a skull, a leg bone and a tail in three squares. Take turns calling out a square like “B2.” If you hit a bone, the other player says which one, and you draw it on your map. The first to find all three of the other player’s bones wins. For a harder game, use a 4 by 4 grid and five bones.

> **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)

The earth God made is full of lessons for those who look carefully. Sue Hendrickson found a giant because she took time to walk, look and notice small pieces of bone at the foot of a cliff.

Practice answers

1. Sue Hendrickson found it in South Dakota in 1990 (on August 12, near the town of Faith).
2. C3: tail bones. C2: a leg bone.
3. 5 rulers. 5 × 30 = 150 centimeters, which is 1.5 meters (about one and a half meters).
4. 2 hands, because 6 + 6 = 12.
5. 10 third graders, because 60 × 10 = 600. The real skull is too heavy to hold up safely on the skeleton, so it sits in its own case where scientists can study it, and a lighter copy is on the skeleton.
6. The map helped: 5 more bones were placed correctly (8 − 3 = 5). Sample explanation: Paleontologists map bones because once a bone is lifted, its exact place is lost forever. The map shows which bones belong together and gives clues about how the animal died and was buried.

6.3 How a Skeleton Is Mounted

OBJECTIVES

- Describe the steps that take a dinosaur skeleton from the ground to a museum hall: digging, jacketing, cleaning, casting and mounting.
- Explain what an armature, a mold and a cast are, and why museums often show copies of bones.
- Build a model skeleton on a stand and test where the support must go for it to balance.

Warm-up. Try to stand a fork upright on its handle on the table. It falls! Now push the handle into a lump of clay or play dough. What did the clay do? Museum workers face the same problem with a skeleton weighing thousands of pounds. Talk about what they might use to hold it up.

Video. Coming soon. How museums mount a dinosaur skeleton: fossil preparation labs, molds and casts, steel armatures; search the Field Museum, Smithsonian National Museum of Natural History (Deep Time hall installation), American Museum of Natural History, Carnegie Museum of Natural History, and museum behind-the-scenes clips.

KEY TERMS

mount
To put a skeleton together and stand it up for people to see. The finished skeleton is also called a mount.

armature
A frame of steel (or iron, long ago) that holds the bones of a mounted skeleton in place.

preparator
A museum worker who carefully cleans rock away from fossil bones and repairs them.

mold
A hollow shape made around a bone, often of rubber, that shows every bump and groove.

cast
A copy of a bone made by filling a mold with plaster or plastic that hardens.

CORE IDEAS

The story. In 1868, in Philadelphia, an English artist named Benjamin Waterhouse Hawkins did something no one had done before. Working with the scientist Joseph Leidy, he stood up a dinosaur skeleton for people to see. The bones belonged to *Hadrosaurus*, a duck-billed dinosaur found ten years earlier in a pit at Haddonfield, New Jersey. Many bones were missing, including the skull, so Hawkins shaped the missing parts from plaster. He bent iron pipes into a frame to hold the real bones and stood the dinosaur up on its back legs like a

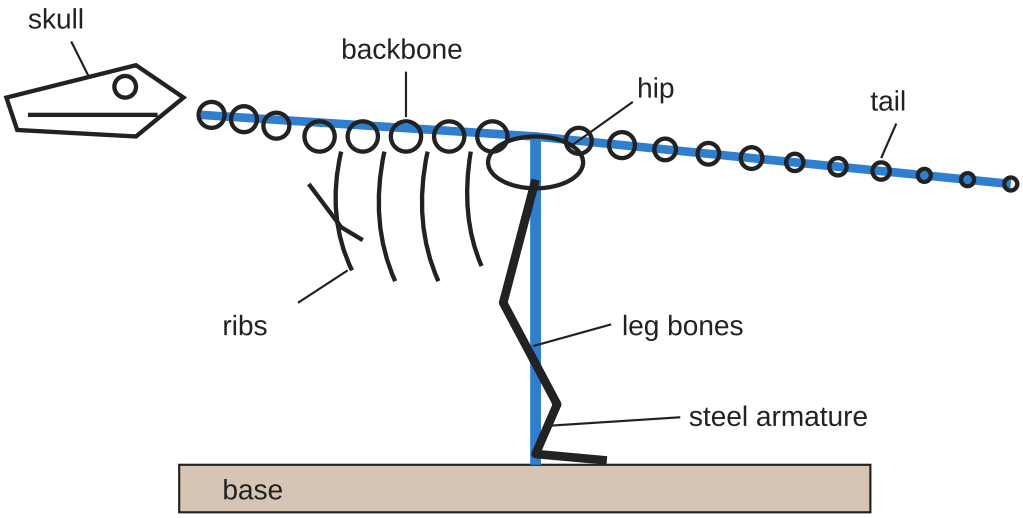
giant kangaroo. It was the first **mounted** dinosaur skeleton in the world, and crowds came to see it.

How they figured it out. Mounting a skeleton happens in steps. First, the bones are dug up and wrapped in plaster jackets. At the museum, a **preparator** opens each jacket and removes the rock grain by grain with brushes, needles and a tiny air-powered tool like a pen-sized jackhammer. Cracked bones are glued. Next, workers often make a rubber **mold** of each bone and fill it with plaster or plastic to make a light **cast**. Missing bones can be copied from another skeleton of the same kind, or from the bone on the other side of the body, turned around like a mirror image. Finally, metal workers bend and weld a steel **armature**, and the bones or casts are fastened to it.

The big idea. A museum skeleton is a mix of careful science and careful building. Many skeletons you see are casts, so the real bones stay safe in drawers where scientists can study them. Real bones are also very heavy. That is why the skull on Sue the T. rex is a lighter copy. Some modern mounts are even built so one bone can be lifted off for study. Poses change as scientists learn more. Hawkins and the scientists of his day stood dinosaurs upright with tails on the ground. Today most mounts hold the tail up in the air, because dinosaur footprint trails almost never show marks of a dragging tail.

Try it and see. A two-legged dinosaur must balance over its hips, like a seesaw with the head on one end and the tail on the other. In this lesson you will build a model skeleton and test where to put its support post: under the chest, under the hips or under the tail. You will see why museum builders put the main post near the hips.

God’s handiwork. When preparators fit a skeleton together, they see how well every bone was made to fit its neighbor: the leg bone into the hip, each backbone onto the next. The prophet Ezekiel saw a vision of dry bones coming together, “bone to his bone.” Only God can give life to bones. But putting a skeleton together carefully helps us see how wisely He designed the creatures He made.



Parts of a mounted skeleton. The steel armature (blue) runs along the backbone and down through a post near the hips, where the skeleton balances.

PICTURE STUDY



The Hadrosaurus Skeleton Mounted at the Academy of Natural Sciences, Unknown photographer, about 1868 · Black-and-white photograph · Academy of Natural Sciences of Drexel University, Philadelphia

This old photograph shows the first dinosaur skeleton ever mounted, the *Hadrosaurus* that Benjamin Waterhouse Hawkins and Joseph Leidy put up in Philadelphia in 1868. Hawkins had already become famous in England for building life-size dinosaur sculptures. Here he worked with real bones and filled in the missing ones with plaster.

Today scientists think *Hadrosaurus* usually walked with its body level and could walk on all four legs, so this pose is now known to be wrong. But it was the best idea of its time, and it showed thousands of people how big a dinosaur really was.

Look closely

- Find the person in the photograph. How tall is the skeleton compared with him?
- Find the tail. What is it doing to help the skeleton stand?
- Look for parts that might be iron rods or supports instead of bone.
- Look at the head. Remember that the real skull was never found. What did Hawkins use instead?

Talk about it

1. How is this pose different from the way dinosaur skeletons are mounted today?
2. Why do you think Hawkins chose a kangaroo-like pose?
3. Should a museum label tell visitors which parts are real bone and which are made of plaster? Why?

> **Safety first.** Wire and pipe-cleaner ends can poke. Ask an adult to cut wire and bend the ends into small loops, and keep wire away from eyes.

EXPERIMENT: BALANCE THE DINOSAUR

You will build a model dinosaur skeleton on a wire armature and test one question: where must the support post go for the skeleton to stand without tipping?

You will need

- 4 to 6 pipe cleaners or a piece of soft craft wire about 24 inches long
- Dry pasta: tube pasta or macaroni for backbones, bow ties or shells for the skull and hips
- A lump of modeling clay or play dough about the size of a tennis ball (the base)
- A craft stick or a stiff 6-inch piece of wire (the support post)
- A ruler, a timer and a notebook

Steps

1. Thread tube pasta onto one long pipe cleaner to make the backbone and tail. Leave room at the front for the skull.
2. Fasten a pasta skull to the front end with a bit of clay. Twist two more pipe cleaners around the middle for legs, and add pasta “ribs” if you like.
3. Press the clay onto the table to make a base. Stand the support post up in the base.
4. **Question:** Write: “Where should the support post go so the skeleton balances: under the chest, under the hips or under the tail?” **Prediction:** Write your guess.

5. **Keep the same:** the same skeleton, the same base and the same post for every test. **What we change:** the place where the post touches the skeleton.
6. Test 1: rest the skeleton on the post under the chest. Let go and count seconds until it tips, up to 30 seconds.
7. Test 2: rest it under the hips. Test 3: rest it under the tail. Count seconds each time.
8. **Record:** Make a table: Post position, Seconds before tipping. Do each test twice.
9. When you find the balance point, twist the skeleton to the post there. Your model is now mounted!

Tips

- If your skull is very heavy, the balance point may move forward a little. That is a real problem museum builders solve too.
- Lift the tail up level with the back, the way modern mounts do.
- Label your model with its name and a card saying which parts are “real” (pasta) and which are “support” (wire and clay).

Check your work

- I changed only one thing: where the post touched the skeleton.
- I timed each test and recorded the results in a table.
- I found the balance point and mounted my skeleton there.
- I can name the parts of a mount: skeleton, armature and base.

FIELD NOTEBOOK

1. Draw your mounted model from the side. Label the skull, backbone, tail, legs, armature and base.
2. Draw a bone, its rubber mold and its cast side by side, and write one sentence about how a cast is made.
3. Draw the old Hadrosaurus pose and a modern pose side by side. Circle what changed.

> **From history.** Before he came to America, Benjamin Waterhouse Hawkins built life-size models of prehistoric animals for the Crystal Palace park in London. On the last evening of 1853, a group of scientists and guests famously sat down to dinner inside the half-built mold of his *Iguanodon*. The sculptures opened to the public in 1854 and can still be seen in Crystal Palace Park today.

WORKED EXAMPLES

Example 1. A museum builder is making a model skeleton. Its backbone is 24 inches long, and she needs one metal bracket every 4 inches to hold the bones. How many brackets does she need?

1. We need to know how many 4-inch pieces fit in 24 inches.
2. Count by 4s: 4, 8, 12, 16, 20, 24. That is 6 fours.
3. So $24 \div 4 = 6$.

Answer: She needs 6 brackets.

Example 2. You want to build a scale model of Sue the T. rex using 1 inch for every 1 foot. Sue is about 40 feet long and about 13 feet tall at the hips. How long and how tall will your model be? Will it fit on a table 36 inches long?

1. Each foot of Sue becomes 1 inch on the model.
2. Length: 40 feet becomes 40 inches.
3. Height at the hips: 13 feet becomes 13 inches.
4. Compare: 40 inches is more than 36 inches. $40 - 36 = 4$.

Answer: The model will be 40 inches long and 13 inches tall at the hips. It will not fit on the table: it is 4 inches too long.

PRACTICE

1. EASY What is an armature?
2. EASY What is the difference between a mold and a cast?
3. MEDIUM *Triceratops* was about 30 feet long. If you build a model using 1 inch for every foot, how long is the model? Is it longer or shorter than a yardstick (36 inches), and by how much?
4. MEDIUM A preparator cleans rock from a leg bone for 2 hours every day for 5 days. How many hours does she work on the bone?
5. HARD Kate tested her model. Post under the chest: tipped after 4 seconds. Post under the hips: still standing at 30 seconds. Post under the tail: tipped after 2 seconds. What one thing did she change? Where should the post go, and why?
6. CHALLENGE Old dinosaur mounts, like the 1868 *Hadrosaurus*, rested their tails on the ground. Most new mounts hold the tail up in the air. Give one clue scientists used to change their minds, and explain why museums sometimes rebuild old mounts.

COMMON MISTAKES

- Thinking every museum skeleton is made of real bone. Many are casts, and many real skeletons have some missing parts filled in with copies.
- Thinking a skeleton's pose is certain. Poses are scientists' best ideas from the bones and footprints, and they change as we learn more.
- Thinking a two-legged dinosaur balanced like a person, standing straight up. It balanced over its hips with its head forward and its tail back.

Make it a game · Build-a-Mount Relay. Write the steps on cards: Dig, Map, Plaster jacket, Clean (prepare), Make a mold, Make a cast, Build the armature, Mount the bones. Shuffle them. Race a timer to lay them in the right order, then say one sentence about each step. Beat your best time to win. For a harder round, a parent removes one card and you must name the missing step.

Scripture. "So I prophesied as I was commanded: and as I prophesied, there was a noise, and behold a shaking, and the bones came together, bone to his bone." (Ezekiel 37:7, KJV)

In Ezekiel's vision, God brings dry bones together and gives them life, a picture of how He would restore His people. Museum workers can only fit bones in place, but their work helps us see how wonderfully God made each bone to fit the next.

Practice answers

1. A metal frame (steel today, iron long ago) that holds the bones of a mounted skeleton in place.
2. A mold is the hollow shape made around a bone. A cast is the copy made by filling the mold with plaster or plastic.
3. 30 inches long. It is shorter than a yardstick by 6 inches ($36 - 30 = 6$).
4. 10 hours, because $2 \times 5 = 10$.
5. She changed only where the post touched the skeleton. The post should go under the hips, because the weight of the head and chest in front balances the weight of the tail behind, like a seesaw.
6. Clue: dinosaur footprint trails almost never show a groove from a dragging tail, so scientists think the tail was held up. Museums rebuild old mounts so the skeleton shows what scientists understand now, and to repair and protect the bones.

6.4 Soft Tissue in Dinosaur Bone (Mary Schweitzer, 2005)

OBJECTIVES

- Tell how Mary Schweitzer found soft, stretchy tissue inside a T. rex leg bone and announced it in 2005.
- Explain the difference between the hard minerals and the soft tissue in bone, and show it with a vinegar-bone experiment that has a control.
- Read a museum sign about time carefully: tell what the sign says, what scientists actually observed, and how many Christians read it.

Warm-up. Hold a chicken bone (cleaned by an adult) and a rubber band. Which one bends? Which one is hard and stiff? Now think about your own bones. Are they only hard rock, or is there something softer inside them too? Write down your guess.

Video. Coming soon. Mary Schweitzer and soft tissue in a T. rex bone, plus the classic vinegar “rubber bone” experiment; search the Smithsonian, NOVA and PBS science clips, North Carolina State University, Museum of the Rockies, Science Max, SciShow Kids and Homeschool Pop (Alternate) (check any clip for deep-time claims and use the ⏳ box to discuss them).

KEY TERMS

soft tissue
The soft parts of a body, such as skin, muscle, blood vessels and cells, not the hard bone or teeth.

blood vessel
A tiny tube that carries blood through the body, even through the inside of bones.

mineral
A hard, natural, nonliving solid. Bone is made hard by a mineral that contains calcium.

protein
One of the building materials of living bodies. A protein called collagen makes bone a little bendy and strong instead of brittle.

microscope
A tool with lenses that makes tiny things look many times bigger.

CORE IDEAS

The story. In 2000, in the dry, rocky badlands of eastern Montana, a worker from the Museum of the Rockies named Bob Harmon spotted dinosaur bones in a cliff. They belonged to a *Tyrannosaurus rex*. The team dug for several summers. One plaster jacket, holding a huge thigh bone, was too heavy for the helicopter that had to carry it out. So the diggers

broke the bone in two to make the load lighter, and small pieces fell out. Those pieces went to a scientist named Mary Schweitzer, and what she found inside them amazed the world.

How they figured it out. Bone has two parts: a hard **mineral** that makes it stiff, and softer material woven through it. Dr. Schweitzer put bits of the T. rex bone in a gentle chemical bath that slowly dissolved the minerals. When the hard part was gone, something was left. Under a **microscope** she saw soft, stretchy, see-through tubes that branched like tiny **blood vessels**. When she pulled on the soft material, it stretched and then sprang back. Inside the tubes were small round red-brown shapes, and in the bone were tiny shapes with branching arms that looked like bone cells. In March 2005 she and her team shared their discovery in the science journal *Science*.

The big idea. Before this, many people thought every dinosaur fossil had turned completely to rock, so nothing soft could be left. But Dr. Schweitzer found **soft tissue** still inside a T. rex bone. Later she and other scientists reported tiny bits of **protein**, including collagen, in T. rex bone and in the bone of a duck-billed dinosaur. No one has found dinosaur DNA, and scientists still argue about how the soft parts lasted. Dr. Schweitzer's work shows how science grows: someone looks closely, sees something unexpected, tests it again and again, and shares it so others can check.

Try it and see. You can see the two parts of bone at home. Vinegar is a weak acid that slowly dissolves the calcium mineral in a chicken bone, just as Dr. Schweitzer's bath dissolved the minerals in her sample. After several days the bone becomes rubbery and bends, because the soft protein is left behind. A second bone kept in plain water will be your *control*, so you know the vinegar made the difference.

God's handiwork. Job said to God, "Thou hast clothed me with skin and flesh, and hast fenced me with bones and sinews." God made bones to be both hard and a little flexible, so they can hold us up without snapping like chalk. The more closely scientists look, even inside a giant's bone, the more wonderful His design turns out to be.

> ⏳ **Thinking About Time**
>
> **What the sign says.** What the sign says: Museum signs and textbooks say T. rex lived near the end of the "age of dinosaurs," many millions of years ago. Most scientists who study these bones, including Dr. Schweitzer, think something special, such as iron from the animal's own blood, helped the soft parts last that long.
>
> **What we observe.** What we observe: Inside a real T. rex leg bone, scientists saw soft, stretchy blood vessels and tiny shapes that look like bone cells, and later found bits of protein. In laboratories, proteins and soft tissue are known to break down and fall apart over time.
>
> **How Christians read it.** How Christians read it: Many Christians who read Genesis as true history think this dinosaur was buried quickly in mud during Noah's Flood, not nearly so long ago. They see soft, stretchy tissue as a much better fit with a younger age

than with many millions of years. Both sides agree the bones are real and worth careful study.

Try it. Leave a slice of apple on a plate for three days and draw it each day. What happens to soft things left alone?

Genesis 7:21

PICTURE STUDY



Portrait of Antonie van Leeuwenhoek, Jan Verkolje, about 1680–1686 · Oil on canvas · Rijksmuseum, Amsterdam

Antonie van Leeuwenhoek was a cloth merchant in Delft, in the Netherlands, who taught himself to make tiny, powerful lenses. With his homemade microscopes he became one of the first people ever to see living things too small for the eye, and in 1674 he described red blood cells.

Jan Verkolje, a painter born in Amsterdam who settled in Delft, painted Leeuwenhoek's portrait. More than three hundred years later, Mary Schweitzer used a far stronger microscope to look for blood vessels and cells inside a dinosaur bone. She was following the path Leeuwenhoek began: looking very closely at what God made.

Look closely

- Look at Leeuwenhoek's face. Does he look like a patient, careful person?
- Look at his clothes and hair. What do they tell you about the time when he lived?
- Find what he is holding or resting his hands on.
- Look at the objects on the table. Why might a painter include them?

Talk about it

1. Leeuwenhoek made his own microscopes. Why do new tools often lead to new discoveries?
2. What would you most like to look at under a microscope, and why?
3. How is Mary Schweitzer's work like Leeuwenhoek's?

> **Safety first.** Raw chicken can carry germs. An adult should cook the chicken, remove all the meat and scrub the bones clean. Wash your hands after handling bones, and do not eat or drink the vinegar or the bones. Keep vinegar out of your eyes; if it splashes, rinse with plenty of water.

EXPERIMENT: THE RUBBER BONE EXPERIMENT

Dr. Schweitzer dissolved the hard minerals out of a dinosaur bone to find what was left. You will do the same thing to a chicken bone with vinegar, and use a second bone in water as a control.

You will need

- 2 cooked chicken leg bones (drumsticks), cleaned of all meat by an adult, about the same size
- 2 clear jars with lids, labeled "Vinegar" and "Water"
- White vinegar and tap water, enough to cover each bone
- A ruler with centimeters
- Paper towels, a notebook and a pencil

Steps

1. **Question:** Write: "What happens to a bone when the hard minerals are dissolved?" **Prediction:** Write what you think the vinegar bone will feel like after a week.
2. Before you start, try gently bending each bone. Draw both bones and write how they feel.
3. Put one bone in the vinegar jar and one in the water jar. Cover each completely and put on the lids.
4. **Keep the same:** bone size, jar size, amount of liquid and where the jars sit. **What we change:** the liquid (vinegar or water). The water bone is the control.
5. Look at the jars every day. Write what you see, such as tiny bubbles on the vinegar bone.
6. On days 1, 4 and 7, take each bone out with a paper towel, rinse it and press the middle gently with one finger, about the same each time. Hold the ruler beside it and measure how many centimeters the tip moves. Put the bone back.
7. On day 4, after measuring, an adult may pour out the old vinegar and add fresh vinegar to speed things up.

8. **Record:** Make a table with columns Day, Vinegar bone bend (cm), Water bone bend (cm).
9. On day 7, try to bend the vinegar bone into a curve. Write two sentences: What was dissolved? What was left behind?

Tips

- Thin bones like chicken wing bones soften faster than thick leg bones.
- The bubbles are a gas made as the vinegar reacts with the calcium mineral in the bone.
- Throw the bones away in the trash when you finish, and wash the jars well.

Check your work

- I used a control bone in water and kept everything else the same.
- I measured and recorded the bend on days 1, 4 and 7.
- I can explain that vinegar dissolved the hard mineral and left the soft protein.
- I can explain how my experiment is like Mary Schweitzer's.

FIELD NOTEBOOK

1. Draw both chicken bones on day 1 and day 7. Label which is the control.
2. Draw what Mary Schweitzer saw under the microscope: branching soft tubes with small round shapes inside. Label "blood vessel."
3. Make a three-box chart titled "Thinking About Time" with the headings What the sign says, What we observe, How Christians read it, and fill in each box in your own words.

> **From history.** Mary Schweitzer's first surprise came years before 2005. While studying a thin slice of a different T. rex bone in Montana in the early 1990s, she saw small round red shapes that looked like blood cells. Her teacher, the paleontologist Jack Horner, told her to try to prove they were not blood cells. That habit of testing an idea hard, instead of believing it right away, led to her careful work on the 2005 bone.

WORKED EXAMPLES

Example 1. A hand lens makes things look 10 times bigger. A grain of sand is 1 millimeter wide. How wide does it look through the hand lens? How wide would it look through a microscope that makes things look 40 times bigger?

1. Through the hand lens: 1 millimeter × 10 = 10 millimeters.
2. 10 millimeters is the same as 1 centimeter, about the width of your fingernail.
3. Through the microscope: 1 millimeter × 40 = 40 millimeters, which is 4 centimeters.

Answer: Through the hand lens the sand grain looks 10 millimeters (1 centimeter) wide. Through the microscope it looks 40 millimeters (4 centimeters) wide.

Example 2. Sam measured how far the tip of each chicken bone moved when he pressed it. Day 1: vinegar bone 0 cm, water bone 0 cm. Day 4: vinegar bone 1 cm, water bone 0 cm. Day 7: vinegar bone 4 cm, water bone 0 cm. How much more did the vinegar bone bend on day 7 than on day 4? Which bone is the control, and what does it show?

1. Day 7 bend: 4 cm. Day 4 bend: 1 cm.
2. Subtract: $4 - 1 = 3$ cm.
3. The water bone is the control, because everything was the same except the liquid.
4. The water bone never bent (0 cm every time), so soaking alone did not make bone bendy. The vinegar made the difference.

Answer: The vinegar bone bent 3 cm more on day 7 than on day 4. The water bone is the control; it shows that the vinegar, not just being wet, made the bone bend.

PRACTICE

1. EASY Who announced in 2005 that she had found soft tissue inside a T. rex bone?
2. EASY Name two kinds of soft tissue.
3. MEDIUM A tiny seed is 2 millimeters long. How long does it look through a hand lens that makes things look 10 times bigger? Give the answer in millimeters and centimeters.
4. MEDIUM Look back at Sam's table in the worked example. How many centimeters did the water bone bend on day 7? What does that tell you?
5. HARD Lily wants to test whether vinegar softens bone faster than lemon juice. Name what she should change, two things she should keep the same, and what she should measure.
6. CHALLENGE A museum sign says a T. rex bone is many millions of years old. Using the ⏳ box, write three short sentences: one for what the sign says, one for what scientists observed in Mary Schweitzer's bone, and one for how many Christians read it.

COMMON MISTAKES

- Thinking Mary Schweitzer found living dinosaur cells or dinosaur DNA. She found soft tissue, cell-like shapes and bits of protein, but nothing alive and no dinosaur DNA.
- Thinking a fossil bone is always solid rock all the way through. Many dinosaur bones still contain real bone mineral, and some have even kept bits of soft material.
- Thinking bone is only hard mineral. Living bone also has protein woven through it, which keeps it from snapping like chalk. The vinegar experiment shows both parts.

Make it a game · Hard or Soft?. A parent calls out a body part or material: skull, skin, tooth, blood vessel, muscle, eggshell, tongue, backbone, heart, rib. Stand tall like a stiff bone if it is hard, or wiggle like a rubber bone if it is soft. Get it right for a point. Bonus point: say whether it would usually last in a fossil. Play to ten.

> **Scripture.** “Thou hast clothed me with skin and flesh, and hast fenced me with bones and sinews.” (Job 10:11, KJV)

God made bodies with hard parts and soft parts working together. Mary Schweitzer’s discovery reminds us that there is still more to learn about the creatures He made, even inside a bone that looks like stone.

Practice answers

1. Mary Schweitzer (Dr. Mary Schweitzer).
2. Any two of: skin, muscle, blood vessels, cells, nerves, organs (such as the heart).
3. 20 millimeters (2 × 10 = 20), which is 2 centimeters.
4. 0 centimeters. It tells us water alone does not soften a bone; the vinegar caused the change.
5. Change: the liquid (vinegar or lemon juice). Keep the same (any two): the size and kind of bone, the amount of liquid, the size of the jar, the place the jars sit, the number of days. Measure: how far each bone bends (in centimeters) on the same days.
6. Sample answer: The sign says T. rex lived many millions of years ago, and most scientists think something like iron helped the soft parts last. Scientists observed soft, stretchy blood vessels, cell-like shapes and bits of protein inside a T. rex bone. Many Christians think the dinosaur was buried in Noah’s Flood not nearly so long ago, so soft tissue fits a younger age better.

Unit 6 review

A parent may read each question aloud. Answer in words, a short sentence or a drawing with labels. Show your work for any number questions. The quiz is worth 40 points (4 points each).

1. (4 pts) Who were Edward Drinker Cope and Othniel Charles Marsh, and what were the Bone Wars?
2. (4 pts) Name two dinosaurs Marsh named and one Cope named.
3. (4 pts) *Apatosaurus* was about 70 feet long and *Coelophysis* about 10 feet long. How much longer was *Apatosaurus*? How many *Coelophysis* nose to tail would match it?
4. (4 pts) Who found Sue the T. rex, in what state, and in what year? What museum has Sue now?
5. (4 pts) Why do paleontologists mark a dig with a grid and draw a map before lifting bones out?
6. (4 pts) Sue is about 40 feet (12 meters) long. A car is about 15 feet long. Is Sue longer than two cars parked end to end? By how many feet?
7. (4 pts) What is an armature? What is a cast? Why do museums often show casts instead of real bones?
8. (4 pts) Put these steps in order: build the armature, dig and jacket the bones, clean the bones in the lab, mount the bones. Then tell why most new mounts hold the tail up.
9. (4 pts) What did Mary Schweitzer find inside a T. rex leg bone, and how did she find it?
10. (4 pts) In the vinegar experiment, why does the chicken bone in vinegar become bendy, and why do we also put a bone in plain water? Then name the three parts of the ⏳ Thinking About Time box.

Unit project: my dinosaur dig report

Put together a dig report like a real paleontologist’s. Include your grid dig map from Lesson 6.2 with a title, date and the size of each square; a photo or drawing of your balanced model skeleton from Lesson 6.3 with its parts labeled; your cookie-dig and rubber-bone data tables; and a bar graph comparing the lengths of at least three dinosaurs in feet with meters beside them. Finish with a short paragraph telling which dig story in this unit you liked best and one thing it taught you about doing science carefully and honestly.

- **Accuracy**: Names, dates, lengths and labels are correct, and the bar graph matches the numbers.
- **Records**: The dig map and data tables are complete, dated and neatly filled in, like a scientist’s field notebook.
- **Explanation**: The paragraph clearly tells what was learned and why careful, honest work matters in science.
- **Care**: The report is neat, colorful and easy to read, with drawings labeled.

Answer key

1. They were two American paleontologists (fossil scientists) who began as friends and became rivals. The Bone Wars was their race to dig up and name new dinosaurs and other fossils in the American West, with crews spying, rushing and sometimes breaking bones.
2. Marsh (any two): *Stegosaurus*, *Triceratops*, *Allosaurus*, *Apatosaurus*, *Brontosaurus*. Cope (any one): *Camarasaurus*, *Coelophysis*.
3. 60 feet longer (70 − 10 = 60). It would take 7 *Coelophysis* (70 ÷ 10 = 7).
4. Sue Hendrickson found it in South Dakota in 1990. Sue is at the Field Museum in Chicago.
5. So they can record exactly where each bone lay. Once a bone is lifted, its place is lost; the map shows which bones belong together and gives clues about how the animal died and was buried.
6. Yes. Two cars are 15 + 15 = 30 feet, and 40 − 30 = 10, so Sue is 10 feet longer than two cars.
7. An armature is the metal frame that holds a mounted skeleton. A cast is a copy of a bone made by filling a mold with plaster or plastic. Museums show casts because they are lighter and they let the real bones stay safe where scientists can study them.
8. Dig and jacket the bones; clean the bones in the lab; build the armature; mount the bones. Most new mounts hold the tail up because dinosaur footprint trails almost never show tail-drag marks, and a two-legged dinosaur balanced over its hips with its tail held out behind.
9. She found soft, stretchy, see-through tissue that looked like blood vessels, with small round shapes inside and tiny shapes like bone cells. She dissolved away the hard minerals with a gentle chemical bath and looked at what was left under a microscope.
10. Vinegar dissolves the hard calcium mineral, leaving the soft protein, so the bone bends. The bone in water is the control: it shows the vinegar, not just soaking, caused the change. The three parts are What the sign says, What we observe and How Christians read it.

UNIT 7

Gems and Ores

God hid treasures in the rocks. Some are **gems**, beautiful stones that are rare and hard enough to be cut, polished and worn. Others are **ores**, plain-looking rocks with useful metals locked inside. “Surely there is a vein for the silver, and a place for gold where they fine it,” says Job 28:1. In this unit you will use the tests you learned in Unit 1, hardness, streak, luster and the magnet, to tell gems, ores and metals apart, and you will see why the pattern of tiny atoms inside a mineral matters so much.

You will begin at Mount Sinai with the twelve stones of the high priest’s breastplate, each carved with a tribe’s name. You will stand in New York Harbor as the copper Statue of Liberty, held up by an iron skeleton and crowned with a gold-covered flame, is unveiled. You will crouch beside James Marshall at Sutter’s Mill as he pounds a flake of yellow metal to see whether it is gold or fool’s gold, and you will watch Smithson Tennant burn a diamond to prove it is made of carbon, the same stuff as charcoal and pencil lead.

Along the way you will test stones with a flashlight, race iron, copper and aluminum in salt water, pan for gold you make yourself, and build marshmallow models of graphite and diamond. At the end you will make a dozen-stone display case of your own, labeled like a real museum.

BEFORE YOU BEGIN

- Knows the Mohs hardness scale and how to do a scratch test and streak test (Unit 1)
- Knows that coal is a rock made from buried plants (Lesson 3.3)
- Can add, subtract and multiply small whole numbers and divide by 5 (such as 45 ÷ 5)
- Can measure with a ruler in inches and read centimeters

MASTERY CHECKLIST

- I can describe the high priest’s breastplate and name stones from its four rows.
- I can sort stones as transparent, translucent or opaque and use Mohs numbers to tell which gem scratches another.
- I can explain what an ore is, how smelting works, and identify hematite, magnetite and malachite.
- I can explain why iron rusts, copper turns green and gold stays bright.
- I can explain why gold stays in a pan and tell gold from pyrite with at least two tests.
- I can explain why diamond and graphite are both carbon but are so different, and change carats to grams.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free. The museum’s website has photographs from its Hall of Geology, Gems and

Minerals, including the Hope Diamond (Lesson 7.4), gold nuggets, emeralds and sapphires. Visit in person if you are ever in Washington, D.C.

- **Statue of Liberty National Monument (National Park Service)** (https://www.nps.gov/stli/): Free. Photographs and facts about the statue's copper skin, its inner framework and its gold-covered torch flame (Lesson 7.2).
- **Gemological Institute of America (GIA)** (https://www.gia.edu/): Free to browse. The GIA's online gem encyclopedia has clear photographs of emerald, sapphire, topaz, amethyst, garnet, jasper and many more. A parent can choose the pictures to show for Lesson 7.1.

7.1 Gems of the High Priest's Breastplate (Exodus 28)

★

OBJECTIVES

- Describe the high priest's breastplate in Exodus 28: its size, its four rows of three stones, and the names engraved on them.
- Define a gem and sort stones as transparent, translucent or opaque.
- Use Mohs hardness numbers to tell which gem can scratch another and explain why harder gems keep their polish.

Warm-up. Gather four small things that shine: a glass marble, a button, a piece of costume jewelry and a pebble. Hold each one up to a sunny window (look at the stone, never at the sun). Can you see the window through it, does light only glow through it, or does it block the light completely? Put them in three piles and give each pile a name of your own.

Video. Coming soon. Precious gemstones and how they are cut and polished, plus the high priest's breastplate of Exodus 28: search the Smithsonian National Museum of Natural History (Hall of Geology, Gems and Minerals), the Gemological Institute of America (GIA) learning videos, SciShow Kids, Homeschool Pop (Alternate) and Bible-history channels with tabernacle model footage.

KEY TERMS

gem
A stone that is beautiful, rare and tough enough to be cut, polished and worn. Most gems are minerals, such as emerald, sapphire and amethyst.

breastplate
The square, folded pouch of woven cloth that Israel's high priest wore over his heart, set with twelve precious stones (Exodus 28:15–21).

span
An old Bible measure: the width of a grown man's hand stretched wide, from thumb tip to little-finger tip. It is about 9 inches (about 23 centimeters).

transparent
Clear enough to see through, like a window. Translucent things let light glow through but you cannot see shapes clearly.

opaque
Letting no light through at all. Jasper and onyx are opaque gems.

CORE IDEAS

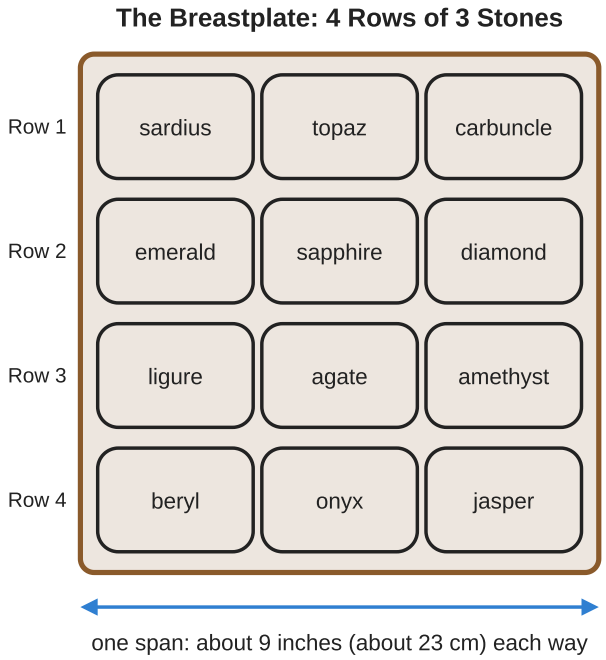
The story. Long ago, on Mount Sinai, God gave Moses careful instructions for the clothes of Israel's first high priest, Moses' brother Aaron. Over his heart Aaron would wear a square pouch of fine woven cloth called the **breastplate**, folded double, one span long and one span wide (Exodus 28:16). A span is a grown man's hand stretched wide, about 9 inches. On the front were twelve precious stones set in gold, in four rows of three. Each stone was engraved with the name of one of the twelve tribes of Israel, "like the engravings of a signet," so that Aaron carried the names of God's people on his heart whenever he went into the holy place (Exodus 28:21, 29). A gifted craftsman named Bezaleel led the work (Exodus 31:1–5; 39:8).

How they figured it out. Which stones were they? The Bible lists them: sardius, topaz, carbuncle; emerald, sapphire, diamond; ligure, agate, amethyst; beryl, onyx, jasper. These English names were chosen by translators long after Moses, from old Hebrew words. Scholars study ancient gems and seals to make their best guesses. A carbuncle was a glowing red stone, perhaps a garnet. Many think the ancient "sapphire" was lapis lazuli, a deep blue stone with golden flecks. The "diamond" may have been a different stone, because a real diamond is so hard that ancient engravers could hardly cut letters into it. We do not know every answer, and that is all right. A good scientist says plainly what is known and what is still a question.

The big idea. A **gem** is a stone that is beautiful, rare and tough enough to be cut, polished and worn. Most gems are minerals. Gem cutters judge a stone by its color, by how it lets light through, and by its hardness. Some gems are **transparent**: you can see clearly through them, like a window. Others are **translucent**, letting light glow through like a frosted lamp, and some are **opaque**, letting no light through at all. Several breastplate names belong to the same mineral family. Amethyst is purple quartz, and agate, onyx and jasper are also kinds of quartz, about 7 on the Mohs scale. Emerald is green beryl, about 7½ to 8. Topaz is 8. Sapphire is the mineral corundum, 9, and diamond is 10. A harder gem keeps its polish longer, because ordinary dust and grit cannot scratch it.

Try it and see. Shine a flashlight through a marble, a piece of sea glass, a button and a pebble. Which are transparent, translucent or opaque? Then set your "gems" in four rows of three on a cardboard square 9 inches (about 23 centimeters) on each side, the size of a span. Measure your own span too. It will be shorter than 9 inches, because your hand is still growing.

God's handiwork. God did not have to make the earth beautiful, but He did. He hid red, green, blue and purple crystals in the rocks for people to find, and He chose some of them to carry the names of His people over the high priest's heart. At the end of the Bible, John sees a holy city whose wall foundations "were garnished with all manner of precious stones" (Revelation 21:19), and many of the same names appear again: jasper, sapphire, emerald, beryl, topaz and amethyst. People treasure gems, and God treasures His people even more.



The twelve stones of the breastplate as named in Exodus 28:17–20 (KJV), four rows of three.

PICTURE STUDY



God Enthroned, with a Jeweled Crown at His Feet, from the Ghent Altarpiece, Hubert and Jan van Eyck, completed 1432 · Oil on oak panel · St. Bavo's Cathedral, Ghent, Belgium

The Ghent Altarpiece is a great folding set of painted wooden panels made for a church in Ghent, in what is now Belgium. An old inscription on it says that Hubert van Eyck began it and his brother Jan finished it in 1432. In the upper middle panel sits a crowned King in a red robe, often called God the Father or Christ the King. Jan van Eyck was famous for painting things so carefully that they look real enough to touch.

Look closely at the gems. Van Eyck painted each pearl and stone with a tiny spot of white where the light hits it, just the way a real polished gem catches light. Painters in his day had no photographs, so he must have studied real jewels for hours to paint them this way.

Look closely

- Find the crown lying at the King’s feet. How many different colors of stones can you count on it?
- Look along the edges of the red robe. What has the painter sewn there?
- Find a tiny bright spot of white on a pearl or a stone. Why do you think the painter added it?
- Which stones look transparent, and which look opaque?

Talk about it

1. Why do you think the painter put the finest gems near the King?
2. How is this crown like the high priest’s breastplate? How is it different?
3. If you could paint one gem, which color would you choose, and why?

> **Safety first.** Keep marbles, beads and small stones away from babies and toddlers, who may swallow them. When you hold stones up to a window, look at the stone, never at the sun.

EXPERIMENT: LIGHT TEST AND A BREASTPLATE MODEL

Gem cutters look at how light passes through a stone. In this small experiment you will test twelve “gems” with a flashlight, sort them, and then set them in a breastplate model the true size of a span.

You will need

- 12 small shiny things: glass marbles, sea glass, beads, buttons, pebbles, a piece of wrapped hard candy, plastic gems from a craft store
- A flashlight
- A square of cardboard 9 inches by 9 inches (about 23 by 23 centimeters)
- Yellow or gold paper or aluminum foil, glue and a marker
- A ruler and your science notebook

Steps

1. **Question:** Which of my twelve “gems” let light through, and which block it?
2. **Prediction:** Before you test, write T (transparent), L (translucent) or O (opaque) next to each object’s name.
3. **What we keep the same:** Darken the room. Hold the flashlight the same distance behind every object, about 4 inches (10 centimeters), and look from the same spot each time.

4. **What we change:** Only the object being tested.
5. **What we record:** Make a table with three columns: Transparent, Translucent, Opaque. Write each object in the column that matches what you saw.
6. Count how many objects are in each column. How many of your predictions were right?
7. Now cover the cardboard square with gold paper or foil. Draw four rows of three circles. Glue one “gem” in each circle and write a stone name from Exodus 28:17–20 under it, in order.
8. Measure your own span with the ruler and write it beside the model: “My span is ___ inches. A span in the Bible is about 9 inches.”

Tips

- Hard candy and colored glass are often translucent, not transparent. Look for whether you can see a shape, such as your fingers, clearly through them.
- If a button lets a little light through at its thin edge but none in the middle, call it opaque and write a note about the edge.

Check your work

- I can sort stones as transparent, translucent or opaque.
- I compared my results with my predictions.
- My breastplate model has four rows of three stones in the right order.

FIELD NOTEBOOK

1. Draw the breastplate as four rows of three circles. Color each stone the way you imagine it, and write its name underneath.
2. Draw three “windows”: one clear, one frosted and one solid. Label them transparent, translucent and opaque, and draw a gem beside each.
3. Trace your hand with fingers stretched wide. Draw a line from thumb tip to little-finger tip and write how many inches and centimeters your span is.

> **From history.** The idea of a special stone for each month grew partly out of the twelve stones of the breastplate, which early Christian and Jewish writers often connected to the twelve months. In 1912 a national association of American jewelers met in Kansas City and agreed on a list of birthstones for each month. With a few changes, it is the list most American jewelers still use.

WORKED EXAMPLES

Example 1. The breastplate had four rows of stones with three stones in each row. How many stones were there, and what did that number stand for?

(Use the map or drawing "Count the rows and the stones in each row." shown earlier in this lesson.)

1. Count by rows: 3 + 3 + 3 + 3 = 12.
2. Or multiply: 4 rows × 3 stones = 12 stones.
3. Exodus 28:21 says the stones carried the names of the twelve tribes of Israel, one name on each stone.

Answer: 12 stones, one for each of the twelve tribes of Israel.

Example 2. Here are the Mohs hardness numbers of four gems as we know them today: amethyst (quartz) 7, topaz 8, sapphire (corundum) 9, diamond 10. Put them in order from softest to hardest. Which of the other three can scratch amethyst?

1. Softest has the smallest number: amethyst 7.
2. Next come topaz 8, then sapphire 9, then diamond 10.
3. A mineral scratches anything with a smaller number. Topaz (8), sapphire (9) and diamond (10) all have bigger numbers than 7.

Answer: Amethyst 7, topaz 8, sapphire 9, diamond 10. Topaz, sapphire and diamond can all scratch amethyst.

PRACTICE

1. EASY How many rows of stones were on the breastplate, and how many stones were in each row? Name the three stones of the first row.
2. EASY What was engraved on each stone, and why did Aaron wear them over his heart?
3. MEDIUM The breastplate was a square, one span on each side. If a span is 9 inches, how far is it all the way around the edge?
4. MEDIUM A row of three stones fits exactly across the 9-inch breastplate. If all three stones are the same width with no gaps, how wide is each stone? About how many centimeters is that? (1 inch is about 2½ centimeters.)
5. HARD Grace tested 10 objects with a flashlight. Her table showed 3 transparent and 2 translucent. The rest were opaque. How many were opaque? What did she need to keep the same for a fair test?
6. CHALLENGE Why are Bible scholars not completely sure which modern stones match all twelve names in Exodus 28? Write two or three sentences.

COMMON MISTAKES

- Thinking every gem is clear and sparkly. Many gems, such as jasper and onyx, are opaque and are treasured for their colors and patterns instead of their sparkle.
- Thinking a bigger gem is a harder gem. Hardness depends on what mineral the gem is, not on its size. A tiny sapphire (9) can scratch a huge amethyst (7).
- Thinking every gem name is a different mineral. Amethyst, agate, onyx and jasper are all kinds of quartz, and emerald is a green kind of beryl.

Make it a game · Twelve-Stone Memory. Write each of the twelve stone names on two index cards, making 24 cards. Mix them and lay them face down. Take turns flipping two cards. When you find a match, keep it only if you can say which row the stone was in, or give one gem fact (for example, “amethyst is purple quartz” or “sapphire is 9 on the Mohs scale”). The player with the most pairs wins.

Scripture. “And thou shalt set in it settings of stones, even four rows of stones: the first row shall be a sardius, a topaz, and a carbuncle: this shall be the first row. And the second row shall be an emerald, a sapphire, and a diamond. And the third row a ligure, an agate, and an amethyst. And the fourth row a beryl, and an onyx, and a jasper: they shall be set in gold in their inclosings.” (Exodus 28:17–20, KJV)

God gave careful, exact instructions, and His people followed them with skill. Every name was carved in a precious stone and set in gold, because every one of God’s people was precious to Him.

Practice answers

1. Four rows of three stones. The first row was a sardius, a topaz and a carbuncle (Exodus 28:17).
2. The name of one of the twelve tribes of Israel. Aaron carried the names of God’s people on his heart when he went into the holy place, as a memorial before the Lord (Exodus 28:29).
3. 9 + 9 + 9 + 9 = 36 inches (or 4 × 9 = 36 inches), which is 3 feet.
4. 9 ÷ 3 = 3 inches wide. 3 × 2½ = 7½, so about 7½ centimeters.
5. 10 − 3 − 2 = 5 opaque. She needed to keep the flashlight at the same distance, the room equally dark and her viewing spot the same for every object.
6. The names come from old Hebrew words that were translated into English long after Moses, and ancient people sometimes used one name for stones we now know are different minerals. The breastplate itself has not been found to examine. For example, the “diamond” may have been another stone, because real diamond is too hard for ancient engravers to cut letters into easily.

7.2 Iron, Copper, Gold

OBJECTIVES

- Explain what an ore is and how smelting gets metal out of rock.
- Identify hematite, magnetite and malachite by color, streak and the magnet test, and name the metal each gives.
- Compare iron, copper and gold, including why iron rusts, copper turns green and gold stays bright, using the Statue of Liberty as an example.

> **Warm-up.** Take a fridge magnet on a hunt around the kitchen. Touch it to a steel spoon, a piece of aluminum foil, a coin, a nail, a paper clip and a gold-colored ring or button. Make two lists: Sticks and Does Not Stick. What do the things in the Sticks list have in common?

> **Video.** Coming soon. How ore becomes metal (mining, smelting, rust and copper's green patina) and the Statue of Liberty's copper skin and iron frame: search the National Park Service (Statue of Liberty), USGS, the Smithsonian, SciShow Kids, Science Max, Homeschool Pop (Alternate) and historic iron-furnace or blacksmith demonstration footage.

KEY TERMS

ore
A rock with enough metal in it to be worth digging out. Hematite is an iron ore.

smelting
Heating crushed ore very hot in a furnace so the metal melts free from the rock.

native metal
A metal found pure in nature, not locked inside an ore. Gold nuggets are native gold.

rust
The flaky red-brown stuff that forms when iron joins with oxygen from the air and water.

patina
A thin coat that forms on the outside of a metal over time. Copper grows a green patina that protects the metal underneath.

CORE IDEAS

The story. On October 28, 1886, crowds stood in the rain and fog of New York Harbor as a giant copper lady was unveiled: the Statue of Liberty, a gift from the people of France. The sculptor, Frédéric Auguste Bartholdi, had her skin made from thin sheets of **copper**, hammered by hand over wooden forms. The copper is only about 3/32 of an inch thick, about as thick as two pennies stacked together. Copper that thin could never stand up by itself, so the engineer Gustave Eiffel, who later built the Eiffel Tower, designed a strong **iron** skeleton

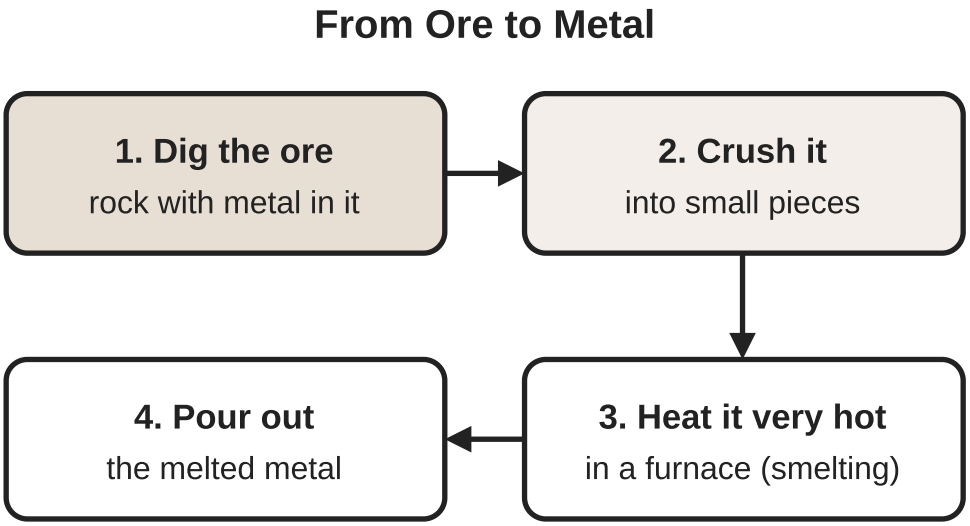
inside to hold her up. Today her torch flame is covered with a thin layer of real **gold**. Iron, copper and gold: three metals in one statue, and every one of them came out of the ground.

How they figured it out. Metals are hardly ever found lying around in shiny bars. Most are hidden inside rocks called **ores**. Miners learned to know ores by the tests you learned in Unit 1. **Hematite**, the most important iron ore, may be silvery gray or rusty red, but its streak is always reddish brown. **Magnetite**, another iron ore, is black and pulls on a magnet. A favorite copper ore is bright green **malachite**. To get the metal out, people crush the ore and heat it in a very hot furnace with charcoal or coke (baked coal). This is called **smelting**. The metal melts free, and the waste rock is left behind as glassy slag. The book of Job says it simply: “Iron is taken out of the earth, and brass is molten out of the stone” (Job 28:2). In the King James Bible, “brass” usually means copper or bronze.

The big idea. Each metal has its own gifts. **Iron** is strong and plentiful, so it becomes nails, rails and bridges, and with a little carbon mixed in it becomes steel. But iron **rusts**: oxygen and water join with it and slowly turn it into flaky red-brown rust. **Copper** bends easily and carries electricity well, so it fills the wires inside your walls. Out in the weather, copper slowly grows a thin green coat called a **patina**. That is why the Statue of Liberty, once shiny brown like a new penny, is green today. **Gold** is soft, heavy and so steady that it never rusts or turns green. It is often found as **native** metal, in pure nuggets and flakes, with no smelting needed.

In the world today. Where the statue’s iron bars touched the copper skin in damp, salty sea air, the iron rusted badly. In the 1980s workers replaced the bars, one at a time, with stainless steel, which does not rust. Ores are still mined in America: iron in Minnesota and Michigan, copper in Arizona and Utah, gold in Nevada. Every metal thing in your house began as rock in the ground.

God’s handiwork. Job 28 is one of the oldest descriptions of mining ever written. It tells of miners cutting paths deep in the rock that no bird has ever seen. Metals are treasures God placed in the earth for people to find and use. Of the land of Havilah, near the garden of Eden, the Bible says, “the gold of that land is good” (Genesis 2:12). Yet Job 28 ends by pointing to a greater treasure: “the fear of the Lord, that is wisdom” (Job 28:28).



Gold is often found already pure, so it may need no smelting.

How ore becomes metal.

PICTURE STUDY



An Iron Forge, Joseph Wright of Derby, 1772 · Oil on canvas · Tate Britain, London

You met Joseph Wright of Derby in Unit 2, when you looked at his painting of a glowing volcano. Wright lived in the English Midlands at the time when the first great ironworks and factories were being built, and he loved to paint scenes lit by a single bright light. In this painting the light comes from a bar of red-hot iron just pulled from the fire.

In a forge like this one, iron from the smelting furnace was heated and pounded to squeeze out bits of slag and make it tough. The great hammer was lifted and dropped by a water wheel turning outside. Wright painted the ironworker as a strong, proud man whose family has come to watch him work.

Look closely

- Find the bar of hot iron. It is the brightest thing in the painting. What color is it?
- Find the giant hammer above the bar. What would it sound like when it came down?
- Look at the faces. Where is the light on them coming from?
- Find the children. How do you think they feel about the forge?

Talk about it

1. Why do you think the painter made everything around the hot iron so dark?
2. Wright painted a working man as a hero. What kind of work do you think is worth painting?
3. What iron or steel things in your house might have started in a forge or furnace like this?

> **Safety first.** Nails can be sharp, and old rusty metal can scratch, so handle them carefully and wash your hands after the experiment. Salt water is not for drinking. Keep magnets away from babies and toddlers; swallowed magnets are dangerous.

EXPERIMENT: THE RUST RACE AND THE MAGNET TEST

Iron rusts, copper changes color, and gold stays bright. In this experiment you will find out for yourself which metals change in salt water, and you will use a dry nail to see what water has to do with rust.

You will need

- 2 plain steel nails (not shiny silver galvanized nails)
- A piece of bare copper wire about 4 inches (10 centimeters) long, or a clean copper-colored penny
- A small ball of aluminum foil
- 4 clear cups or jars, masking tape and a marker for labels
- Paper towels, 1 cup of warm water and 1 teaspoon of salt
- A magnet and your science notebook

Steps

1. **Magnet test first.** Touch the magnet to each metal. Record which ones stick. (The nails are iron and steel, so they stick. Copper and aluminum do not.)
2. **Question:** Which metal will change the most in salt water: iron, copper or aluminum?
3. **Prediction:** Write your guess and why.

4. Label the cups: Wet Nail, Dry Nail, Copper, Foil. Stir the salt into the water until it disappears.
5. **What we keep the same:** Fold a paper towel into each of the Wet Nail, Copper and Foil cups and pour in the same amount of salt water, 2 tablespoons each. Put all four cups in the same place.
6. **What we change:** The kind of metal. The Dry Nail cup gets a dry paper towel and no water. It is our *control*: it shows what happens to iron without water.
7. **What we measure:** Every day for 5 days, give each metal a rust or color-change score: 0 = no change, 1 = a little, 2 = some, 3 = a lot. Record the scores in a table with one row for each cup and one column for each day.
8. On Day 5, look closely with a magnifying glass if you have one. Draw each metal and write one sentence telling which changed most.

Tips

- Add a spoonful of salt water to the wet cups each day if the towels start to dry out, the same amount to each.
- Rust shows first as tiny orange-brown spots. Copper may darken or get a hint of green. Look closely every day.

Check your work

- I recorded which metals stuck to the magnet.
- I kept everything the same except the kind of metal, and I used a dry nail as a control.
- I can explain from my results that iron needs water and air to rust.

FIELD NOTEBOOK

1. Draw the Statue of Liberty and label her three metals: iron (now stainless steel) skeleton inside, copper skin, gold-covered flame.
2. Draw the four steps from ore to metal as a comic strip: dig, crush, heat, pour.
3. Draw your rust-race cups on Day 1 and on Day 5 side by side. Use colored pencils to show the changes.

> **From history.** In 1779, at Coalbrookdale in England, the ironmaster Abraham Darby III finished a bridge across the River Severn made almost entirely of cast iron. People had never seen anything like it. They came from far away to walk across it, and the village that grew up beside it is still called Ironbridge. The bridge still stands today, and people can still walk across it.

WORKED EXAMPLES

Example 1. A rock collector has three samples. Sample A is silvery gray, does not pull on a magnet, and leaves a reddish-brown streak. Sample B is black and pulls on a magnet. Sample C is bright green with a light green streak. Name each ore and the metal it gives.

(Use the map or drawing "Each of these ores would go through these four steps to become metal." shown earlier in this lesson.)

1. A reddish-brown streak is the clue for hematite, even when the rock itself looks gray. Hematite is an iron ore.
2. A black ore that pulls on a magnet is magnetite, another iron ore.
3. A bright green ore with a light green streak is malachite, a copper ore.

Answer: A is hematite (iron). B is magnetite (iron). C is malachite (copper).

Example 2. Pure hematite is about 7 parts iron out of every 10 parts by weight. About how many pounds of iron could be smelted from 20 pounds of pure hematite? About how many kilograms is that? (1 pound is a little less than half a kilogram.)

1. 10 pounds of hematite gives about 7 pounds of iron.
2. 20 pounds is two groups of 10 pounds, so the iron is 7 + 7 = 14 pounds.
3. Half of 14 is 7, and a pound is a little less than half a kilogram, so 14 pounds is a little less than 7 kilograms, about 6 kilograms.

Answer: About 14 pounds of iron, which is about 6 kilograms. (Real ore in the ground is mixed with other rock, so miners get less.)

PRACTICE

1. EASY What is an ore?
2. EASY Name the three metals in the Statue of Liberty and tell what part each one makes.
3. MEDIUM Two dark rocks look almost alike. One pulls on a magnet and one does not, but it leaves a reddish-brown streak. Which is magnetite and which is hematite?
4. MEDIUM If 10 pounds of pure hematite gives about 7 pounds of iron, how much iron comes from 30 pounds?
5. HARD Sam's rust-race scores (0 = no change, 3 = a lot) were: Wet nail: Day 1 = 0, Day 3 = 2, Day 5 = 3. Dry nail: 0, 0, 0. Copper: 0, 0, 1. Foil: 0, 0, 0. Which metal changed the most? What does the dry nail teach?
6. CHALLENGE Miners often find gold as pure nuggets, but they almost never find pure iron lying in the ground. Explain why in two sentences.

COMMON MISTAKES

- Thinking all metals stick to a magnet. Iron and steel do, but copper, gold and aluminum do not.
- Thinking the Statue of Liberty was painted green. The green is a natural patina that formed on the copper in the weather, and it protects the metal underneath.
- Thinking rust is dirt sitting on top of iron. Rust is the iron itself, changed after joining with oxygen and water. That is why a rusty nail gets thinner and weaker.

> **Make it a game · Ore Detective.** A parent reads a clue card, such as “I leave a reddish-brown streak,” “I pull on a magnet,” “I am bright green,” “I am found as pure nuggets,” “I turn green in the weather” or “I rust in water.” The player names the ore or metal (hematite, magnetite, malachite, gold, copper, iron). Score one point for the name and a bonus point for naming something made from that metal. Play to ten points, then switch roles.

> **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)

Long before modern mining, the book of Job described veins of silver, places where gold is refined, iron dug from the earth and copper melted out of stone. God hid these useful treasures in His world for people to find and work.

Practice answers

1. A rock with enough metal in it to be worth digging out, such as hematite for iron or malachite for copper.
2. Copper makes her skin, iron (now replaced with stainless steel) made the skeleton inside that holds her up, and gold covers her torch flame.
3. The one that pulls on the magnet is magnetite. The one with the reddish-brown streak is hematite. Both are iron ores.
4. 30 pounds is three groups of 10, so 7 + 7 + 7 = 21 pounds of iron.
5. The wet nail (iron) changed the most, reaching a score of 3. The dry nail never rusted, so it shows that iron needs water (along with air) to rust. Everything else was the same, so the water made the difference.
6. Iron joins easily with oxygen and water, so in nature it is almost always locked up in ores like hematite and magnetite (or turns to rust). Gold does not rust or join easily with oxygen, so it can stay pure in the ground for a very long time.

7.3 Panning for "Gold"

OBJECTIVES

- Tell how James Marshall found and tested gold at Sutter's Mill in 1848.
- Explain why panning works: gold is dense, so it sinks while light sand washes away.
- Tell gold from pyrite (fool's gold) using hardness, streak and the hammer test, and run a fair test of panning with a control.

Warm-up. Fill a clear jar about two-thirds full of water. Add a big spoonful of sand and two or three metal washers or nuts. Put the lid on tight, shake it hard, set it down and watch closely. What reaches the bottom first? What is still floating around? Draw what you see after one minute.

Video. Coming soon. How to pan for gold, gold versus fool's gold (pyrite), and the California Gold Rush of 1848–1849 at Sutter's Mill: search California State Parks (Marshall Gold Discovery), the Smithsonian, USGS, SciShow Kids, Homeschool Pop (Alternate), Science Max and real gold-panning demonstration footage.

KEY TERMS

dense
Heavy for its size. Gold is very dense: a small flake weighs much more than a sand grain of the same size.

placer gold
Gold found loose in sand and gravel, washed out of rocks by water (say PLASS-er).

panning
Shaking and swirling gravel and water in a shallow pan so the light sand washes out and heavy gold stays at the bottom.

pyrite
A brassy yellow mineral nicknamed "fool's gold." It is hard and brittle and leaves a greenish-black streak.

vein
A crack in rock that has been filled with minerals such as quartz, and sometimes gold.

CORE IDEAS

The story. On the morning of January 24, 1848, a carpenter named James Marshall walked along a ditch below a sawmill he was building on the American River at Coloma, California. The mill was a partnership with John Sutter, and water rushed through the ditch, called the tailrace, to turn the mill wheel. In the gravel at the bottom Marshall saw something shine: a few small flakes of yellow metal. Was it gold, or only a pretty mineral that fools people?

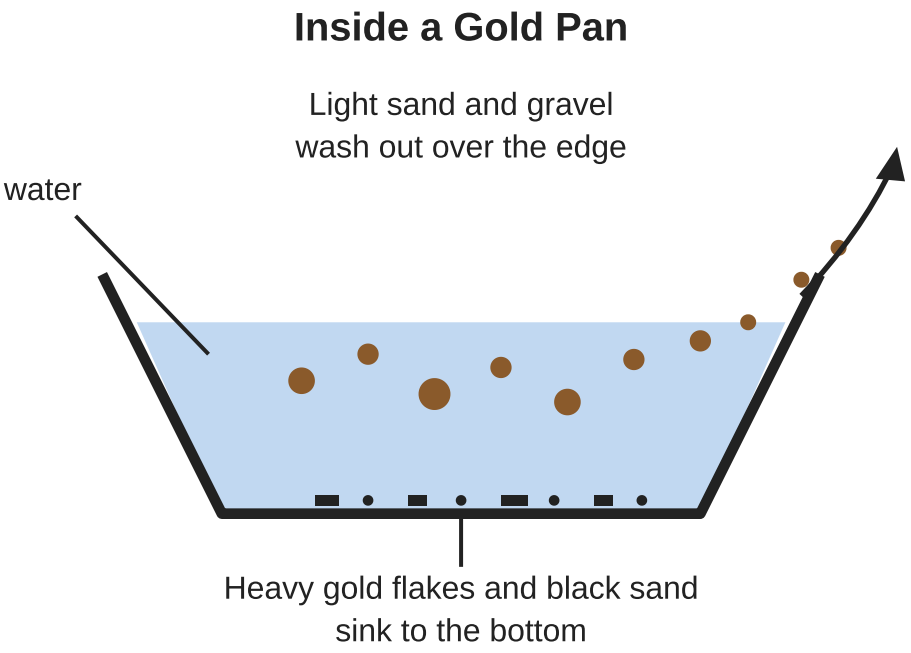
Within months the news had spread, and by 1849 tens of thousands of people were rushing to California. They were called the forty-niners.

How they figured it out. Marshall tested his flakes like a scientist. He laid one on a rock and pounded it with another rock. It flattened out thin without breaking. Pyrite, the shiny mineral called **fool's gold**, would have shattered into powder. Then Jennie Wimmer, who cooked for the mill workers, dropped a piece into her kettle of boiling lye soap. When it came out, it was as bright as ever, because real gold does not tarnish. Today we can add two tests from Unit 1. Gold is soft, only about 2½ to 3 on the Mohs scale, while pyrite is about 6 to 6½, too hard for a steel nail to scratch. Gold leaves a golden-yellow streak, but pyrite leaves a greenish-black one.

The big idea. How did gold get into a stream? Gold forms in **veins** inside hard rock, often together with quartz. When that rock cracks and wears away, water carries the pieces downhill. Gold is very **dense**: heavy for its size. A piece of gold is about 19 times as heavy as the same amount of water and about 7 times as heavy as the same amount of quartz sand. When a stream slows down, behind a boulder or on the inside of a bend, the heavy gold drops first and settles into cracks at the bottom. Gold found loose in sand and gravel like this is called **placer gold**.

Try it and see. Panning uses that heaviness. A miner scoops gravel and water into a wide, shallow pan, often about 14 inches (about 36 centimeters) across. Shaking the pan from side to side makes the heavy bits sink to the bottom. Then the miner tips the pan a little and swirls it, so the water carries the light sand over the edge. Little by little the pan is washed down until only a spoonful of heavy black sand is left. That black sand is mostly magnetite, the iron ore from Lesson 7.2. In it, if the miner is blessed, lie a few bright flakes of gold. In your project you will pan for "gold" you make yourself and test whether heaviness or color keeps it in the pan.

God's handiwork. Job 28:6 speaks of a place in the rocks that "hath dust of gold." Gold dust is real, and God put it where patient, careful people could find it. Yet most forty-niners found very little, and many of the people who did best were the ones who sold miners shovels, food and boots. The Bible reminds us of a better treasure: "How much better is it to get wisdom than gold!" (Proverbs 16:16).



Inside a gold pan: light sand washes out, and heavy gold and black sand sink to the bottom.

PICTURE STUDY



Washing Gold with a Sluice and a Pan, a Woodcut from De re metallica, Woodcut made for Georgius Agricola's book, 1556 (this print is from the German edition of 1557) · Woodcut print · Printed in Basel, Switzerland; this copy is in the National Library of Poland, Warsaw

Georgius Agricola was the Latin name of Georg Bauer, a German doctor who lived in the mining towns of the mountains between Germany and Bohemia. For many years he visited mines, talked with miners and wrote down everything he learned. His great book, *De re*

metallica (“On the Nature of Metals”), was printed in 1556 with hundreds of woodcut pictures showing how miners dug, pumped, crushed, washed and smelted ore.

In 1912 a young American mining engineer named Herbert Hoover and his wife, Lou Henry Hoover, translated the whole book from Latin into English. Years later Herbert Hoover became President of the United States. This woodcut shows workers washing gold-bearing sand in a sloping trough called a sluice and in pans, where flowing water carries away the light sand and the heavy gold stays behind, just as in your gold pan.

Look closely

- Find the water. Where does it come from, and where does it go?
- Find the long sloping trough. Why do you think it slants downhill?
- Look at the workers’ tools. What is each person using, and what job is he doing?
- Find the place where the heavy gold would be caught. How is it like the bottom of a gold pan?

Talk about it

1. How is washing sand in a sluice like panning for gold? How is it different?
2. Why would a picture be helpful in a book about mining, even for people who could read?
3. What would you draw if you were making a picture to teach someone how to pan for gold?

> **Safety first.** Do this project outdoors or in a large tub, and wipe up spills so no one slips. Let an adult help with paint and use it where there is fresh air. Keep small nuts, washers and pebbles away from little children. If you ever pan in a real stream, go only with an adult, never alone, stay out of fast or deep water, and pan only where you have permission.

EXPERIMENT: PAN FOR “GOLD”: IS IT THE WEIGHT OR THE COLOR?

You will make two kinds of pretend gold that look exactly alike: heavy metal washers and light pebbles, both painted gold. Then you will pan them and find out which kind stays in the pan. This is a fair test because only one thing is different.

You will need

- A round aluminum pie pan or cake pan, about 9 inches (about 23 centimeters) across
- A dishpan or bucket of water
- 2 cups of sand and 1 cup of small gravel or aquarium gravel
- 10 small steel nuts or washers, about ½ inch (about 1 centimeter) across
- 10 small pebbles about the same size as the washers
- Gold acrylic paint or gold nail polish (with an adult), and newspaper
- Your science notebook

Steps

1. With an adult, paint the 10 washers and the 10 pebbles gold on newspaper. Let them dry completely.
2. **Question:** When I pan, does my “gold” stay in the pan because of its color or because it is heavy for its size?
3. **Prediction:** Write how many washers and how many pebbles you think will still be in the pan at the end.
4. **What we keep the same:** The same pan, the same amount of sand and gravel, the same color paint, and the same number of shakes and swirls each time.
5. **What we change:** Only what the “gold” is made of: heavy steel or light stone.
6. Put 1 cup of sand, ½ cup of gravel, 5 washers and 5 pebbles in the pan. Dip the pan into the water to fill it.
7. Shake the pan side to side 10 times. Then tip it slightly away from you and swirl it 10 times so water and sand spill over the far edge. Dip and repeat until most of the sand is gone.
8. **What we measure:** Count how many washers and how many pebbles are left in the pan. Record them in a table. Do 3 trials, starting fresh each time, and add up your totals.

Tips

- Tip the pan only a little. Real miners take their time with the pan.
- If your pebbles are much bigger than the washers, the test is not fair. Choose pebbles close in size.

Check your work

- I kept everything the same except what my “gold” was made of.
- I did 3 trials and added up my results.
- I can explain from my results that heaviness, not color, keeps gold in the pan.

FIELD NOTEBOOK

1. Draw a side view of your gold pan and label the water, the light sand washing out, and the heavy “gold” at the bottom.
2. Draw a stream with a bend and a big boulder. Put an X everywhere you think gold might settle, and write why.
3. Make a two-column chart, Gold and Pyrite, and fill in hardness, streak color and what happens when you pound it.

> **From history.** News of Marshall’s find spread slowly at first. Then, on December 5, 1848, President James K. Polk told Congress that the reports of gold in California were true. After that, people poured in by ship and by covered wagon from the eastern states and

from countries around the world. So many people arrived so fast that California became a state in 1850, only two years after the gold was found.

WORKED EXAMPLES

Example 1. A family panned four pans of gravel at a gold-panning park and counted the tiny flakes in each: Pan 1 had 4, Pan 2 had 7, Pan 3 had 2 and Pan 4 had 5. How many flakes did they find in all? Which pan had the most, and how many more did it have than the pan with the fewest?

(Use the map or drawing "The flakes they counted were the heavy bits left at the bottom of each pan." shown earlier in this lesson.)

1. Add all four pans: 4 + 7 + 2 + 5 = 18.
2. The biggest number is 7, so Pan 2 had the most.
3. The smallest number is 2 (Pan 3). Subtract: 7 − 2 = 5.

Answer: 18 flakes in all. Pan 2 had the most, 5 more than Pan 3.

Example 2. Here is how much a cube 1 centimeter on each side (about the size of a sugar cube) weighs for four materials: water about 1 gram, quartz sand about 3 grams, iron about 8 grams, gold about 19 grams. Which would settle first in a stream? How many grams heavier is the gold cube than the iron cube?

1. The heaviest for its size settles first. Gold, at about 19 grams, is the heaviest.
2. Subtract: 19 − 8 = 11.
3. So gold drops out of the water first, then iron-rich black sand, and the light quartz sand is carried farthest.

Answer: Gold settles first. The gold cube is about 11 grams heavier than the iron cube. (A gold cube 1 inch on each side weighs about 11 ounces, almost three-quarters of a pound.)

PRACTICE

1. EASY Who found gold at Sutter's Mill, and in what month and year?
2. EASY Why does gold stay at the bottom of a pan while sand washes out?
3. MEDIUM A shiny yellow grain leaves a greenish-black streak, and a steel nail cannot scratch it. When you tap it with a hammer, it breaks into pieces. Is it gold or pyrite? Give two reasons.
4. MEDIUM A gold pan is 14 inches across. One inch is about 2½ centimeters. About how many centimeters across is the pan?
5. HARD In three trials, Ben started with 15 gold-painted washers and 15 gold-painted pebbles in all. At the end, 15 washers and 4 pebbles were left in his pan. What does this show? Why did Ben paint both kinds gold?

6. CHALLENGE You are panning in a stream with a big boulder and a sharp bend. Where would you dig your gravel, and why? Write two sentences.

COMMON MISTAKES

- Thinking anything shiny and gold-colored is gold. Pyrite and even flakes of mica can glitter like gold; real gold is soft, bends instead of breaking, and has a golden-yellow streak.
- Thinking gold sinks because the pieces are big. Even tiny gold flakes sink fast, because gold is heavy for its size (dense), not because it is large.
- Thinking you pan by scooping the gold out of the water. You do the opposite: you wash the light sand away and let the gold stay behind.

> **Make it a game · Gold or Fool's Gold?.** A parent reads a clue: "I am soft enough to scratch with a nail," "I leave a greenish-black streak," "I flatten when I am pounded," "I break into pieces when I am hit," "I am heavy for my size," "I grow in little cubes." The player shouts "Gold!" or "Fool's gold!" and gets a point for each right answer. (Pyrite often grows in cube-shaped crystals.) Five right in a row earns a "nugget" (a gold-painted pebble from the project).

> **Scripture.** "How much better is it to get wisdom than gold! and to get understanding rather to be chosen than silver!" (Proverbs 16:16, KJV)

The forty-niners crossed mountains and oceans for gold. Solomon says wisdom is worth even more, and it is worth seeking with the same patience a good miner uses at his pan.

Practice answers

1. James Marshall, a carpenter building the mill, found it in January 1848 (January 24) at Coloma, California.
2. Gold is very dense, much heavier for its size than sand, so it sinks to the bottom and the moving water carries the lighter sand over the edge.
3. Pyrite. Gold leaves a golden-yellow streak (not greenish-black), gold is soft enough for a nail to scratch, and gold flattens when hammered instead of breaking.
4. 14 × 2 = 28, and half of 14 is 7, so 28 + 7 = 35. About 35 centimeters.
5. All the heavy washers stayed but most of the light pebbles washed out, so heaviness for size (density), not color, keeps "gold" in the pan. He painted both gold so color was the same and only the material was different, making it a fair test.
6. I would dig just downstream of the boulder or on the inside of the bend, especially in cracks near the bottom. In those places the water slows down, and the heavy gold drops out first and settles there.

7.4 Diamonds and Coal: Both Carbon

OBJECTIVES

- Tell how Smithson Tennant showed in 1797 that diamond is made of carbon, the same stuff as charcoal.
- Explain that diamond and graphite are both carbon but are very different because their atoms are arranged in different patterns, and that coal is a rock made mostly of carbon.
- Change carats to grams and use Mohs numbers to compare diamond and graphite.

Warm-up. Scribble hard with a soft pencil on a scrap of paper until you have a dark gray patch. Rub it with your fingertip. How does it feel? Look at your finger. Now look at a piece of unlit charcoal from a grill or a photo of a lump of coal and a photo of a diamond ring. Make a guess: what could a pencil, a lump of coal and a diamond have in common?

Video. Coming soon. Diamond and graphite as two forms of carbon, how natural diamonds reach the surface in kimberlite pipes, how diamonds are made in laboratories, and the Hope Diamond: search the Smithsonian National Museum of Natural History, USGS, the Gemological Institute of America (GIA), SciShow Kids, Science Max and Homeschool Pop (Alternate).

KEY TERMS

carbon
One of the basic building materials God made. Diamond and graphite are pure carbon, coal is mostly carbon, and every living thing contains carbon.

atom
One of the tiny building blocks that everything is made of, far too small to see even with a microscope at home.

graphite
A soft, gray, slippery mineral made of carbon atoms in flat sheets. Pencil “lead” is graphite mixed with clay.

carat
A unit for weighing gems. 5 carats make 1 gram.

kimberlite
A kind of volcanic rock that rose up from very deep in the earth in narrow pipes and carried diamonds with it. It is named for the town of Kimberley in South Africa.

CORE IDEAS

The story. In 1797 an English chemist named Smithson Tennant burned up a diamond on purpose, to find out what it is made of. He sealed a small diamond in a gold tube with a chemical called saltpeter and heated it until the diamond was gone. Then he carefully caught

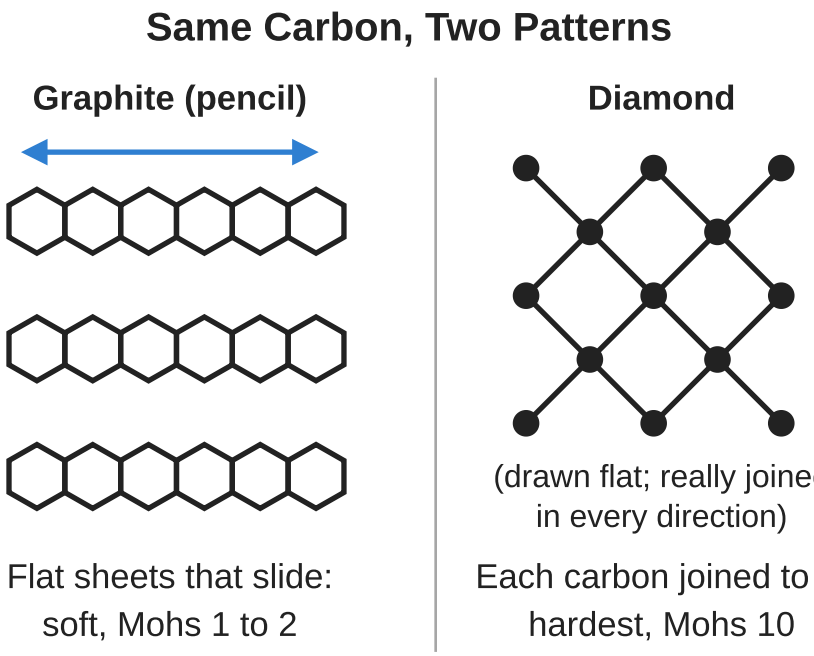
and measured the gas that came off. It was carbon dioxide, the same gas that comes from burning charcoal. And here was the surprise: a diamond made the same amount of that gas as the same weight of charcoal. The sparkling diamond and the black, crumbly charcoal were made of the very same stuff: **carbon**.

How they figured it out. Tennant was not the first to try. In 1772 the French scientist Antoine Lavoisier and his fellow chemists put diamonds under a giant burning lens, a magnifying glass so large it could focus sunlight hot enough to make a diamond burn away. They found that the diamonds turned into the same kind of gas as burning charcoal. Tennant's careful weighing finished the job. Scientists now know that diamond is pure carbon, and so is **graphite**, the soft gray mineral in your pencil. Coal is a rock made mostly of carbon too, from plants that were buried and squeezed, as you learned in Lesson 3.3.

The big idea. If diamond and pencil lead are both carbon, why is one the hardest natural mineral and the other so soft it rubs off on paper? The answer is the **pattern** of the **atoms**, the tiny building blocks of everything. In graphite, carbon atoms are joined in flat sheets, like layers of chicken wire stacked up. The sheets hold on to each other only weakly, so they slide apart. That is why graphite feels slippery and leaves a gray line when you write. Graphite is only about 1 to 2 on the Mohs scale. In diamond, every carbon atom is locked tightly to four neighbors, in every direction, like a never-ending jungle gym. Nothing slides, so diamond is a 10. Coal is different again: it has no one neat pattern, just a jumble of carbon mixed with other things.

In the world today. Many people think diamonds are made from coal, but that is a myth. Coal forms from buried plants in layers of rock not far below the surface. Natural diamonds form much deeper, about 100 miles (about 160 kilometers) down, where the heat and squeezing are enormous, and most were carried up in pipes of kimberlite. On December 16, 1954, Tracy Hall, a scientist at the General Electric laboratory in Schenectady, New York, made diamonds in a machine that squeezed and heated carbon. Nearly all diamonds used on saw blades and drill bits are now made this way. The famous deep blue Hope Diamond, a natural diamond, weighs about 45½ **carats** and is on display at the Smithsonian in Washington, D.C.

God's handiwork. The prophet Jeremiah wrote of words carved "with the point of a diamond" (Jeremiah 17:1). People in his day knew that a point of very hard stone can engrave what softer tools cannot. (As with the breastplate, the Hebrew word may mean diamond or another very hard stone.) God built His world from a small number of building blocks and arranged them with great wisdom. The same carbon is in a pencil, a lump of coal, a diamond ring and the cells of your own body. What it becomes depends on how the Maker puts it together.



Same carbon, two patterns. In these simple drawings each corner or dot stands for a carbon atom.

PICTURE STUDY



Antoine-Laurent Lavoisier and His Wife, Marie-Anne Pierrette Paulze, Jacques-Louis David, 1788 · Oil on canvas · The Metropolitan Museum of Art, New York

Antoine Lavoisier was one of the greatest chemists who ever lived, and he was one of the scientists who burned diamonds under a giant lens in 1772. His wife, Marie-Anne, worked beside him in his laboratory. She kept careful notes, translated science books from English for him, and drew the pictures of his equipment that were engraved for his famous chemistry book.

Marie-Anne had taken drawing lessons from the painter of this portrait, Jacques-Louis David, one of the most famous artists in France. David painted the couple as partners in science, surrounded by the glass and brass tools of their work.

Look closely

- Find the glass equipment. How many pieces can you count on the table and on the floor?
- What is Lavoisier holding, and what do you think he is doing?
- Where is Marie-Anne looking? Why do you think the painter had her look at us?
- Find the brightest colors in the painting. Where does your eye go first?

Talk about it

1. Why do you think the Lavoisiers wanted their scientific tools in their portrait?
2. How did careful notes and drawings help scientists like Lavoisier and Tennant?
3. If someone painted you doing science, what tools would you want in the picture?

> **Safety first.** Toothpick points are sharp, so build carefully and keep toothpicks away from little children. Do not eat marshmallows that have been handled during the experiment. Never try Lavoisier's burning-lens experiment: a magnifying glass in sunlight can start fires and burn skin, and you must never look at the sun through a lens or without one.

EXPERIMENT: SHEETS OR JUNGLE GYM? A CARBON MODEL TEST

You cannot see atoms, but you can build models of them. You will use the same number of marshmallows to build a "graphite" model and a "diamond" model, then test which one holds up better when you press on it.

You will need

- 24 mini marshmallows or gumdrops (12 for each model)
- About 40 round toothpicks
- A paper plate cut into a 4-inch (10-centimeter) square
- A pile of pennies (about 50)
- A ruler and your science notebook

Steps

1. **Question:** If two models are made of the same pieces, does the pattern change how strong they are?
2. **Prediction:** Write which model you think will hold more pennies before it slides or falls apart.
3. **Graphite model:** Make two flat rings, each with 6 marshmallows joined by 6 toothpicks into a six-sided shape. Lay one ring flat on the table and set the second ring on top of it. Do not join the two rings together.

4. **Diamond model:** Use the other 12 marshmallows. Join each one to as many neighbors as you can, up, down and sideways, like a small jungle gym, so the model stands up as one piece.
5. **What we keep the same:** The number of marshmallows (12), the kind of toothpicks, the same paper-plate square on top, and adding pennies one at a time in the center.
6. **What we change:** Only the pattern of the model.
7. **What we measure:** Set the plate square on top of each model. Add pennies one at a time. Stop when the model slides apart or squashes down about ½ inch (about 1 centimeter). Record the number of pennies.
8. Finally, gently push the top of each model sideways with one finger. Which one slides? Write a sentence comparing your models with real graphite and real diamond.

Tips

- Push toothpicks about halfway into each marshmallow so they grip well.
- If the top ring of the graphite model slides off before you even add pennies, that is a result too. Record it as 0 pennies and explain why.

Check your work

- I built both models from the same number of marshmallows.
- I added pennies the same way to each model and recorded the numbers.
- I can explain how the sliding sheets match graphite and the joined-up model matches diamond.

FIELD NOTEBOOK

1. Draw a pencil, a lump of coal and a diamond in a row. Over all three, write “carbon.” Under each one, write one word that describes it.
2. Draw your two marshmallow models and label them graphite and diamond. Draw arrows to show which one slid.
3. Copy this sentence and finish it: “Diamond and graphite are both carbon, but they are different because …”

> **From history.** In 1958 the New York jeweler Harry Winston gave the Hope Diamond to the Smithsonian Institution. He sent it to Washington, D.C., through the United States mail, wrapped in a plain brown paper package and sent by registered mail. It arrived safely, and it has been one of the most visited treasures in the Smithsonian’s National Museum of Natural History ever since.

WORKED EXAMPLES

Example 1. Gem weights are measured in carats, and 5 carats equal 1 gram. The Hope Diamond weighs about 45 carats. About how many grams is that? A paper clip weighs about 1 gram. How many paper clips would balance it?

1. Every 5 carats make 1 gram, so count how many fives are in 45.
2. 45 ÷ 5 = 9 (because 9 × 5 = 45).
3. 9 grams is about the weight of 9 paper clips.

Answer: About 9 grams, about the same as 9 paper clips. (That is about one-third of an ounce.)

Example 2. Use these Mohs numbers: graphite about 1 to 2, your fingernail about 2½, glass about 5½, diamond 10. Can your fingernail scratch graphite? Can graphite scratch glass? Can diamond scratch glass?

(Use the map or drawing "The pattern explains the hardness." shown earlier in this lesson.)

1. A material scratches anything with a smaller number.
2. Fingernail (2½) is bigger than graphite (1 to 2), so yes, a fingernail can scratch graphite.
3. Graphite (1 to 2) is smaller than glass (5½), so no, graphite cannot scratch glass.
4. Diamond (10) is bigger than glass (5½), so yes, diamond scratches glass.

Answer: Fingernail scratches graphite: yes. Graphite scratches glass: no. Diamond scratches glass: yes. Both are carbon, but the pattern of their atoms makes one soft and the other the hardest.

PRACTICE

1. EASY What are diamond and graphite both made of? What does coal have mostly in it?
2. EASY Why does a pencil leave a gray line on paper?
3. MEDIUM A diamond weighs 10 carats. If 5 carats make 1 gram, how many grams does it weigh?
4. MEDIUM The largest gem diamond ever found, the Cullinan Diamond, was dug up in South Africa in 1905. It weighed about 3,100 carats. About how many grams is that? Is it more or less than 1 pound (about 450 grams)?
5. HARD Lily's results: her graphite model slid apart after 6 pennies, and her diamond model held 30 pennies before it squashed. How many more pennies did the diamond model hold? What did she keep the same, and what does her result show?
6. CHALLENGE A friend says, "Diamonds are just coal that got squeezed." Explain in two or three sentences why this is not right.

COMMON MISTAKES

- Thinking diamonds are made from coal. Both are carbon, but natural diamonds form far deeper in the earth than coal ever does and come up in kimberlite.
- Thinking a diamond cannot break. Diamond is the hardest mineral, so nothing natural can scratch it, but a sharp blow can split it. Hard is not the same as unbreakable.
- Thinking pencil “lead” is the metal lead. It is graphite (carbon) mixed with clay. The old name stuck from long ago, when people thought graphite was a kind of lead.

Make it a game · Pencil, Coal or Diamond?. A parent reads a clue and the player answers “pencil,” “coal,” “diamond” or “all three”: “I am made of carbon” (all three), “I am the hardest mineral” (diamond), “I am a rock made from buried plants” (coal), “My sheets slide” (pencil), “I burn in a stove” (coal), “I am weighed in carats” (diamond), “I came up in kimberlite” (diamond). One point for each right answer; two points for explaining why.

Scripture. “The sin of Judah is written with a pen of iron, and with the point of a diamond: it is graven upon the table of their heart, and upon the horns of your altars;” (Jeremiah 17:1, KJV)

A diamond point carves marks that do not wear away, and Jeremiah used it as a picture of something written very deep. Later in the same book God promises to write His law in His people’s hearts instead (Jeremiah 31:33).

Practice answers

1. Diamond and graphite are both pure carbon. Coal is a rock made mostly of carbon.
2. Pencil lead is graphite, which is made of flat sheets of carbon atoms that slide apart easily. Thin sheets rub off onto the paper and make the line.
3. 10 ÷ 5 = 2 grams.
4. 3,100 ÷ 5 = 620 grams. That is more than 1 pound (620 is more than 450), about 1⅓ pounds.
5. 30 − 6 = 24 more pennies. She kept the number of marshmallows, the toothpicks, the plate square and the way she added pennies the same, and changed only the pattern. It shows that the same pieces joined in every direction (like diamond) are much stronger than flat sheets that can slide (like graphite).
6. Diamond and coal are both made of carbon, but they form in different places. Coal forms from buried plants in rock layers not far below the surface, while natural diamonds form about 100 miles deep and were carried up in kimberlite pipes. Coal is also a jumbled rock, while diamond is pure carbon locked in one neat pattern.

Unit 7 review

A parent reads each question aloud or the student reads it. Answer in complete sentences, and show your work for the number question. The quiz is worth 40 points in all: 10 questions, 4 points each.

1. (4 pts) Describe the high priest’s breastplate. How many stones did it have, how were they arranged, and what was carved on them?
2. (4 pts) Name the word for each: (a) a stone you can see clearly through, (b) a stone that lets light glow through but not clear shapes, (c) a stone that lets no light through.
3. (4 pts) Sapphire is 9 on the Mohs scale and amethyst is 7. Which one can scratch the other? Which one will keep its polish longer?
4. (4 pts) What is an ore? Name one iron ore and one copper ore.
5. (4 pts) Identify the ore: it is black, and it pulls on a magnet. What metal does it give?
6. (4 pts) The Statue of Liberty was once shiny brown like a new penny. Why is it green today? Why did workers replace its iron bars with stainless steel?
7. (4 pts) Explain why gold stays in the bottom of a gold pan while sand washes away.
8. (4 pts) Give two tests that tell real gold from pyrite (fool’s gold), and tell what each one shows.
9. (4 pts) Diamond and graphite are both made of carbon. Why is diamond the hardest mineral while graphite is soft enough to write with?
10. (4 pts) A diamond weighs 20 carats. If 5 carats make 1 gram, how many grams does it weigh? Then tell whether this sentence is true or false: “Diamonds are made from coal.”

Unit project: my dozen-stone display case

Turn a clean cardboard egg carton into a small museum case with 12 spaces, one for each stone of the high priest’s breastplate. Fill the spaces with real samples or small drawings: include at least three gems (or gem pictures), three ores or metals (such as hematite, magnetite, malachite, a copper wire and a steel nail), one piece of pyrite or a gold-painted “nugget,” and graphite, coal and a diamond picture to show the three faces of carbon. Write a tiny label for each space with its name, whether it is a gem, an ore, a metal or a carbon form, and one test result (hardness, streak, magnet or light test).

Inside the lid, glue a short written card explaining your favorite discovery from this unit, and add your results from the rust race, the panning test and the marshmallow model test. Show your case to your family and explain three of the samples like a museum guide.

- **Accuracy**: Every sample is named correctly and sorted correctly as a gem, ore, metal or form of carbon.
- **Testing**: Each label includes a real test result, and the lid includes the recorded results of the three unit experiments.

- **Explanation**: The student explains three samples clearly, including why gold stays in a pan and why diamond and graphite differ.
- **Care**: The case is neat, labels are easy to read, and samples are firmly set in their spaces.

Answer key

1. It had 12 precious stones set in gold in four rows of three, on a square pouch one span (about 9 inches) on each side. Each stone was engraved with the name of one of the twelve tribes of Israel.
2. (a) transparent, (b) translucent, (c) opaque.
3. Sapphire can scratch amethyst, because 9 is bigger than 7. Sapphire will keep its polish longer, because fewer things are hard enough to scratch it.
4. An ore is a rock with enough metal in it to be worth digging out. Iron ores: hematite or magnetite. Copper ore: malachite (or chalcopyrite).
5. Magnetite. It gives iron.
6. Its copper skin slowly grew a green patina in the weather, which protects the copper underneath. The iron bars rusted badly in the damp, salty air where they touched the copper, and stainless steel does not rust.
7. Gold is very dense, much heavier for its size than sand (about 19 times as heavy as water). When the pan is shaken and swirled, the gold sinks to the bottom and the water carries the lighter sand over the edge.
8. Any two: Pound it: gold flattens, pyrite breaks into pieces. Streak: gold leaves a golden-yellow streak, pyrite a greenish-black one. Hardness: a steel nail scratches gold (2½ to 3) but not pyrite (6 to 6½). Tarnish: gold stays bright even in boiling lye soap.
9. Their atoms are arranged in different patterns. In graphite the carbon atoms are in flat sheets that slide apart easily, so it is soft (about 1 to 2). In diamond every carbon atom is locked to four neighbors in every direction, so nothing slides and it is a 10.
10. 20 ÷ 5 = 4 grams. False: both are carbon, but natural diamonds form far deeper in the earth than coal and come up in kimberlite pipes.

UNIT 8

My Rock Collection

All year you have tested minerals, sorted rocks into families, followed fossils and panned for "gold." Now it is time to gather it all into something that is truly yours: **a rock collection**. A real collection is more than a box of stones. Each specimen has a number, a label and a page in a field notebook that tells where it was found and how you know what it is. In this unit you will learn to collect, label and record like a real geologist, visit a museum or rock shop, open your own small museum, and review the whole year with a game you build yourself.

You will travel up the Missouri River with Lewis and Clark, who numbered their rock samples and wrote down where each one was found. You will meet James Smithson, a mineral scientist who gave his fortune to found the Smithsonian; Ole Worm, who showed his visitors that "unicorn horns" were really narwhal tusks; and Louis Agassiz, who taught a student to look at one fish for three days. In every lesson you will practice the habits of a careful naturalist: look closely, write it down, share your evidence and look again.

BEFORE YOU BEGIN

- Can do streak, scratch (fingernail, penny, nail, glass) and vinegar tests from Unit 1
- Can name the three rock families and give two examples of each
- Can measure with a ruler in inches and centimeters and add and subtract small numbers
- Can make a simple tally chart and bar graph

MASTERY CHECKLIST

- I can number a specimen and make a label with its number, name, locality, date and collector.
- I can keep a field notebook page with measurements in inches and centimeters, test results and a sketch.
- I can read a museum label, find the locality, and tell an observation from an idea about the long-ago past.
- I can sort my collection into a labeled display with a catalog and give a three-part talk: what it is, where I found it and how I know.
- I can use a simple identification key to name a mystery mineral.
- I can explain the big ideas of the year about minerals, rocks, fossils, gems and ores.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History** (https://naturalhistory.si.edu/): Free. The museum's website offers online exhibits and a virtual tour, including the Hall of Geology, Gems and Minerals. Use it for Lesson 8.2 if you cannot visit a museum in person.

- **U.S. Geological Survey (USGS)** (https://www.usgs.gov/): Free. Photographs and short articles about rocks and minerals, plus geologic information about your own state, to help you find good collecting places and name what you find.
- **American Federation of Mineralogical Societies** (https://www.amfed.org/): Free to browse. Lists local rock and mineral clubs, many of which welcome families on field trips and hold gem and mineral shows. Read its collector’s code of ethics with your parent before you go collecting.

8.1 Labels and a Field Notebook ★

OBJECTIVES

- Tell how Lewis and Clark numbered their rock and mineral samples and wrote down where each one was found.
- Number a rock, make a specimen label with five parts, and keep a field notebook page for it.
- Measure a specimen in inches and centimeters and read a bar graph of a rock collection.

Warm-up. Your parent puts three pebbles from outside on the table and mixes them up with three more pebbles from somewhere else. Can you tell which three came from which place? Now think: what could you have done before mixing them so you would always know?

Video. Coming soon. How to start a rock collection, number specimens and keep a field notebook for kids; search Smithsonian, USGS, rock and mineral club (rockhound) channels, SciShow Kids and Homeschool Pop (Alternate); also short videos about Lewis and Clark's journals from the National Park Service.

KEY TERMS

specimen
One sample kept for study, such as one rock, one mineral or one fossil in a collection.

specimen number
A number written on a specimen and on its label and notebook page, so the three always match.

label
A small card that tells a specimen's number, name, where it was found, the date and who found it.

locality
The exact place where a specimen was found.

field notebook
A notebook a scientist carries outdoors to write, measure and sketch what they find, right where they find it.

CORE IDEAS

The story. In May 1804, Meriwether Lewis and William Clark set out up the Missouri River from near St. Louis with a small band of men called the Corps of Discovery. President Thomas Jefferson had asked them to write down everything they could about the land: its plants, its animals, its rivers and its rocks and minerals. So every day the captains wrote in

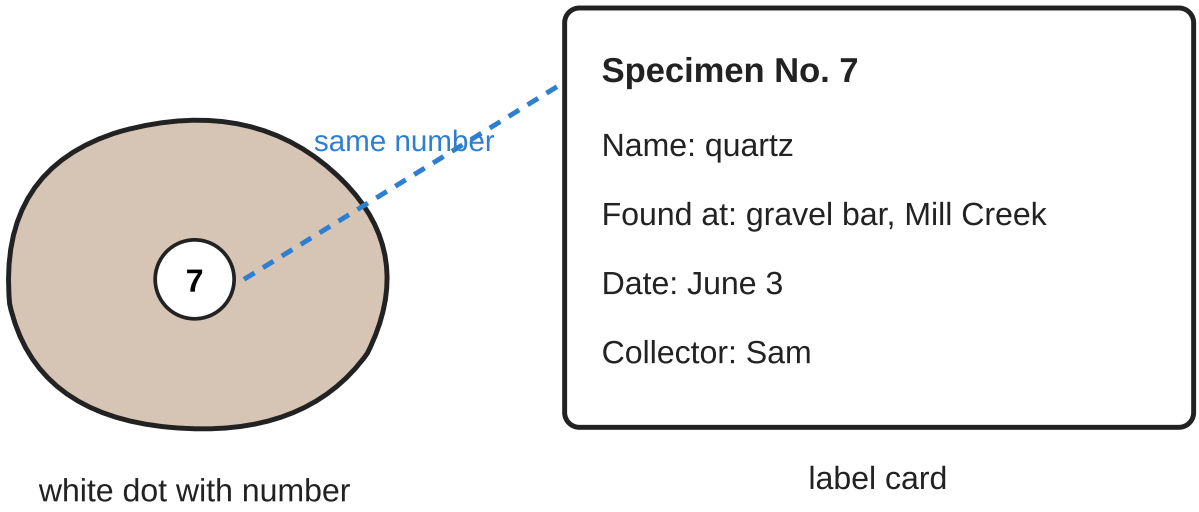
their journals. They wrote the date, the weather, how far they traveled and what they saw. That first winter they built Fort Mandan, in what is now North Dakota. In April 1805 they sent a boat back down the river loaded with boxes for Jefferson: plants, animal skins and bones, and rock and mineral samples. Each rock sample had a number, and Lewis wrote a list telling what each numbered sample was and where along the river it had been picked up.

How they figured it out. Why go to all that trouble? Because a rock with no note is just a rock. A rock with a number and a note is *evidence*. Jefferson and the scientists in Philadelphia could never walk the Missouri River themselves, but by reading Lewis's list they knew which stone came from which bluff or sandbar. The notes made the samples useful to people far away and long after. Real geologists today still follow the same rule: write it down right away, at the place, before you forget.

The big idea. A good collection has three things that match. First, the **specimen** itself, with a small **specimen number** painted on it. Second, a **label** card with five parts: the number, the name (or "unknown" if you do not know yet), the **locality**, the date and the collector's name. Third, a page in your **field notebook** with the same number, where you write what the rock looks like, how big it is, what your tests showed, and a sketch. The locality is often the most important part. A name can be found later, but if you forget where a rock came from, no one can ever find that out again.

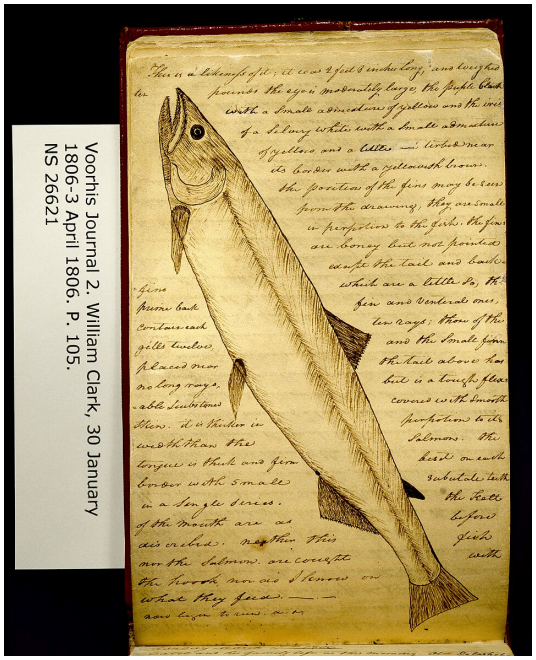
Try it and see. Start with rocks close to home: the driveway, a creek bank, a garden bed, a road cut you visited with your family. Measure each rock with a ruler. In the United States we often measure in inches, but scientists all over the world use centimeters. One inch is about 2½ centimeters, so a rock 2 inches long is about 5 centimeters long. Write both. Then do the tests you already know: the streak plate, your fingernail, an old penny, a steel nail and a drop of vinegar.

God's handiwork. In the garden, God brought the animals to Adam "to see what he would call them" (Genesis 2:19). Looking closely, naming and writing things down is very old work that God gave to people. When you number and label your rocks, you are learning to take careful notice of the things He made.



The number on the rock, the number on the label and the number in your notebook always match.

PICTURE STUDY



A White Salmon Trout, from William Clark's Field Journal, William Clark, 1806 · Ink drawing with handwritten notes in a field journal · Missouri Historical Society, St. Louis

During the rainy winter of 1805 to 1806, the Corps of Discovery camped at Fort Clatsop near the Pacific Ocean. There William Clark drew a fish he called the white salmon trout right on the page of his journal, with his notes written above and below it. He was not an artist. He was an explorer who wanted to remember exactly what he saw.

This is what a real field notebook looks like: words and pictures together, made on the spot. Your rock notebook can work the same way.

Look closely

- Find the drawing. Where on the page did Clark put it?
- Look at the fins and the scales. Did Clark draw the fish quickly or carefully?
- Look at the writing around the drawing. Why do you think he wrote words and drew a picture?
- Look at how the words and the drawing share the page. Is there wasted space?

Talk about it

1. What could a scientist learn from this page who never saw the fish?
2. Why is a drawing sometimes more useful than a long description?
3. What would you draw and write on a field notebook page about your favorite rock?

> **Safety first.** Collect only with a grown-up. Stay away from fast or deep water, cliff edges and the sides of busy roads. Ask permission before collecting on someone else's land, and never collect in a national park, where it is against the law. Let a grown-up help with white correction fluid or nail polish, use it in a room with open air, and wash your hands after handling rocks.

EXPERIMENT: START MY ROCK COLLECTION

You will collect, number, label and record your first six to twelve specimens the way Lewis and Clark did. Along the way you will run a small experiment: do rocks from two different places look different?

You will need

- 6 to 12 rocks from two different places near home (for example, a creek bank and the driveway), each no bigger than your fist
- Two zip-top bags and a permanent marker
- An old toothbrush and a bowl of water
- White correction fluid or white nail polish and a fine-tip permanent marker
- Index cards cut in half for labels
- A small notebook (your field notebook), a pencil and colored pencils
- A ruler with inches and centimeters
- Your testing kit: streak plate, old copper penny, steel nail, small cup of vinegar
- An egg carton or shoebox to hold the collection

Steps

1. **Question.** Write at the top of a notebook page: "Do rocks from Place A look different from rocks from Place B?"
2. **Prediction.** Write what you think, such as "Creek rocks will be rounder and smoother."
3. **Collect.** At Place A, put three to six rocks in a bag and write the place and date on the bag right away. Do the same at Place B with the second bag. Collect the same number

from each place. That is what you keep the same.

4. **Clean.** At home, scrub each rock with the toothbrush and water and let it dry.
5. **Number.** Paint a small white dot, about the size of a pencil eraser, on a flat spot of each rock. When it is dry, write a number on it with the fine marker: 1, 2, 3 and so on. Never use the same number twice.
6. **Measure and test.** For each rock, write a notebook entry: number, place, date, length in inches and in centimeters, color, smooth or rough, round or sharp-edged, streak color, hardness clues and whether it fizzes in vinegar. Add a small sketch.
7. **Label.** Make a label card for each rock with the five parts: number, name (or "unknown"), locality, date and collector.
8. **Record.** Make a table with two columns, Place A and Place B. Count how many rocks from each place are round and how many are sharp-edged.
9. **Conclusion.** Write one or two sentences: Was your prediction right? What was different about the two places?

Tips

- Write the locality as exactly as you can: "gravel bar on Mill Creek below the footbridge" is better than "creek."
- It is fine to write "unknown" for a name. Real museums have drawers of specimens still waiting to be named.
- Keep each rock and its label in the same egg cup or box space so they never get separated.

Check your work

- Every rock has a number, and no two numbers are the same.
- Every label has all five parts.
- Every rock has a notebook entry with a measurement in inches and centimeters.
- I wrote a prediction and a conclusion for my experiment.

FIELD NOTEBOOK

1. Make a field notebook page for your favorite specimen: number at the top, a careful pencil sketch in the middle, and notes around it like William Clark's fish page.
2. Draw a map of where you collected, from the house to Place A and Place B, and mark each spot with an X and the specimen numbers found there.
3. Trace around one rock on your page. Use a ruler to measure the longest line across the tracing and write it in inches and in centimeters.

> **From history.** Thomas Jefferson passed many of the rock and mineral samples from the Corps of Discovery to the American Philosophical Society in Philadelphia, a society for science that Benjamin Franklin had helped start. Because Lewis had numbered the samples and listed where each came from, scientists who never traveled west could still study the land along the Missouri River.

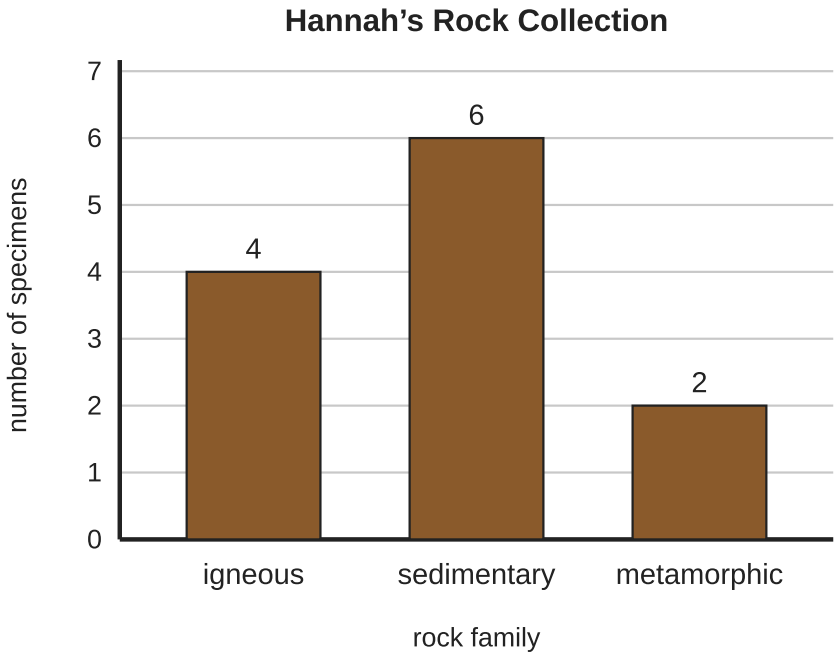
WORKED EXAMPLES

Example 1. Specimen No. 3, a piece of granite, is 3 inches long and 2 inches wide. Write its size in centimeters too. Use 1 inch ≈ 2½ centimeters.

1. Each inch is about 2½ centimeters, so multiply the number of inches by 2½.
2. Length: 3 × 2½ = 2½ + 2½ + 2½ = 7½ centimeters.
3. Width: 2 × 2½ = 2½ + 2½ = 5 centimeters.
4. Write both units in the notebook: “3 in × 2 in (about 7½ cm × 5 cm).”

Answer: About 7½ centimeters long and 5 centimeters wide.

Example 2. Hannah sorted her collection and made this bar graph. How many specimens does she have in all? Which rock family has the most? How many more sedimentary rocks than metamorphic rocks does she have?



Hannah’s collection sorted into the three rock families.

1. Read the top of each bar: igneous 4, sedimentary 6, metamorphic 2.
2. Add to find the total: 4 + 6 + 2 = 12 specimens.
3. The tallest bar is sedimentary, with 6.
4. Subtract: 6 − 2 = 4 more sedimentary rocks than metamorphic rocks.

Answer: 12 specimens in all; sedimentary has the most; 4 more sedimentary than metamorphic.

PRACTICE

1. EASY Name the five parts of a good specimen label.
2. EASY Why do collectors paint a small number right on the rock?
3. MEDIUM A piece of sandstone is 4 inches long. About how many centimeters long is it? (1 inch ≈ 2½ centimeters)
4. MEDIUM Your notebook lists 15 specimens. Numbers 1 through 9 came from the creek. The rest came from the driveway. How many came from the driveway?
5. HARD Label A says: “Pretty rock.” Label B says: “No. 7, quartz, gravel bar on Mill Creek, June 3, collected by Sam.” Which label is better, and why?
6. CHALLENGE You want to find out whether creek rocks are rounder than driveway gravel. What should you keep the same, and what should you record?

COMMON MISTAKES

- Waiting to write labels later. Memory fades fast; write the place and date on the bag or in the notebook right where you find the rock.
- Thinking the name is the most important part of a label. The locality matters most, because a name can be found later but a lost place cannot.
- Collecting only the prettiest rocks. Plain gray rocks are evidence too, and they often tell the most about a place.

> **Make it a game · Label Detective.** Your parent makes four labels for rocks in your collection but leaves one part off each label (the number, the name, the place, the date or the collector). Race to find what is missing on each label and fill it in from your notebook. Score a point for each correct fix. Then switch: you make the broken labels and your parent plays detective.

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

People who delight in God’s works want to look at them closely. A field notebook is one way of seeking out His works with care.

Practice answers

1. Specimen number, name (or “unknown”), locality (where it was found), date and collector.
2. So the rock can always be matched to its label and notebook page, even if the label falls off or the rocks get mixed up.
3. 4 × 2½ = 10, so about 10 centimeters.
4. 15 − 9 = 6 specimens came from the driveway (numbers 10 through 15).
5. Label B. It has all five parts. Most of all, it tells exactly where the rock was found, which can never be figured out later. Label A tells nothing a scientist could use.
6. Keep the same: the number of rocks collected from each place and the way you choose them (for example, the first six rocks you pick up without choosing pretty ones). Record: for each

rock, its place and whether it is round or sharp-edged, then count each kind for each place and compare.

8.2 A Rock-Shop or Museum Trip

OBJECTIVES

- Tell how James Smithson, a scientist who studied minerals, came to found the Smithsonian Institution.
- Read a museum or rock-shop label and find the specimen's name, kind and locality.
- Plan and carry out a museum or rock-shop visit with a field notebook, a tally and a spending plan.

> **Warm-up.** Look at a cereal box, a can of soup or a seed packet. Find three facts the label tells you. What would you not know about the food if the label were torn off?

> **Video.** Coming soon. Smithsonian National Museum of Natural History Hall of Geology, Gems and Minerals tour, the Hope Diamond, and how a museum cares for its mineral collection; search Smithsonian channels, USGS, state geological survey and university geology museum channels, and rock and gem show (rockhound) channels.

KEY TERMS

museum
A building where specimens and other treasures are kept, cared for, labeled and shown to the public.

catalog number
The number a museum gives each specimen, written on the specimen and in the museum's record book, like your specimen number.

variety
A special kind of a mineral with its own color or look; amethyst is a purple variety of quartz.

dealer
A person who buys and sells specimens, such as the owner of a rock shop.

CORE IDEAS

The story. James Smithson was an English scientist who loved minerals. He tested them with heat and chemicals, wrote papers about them and kept a large mineral collection. When he died in 1829, his will said something surprising. If his nephew died without children, all of Smithson's money should go to the United States of America, "to found at Washington, under the name of the Smithsonian Institution, an Establishment for the increase & diffusion of knowledge among men." Smithson had never visited America. The nephew died in 1835, and in 1838 a ship brought more than a hundred thousand gold coins across the ocean. In 1846 Congress founded the Smithsonian. Today its National Museum of Natural History in

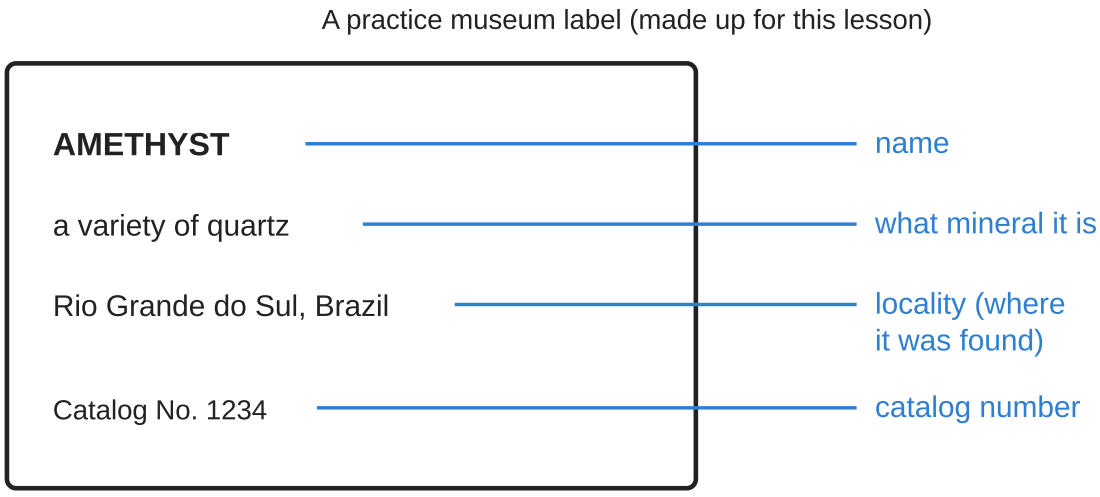
Washington, D.C., has one of the great rock, mineral and gem collections of the world, and anyone may walk in for free.

How they figured it out. A museum is a rock collection grown very large, and it works just the way yours does. Every specimen has a **catalog number** written on it and in the record books. The label in the case tells its name, sometimes its **variety**, and its locality. A museum label might say: “Amethyst, a variety of quartz, Rio Grande do Sul, Brazil.” Now you know the mineral (quartz), its special kind (amethyst) and where in the world it came from. A rock shop has labels too, plus price tags. A good **dealer** can tell you where a specimen was found. If the dealer does not know, write “locality unknown” on your label.

The big idea. Labels hold two kinds of sentences. Some tell what anyone can see or test: “This crystal is purple. It scratches glass.” Others tell what someone thinks happened long ago. Some signs use **museum words** such as *Jurassic* or *Ice Age*, or give an age of millions of years. Learn the museum words so you can read any sign. Then sort what is seen from what is supposed, the same careful way a scientist does.

Try it and see. Bring your field notebook, a pencil and a plan. Make a scavenger list before you go: one igneous, one sedimentary and one metamorphic rock, a crystal, a fossil, a gem, and as many Mohs scale minerals as you can find. Make tally marks as you find them. Choose one specimen and sketch it carefully, copying its label word for word. Look but do not touch, unless there is a touch table. At a rock shop, decide how much you will spend before you go in, and look closely: some bright blue or hot pink “agates” are dyed, and the dye collects in the cracks.

God’s handiwork. A mineral hall is like a treasure chest that has been opened. Purple amethyst, golden pyrite cubes, green malachite and clear quartz points all came out of the ground just as God made them. Walking past case after case, you can say with the psalmist, “the earth is full of thy riches” (Psalm 104:24).



A practice museum label (made up for this lesson). Find the name, the mineral, the locality and the catalog number.

⏳ Thinking About Time

What the sign says. What the sign says: Some museum and rock-shop signs give a rock, mineral or fossil an age of millions of years, or use museum words like Jurassic or Ice Age. These words name parts of earth's history the way most museums tell it.

What we observe. What we observe: We can see and test the specimen itself: its color, crystals, layers, hardness and fossils, and the place where it was found. No one watched the rock form. An age on a sign is worked out from ideas about how fast things happened long ago.

How Christians read it. How Christians read it: Many Christians read the rocks in the light of Genesis. God made the heaven and the earth not so very long ago, and much of the layered rock and many fossils were laid down quickly in the great Flood. We can read the sign carefully and politely, copy the museum words, and think about the age claim with care.

Try it. Copy one museum sign word for word. Underline the parts you could see or test yourself, and circle any part that tells what someone thinks happened long ago.

Job 38:4

PICTURE STUDY



The Museum of Ferrante Imperato, from Dell'Historia Naturale, Unknown engraver, for Ferrante Imperato's book, 1599 · Engraving printed in a book · Printed in Naples, Italy; copies are kept in many rare-book libraries

Ferrante Imperato was a druggist in Naples, Italy, who collected rocks, minerals, shells, plants and animals and wrote a book about natural history. This picture of his collection room was printed in that book in 1599. It is one of the oldest printed pictures of a natural history museum.

Look closely and you will see visitors. Even then, people went on trips to see collections, and someone was ready to show them around.

Look closely

- Find the visitors. Who seems to be showing them the collection, and what is he pointing at?
- Look at the ceiling. What animals can you find hanging there?
- Look at the shelves and cabinets along the walls. How did Imperato keep his specimens in order?
- Find something in the picture that you might also find in a museum today.

Talk about it

1. How is Imperato's museum like a museum you have visited or seen in pictures? How is it different?
2. Why do you think he hung so many things on the ceiling?
3. If you could ask Imperato about one thing in his room, what would you ask?

EXPERIMENT: MY MUSEUM OR ROCK-SHOP FIELD TRIP

Visit a natural history museum, a university geology museum, a state park visitor center, a rock shop or a gem and mineral show. If none is near, take the Smithsonian National Museum of Natural History's free online tour together. You will collect observations instead of rocks, and test one prediction with a tally.

You will need

- Field notebook, pencil and colored pencils
- A scavenger list (made in step 2)
- A clipboard or stiff cardboard to write on
- For a rock shop: a set amount of spending money agreed on with a parent, such as $10
- A ruler with inches and centimeters (for rock shops, where you may hold specimens)

Steps

1. **Question.** Write: "Which kind of specimen will I see the most of: igneous rocks, sedimentary rocks, metamorphic rocks, minerals or fossils?"
2. **Prediction.** Write your guess and why.
3. **Scavenger list.** Make a table with five rows: igneous, sedimentary, metamorphic, mineral, fossil. Leave room for tally marks. Below it, list the ten Mohs minerals and check off each one you find.

4. **What we keep the same.** Count in one hall or one room of the shop only, and spend the same amount of time looking, about 20 minutes, so your count is fair.
5. **Tally.** As you walk, make one tally mark for each labeled specimen you find in each row.
6. **Sketch and copy.** Choose one specimen. Sketch it and copy its label word for word, including the locality.
7. **Buy wisely (rock shop only).** Before you buy, ask the dealer where the specimen was found and write it down. Add up the prices before you pay.
8. **Record.** At home, count your tallies and make a bar graph with five bars.
9. **Conclusion.** Write: Was my prediction right? What surprised me most?

Tips

- Ask a museum worker or dealer one good question. Many love to talk about their specimens.
- Many museums have a touch table or drawers you may open. Ask before touching anything.
- A specimen you buy goes into your collection with a new number, a label and a notebook page, just like the ones you found yourself.

Check your work

- I made a tally of five kinds of specimens and turned it into a bar graph.
- I copied one label word for word and sketched its specimen.
- I can point to the locality on the label I copied.
- I wrote a conclusion about my prediction.

FIELD NOTEBOOK

1. Sketch the most beautiful crystal you saw. Color it carefully and copy its name and locality underneath.
2. Draw the museum hall or rock shop from above, like a map, and mark where the minerals, fossils and gems were.
3. Copy one sign that used a museum word or gave an age. Underline what you could see for yourself and circle the age claim.

> **From history.** In January 1865 a fire swept through the Smithsonian’s first building, the red stone “Castle,” and destroyed James Smithson’s own mineral collection and many of his papers. In 1904 Alexander Graham Bell, the inventor of the telephone, who was helping to run the Smithsonian, traveled to Genoa, Italy, and brought Smithson’s remains to Washington. Smithson rests today inside the Castle, in the country he never visited but chose to bless.

WORKED EXAMPLES

Example 1. At a rock shop, Eli has $10. The prices are: pyrite cube $3, shark tooth $2, amethyst point $4, small geode $5. He buys the pyrite cube, the shark tooth and the amethyst point. How much does he spend, and how much is left? Could he also buy the geode?

1. Add the prices: $3 + $2 + $4 = $9.
2. Subtract from what he had: $10 − $9 = $1 left.
3. The geode costs $5, and $1 is less than $5, so he cannot buy it too.
4. Before leaving, he asks where each specimen was found and writes it in his notebook.

Answer: He spends $9 and has $1 left. He cannot also buy the $5 geode.

Example 2. A museum case shows four minerals with their hardness on the Mohs scale: calcite 3, fluorite 4, quartz 7, topaz 8. A steel nail is about 5½. Which of these minerals could the nail scratch? Which could scratch the nail?

1. The harder one scratches the softer one.
2. Calcite (3) and fluorite (4) are less than 5½, so the nail can scratch them.
3. Quartz (7) and topaz (8) are more than 5½, so they are harder than the nail and could scratch it.
4. In a museum we only read the numbers. We never test the museum’s specimens!

Answer: The nail could scratch calcite and fluorite. Quartz and topaz could scratch the nail.

PRACTICE

1. EASY Who left his money to found the Smithsonian Institution, and what did he like to study?
2. EASY Use the practice museum label in this lesson. What is the locality of the amethyst, and what mineral is amethyst a variety of?
   (Use the map or drawing “Use the label to answer.” shown earlier in this lesson.)
3. MEDIUM A geode in a rock shop is 6 inches across. About how many centimeters is that? (1 inch ≈ 2½ centimeters)
4. MEDIUM Ruth’s museum tally: igneous rocks 5, sedimentary rocks 7, metamorphic rocks 3, minerals 12, fossils 9. Which kind did she see most? How many rocks (not minerals or fossils) did she see in all?
5. HARD A sign says: “This sandstone has ripple marks. It formed during the Jurassic.” Which sentence tells something you can see, and which tells what someone thinks happened long ago?

6. CHALLENGE A rock shop sells bright hot-pink “agate.” How could you check whether the color is natural or dyed? Give two clues.

COMMON MISTAKES

- Thinking the price shows how special a mineral is to science. A plain, well-labeled rock with a known locality can be worth more to a scientist than a costly polished stone with no label.
- Reading every sentence on a sign as something someone saw. Some sentences tell observations, and some tell ideas about the long-ago past.
- Thinking amethyst and quartz are different minerals. Amethyst is a purple variety of quartz, with the same hardness of 7.

Make it a game · Seen or Supposed?. Your parent reads short sentences like ones on museum signs, such as “This crystal is purple,” “It fizzes in acid,” “It formed long ago in a warm sea” or “It came from Arkansas.” Hold up an open hand for something anyone can see or check today, and a closed fist for an idea about what happened long ago. One point for each right answer. Then you write five sentences for your parent to sort.

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)

“Manifold” means many and of many kinds. A mineral hall shows how many kinds of riches God put into the earth.

Practice answers

1. James Smithson, an English scientist. He studied minerals.
2. The locality is Rio Grande do Sul, Brazil. Amethyst is a variety of quartz.
3. 6 × 2½ = 15, so about 15 centimeters.
4. Minerals, with 12. Rocks: 5 + 7 + 3 = 15.
5. “This sandstone has ripple marks” is something you can see. “It formed during the Jurassic” uses a museum word and tells what someone thinks about when it formed, which no one watched.
6. Any two: ask the dealer whether it is dyed; look in the cracks with a magnifying glass, because dye collects there and looks darker; notice that natural agate is usually soft white, gray, tan, brown or reddish in bands, while very bright pinks and blues are often dyed; compare it with an agate that is labeled natural.

8.3 Sharing the Collection

OBJECTIVES

- Tell how Ole Worm shared his collection in Copenhagen and used evidence to show that “unicorn horns” were narwhal tusks.
- Sort and arrange a rock collection into a labeled display and write a simple catalog.
- Give a short talk that tells what each specimen is, where it was found and how you know, and show one test.

Warm-up. Pick one object from your room and tell your family about it in exactly three sentences: what it is, where it came from, and one thing that makes it special. Did three sentences feel like too few or too many?

Video. Coming soon. How to display and label a rock and mineral collection, and cabinets of curiosities (early museums such as Ole Worm’s); search Smithsonian, natural history museum channels, rock and mineral club (rockhound) channels, Homeschool Pop (Alternate) and SciShow Kids.

KEY TERMS

display
An orderly arrangement of specimens with labels, set out so other people can look and learn.

catalog
A numbered list of every specimen in a collection, with its name and locality.

evidence
Things you can see, measure or test that show whether an idea is true.

demonstration
Showing a test or experiment in front of other people so they can see the result for themselves.

CORE IDEAS

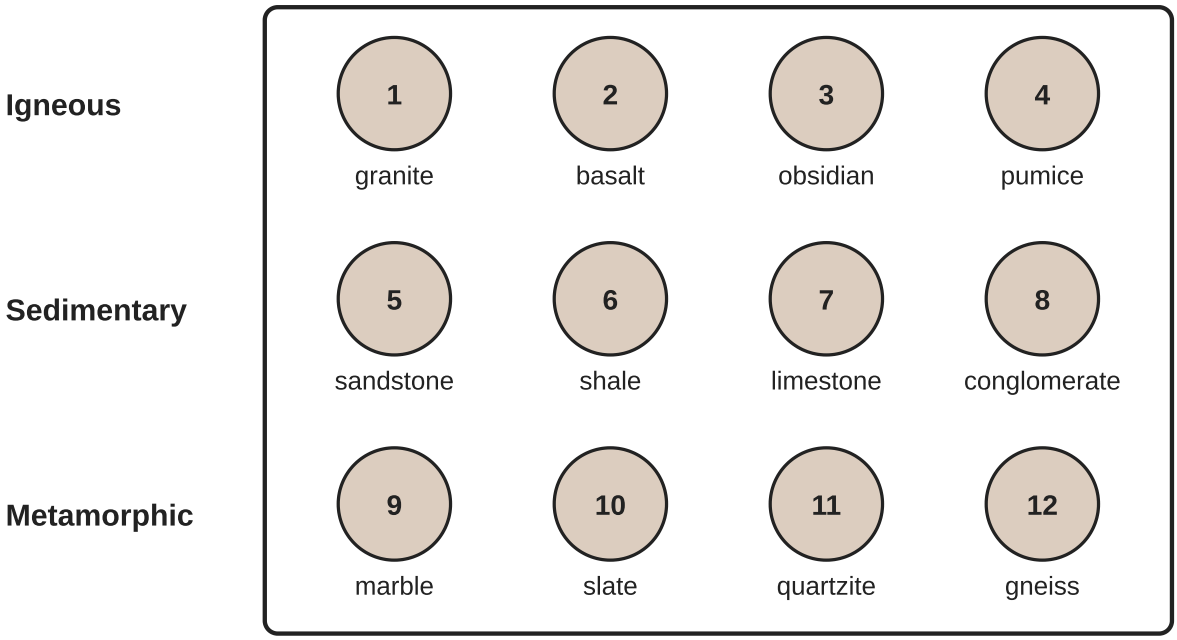
The story. Ole Worm was a doctor and teacher in Copenhagen, Denmark, in the days when the Pilgrims were settling in New England. In his house he kept a famous collection: rocks, minerals, crystals, fossils, shells, stuffed animals, skulls, antlers, old tools and more. Visitors came from far away to see it, and Worm loved to show them around. In 1638 he shared something important. People in Europe paid huge sums for “unicorn horns,” long twisted horns said to cure poison. Worm showed that these horns were really the tusks of the narwhal, a whale of the cold northern seas. He had a narwhal skull in his collection with the tusk still attached to it.

How they figured it out. Worm did not just say, “Trust me.” He showed his **evidence**: a real skull with the tusk growing out of it. Anyone could look and see. That is the heart of sharing a collection. You are not only showing pretty things; you are showing what you found, where you found it and how you know what it is. After Worm died, a catalog of his collection was printed in 1655 with a famous picture of his museum room, and his specimens went to the king of Denmark’s own collection.

The big idea. A good **display** has order. Sort your specimens into groups: igneous, sedimentary and metamorphic rocks, then minerals, then fossils. Put them in egg cartons, shoebox lids or a box with cardboard walls, each specimen with its label in front of it. Write a **catalog**, a numbered list of every specimen with its name and locality, just like the list Lewis sent to Jefferson and the book of Worm’s museum. Add a title card that tells who made the collection and what it shows.

Try it and see. When you share, use the three-part talk for each specimen you choose: *What is it? Where did I find it? How do I know?* For example: “This is calcite. I found it in a road cut near our church. I know it is calcite because a penny scratches it but my fingernail does not, and it fizzes in vinegar.” Then do a **demonstration**: let your listeners watch a streak test or the vinegar fizz. Let them try a fingernail scratch on a soft rock. When people see the test for themselves, they learn, just as Worm’s visitors did.

God’s handiwork. When Israel crossed the Jordan River, God told Joshua to have twelve men each carry a stone from the riverbed and set them up together. When children later asked, “What mean ye by these stones?” their parents would tell what God had done (Joshua 4:6–7). Stones can start a conversation. Your collection can help you tell others about the wonderful things God made.



One way to sort twelve rocks into a display tray, by rock family. The numbers match the catalog.

PICTURE STUDY



Ole Worm's Museum, from Museum Wormianum, Engraved for the catalog of Ole Worm's collection, 1655 · Engraving printed in a book · Printed in Leiden, Netherlands; copies are kept in many rare-book libraries

This picture was printed at the front of the catalog of Ole Worm's collection, the year after he died. It shows his museum room in Copenhagen packed from floor to ceiling. It became one of the most famous pictures of an early museum.

Look at how Worm kept order in such a crowded room. Many things sit in boxes on shelves, and the boxes have words written on them, like labels.

Look closely

- Find the shelves of boxes. What is written on them, and why would Worm write on his boxes?
- Look at the walls. What kinds of things are hanging there?
- Look up at the ceiling. What animals can you find?
- Find a place in the picture where you think Worm kept rocks or minerals.

Talk about it

1. How did Worm keep so many things in order?
2. If you were a visitor, what would you ask Worm to show you first?
3. How is Worm's museum like your own rock collection?

> **Safety first.** Small stones can choke little children. Keep the display out of reach of babies and toddlers, and watch younger brothers and sisters during the demonstration. Wash hands after handling rocks, and keep vinegar away from eyes.

EXPERIMENT: MY ROCK COLLECTION MUSEUM

Turn your collection into a small museum and open it to your family or friends. You will test one question: which of my specimens do visitors find most interesting, and why?

You will need

- Your numbered, labeled specimens from Lesson 8.1 and any from Lesson 8.2
- Egg cartons, shoebox lids or a box with cardboard dividers
- Labels on index cards, plus one large title card
- A sheet of paper for the catalog
- Testing kit: streak plate, old copper penny, steel nail, cup of vinegar, dropper or spoon
- Paper slips and a jar or cup for visitor votes

Steps

1. **Sort.** Group your specimens: igneous, sedimentary, metamorphic, minerals, fossils. If you are not sure of a family, make an “unknown” group. That is honest science.
2. **Arrange.** Put each group in its own row or tray with each label in front of its specimen.
3. **Catalog.** On one sheet, list every specimen in number order with its name and locality.
4. **Title card.** Write the name of your museum, your name and one sentence about what the collection shows.
5. **Question and prediction.** Write: “Which specimen will visitors like most?” Write your guess.
6. **Practice your talk.** Choose three specimens. For each, practice the three-part talk: What is it? Where did I find it? How do I know?
7. **Open your museum.** Give your talk and one demonstration, such as the streak test or the vinegar fizz. Let visitors try a scratch test.
8. **Measure.** Give each visitor one slip of paper to vote for a favorite specimen by number. Every visitor gets one vote. That is what you keep the same.
9. **Record and conclude.** Count the votes in a table. Write whether your prediction was right and why you think visitors chose what they did.

Tips

- Speak slowly and hold the specimen up high so everyone can see.
- If a visitor asks something you do not know, say, “I don’t know yet, but I’ll find out,” and write the question in your notebook.
- A magnifying glass on the table makes visitors look longer.

Check your work

- Every specimen is sorted, labeled and listed in the catalog.
- I gave the three-part talk for three specimens.
- I did one demonstration so visitors could see the evidence.
- I counted the votes and wrote a conclusion.

FIELD NOTEBOOK

1. Draw a plan of your display from above before you set it out, showing where each group and each label will go.
2. Draw a narwhal with its long tusk, and next to it the “unicorn horn” people once bought. Label them “What people thought” and “What the evidence showed.”
3. Write your three-part talk for your favorite specimen in your notebook, with a small drawing of the test you will show.

> **From history.** Not long after Worm’s time, collections like his began to grow into public museums. The Ashmolean Museum in Oxford, England, opened in 1683 and is often called the first public museum in Britain. It grew from a collection of natural wonders and curiosities that, like Worm’s, had been shown to visitors who came to look and learn.

WORKED EXAMPLES

Example 1. An egg carton has 2 rows of 6 cups. Ben has 5 igneous rocks, 4 sedimentary rocks and 3 metamorphic rocks. Will they all fit in one carton, one rock per cup?

1. Find the number of cups: 2 rows × 6 cups = 12 cups.
2. Find the number of rocks: 5 + 4 + 3 = 12 rocks.
3. 12 rocks and 12 cups: every cup is filled, with none left over.

Answer: Yes. 12 rocks fit exactly into 12 cups.

Example 2. Eight visitors voted for their favorite specimen in Lucy’s museum: pyrite 3 votes, geode 2, shark tooth fossil 2, mica 1. Did every visitor vote once? Which specimen won, and by how many votes over the geode?

1. Add the votes: 3 + 2 + 2 + 1 = 8. There were 8 visitors, so every visitor voted once.
2. The largest number is 3, for pyrite.
3. Subtract: 3 − 2 = 1 vote more than the geode.

Answer: Yes, 8 votes for 8 visitors. Pyrite won, with 1 more vote than the geode.

PRACTICE

1. EASY What did Ole Worm show the “unicorn horns” really were, and what was his evidence?
2. EASY What are the three questions in a three-part specimen talk?
3. MEDIUM Your display has 3 trays with 4 specimens in each tray. How many specimens are in your display? If you add 2 fossils, how many then?

4. MEDIUM A label card is 3 inches wide. You line up 4 cards side by side on a shelf. How wide is the row in inches? About how many centimeters? (1 inch ≈ 2½ centimeters)
5. HARD Sort these into rock families for your display: granite, slate, sandstone, basalt, marble, shale.
6. CHALLENGE A visitor says, “That white rock is just chalk.” You think it is calcite. What demonstration could you do to show the evidence, and why is a demonstration better than just saying you are right?

COMMON MISTAKES

- Thinking a display is just for showing pretty things. A good display teaches: each specimen has a label, a place in order and a reason it is there.
- Telling only the name in a talk. Visitors learn most from where you found a specimen and how you know what it is.
- Thinking a mystery specimen should be left out. An honest “unknown” label is good science and makes a great question for visitors.

Make it a game · Museum Guide. One player is the museum guide and stands by the display. The others are visitors who take turns pointing to a specimen. The guide must give the three-part talk in under 30 seconds: what it is, where it was found and how we know. One point for each part done right. Then switch guides. Bonus point for a guide who does a quick demonstration.

Scripture. “That this may be a sign among you, that when your children ask their fathers in time to come, saying, What mean ye by these stones?” (Joshua 4:6, KJV)

God used stones to help parents tell their children what He had done. When someone asks about your collection, you can tell what you learned and thank the God who made the rocks.

Practice answers

1. Narwhal tusks. His evidence was a narwhal skull with the tusk still attached.
2. What is it? Where did I find it? How do I know?
3. 3 × 4 = 12 specimens. 12 + 2 = 14 specimens.
4. 4 × 3 = 12 inches. 12 × 2½ = 30, so about 30 centimeters.
5. Igneous: granite, basalt. Sedimentary: sandstone, shale. Metamorphic: slate, marble.
6. Do a scratch test: chalk is soft and powdery, and calcite is not scratched by a fingernail but is scratched by a penny. You can also do a streak test and show clear calcite crystals. (Both chalk and calcite fizz in vinegar, because chalk is made of calcite, so the fizz test alone cannot tell them apart.) A demonstration is better because the visitor sees the evidence for themselves, the way Worm let people see the narwhal skull.

8.4 Review Game

OBJECTIVES

- Tell how Louis Agassiz taught Samuel Scudder to look again and again at a single fish, and use that habit to review.
- Use a simple identification key to name a mystery mineral from its luster, streak, hardness and other tests.
- Review the big ideas of the year (minerals, the three rock families, fossils, gems and ores) by playing and building a quiz game.

Warm-up. Set a timer for one minute and look at one rock from your collection. Then hide it and write down everything you noticed. Now look at it again for two more minutes. How many new things did you notice the second time?

Video. Coming soon. Review of minerals, the rock cycle, the three rock families and how fossils form for kids, plus how to use a mineral identification key; search USGS, Smithsonian, SciShow Kids, Homeschool Pop (Alternate), Science Max and rock and mineral club (rockhound) channels.

KEY TERMS

identification key
A list of paired choices that leads you, one step at a time, to the name of a mystery specimen.

property
Something about a mineral you can observe or test, such as color, streak, luster, hardness or how it breaks.

rock family
One of the three main groups of rocks: igneous, sedimentary or metamorphic, sorted by how they formed.

review
Looking again at what you have learned so you remember it better and see it more clearly.

CORE IDEAS

The story. In the late 1850s, a young student named Samuel Scudder went to study at Harvard, in Cambridge, Massachusetts, with the great naturalist Louis Agassiz. On the first day Agassiz set a fish in a tin tray in front of him and told him to look at it. He was not to use any instrument, only his eyes and hands. After ten minutes Scudder thought he had seen everything. Agassiz did not come back for hours. Bored, Scudder picked up a pencil and began to draw the fish, and suddenly he saw things he had missed. When Agassiz returned and heard his list, he said Scudder had not looked carefully enough and must look again.

Scudder studied that one fish for about three days. Years later he called it one of the best lessons of his life.

How they figured it out. Agassiz knew a secret every scientist learns: the first look is never the last look. Each time you look again, you see more. Drawing helps, because your pencil makes your eyes slow down. Asking questions helps too. Scudder later became an expert on insects and fossil insects, and he never forgot to look, look and look again. A **review** is a way of looking again at everything you have learned this year.

The big idea. You now know how to read the earth like a scientist. Minerals are known by their **properties**: streak, luster, hardness on the Mohs scale and how they break. Rocks fall into three **rock families**: igneous rocks cool from melted rock, sedimentary rocks form from layers of sand, mud and shells, and metamorphic rocks are changed by squeezing and heating. Fossils form when living things are buried quickly. Gems are beautiful, hard minerals, and ores are rocks from which we get useful metals. An **identification key** puts these clues to work. It asks one question at a time, with two choices, until only one answer is left.

Try it and see. Take one mystery mineral and use the key in this lesson. Does it shine like metal? Does it scratch glass? Does it peel into sheets? Does it fizz in vinegar? Each answer sends you to the next step, until the key tells you its name. Then play the review game with your family, using questions from every unit, and make your own question cards from your field notebook.

God’s handiwork. Proverbs says, “It is the glory of God to conceal a thing: but the honour of kings is to search out a matter” (Proverbs 25:2). God has hidden wonders in every stone, and He has made you able to search them out. Every time you look again, you find more of His careful work.

Mineral Key (for 7 beginner minerals)

1a. Shines like metal (metallic luster)	go to 2
1b. Does not shine like metal	go to 3
2a. Greenish-black streak, brassy yellow	**PYRITE**
2b. Reddish-brown streak	**HEMATITE**
3a. Scratches glass	go to 4
3b. Does not scratch glass	go to 5
4a. Breaks with curved, shell-shaped surfaces	**QUARTZ**
4b. Breaks along flat, shiny faces	**FELDSPAR**
5a. Peels into thin, bendable sheets	**MICA**
5b. Does not peel into sheets	go to 6
6a. Fizzes in vinegar	**CALCITE**
6b. No fizz; a fingernail scratches it	**GYPSUM**

A simple identification key for seven minerals in a beginner's kit. Start at 1a and 1b.

PICTURE STUDY



The Game of Knucklebones, Jean-Siméon Chardin, about 1734 · Oil on canvas · Baltimore Museum of Art, Baltimore, Maryland

Jean-Siméon Chardin was a French painter who loved quiet scenes of everyday life: a cook at work, a boy blowing bubbles, a girl playing a game. Here a young woman plays knucklebones, a game much like jacks. She tosses a ball and must pick up the little pieces before she catches it.

Long ago this game was played with small bones or with smooth pebbles, and in some places it is still called “fivestones.” People have been playing games with stones for a very long time.

Look closely

- Find the ball. What is she about to do with it?
- Look at her face and eyes. Is she paying close attention?
- Find the game pieces on the table. How many can you count?
- Look at the light. Where is it brightest in the picture?

Talk about it

1. Why does a game like this need quick eyes and careful attention?
2. How is looking closely at a game like looking closely at a rock?
3. Could you play this game with pebbles from your own collection? Which ones would work best?

> **Safety first.** Use vinegar only in small amounts and keep it away from eyes. Glass for scratch tests should be a thick piece with taped or smooth edges, held flat on the table by a grown-up. Never test minerals by tasting them.

EXPERIMENT: LOOK AGAIN, THEN BUILD THE GAME

First you will test Agassiz’s lesson with a small experiment. Then you will build a review quiz game from everything you learned this year.

You will need

- Two rocks from your collection that you have not studied closely yet
- A timer, field notebook and pencil
- About 30 index cards
- Colored markers
- Your testing kit and your field notebook from the whole year

Steps

1. **Question.** Write: “Will I notice more about a rock if I look longer and draw it?”
2. **Prediction.** Write your guess.
3. **Test 1.** Look at Rock A for 1 minute without drawing. Then write a numbered list of everything you noticed.
4. **Test 2.** Look at Rock B for 5 minutes, and draw it as you look. Then write a numbered list of everything you noticed.
5. **What we keep the same.** Use rocks of about the same size, the same light and the same notebook. What we change is the time and the drawing. What we measure is how many things you noticed.

6. **Record and conclude.** Write the two numbers side by side. Was your prediction right?
7. **Build the game.** Make question cards in six colors, one for each topic: minerals, igneous, sedimentary, metamorphic, fossils, gems and ores. Write a question on the front and the answer on the back. Give easy cards 1 point and hard cards 3 points.
8. **Add mystery specimens.** Make three cards that say “Mystery specimen!” For these, a player must name a real rock or mineral from your collection using the key.

Tips

- Use your field notebook pages for ideas. Your own records are the best review.
- Write some questions that need a test, not just a memory, such as “Show how to tell pyrite from gold.”
- Keep the cards in an envelope inside your collection box for next year.

Check your work

- I recorded how many things I noticed in each test and wrote a conclusion.
- I made question cards for every topic of the year.
- I used the identification key to name at least one real mineral.

FIELD NOTEBOOK

1. Choose one rock you have had all year. Draw it again now, slowly, and compare the new drawing with your first notebook page about it.
2. Draw the three rock families as three boxes with arrows between them, and write how each can change into another (melting and cooling, wearing away and layering, squeezing and heating).
3. Make a page called “My Year as a Rock Hound” with your favorite specimen, your favorite test and the most surprising thing you learned.

> **From history.** Louis Agassiz was born in Switzerland and came to the United States in 1846. He founded the Museum of Comparative Zoology at Harvard in 1859, and he filled it with specimens so students could learn from real things, not only from books. Samuel Scudder wrote the story of his fish lesson for a magazine in 1874, and teachers have been reading it to their students ever since.

WORKED EXAMPLES

Example 1. Use the identification key. A mystery mineral does not shine like metal. It does not scratch glass. It does not peel into sheets. It fizzes when a drop of vinegar is put on it. What is it?

(Use the map or drawing "Follow the steps: 1b, 3b, 5b, 6a." shown earlier in this lesson.)

1. Step 1: It does not shine like metal, so 1b sends us to step 3.
2. Step 3: It does not scratch glass, so 3b sends us to step 5.
3. Step 5: It does not peel into sheets, so 5b sends us to step 6.
4. Step 6: It fizzes in vinegar, so 6a says calcite.
5. Check: calcite is 3 on the Mohs scale, too soft to scratch glass (about 5½), which agrees with step 3.

Answer: Calcite.

Example 2. In the review game, Grace sorts 9 cards into rock families: granite, basalt, obsidian, sandstone, shale, limestone, coal, marble, slate. How many are in each family? Which family has the most?

1. Igneous (cooled from melted rock): granite, basalt, obsidian. That is 3.
2. Sedimentary (made from layers): sandstone, shale, limestone, coal. That is 4.
3. Metamorphic (changed by squeezing and heating): marble, slate. That is 2.
4. Check the total: 3 + 4 + 2 = 9 cards.

Answer: Igneous 3, sedimentary 4, metamorphic 2. Sedimentary has the most.

PRACTICE

1. EASY Which mineral scratches the other: fluorite (4) or apatite (5)? Explain.
2. EASY Name the rock family for each: (a) formed when melted rock cooled; (b) formed from layers of sand and mud pressed together; (c) changed by squeezing and heating.
3. MEDIUM Use the key. A mystery mineral shines like metal and leaves a reddish-brown streak. What is it?
4. MEDIUM In a jar of shaken-up soil and water, the layers settle like this: sand 2 inches, silt 1 inch, clay ½ inch. How thick are all the layers together? Which layer settled on the bottom?
5. HARD Why do most living things never become fossils? What must happen for a fossil to form?
6. CHALLENGE You have two white rocks and want to find out which one is limestone. Design a fair vinegar test. What will you keep the same, and what will you look for?

COMMON MISTAKES

- Thinking color is the best clue to a mineral's name. Many minerals come in several colors; streak, hardness and how a mineral breaks are better clues.
- Thinking a key works for every rock in the world. A simple key only works for the specimens it was made for; a bigger collection needs a bigger key.
- Thinking that looking once is enough. Real scientists look again and again, and they find something new nearly every time.

> **Make it a game · Rock Hound Quiz Show.** Lay out the question cards in six piles, one for each topic: minerals, igneous, sedimentary, metamorphic, fossils, gems and ores. Players take turns choosing a pile and a 1-, 2- or 3-point card. A right answer earns the points. If a player draws a "Mystery specimen!" card, they get a rock or mineral from the collection and have two minutes to name it with tests and the key, for 5 points. The first player to 25 points becomes the museum director and leads the next round.

> **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)

God has hidden many wonders in the rocks, and searching them out is an honor. A review is one more search, and it often turns up things we missed the first time.

Practice answers

1. Apatite scratches fluorite, because the harder mineral (the higher number) scratches the softer one.
2. (a) Igneous. (b) Sedimentary. (c) Metamorphic.
3. Step 1a sends you to step 2, and 2b says hematite.
4. 2 + 1 + ½ = 3½ inches. Sand settled on the bottom because its grains are the biggest and heaviest, so they sink first.
5. Most dead plants and animals are eaten, rot or are broken apart and washed away. To become a fossil, a living thing must usually be buried quickly in mud or sand, which protects it so it can be preserved before it is destroyed.
6. Put the same amount of vinegar (for example, 3 drops) on each rock, on pieces about the same size, at the same time, and watch for the same length of time. Limestone is made mostly of calcite, so it will fizz with bubbles; a rock that does not fizz is probably not limestone. You could also test a piece of chalk, which you know fizzes, to compare.

Unit 8 review

Answer each question. Use complete sentences for explanations and show your work for any numbers. The quiz is worth 40 points in all: 10 questions, 4 points each. A parent may read the questions aloud and may hand the student real specimens for questions 9 and 10.

1. (4 pts) Name the five parts of a good specimen label.
2. (4 pts) Why did Lewis number his rock samples and write down where each was found? Why is the locality the most important part of a label?
3. (4 pts) A rock is 4 inches long. About how long is it in centimeters? (1 inch ≈ 2½ centimeters)
4. (4 pts) Who was James Smithson, and what did he leave his money to found?
5. (4 pts) A museum label reads: “Amethyst, a variety of quartz. Rio Grande do Sul, Brazil.” What is the mineral, what is its variety, and what is its locality?
6. (4 pts) A sign says: “This limestone is full of shells. It formed in the Jurassic.” Which sentence is something you can observe, and which is an idea about the long-ago past?
7. (4 pts) What did Ole Worm show about “unicorn horns,” and how did he prove it?
8. (4 pts) Sort these for a display: basalt, shale, marble, granite, sandstone, slate.
9. (4 pts) Identify the mineral: it does not shine like metal, it scratches glass, and it breaks with curved, shell-shaped surfaces.
10. (4 pts) Identify the mineral: it shines like metal, looks brassy yellow and leaves a greenish-black streak. Then tell what Agassiz taught Scudder about looking.

Unit project: my rock collection museum

Finish and display your rock collection as a small museum with at least twelve numbered specimens, sorted into groups (igneous, sedimentary and metamorphic rocks, minerals and fossils, plus an honest “unknown” group if you need one). Every specimen has a label with all five parts and a field notebook page with measurements in inches and centimeters, test results and a sketch. Include a written catalog, a title card, your museum or rock-shop trip page with its bar graph, and the review game you built.

Open your museum to family or friends. Give the three-part talk for at least three specimens and do one demonstration, such as a streak test or the vinegar fizz.

- **Labels and records**: Every specimen has a matching number on the rock, the label and the notebook page; every label has all five parts; the catalog lists every specimen.
- **Accurate science**: Specimens are sorted into the right families, tests are done correctly, and names match the test results (or are honestly marked “unknown”).
- **Sharing and evidence**: The talk tells what each specimen is, where it was found and how we know, and the demonstration lets visitors see the evidence.
- **Care and neatness**: Specimens are clean, the display is orderly, and sketches and labels are careful and easy to read.

Answer key

1. Specimen number, name (or “unknown”), locality (where it was found), date and collector. (Take off 1 point for each missing part.)
2. So scientists far away, like Thomas Jefferson’s friends in Philadelphia, would know which sample came from which place. The locality matters most because a name can be figured out later, but if the place is forgotten no one can ever find it out again.
3. 4 × 2½ = 10, so about 10 centimeters.
4. An English scientist who studied minerals. He left his money to the United States to found the Smithsonian Institution in Washington, for the increase and spread of knowledge.
5. The mineral is quartz, the variety is amethyst, and the locality is Rio Grande do Sul, Brazil.
6. “This limestone is full of shells” can be observed. “It formed in the Jurassic” uses a museum word and tells an idea about when it formed, which no one watched.
7. He showed they were really narwhal tusks. He proved it with evidence anyone could see: a narwhal skull with the tusk still attached.
8. Igneous: basalt, granite. Sedimentary: shale, sandstone. Metamorphic: marble, slate.
9. Quartz (hardness 7).
10. Pyrite (fool’s gold). Agassiz taught him to look again and again (and to draw what he saw), because each new look shows more than the first.

Bonus: Field Lab

All year you have studied rocks, minerals and fossils at the kitchen table. Now it is time to go outside and find them where God put them. In this bonus Field Lab you will work the way real field geologists do: hunting, testing, measuring and writing everything down in a notebook. Each lab is short and playful, and each one uses what you learned in the earlier units.

You will follow Hugh Miller into a Scottish quarry and then hunt all three rock families in your own yard. You will build a streak and scratch field kit like the simple tools field geologists such as Florence Bascom carried through the hills of Pennsylvania. You will read a cliff the way Meriwether Lewis read the White Cliffs of the Missouri River, and you will sift a creek for fossils like the families who hunt shark teeth in New Jersey. Along the way you will keep tally charts, draw bar graphs, measure in inches and centimeters, and label every find with where and when you found it.

Safety comes first in every lab. Always go with a grown-up, ask permission before collecting, never collect in a national park, and never walk along a highway road cut or climb a cliff.

BEFORE YOU BEGIN

- Can name the three rock families and give one example of each (Units 2–4)
- Knows the Mohs hardness scale and the streak test (Unit 1)
- Knows that the bottom layer of rock was laid down first (Unit 3)
- Knows how fossils form by quick burial (Unit 5)

MASTERY CHECKLIST

- I can find rocks outdoors and sort them into igneous, sedimentary and metamorphic families using clues.
- I can use a fingernail, penny, steel nail, glass and streak plate to test a mineral’s hardness and streak.
- I can read an outcrop from a safe place, list its layers from the bottom up and use a person for scale.
- I can use the cross-cutting rule to tell whether a crack or dike is older or younger than the layers it cuts.
- I can find fossils, label each one with its locality and date, and follow the rules for collecting.
- I can make and read a tally chart and a bar graph of my finds.

OPTIONAL BOOKS AND RESOURCES

- **Smithsonian National Museum of Natural History Geogallery** (https://geogallery.si.edu/): Free. Photographs and short descriptions of rocks, minerals

and gems from the Smithsonian collection. Use it to compare your finds with real labeled samples.

- **Call 811 Before You Dig** (https://call811.com/): Free. Before digging the soil pit in Lesson 9.3, a parent can call 811 or use this site so buried gas, water and electric lines can be marked.
- **Leave No Trace: The Seven Principles** (https://lnt.org/): Free. Simple outdoor manners for families, including “leave what you find” in places where collecting is not allowed. Good to read together before each lab.

9.1 Rock Cycle Scavenger Hunt

OBJECTIVES

- Find rocks outdoors and sort them into igneous, sedimentary and metamorphic families using field clues.
- Record finds in a tally chart and read the chart to compare the families.
- Explain how one kind of rock can change into another in the rock cycle.

Warm-up. Pour a handful of driveway gravel, aquarium stones or creek pebbles onto a white plate. Sort them into piles any way you like. Then tell someone your rule: color, size, shape or something else? Keep your piles. Today you will learn a scientist's way to sort them.

Video. Coming soon. The rock cycle for kids and how to tell igneous, sedimentary and metamorphic rocks apart outdoors; search USGS, Smithsonian, SciShow Kids, Homeschool Pop (Alternate), Science Max and family rock-hounding channels.

KEY TERMS

igneous rock
Rock made when melted rock cools and hardens. Look for crystals fitted together like a puzzle, or for dark, fine rock with tiny holes.

sedimentary rock
Rock made of bits of sand, mud or shells that settled in layers and were pressed and stuck together. Look for grains, layers and fossils.

metamorphic rock
Rock that was changed by squeezing and heating deep underground. Look for stripes, wavy bands or flat, shiny sparkles.

rock cycle
The ways any rock can be changed into another kind: broken into bits, squeezed and heated, or melted and cooled.

CORE IDEAS

The story. In 1820, a young Scotsman named Hugh Miller went to work as a stonemason's helper in a sandstone quarry near his town of Cromarty, in the north of Scotland. The work was hard, and his hands blistered. But as he split the stone, Miller began to notice things. Some slabs had wavy ripple marks, just like the sand on the beach below the town. Some held the shapes of creatures. Along the shore, the waves had rolled together pebbles of many colors and kinds. Miller later said that the quarry and the seashore were his best school. He taught himself to read rocks so well that he became one of the most famous rock writers of his day, and his book *The Old Red Sandstone* (1841) was read all over Britain.

The big idea. Every rock you pick up belongs to one of three families, and each family leaves clues. **Igneous rock** cooled from melted rock: look for speckled crystals fitted tightly together, like granite, or dark, fine rock, sometimes with tiny gas holes, like basalt. **Sedimentary rock** is made of settled bits: look for sand grains you can feel, thin layers, fossils, or a fizz when a drop of vinegar touches limestone. **Metamorphic rock** was squeezed and heated: look for stripes or wavy bands, like gneiss, flat sparkles of mica, like schist, or thin, flat sheets, like slate. And in the **rock cycle**, any rock can become another. Granite can be broken into sand that becomes sandstone. Sandstone squeezed and heated can become quartzite. Rock melted deep underground can cool into new igneous rock.

Try it and see. You do not need mountains to hunt rocks. Look in driveway gravel, creek beds, garden borders, a field after plowing, or a pile of landscaping stone. Many yard rocks were carried in by trucks or rolled along by rivers, so all three families may sit side by side, just as on Hugh Miller's beach. Look at buildings too: granite countertops, slate steps and marble gravestones are all rocks you can name. Psalm 104:24 says, "O LORD, how manifold are thy works!" *Manifold* means "many kinds." A rock hunt is a fine way to see just how many.

Rock family	Tally	Count
Igneous (crystals, speckles)		5
Sedimentary (grains, layers, fossils)		4
Metamorphic (stripes, flat sparkles)		3

Mia's scavenger hunt tally chart. Every group of five tally marks is four lines with a fifth line across them.

PICTURE STUDY



Chalk Cliffs on Rügen, Caspar David Friedrich, 1818 · Oil on canvas · Museum Oskar Reinhart, Winterthur, Switzerland

Caspar David Friedrich was a German painter who loved to show people standing quietly before the wonders of creation. In 1818 he visited the island of Rügen in the Baltic Sea, where great white cliffs drop straight down to the water. Those cliffs are **chalk**, a soft white sedimentary rock made mostly of the tiny shells of sea creatures far too small to see without a microscope.

Chalk is the same rock that people once used to write on slate blackboards. In chalk cliffs like these, people also find hard lumps of flint and fossil shells.

Look closely

- Find the white cliffs. Are their edges smooth or jagged? What do you think has worn them away?
- Find the three people. What is each one doing?
- Look at how the trees and the cliffs make a frame around the sea. What does the painter want you to look at?
- Find the tiny boats far out on the water. How do they help you feel how high the cliff is?

Talk about it

1. Chalk is made of tiny shells. Which rock family does it belong to, and what clue tells you?
2. If you could climb down to the beach below these cliffs, what kinds of pebbles do you think you might find?

> **Safety first.** Hunt only with a grown-up and only where you have permission. Never take rocks from national parks, someone else's garden or a cemetery. When you turn over a rock, lift the side away from you first, so anything living under it, such as a stinging insect or a snake, moves away from you, then put the rock back. Do not lift rocks that are too heavy. Do not break rocks with a hammer unless a grown-up helps and everyone wears safety glasses. Wash your hands when you come in.

EXPERIMENT: THE THREE-FAMILY ROCK HUNT

You will hunt in two different places, collect ten rocks in each, and sort them by family using field clues. Then you will compare the two places with a tally chart and a bar graph, like a real field scientist.

You will need

- Two empty egg cartons (one for each hunting place)
- A magnifying glass or hand lens
- A small cup of white vinegar and a dropper or spoon
- Masking tape and a marker for labels
- A small brush or old toothbrush and a cup of water for rinsing
- Lab notebook, pencil and colored pencils

Steps

1. **Question.** Write: Which rock family will I find most often near my home?
2. **Prediction.** Write which family you think will win, and why.
3. Choose two hunting places, such as a gravel driveway and a creek bed, or a garden border and a playground.
4. **What we keep the same.** In each place, hunt for 15 minutes and collect exactly 10 rocks, each about the size of a grape to a walnut, so they fit in the egg carton cups.
5. Rinse each rock and brush off the dirt. Wet rocks show their colors and grains best.
6. Look at each rock with the magnifying glass. Check for clues: crystals fitted together (igneous), grains, layers or fossils (sedimentary), or stripes and flat sparkles (metamorphic). Put one drop of vinegar on any light-colored rock and watch for fizzing.
7. Label each cup with tape: I, S, M, or ? for "not sure." A real geologist has "not sure" rocks too.
8. **What we measure.** Count how many rocks of each family you found in each place. Make a tally chart like Mia's in the lesson.
9. Draw a bar graph with two bars for each family, one for each place, in two colors.
10. **What we change.** Only the place. Write a sentence comparing your two places. Was your prediction right?

Tips

- Look at a freshly broken or wet surface. Old rock surfaces get coated with dirt and stain that hide the clues.
- Color alone does not tell you the family. A pink rock can be granite, sandstone or marble. Look at grains, crystals and layers.
- Keep your best rock from each family for your collection from Unit 8.

Check your work

- I collected 10 rocks in each of two places.
- I sorted each rock using clues, not just color.
- I made a tally chart and a bar graph.
- I wrote whether my prediction was right.

FIELD NOTEBOOK

1. Draw your three best rocks, one from each family, life size. Next to each, write the clue that told you its family.
2. Draw the rock cycle as a triangle with igneous, sedimentary and metamorphic at the corners. Draw an arrow and write one way to get from each corner to the next.
3. Make a map of your hunting place. Mark with an X where you found each family.

> **From history.** Hugh Miller never went to college, but he read, studied and wrote all his life. He was a devoted Christian, and from 1840 he edited a church newspaper in Edinburgh called *The Witness*. In his books about rocks and fossils, he wrote again and again about the wisdom of the Creator that he saw in the stones he had studied since his quarry days.

WORKED EXAMPLES

Example 1. Look at Mia’s tally chart. Which rock family did she find most often? How many more igneous rocks than metamorphic rocks did she find? How many rocks did she find in all?

(Use the map or drawing “Count the tally marks in each row.” shown earlier in this lesson.)

1. Read the counts: igneous 5, sedimentary 4, metamorphic 3.
2. The biggest number is 5, so igneous rocks were found most often.
3. Subtract: $5 - 3 = 2$. She found 2 more igneous rocks than metamorphic rocks.
4. Add all three: $5 + 4 + 3 = 12$.

Answer: Igneous rocks were most common. Mia found 2 more igneous rocks than metamorphic rocks, and 12 rocks in all.

PRACTICE

1. EASY Name the three rock families.
2. EASY You find a tan rock that feels gritty like sandpaper. Sand rubs off on your fingers, and you can see thin layers. Which family is it in? What rock might it be?
3. MEDIUM In Mia’s tally chart, how many sedimentary and metamorphic rocks did she find together?
4. MEDIUM Your biggest rock is 3 inches long. One inch is about 2½ centimeters. About how many centimeters long is your rock?
5. HARD A sandstone pebble is buried deep underground, where it is squeezed and heated. What might it become, and which family would it belong to then? What would happen if it melted and cooled? Explain.

COMMON MISTAKES

- Sorting rocks by color alone. Color can fool you; grains, crystals, layers and stripes are better clues.
- Thinking rocks never change. In the rock cycle, rocks can be broken down, squeezed and heated, or melted and cooled into new rocks.
- Thinking every sparkly rock has gold or metal in it. Most sparkles are crystals of quartz or flakes of mica.

Make it a game · Rock Family Freeze. Mark three spots in the yard with signs: Igneous, Sedimentary and Metamorphic. A parent calls out a clue, such as “speckled crystals,” “layers,” “a fossil shell,” “stripes,” “fizzes in vinegar” or “flat, shiny sparkles.” Everyone runs to the right family and freezes. Anyone at the wrong sign tells the clue they will remember next time. For a harder round, the parent calls a change, such as “granite breaks into sand and is pressed together,” and players run to the family it becomes.

Scripture. “And the foundations of the wall of the city were garnished with all manner of precious stones. The first foundation was jasper; the second, sapphire; the third, a chalcedony; the fourth, an emerald; The fifth, sardonyx; the sixth, sardius; the seventh, chrysolyte; the eighth, beryl; the ninth, a topaz; the tenth, a chrysoprasus; the eleventh, a jacinth; the twelfth, an amethyst.” (Revelation 21:19–20, KJV)

John saw the heavenly city built with “all manner” of stones. The many kinds of rock in your own driveway or creek bed are a small taste of the variety God put into the earth He made.

Practice answers

1. Igneous, sedimentary and metamorphic.
2. Sedimentary. It is probably sandstone.
3. 4 + 3 = 7 rocks.
4. About 7½ centimeters (2½ + 2½ + 2½ = 7½).

5. Squeezed and heated sandstone can become quartzite, a metamorphic rock. If it melted completely and then cooled and hardened, it would become a new igneous rock. This is the rock cycle: any rock can change into another kind.

9.2 Streak and Scratch Field Kit

OBJECTIVES

- Put together a simple field kit and use it to test the hardness and streak of rocks and minerals outdoors.
- Use a scratch ladder of fingernail, copper penny, steel nail and glass to find a mineral's hardness range on the Mohs scale.
- Explain why streak color is a better clue than the color of the outside of a mineral.

Warm-up. Rub a piece of sidewalk chalk across a dark sidewalk, then rub a pencil across white paper. Both leave a line of powder. Now try to scratch a coin with your fingernail. Nothing happens! Talk about it: why can some things leave marks and others not?

Video. Coming soon. Mineral streak test and scratch hardness test with a fingernail, penny, nail and glass, and what a geologist carries in a field kit; search USGS, Smithsonian, SciShow Kids, Homeschool Pop (Alternate), Science Max and rock-hounding club channels.

KEY TERMS

field kit
A small set of tools a scientist carries outdoors to observe and test things right where they are found.

hardness
How well a mineral resists being scratched. A harder mineral scratches a softer one.

streak
The color of the powder a mineral leaves when it is rubbed across a rough white tile.

streak plate
A piece of rough, unglazed white porcelain, like the back of a bathroom tile, used for the streak test.

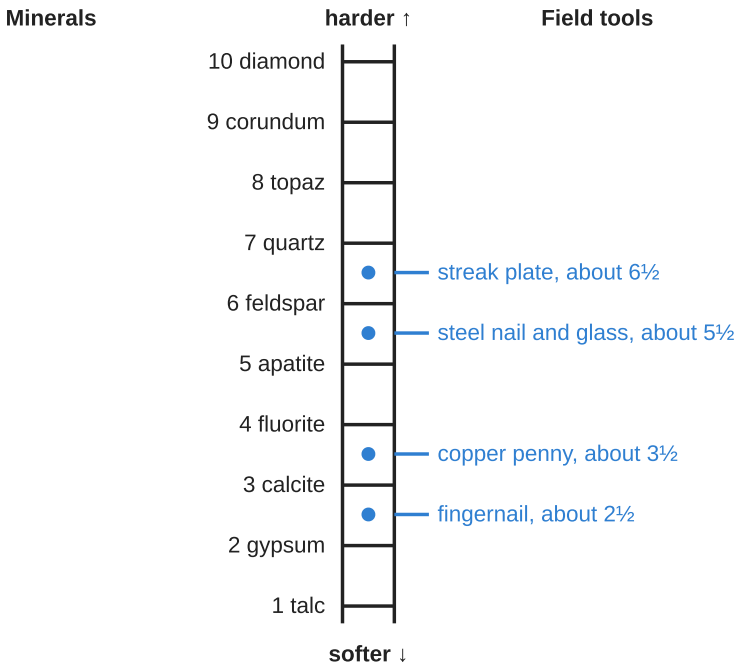
CORE IDEAS

The story. In 1896, a geologist named Florence Bascom joined the United States Geological Survey, the government team that maps the rocks of America. She was the first woman on its staff. Bascom taught at Bryn Mawr College near Philadelphia, and in the summers she walked the hills and stream valleys nearby, mapping the rocks underneath. She could not carry a laboratory into the woods. Field geologists like her carried a few simple tools instead, such as a rock hammer, a hand lens and a notebook. Geologists still carry kits like hers today, because the first and best tests are often made right beside the rock.

How the tests work. You already know the Mohs scale from Unit 1, from talc (1) up to diamond (10). In the field you can build a **scratch ladder** with things from home: your

fingernail is about 2½, a copper penny about 3½, and a steel nail and a piece of glass each about 5½. Try each tool on a mineral, from softest to hardest. If your fingernail leaves no scratch but the nail does, the mineral's **hardness** is between 2½ and 5½. For the **streak** test, rub the mineral across a **streak plate** and look at the powder. The outside of a mineral can fool you, but its streak does not. Hematite can look silvery black, yet its streak is always red-brown. Shiny gold-colored pyrite leaves a greenish-black streak, while real gold leaves a gold-yellow one. Quartz, at 7, is harder than the plate (about 6½), so it scratches the plate and leaves no colored streak at all.

God's handiwork. Every grain of a mineral has the same hardness and the same streak, whether it was found in your backyard or on the other side of the world. That is because God made each mineral with its own order of tiny parts, held together in its own way. A field kit lets you test that order with your own hands, the way Florence Bascom did in the hills of Pennsylvania.



The Mohs scale and the field tools that fit between its rungs. Softer is at the bottom; harder is at the top.

PICTURE STUDY



The Geologist, Carl Spitzweg, about 1860 · Oil on paper mounted on canvas · Von der Heydt Museum, Wuppertal, Germany

Carl Spitzweg was a German painter who loved gentle, often funny scenes of book lovers, scholars and collectors wrapped up in their favorite studies. Here a geologist has gone out to the rocks himself. He has brought a pick to break off fresh pieces and a collecting case to carry them home: the field kit of his day.

Spitzweg shows him so busy looking that he seems to have forgotten everything else. Like Florence Bascom a few years later, he knew that one of the best places to study a rock is right where it is found.

Look closely

- Find the geologist. What is he holding, and how close is he looking?
- Find his tools. Which ones would you put in your own field kit?
- Look at the rock face around him. Can you see cracks or layers?
- Where is the brightest light in the picture? Where does your eye go first?

Talk about it

1. What tests could he do right there with a field kit like yours?
2. Why is it helpful to test a rock where you find it instead of only at home?
3. A ruby and a sapphire are both the mineral corundum, 9 on the Mohs scale. Could he scratch one with a steel nail? Why or why not?

> **Safety first.** A grown-up should prepare the glass: use a small, thick glass jar, or tape all the edges of a glass square with duct tape. Lay the glass flat on a table and hold it down

> with one hand on the tape; never hold it in the air in your palm. Scratch away from your body. Keep the steel nail point down when you carry it. Do not taste minerals. Wash your hands after testing.

EXPERIMENT: BUILD AND USE A STREAK AND SCRATCH FIELD KIT

You will put together your own field kit in a box or bag, then test at least five rocks or minerals and record their hardness range and streak color. This is a small experiment, so you will test each sample the same careful way.

You will need

- A small box, pencil case or zipper bag for the kit
- Streak plate: a white bathroom tile turned over to its rough, unglazed back (from a hardware store)
- A copper penny
- A steel nail
- A small thick glass jar, or a glass square with taped edges
- A magnifying glass
- A small magnet
- A small bottle of white vinegar with a dropper
- Five samples: rocks from Lesson 9.1, or minerals from a rock shop such as quartz, calcite, gypsum, hematite and pyrite
- Lab notebook and pencil

Steps

1. Pack your field kit and draw it in your notebook with each tool labeled.
2. **Question.** Write: Which of my samples is the hardest, and which is the softest?
3. **Prediction.** Look at your samples and guess. Write your guess.
4. Make a table with columns: Sample, Color outside, Streak color, Fingernail?, Penny?, Nail?, Scratches glass?, Hardness range.
5. **What we keep the same.** Test each sample on a fresh, flat spot. Press the same amount each time, about as hard as you press to write with a pencil.
6. Try to scratch each sample with your fingernail, then the penny, then the nail. After each try, rub the spot with your thumb. A real scratch is a groove that stays; a line of powder rubs away.
7. Next, try to scratch the glass with the sample. Write yes or no.
8. Rub each sample across the streak plate and write the color of the powder.
9. Bonus tests: does the magnet stick? Does a drop of vinegar fizz?
10. **What we measure.** Write each hardness range, such as “between 2½ and 3½.”
11. **What we change.** Only the sample. Line your samples up from softest to hardest. Was your prediction right?

Tips

- If a softer tool leaves a mark on a harder mineral, it is the tool wearing off, like pencil on paper. Rub the mark and look again with the magnifying glass.
- Many pennies made since 1982 are mostly zinc with a thin copper coat, but they still work well enough for the scratch ladder.
- Minerals harder than about 6½ will scratch the streak plate and leave a white or no streak.

Check your work

- I packed a field kit and drew it with labels.
- I tested at least five samples the same careful way.
- I recorded streak color and a hardness range for each one.
- I lined up my samples from softest to hardest.

FIELD NOTEBOOK

1. Draw your field kit spread out on a table, with every tool labeled.
2. Draw the scratch ladder from the lesson and add your own samples on the rungs where they belong.
3. Make two streaks side by side on paper by drawing them in colored pencil: hematite (red-brown) and pyrite (greenish black). Under them, write the color each mineral looks on the outside.

> **From history.** The streak test is very old. Long ago, goldsmiths and merchants used a smooth black stone called a **touchstone**. They rubbed a piece of gold across it and compared the color of the streak with streaks from gold they already knew. Pure gold leaves a rich yellow streak, while gold mixed with other metals leaves a paler or redder one. That is where we get the saying that something is a “touchstone,” meaning a test of what is true.

WORKED EXAMPLES

Example 1. You test a purple mineral. Your fingernail does not scratch it. The penny does not scratch it. The steel nail does scratch it. What is its hardness range? Which mineral from the Mohs scale could it be?

(Use the map or drawing "Find the rungs between the penny and the nail." shown earlier in this lesson.)

1. The fingernail (about 2½) cannot scratch it, so it is harder than 2½.
2. The penny (about 3½) cannot scratch it, so it is harder than 3½.
3. The steel nail (about 5½) can scratch it, so it is softer than 5½.
4. So the hardness is between 3½ and 5½. On the Mohs scale, fluorite (4) and apatite (5) fit in that range.
5. Fluorite is often purple, so fluorite is a good guess. A streak test helps check: fluorite leaves a white streak.

Answer: Its hardness is between 3½ and 5½. It could be fluorite (4) or apatite (5); because it is purple, fluorite is the best guess.

PRACTICE

1. EASY What is a streak? What do you need to test it?
2. EASY Which is harder, your fingernail or a steel nail? How can you tell?
3. MEDIUM Gypsum is 2, calcite is 3 and quartz is 7 on the Mohs scale. Your fingernail is about 2½. Which of these three can your fingernail scratch? How much harder is quartz than calcite?
4. MEDIUM A mineral looks silvery black, but it leaves a red-brown streak. What mineral is it probably? Why is streak a better clue than outside color?
5. CHALLENGE Your brother tests one rock by pressing hard with the penny and another by pressing softly. He says the first rock is softer because the penny scratched it. Is this a fair test? How would you fix it?

COMMON MISTAKES

- Thinking a line of powder is a scratch. A soft tool can leave its own powder on a hard mineral; rub it off and look for a real groove.
- Thinking a mineral's streak is the same color as its outside. Hematite looks silvery black but has a red-brown streak.
- Thinking hard means unbreakable. Diamond is the hardest mineral, but a hard hammer blow can still crack it. Hardness only means it resists scratching.

Make it a game · Scratch Ladder Line-Up. Write each of these on its own card: talc, gypsum, fingernail, calcite, penny, fluorite, apatite, steel nail, glass, feldspar, streak plate, quartz, topaz, corundum, diamond. Shuffle and deal the cards. Players take turns laying a

card on the floor in a line from softest to hardest. If you put a card in the wrong place, the next player may move it and score a point. Remember that the steel nail and glass are about the same, so they can share a spot.

Scripture. “And thou shalt set in it settings of stones, even four rows of stones: the first row shall be a sardius, a topaz, and a carbuncle: this shall be the first row. And the second row shall be an emerald, a sapphire, and a diamond. And the third row a ligure, an agate, and an amethyst. And the fourth row a beryl, and an onyx, and a jasper: they shall be set in gold in their inclosings.” (Exodus 28:17–20, KJV)

Each stone in the high priest’s breastplate was engraved with the name of one of the tribes of Israel (Exodus 28:21). To cut a name into a hard stone, the craftsmen had to know which materials were harder than which. God gave His people skill to work with the stones He made.

Practice answers

1. A streak is the color of the powder a mineral leaves when you rub it on a rough white tile. You need a streak plate, such as the unglazed back of a white bathroom tile.
2. The steel nail (about 5½) is harder than a fingernail (about 2½). The nail can scratch things that a fingernail cannot.
3. Only gypsum, because 2 is less than 2½. Quartz is 4 steps harder than calcite ($7 - 3 = 4$).
4. It is probably hematite. The outside color of a mineral can change with stains, weathering or tiny bits of other things, but the color of its powder stays the same.
5. It is not a fair test, because he changed two things: the rock and how hard he pressed. To fix it, press the same amount on both rocks, test a fresh flat spot each time, and rub the mark to check that it is a real scratch and not just copper powder. Then only the rock is changed.

9.3 Reading a Road Cut

OBJECTIVES

- Read a real road cut, cliff, creek bank or soil pit from a safe place, counting and describing its layers from bottom to top.
- Estimate the thickness of layers using a person or a measuring stick for scale, in feet and inches with centimeters.
- Use the cross-cutting rule to tell whether something that cuts across the layers is older or younger than they are.

Warm-up. Stand next to a doorway with a grown-up. The grown-up is about 5 feet tall, and the door is about 7 feet tall. Now look at your house or a tree outside. About how many grown-ups tall is it? Scientists use a person standing in a photo the same way, to tell how big a cliff is.

Video. Coming soon. How to read rock layers in road cuts, cliffs and stream banks, dikes cutting across layers, and the White Cliffs of the Missouri River; search USGS, National Park Service, Bureau of Land Management, state geological surveys, Smithsonian and family geology field-trip channels.

KEY TERMS

outcrop
A place where bare rock shows at the surface, such as a cliff, a creek bank or a road cut.

scale
Something of known size in a picture or a view, like a person or a measuring stick, that helps you tell how big other things are.

dike
A wall-shaped body of igneous rock that formed when melted rock pushed up through a crack and hardened.

cross-cutting rule
Anything that cuts across rock layers, such as a crack or a dike, is younger than the layers it cuts.

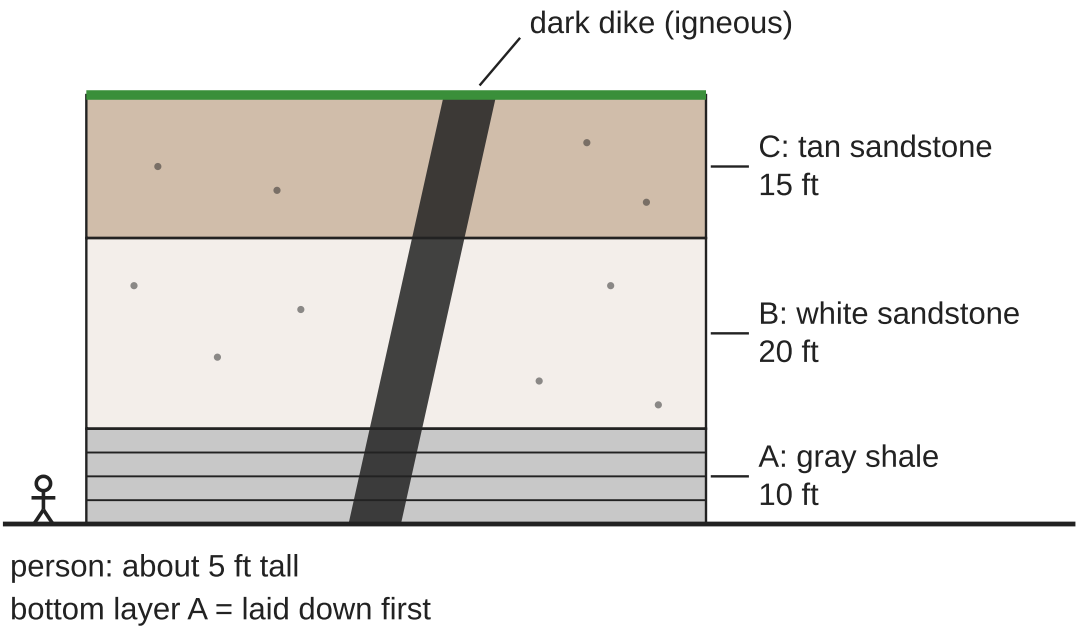
CORE IDEAS

The story. On May 31, 1805, Meriwether Lewis and the men of the Lewis and Clark expedition were pulling their boats up the Missouri River in what is now Montana. President Thomas Jefferson had asked them to write down the rocks and minerals they saw, and that day Lewis filled pages of his journal. Tall white cliffs of soft sandstone rose from both sides of the river, worn by wind and water into shapes that looked to him like ruined buildings, towers and statues. Running straight across the white cliffs were narrow walls of hard, dark

stone, so straight and even that they looked to Lewis almost as if they had been built by hand. Today that stretch of river is called the White Cliffs, and geologists know Lewis's dark walls are **dikes**: melted rock that pushed up through cracks in the sandstone and hardened.

The big idea. A road cut, cliff or creek bank is an **outcrop**, a window into the ground. To read one like a field geologist, first stand back and draw the whole thing. Count the layers from the bottom up, because the bottom layer was laid down first. Use **scale** to judge thickness: if a grown-up about 5 feet tall stands beside the cut, and a layer is as thick as two grown-ups, it is about 10 feet thick. Look at the loose pieces that have already fallen to the bottom to see grains, crystals and fossils. Last, look for anything that runs across the layers instead of along them. By the **cross-cutting rule**, a crack or a dike that cuts through layers must be younger than the layers, because the layers had to be there before anything could cut them.

Try it and see. You may find an outcrop at a park trail, a riverbank, a roadside rest area or a scenic overlook. If you cannot, make your own: with a grown-up, dig a small hole in the yard about 1 foot deep and look at the side. You will see layers in the soil too: dark topsoil full of roots on top, and lighter, harder soil or gravel below. Job 28 describes miners who cut through rock to find what is hidden. "He putteth forth his hand upon the rock" (Job 28:9). When you read a road cut, you are reading the rocks God made.



A model outcrop. The person is about 5 feet tall. The dark dike cuts across layers A, B and C.

PICTURE STUDY



Ancient Ruins in the Cañon de Chelle, Timothy H. O’Sullivan, 1873 · Albumen print photograph · Prints in the Library of Congress, the National Archives and other collections

Timothy O’Sullivan was an American photographer who traveled with government survey teams mapping the West. In 1873 he set up his large wooden camera in Canyon de Chelly and photographed this huge cliff. The title says New Mexico, but the canyon is in northeastern Arizona. The little stone houses were built long ago by the Pueblo people, tucked into a hollow in the cliff.

O’Sullivan had to coat a glass plate with chemicals, take the picture and develop it right there, so he carried a dark tent and his whole darkroom with him. The cliff is red sandstone, and the dark streaks were left by water running down its face.

Look closely

- Find the stone houses. How do they help you tell how tall the cliff is? They are your scale.
- Find the long dark streaks. Do they run along the layers or down across them?
- Look for lines in the rock that run sideways. Can you find any layers?
- Find the hollow where the houses sit. What do you think wore it out of the cliff?

Talk about it

1. If one house is about 10 feet tall, about how tall do you think the whole cliff is? How did you decide?
2. Why do you think a survey team wanted photographs, and not only drawings, of the rocks they saw?

> **Safety first.** Never walk or stand along a highway road cut. Traffic is fast, and rocks can fall from the cut without warning. Look only from a safe pull-off, overlook, park trail or parking area with a grown-up. Never climb a road cut, cliff or steep creek bank, and do not dig into the bottom of one. Pick up only pieces that have already fallen and are well away from the cliff. Before digging a hole in the yard, a grown-up should call 811 so buried pipes and wires can be marked.

EXPERIMENT: MY OUTCROP LOG

You will read a real outcrop, or a soil pit you dig yourself, and record it in a log the way field geologists do: a drawing, a measured list of layers from the bottom up, and notes on anything that cuts across.

You will need

- A tape measure or yardstick marked in inches and centimeters
- A grown-up to stand in as scale (or a stick of known length)
- Magnifying glass and a dropper of vinegar
- A trowel or small shovel (for a soil pit)
- Lab notebook, pencil and colored pencils
- A camera or phone, if you have one

Steps

1. **Question.** Write: How many layers can I find in this outcrop, and in what order were they laid down?
2. **Prediction.** Before you look closely, guess how many layers you will find.
3. Find a safe place to look, or with a grown-up dig a hole about 1 foot deep with one straight side.
4. Stand back and draw the whole outcrop. If you have a camera, take a picture with a person or a yardstick next to it for scale.
5. **What we measure.** Starting at the bottom, measure or estimate the thickness of each layer. For a soil pit, use the tape measure in inches and centimeters. For a big outcrop, count how many grown-ups tall each layer is.
6. For each layer, write: letter (A for the bottom), thickness, color, and what it is made of (sand, mud, gravel, roots, crystals, fossils).
7. Look for anything that cuts across the layers: a crack, a root, an animal burrow or a dark dike. Write which layers it cuts.
8. **What we keep the same.** Measure every layer straight up and down, not at a slant.
9. Write the order the layers were laid down, oldest to youngest, and add the cutting things in the right place.

Tips

- Layers are easier to see when the outcrop is a little damp, or in the slanting light of morning or evening.
- A layer may be thick in one spot and thin in another. Measure in the middle of the cut and write where you measured.
- In a soil pit, roots and worm burrows cut across the soil layers. By the cross-cutting rule, they came after the layers formed.

Check your work

- I read an outcrop or soil pit from a safe place.
- I drew it and labeled the layers from A at the bottom.
- I measured or estimated each layer’s thickness.
- I used the cross-cutting rule for anything that cut across the layers.

FIELD NOTEBOOK

1. Draw Lewis’s White Cliffs with the dark stone walls running across them. Label the sandstone and the dike, and write which is younger.
2. Draw your soil pit or outcrop with a ruler drawn beside it, marked in inches.
3. Copy the model outcrop from the lesson and color it. Draw a small person beside it for scale.

> **From history.** Before Lewis and Clark set out in 1804, Thomas Jefferson wrote them careful instructions. Along with plants, animals and the weather, he asked them to record the minerals of every kind they found, especially metals, limestone, coal and saltpeter. The explorers brought back rock and mineral samples along with their journals, and their notes were among the first written descriptions of the rocks of the American West.

WORKED EXAMPLES

Example 1. Look at the model outcrop. The person beside it is about 5 feet tall. Layer A is 2 people thick, Layer B is 4 people thick and Layer C is 3 people thick. How thick is each layer, and how tall is the whole cliff? Is the dike older or younger than Layer C?

(Use the map or drawing "Use the person to measure each layer." shown earlier in this lesson.)

1. Layer A: 2 × 5 feet = 10 feet.
2. Layer B: 4 × 5 feet = 20 feet.
3. Layer C: 3 × 5 feet = 15 feet.
4. Add them: 10 + 20 + 15 = 45 feet. (Check: 2 + 3 + 4 = 9 people, and 9 × 5 = 45.)
5. The dike cuts all the way through Layer C, so by the cross-cutting rule it is younger than Layer C.

Answer: Layer A is 10 feet, Layer B is 20 feet and Layer C is 15 feet thick. The whole cliff is 45 feet tall. The dike is younger than Layer C, and younger than all three layers.

PRACTICE

1. EASY Name two safe places to look at a road cut or outcrop, and one place that is not safe.
2. EASY In the model outcrop, which layer was laid down first? Which was laid down last?
3. MEDIUM In the model outcrop, how much thicker is Layer B (20 feet) than Layer A (10 feet)?
4. MEDIUM In your soil pit, the dark topsoil is 4 inches thick and the lighter soil below it is 8 inches thick. How deep is the hole to the bottom of the lighter soil? About how many centimeters is that? (1 foot is about 30 centimeters.)
5. HARD Lewis saw dark stone walls cutting straight through the white sandstone cliffs. Which came first, the sandstone or the dark walls? Explain how you know.

COMMON MISTAKES

- Thinking every stripe in a cliff is a layer. Look at its direction: layers run along the cliff, but dikes, cracks and water streaks run across or down it.
- Thinking something that cuts through layers is older than they are. The layers had to be there first to be cut.
- Guessing size with no scale. A cliff in a photograph can look small or huge; a person, a car or a ruler beside it tells the truth.

Make it a game · Human Outcrop. Give each player a different colored towel or blanket. The first player lies down as Layer A, the next lies down beside them as Layer B, and so on, while the reader calls out what each layer is, such as "gray shale." Then one player is the dike and walks in a straight line across all the layers. The reader asks:

Which layer came first? Which came last? Is the dike older or younger than Layer A? Each right answer earns a point. Switch jobs and play again.

Scripture. “He putteth forth his hand upon the rock; he overturneth the mountains by the roots. He cutteth out rivers among the rocks; and his eye seeth every precious thing.” (Job 28:9–10, KJV)

Job describes miners cutting deep into the rock to bring hidden things to light. A road cut opens the rock in the same way. God sees every layer and every precious thing inside the earth, and He lets us look and learn too.

Practice answers

1. Safe: a scenic overlook, a rest area, a pull-off, a park trail or a riverbank with a grown-up. Not safe: walking along the edge of a highway, or climbing on a road cut or cliff.
2. Layer A (gray shale), on the bottom, was laid down first. Layer C (tan sandstone), on top, was laid down last.
3. 10 feet thicker (20 − 10 = 10). Layer B is twice as thick as Layer A.
4. 4 + 8 = 12 inches, which is 1 foot, or about 30 centimeters.
5. The sandstone came first. The dark walls are dikes that cut across the sandstone layers. By the cross-cutting rule, the layers had to be there first, with cracks in them, before melted rock could push up through the cracks and harden into the walls.

9.4 Fossil Hunt

OBJECTIVES

- Search a creek bed, gravel pile or sedimentary outcrop for fossils and tell a fossil from an ordinary pebble.
- Label each find with what it is, where it was found and the date, and follow the rules for collecting.
- Make and read a bar graph of fossil finds.

Warm-up. Press a seashell, a leaf or a key firmly into a flat ball of play dough, then lift it out. The hollow it leaves is a **mold**. Now look at the mold with a magnifying glass. What details of the shell or leaf can you still see? A fossil hunter looks for clues just as small.

Video. Coming soon. Fossil hunting for kids in creeks and gravel, finding shark teeth, shells and crinoid stems, and the rules for collecting fossils; search Smithsonian, National Park Service, state geological surveys and museums, SciShow Kids, Homeschool Pop (Alternate) and family fossil-hunting channels.

KEY TERMS

fossil
Any trace of a living thing preserved in rock or sediment: a bone, tooth, shell, leaf print, track or burrow.

mold and cast
A mold is a hollow left in rock where a shell or bone used to be. A cast is what forms when that hollow fills with mud or minerals and makes a copy of the shape.

crinoid
A sea animal, also called a sea lily, with a long stem made of round pieces stacked like buttons. Its stem pieces are common fossils.

locality
The exact place where a rock or fossil was found. A fossil with its locality written down is far more useful to a scientist.

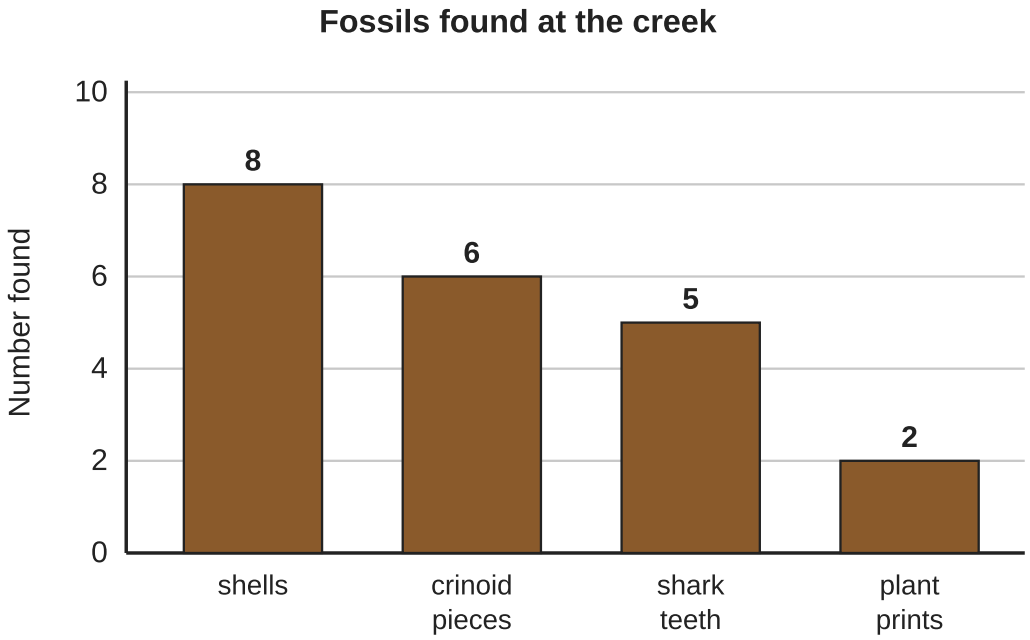
CORE IDEAS

The story. In 1866, workers digging marl, a crumbly greensand used to enrich farm fields, found a pile of big bones in a pit near Barnsboro, in southern New Jersey. Edward Drinker Cope, a young scientist from Philadelphia, studied them and saw sharp, curved claws and jagged teeth. He named the meat-eating dinosaur *Laelaps*. About thirty years later, Cope worked with a young artist named Charles R. Knight, and in 1897 Knight painted two of these dinosaurs fighting, one leaping through the air. Today families still sift the gravel of

New Jersey creeks, such as Big Brook in Monmouth County, and go home with shark teeth and fossil shells.

The big idea. Fossils are found in sedimentary rock and in the gravel and sand that wear out of it, because animals and plants were preserved when they were quickly buried in mud and sand. So look where sedimentary rock or gravel is open to the sky: creek beds after a rain, beaches, gravel driveways made of crushed limestone, and the loose pieces at the bottom of a shale or limestone outcrop. Your eyes will learn to spot shapes that are too regular to be ordinary pebbles: the ribs of a clam shell, the spiral of a snail, the round "buttons" of a **crinoid** stem, the shiny black point of a shark tooth, or a leaf print on a flat piece of shale. Some finds are **molds** and **casts** rather than the shell itself.

Try it and see. A real fossil hunter writes down the **locality** of every find: where it was, the date, and which layer or gravel bar it came from. Without that, even a wonderful fossil tells scientists very little. Follow the rules, too. You may never collect anything in a national park. On private land, ask the owner first. In public parks, follow the posted rules. If you ever find a large bone, take a photograph with a coin beside it, leave it where it is, and tell a museum or park ranger. Job 28:11 says God "bringeth forth to light" the thing that is hid. Each fossil you find is a hidden thing brought into the light.



One family's fossil finds from an afternoon at a creek.

PICTURE STUDY



The Exhumation of the Mastodon, Charles Willson Peale, 1806–1808 · Oil on canvas · Maryland Center for History and Culture, Baltimore, Maryland

Charles Willson Peale was an American painter who also ran one of the first natural history museums in America, in Philadelphia. In 1801 he heard that farmers near Newburgh, New York, had dug huge bones out of a marl pit, much like the pit where the *Laelaps* bones were found. Peale went to dig for more. The pit kept filling with water, so his crew built a giant wooden wheel. Men walked inside it to turn a chain of buckets that lifted the water out.

Peale painted himself and many members of his family watching the dig. The bones were put together into a mastodon skeleton, an animal something like a big, shaggy elephant, and shown in his museum. Like your sieve survey, the dig took patience, the right tools and careful records.

Look closely

- Find the giant wheel. What is it doing?
- Find the buckets. Where is the water going?
- Find the workers down in the pit. What tools are they using?
- Find the people watching. Can you find any children?

Talk about it

1. Why did Peale need a machine to get the bones out?
2. How is Peale’s dig like your fossil sieve survey? How is it different?
3. Why do you think Peale put his family in the painting?

> **Safety first.** Hunt in creeks only with a grown-up, only in shallow, slow water, and never after heavy rain when the water is high or fast. Wear old shoes, not bare feet. Do not climb or dig into steep banks or cliffs, because they can collapse. Watch out for poison ivy and check for ticks when you come home. Never collect in a national park, and always ask before collecting on private land. Wash your hands when you are done.

EXPERIMENT: THE FOSSIL SIEVE SURVEY

You will hunt fossils in a creek, beach, gravel pile or bag of gravel from a garden store, using a simple sieve. You will sort your finds into kinds, label each one with its locality, and make a bar graph. Garden-store limestone gravel and many creeks hold crinoid pieces and shells.

You will need

- A kitchen colander or a homemade sieve (window screen stapled over a wooden frame, or a plastic basket with holes)
- A bucket or a small trowel
- An egg carton or muffin tin for sorting
- Magnifying glass and a coin to use for scale in photographs
- Masking tape, a marker and small zipper bags
- Ruler with inches and centimeters
- Lab notebook and pencil

Steps

1. **Question.** Write: What kind of fossil will I find most often here?
2. **Prediction.** Write your guess and why.
3. Write the locality at the top of a notebook page: the place, the date, and whether you sifted a gravel bar, a beach or a bag of gravel.
4. **What we keep the same.** Sift the same amount each time: 10 scoops with the trowel or bucket, one scoop at a time.
5. Shake each scoop gently in the sieve. If you are at a creek, dip the sieve in the shallow water to wash away the mud.
6. Look over what is left with the magnifying glass. Pick out anything with ribs, spirals, buttons, points or prints.
7. Sort your finds in the egg carton: shells, crinoid pieces, shark teeth, plant prints and “not sure.”
8. **What we measure.** Count each kind. Measure your largest find in inches and centimeters.
9. Make a bar graph of your finds like the one in the lesson.
10. Label a zipper bag for each kind with what it is, the locality and the date.
11. **What we change.** If you can, sift a second place the same way and compare the two graphs.

Tips

- Look for fossils on a sunny day after a rain, when stones are washed clean.
- Lay your finds on a white paper plate. Shapes and colors show up better.
- Shark teeth are often shiny and dark, with a smooth point and a rough root. Look at the gravel at the bottom of a riffle, where water runs fast over stones.

Check your work

- I sifted the same amount of gravel each time.
- I sorted my finds into kinds and counted them.
- I made a bar graph of my finds.
- Every find has a label with what it is, where I found it and the date.

FIELD NOTEBOOK

1. Draw your best fossil find life size, with a ruler drawn beside it. Write its locality and the date under the drawing.
2. Draw a crinoid as it looked alive, a flower-like animal on a long stem, and next to it draw the button-shaped stem pieces that you find as fossils.
3. Draw a shell, its mold and its cast side by side, and label each one.

> **From history.** Cope’s dinosaur did not keep its name. The name *Laelaps* had already been given to a tiny mite, and in science no two animals in the same group may share a name. So in 1877 Cope’s rival, Othniel Charles Marsh, renamed it *Dryptosaurus*, which means “tearing lizard.” Museum labels today use Marsh’s name, but Knight’s famous painting is still called *Leaping Laelaps*.

WORKED EXAMPLES

Example 1. Look at the bar graph of fossils found at the creek. How many fossils were found in all? Which kind was found most often? How many more shells than plant prints were found?

(Use the map or drawing “Read the number at the top of each bar.” shown earlier in this lesson.)

1. Read the top of each bar: shells 8, crinoid pieces 6, shark teeth 5, plant prints 2.
2. Add them: 8 + 6 = 14. 14 + 5 = 19. 19 + 2 = 21.
3. The tallest bar is shells, at 8.
4. Subtract: 8 − 2 = 6.

Answer: 21 fossils were found in all. Shells were found most often. There were 6 more shells than plant prints.

PRACTICE

1. EASY What is a fossil? Name three kinds of fossils you might find in a creek.

2. EASY You find a hollow in a rock shaped exactly like a clam shell, but the shell is gone. Is it a mold or a cast?
3. MEDIUM On the bar graph, how many more crinoid pieces than shark teeth were found? How many shark teeth and plant prints together?
4. MEDIUM Your biggest shark tooth is 2 inches long. One inch is about 2½ centimeters. About how many centimeters long is the tooth?
5. HARD Two children each find a shark tooth. One writes “shark tooth” on the bag. The other writes “shark tooth, Big Brook gravel bar below the bridge, June 10.” Why is the second label more useful to a scientist?

COMMON MISTAKES

- Thinking fossils are found in any kind of rock. Most fossils are in sedimentary rock and the gravel worn from it, not in granite or other igneous rock.
- Thinking a fossil must be a bone. Shells, teeth, leaf prints, tracks, burrows, molds and casts are fossils too.
- Thinking it is fine to take fossils from anywhere. Collecting is not allowed in national parks, and on private land you must ask the owner first.

> **Make it a game · Fossil Sieve Race.** A parent hides 20 small “fossils” in a tub of sand or gravel: dried pasta shells, buttons for crinoid pieces, and pumpkin seeds for shark teeth. Each player gets one minute to sift with a colander. When time is up, sort and count your finds by kind and make a quick tally chart. Score one point for each fossil and a bonus point if you correctly name every kind. Then add up everyone’s finds to see whether all 20 were found.

> **Scripture.** “He bindeth the floods from overflowing; and the thing that is hid bringeth he forth to light.” (Job 28:11, KJV)

God knows every hidden thing in the earth, and He brings what is hidden into the light. When a shell or tooth washes out of a creek bank into your sieve, you get to see something God kept hidden in the rock until that very day.

Practice answers

1. A fossil is any trace of a living thing preserved in rock or sediment. In a creek you might find fossil shells, crinoid stem pieces, shark teeth, snails or plant prints.
2. It is a mold, the hollow left where the shell used to be.
3. 1 more crinoid piece (6 − 5 = 1). Shark teeth and plant prints together: 5 + 2 = 7.
4. About 5 centimeters (2½ + 2½ = 5).
5. The second label tells the locality and the date, so a scientist knows exactly where the tooth came from and can go back to look for more, compare it with other finds from the same place, and know which layers or gravel it washed out of. A fossil with no locality cannot tell us much.

Unit 9 review

Answer each question. Use your field notebook if you like. Show your work for any adding, subtracting or measuring, and use complete sentences for explanations. The review is worth 40 points.

1. (7 pts) Name the rock family for each rock: (a) a gray rock with tiny holes from gas bubbles; (b) a rock with thin layers and a fossil shell in it; (c) a rock with wavy light and dark stripes.
2. (7 pts) Your fingernail does not scratch a mineral, but a copper penny does. What is its hardness range? Which Mohs mineral could it be?
3. (6 pts) A mineral looks silvery black but leaves a red-brown powder on the streak plate. What is it probably, and why do geologists trust the streak more than the outside color?
4. (7 pts) A cliff has three layers. A grown-up about 5 feet tall stands beside it. The bottom layer is 2 grown-ups thick, the middle layer is 3 grown-ups thick and the top layer is 1 grown-up thick. How tall is the cliff? Which layer is oldest?
5. (6 pts) A dark dike cuts straight through all the layers of a cliff. Is the dike older or younger than the layers? Name one safe place and one unsafe place to look at a road cut.
6. (7 pts) Name two places where you might find fossils and two things you should write on a fossil’s label. Name one place where you may never collect fossils.

Unit project: my field lab collection

Gather your best finds from all four labs into one display, such as a labeled egg-carton tray or a shoebox lid with sections: at least one rock from each family, your tested minerals and your fossils. Give every item a small label with its name, its locality and the date. Beside the display, include your field notebook pages: the rock hunt tally chart and bar graph, your streak and scratch table, your outcrop log drawing and your fossil bar graph. Then give a short field report to your family, explaining one test or rule you used in each lab.

- **Accuracy**: Rocks are sorted into the right families, minerals have correct hardness ranges and streak colors, and fossils are named correctly.
- **Records**: Every item has a label with name, locality and date, and the notebook pages include complete tally charts, tables and graphs.
- **Explanation**: The field report explains the clues for each rock family, the scratch ladder, the cross-cutting rule and why localities matter.
- **Care and safety**: The display is neat and easy to read, and the student can tell the safety and collecting rules followed in each lab.

Answer key

1. (a) Igneous (it could be basalt or pumice). (b) Sedimentary. (c) Metamorphic (it could be gneiss).
2. Its hardness is between 2½ (fingernail) and 3½ (penny). It could be calcite, which is 3.

3. It is probably hematite. The outside color can be changed by stains and weathering, but the color of a mineral’s powder stays the same.
4. 2 + 3 + 1 = 6 grown-ups, and 6 × 5 = 30 feet tall. The bottom layer is oldest, because it was laid down first.
5. The dike is younger, because by the cross-cutting rule the layers had to be there before the dike could cut through them. Safe: an overlook, rest area, pull-off or park trail with a grown-up. Unsafe: walking along the edge of a highway or climbing the cut.
6. Places: a creek bed, a beach, a gravel driveway of crushed limestone, or loose pieces at the bottom of a shale or limestone outcrop. Label: what it is, the locality (exactly where it was found) and the date. You may never collect in a national park.