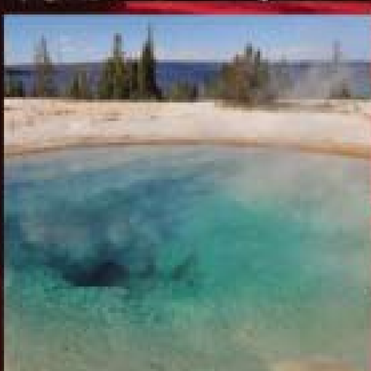
Project Earth Science
GEOLOGY

REVISED SECOND EDITION



By Paul D. Fullagar and Nancy W. West

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Readings

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Introduction

Project Earth Science: Geology is one of the four-volume Project Earth Science series. The other three volumes in the series are *Astronomy, Meteorology,* and *Physical Oceanography*. Each volume contains a collection of hands-on Activities developed for middle-level students plus a series of Readings intended primarily for teachers, but that could also be useful to interested students.

Additions and Changes to Revised 2nd Edition

Activities and Readings have been rewritten to improve clarity and scientific currency, and to suggest additional teaching and learning strategies. The Resources section at the back of this book is almost entirely new. At the beginning of each Activity, there now is a Planner to quickly provide information about that Activity. Material specifically for students, and material specifically for teachers, is more clearly delineated. There are new sections for students within Activities titled What Can I Do? and Fast Fact. Additional new sections included for teachers are How Do We Know This?, Safety Alerts!, Connections, Differentiated Learning, and Assessment.

Within each Activity, there now is a section for teachers titled Preconceptions. A preconception is an opinion or view that a student might have prior to studying a particular topic. These opinions may not be accurate because the student does not have the correct information or does not understand that information. Each possible preconception that we list with each Activity actually is a misconception. Asking students about their preconceptions at the outset of a new instructional topic can provide useful information about what students already know and what misinformation needs to be corrected for them to have a good understanding of the topic. The preconceptions we list are, of course, only examples of incorrect ideas that some students might have. Most groups of students are imaginative enough to come up with many other preconceptions!

About *Project Earth Science: Geology*

Project Earth Science: Geology is built upon the unifying theory of plate tectonics. It explores how this concept can be used to explain the occurrences of volcanoes, earthquakes, and other geologic phenomena. The Activities herein also provide a link among plate tectonics, rock and mineral types, and the rock cycle. Integrated into this foundation are a variety of points regarding the process of scientific investigation and modeling. The intent is to increase student awareness of how scientific knowledge is created.

This book is divided into three sections: Activities, Readings, and Resources. The Activities emphasize the following: The outer part of Earth is composed of plates of rock. These plates move independently on top of a rock layer with different properties called the asthenosphere. Because of their motion, plates interact at their edges causing geological events and features (e.g., volcanic eruptions and earthquakes, volcanoes, mountain ranges). The rocks and minerals around us today are products of complex geological processes. Close study provides insights into the geological processes and environments to which they have been subjected.

An understanding of the concept of density is required for several of the Activities contained in this volume. The Activities are written with the assumption that students have this understanding. If students have not yet learned this concept, there are several activities in *Project Earth Science: Physical*

Oceanography and in *Project Earth Science: Meteorology* that could be used prior to conducting the Activities herein.

A series of overview Readings supports the Activities. By elaborating on concepts presented in the Activities, the Readings are intended to enhance teacher preparation and serve as additional resources for students. The Readings also introduce supplemental topics so that teachers can link contemporary science to broader subjects and other disciplines.

The Resources provide supplemental materials. The Resources section includes *Activities*—collections of hands-on activities and multidisciplinary units; *Audiovisual Materials*—media materials including DVDs and CDs; *Books and Booklets*—examples of useful textbooks and booklets; *Information and References*—additional resources such as periodicals, bibliographies, catalogs, maps, reference booklets, and reports; *Internet Resources*—starting points for exploration of online resources in geology, with an address (URL) for each website plus a brief annotation; *State Resources*—each of the 50 states has its own geological survey, and most can provide materials of use to teachers and students.

Creating Scientific Knowledge

Investigating plate tectonics offers a superb opportunity to encourage student thinking on two subjects: how scientific knowledge is created and how scientific knowledge evolves. The theory of plate tectonics gained wide acceptance only in the 1960s. Its implications produced a revolution within geology, forcing a complete reshaping of basic geological theories and understanding. *Project Earth Science: Geology* presents a variety of opportunities for teachers to discuss the creation and evolution of scientific knowledge. For example, students might consider

- how models help develop—yet sometimes restrict—our conceptions of nature
- how scientific knowledge changes over time
- how our choice of measurement scale affects our perceptions of nature and of change

Models and analogies are extremely effective tools in scientific investigation, especially when the subject under study proves to be too large, too small, or too inaccessible for direct study. Although Earth scientists often use models, students must be reminded that models are not perfect representations of the object or phenomenon under study. It is essential that students learn to evaluate models for strengths and weaknesses, such as which phenomena are accurately represented and which are not. Preconceptions about geological processes can be introduced when models are used beyond their intended range of application. When using models, it is good to discuss both their advantages and their limitations.

As students learn science, it is easy for them to lose sight of the fact that scientific knowledge evolves. As scientists gather more data, test hypotheses, and develop more sophisticated means of investigation, their understanding of natural phenomena often changes. What is now known as the theory of plate tectonics, for example, has evolved significantly over the last century.

"Continental drift" was first proposed in the early 1900s to explain why the outlines of continents seemed to fit so well together—the western coast of Africa and the eastern coast of South America, for example—and to explain why fossils found in rocks on the coasts of different continents were so similar. Having no mechanism to explain how such "drifting" could occur, most geologists rejected these early proposals. In the 1950s, geologists studying patterns in the frequency and location of volcanoes and earthquakes suggested that continents were just parts of enormous "plates" that make up outer Earth. They proposed that as these plates moved and their edges interacted, earthquakes were generated, and magma rose to the surface between plates, producing volcanoes. Many geoscientists remained skeptical of this model, however, partly because they still were unsure what might drive such a process.

In the 1950s and 1960s, much information became available about the seafloor. Geologists found patterns in the relative ages and the magnetic orientations of rock formations on the seafloor. These patterns, combined with newer seismic studies of Earth's interior, provided compelling evidence that Earth's surface *is* composed of moving plates and that the continents are part of them. Since the late 1960s, plate tectonics has been accepted by virtually all scientists as an accurate account of how Earth's surface has changed and continues to change.

With growing information and expanded understanding, scientific knowledge changes; what seemed impossible to many at the start of the 20th century is accepted in the 21st century. Teachers should emphasize this changing nature of science—it is what makes scientific inquiry special as a form of knowledge—and encourage students to investigate in more detail how scientific knowledge evolves.

Because the development of the theory of plate tectonics—a new paradigm for understanding Earth processes—hinged on data, Activities in which students analyze evidence come first in this revised edition. Activities 1–8 allow students to discover tectonic plates and boundaries by examining data. In Activities 9–11, students explore how plate tectonics works. Activity 12 applies plate tectonics to drifting continents over geologic time. Finally, Activities 13–15 are other hands-on activities to help students understand geologic concepts.

Observing and the Problem of Scale

Central to understanding how science evolves is appreciating the limits of our perceptions of change. We observe the world as it *is*, and our thoughts about how it *was* and how it *could be* tend to be quite restricted. That our world is changing constantly can be a difficult concept for students to accept. In several respects, this is a function of the rate at which change sometimes occurs compared to the length of time available to humans for direct observation.

To illustrate this point, ask students to consider the life of an insect that spends its entire existence—from June to August of a single year—in an oak tree. As outside observers, humans can observe seasonal and annual changes in the tree's biology. Because of the relatively short duration of its life, the insect cannot observe these changes.

Likewise, due to the relatively short span of our lifetimes compared to geologic time, people have difficulty appreciating the changes taking place on a million-year scale, to say nothing of billions of years. Continents move at a rate of less than 10 cm per year; average global temperatures may change only a few degrees over thousands of years; mountain ranges can take millions of years to rise. Changes such as these may be imperceptible during a person's life span. It is important for students to understand that while observing these changes may be difficult, Earth's geologic features are continually changing. Comparing events and changes on different scales can be a difficult skill for students to acquire.

Also, diagrams and models often exaggerate or compress relative sizes to make a certain point more obvious or to make the model small enough to be practical. Sometimes one scale is changed, but others are not. For example, displays of our solar system often accurately depict the relative *distances* between planets but misrepresent planets' relative *sizes*. In geology, cross sections often exaggerate the vertical scale to emphasize surface topography or subsurface structures such as folds and faults. The result is that the horizontal axis is at one scale and the vertical at another. It is important for teachers to discuss the concept of scale and encourage students to raise questions about the various measurement scales used in these Activities.

Getting Ready for Classroom Instruction

The Activities in this volume are designed to be hands-on. In developing them, we tried to use materials that are either readily available in the classroom or inexpensive to purchase. Note that many of the Activities also could be done as demonstrations.

Each Activity has two sections: a Student section and a Teachers' Guide. Each Student section begins with Background information to explain briefly, in nontechnical terms, what the Activity is about; the Objective states what students will learn. Then there is Vocabulary, which includes important geological terms used in the Activity. This is followed by a list of the Materials needed and an estimate of the amount of Time that the Activity will take. Following this introduction is a step-by-step Procedure outline and a set of Questions and Conclusions to facilitate student understanding, encourage constructive thinking, and advance the drawing of scientific conclusions.

Each Student section concludes with additional activities for students in What Can I Do?

The Teachers' Guide contains What Is Happening?, a more thorough version of the background information given to students. The section How Do We Know This? explains techniques or research methods geologists currently use to generate knowledge related to the Activity. This is followed by possible student Preconceptions, which can be used to initiate classroom discussions. Next comes a summary of What Students Need to Understand. Then Time Management discusses the estimated amount of time the Activity will take. Preparation and Procedure describes the setup for the Activity. Extended Learning challenges students to extend their study of each topic. Interdisciplinary Study relates the science in each Activity to other disciplines, such as language arts, history, and social sciences. Connections links geology to a similar process or concept in astronomy, meteorology, or physical oceanography. The final portion of each Teachers' Guide includes possibilities for Differentiated Learning, Answers to Student Questions, and suggestions for Assessment.

Although the scientific method often has been presented as a "cookbook" recipe—state the problem, gather information, form a hypothesis, perform experiments, record and analyze data, and state conclusions—students should be made aware that the scientific method provides an approach to understanding the world around us, an approach that is rarely so straightforward. For instance, many factors can influence experimental outcomes, measurement precision, and the reliability of results. Such variables must be taken into consideration throughout the course of an investigation.

As students work through the Activities in this volume, make them aware that experimental outcomes can vary and that repetition of trials is important for developing an accurate picture of concepts they are studying. By repeating experimental procedures, students can learn to distinguish between significant and insignificant variations in outcomes. Regardless of how carefully they conduct an experiment, they can never entirely eliminate error. As a matter of course, students should be encouraged to look for ways to eliminate sources of error. However, they also must be made aware of the inherent variation possible in all experimentation.

Finally, controlling variables is important in maintaining the integrity of an experiment. Misleading results and incorrect conclusions often can be traced to experimentation where important variables were not rigorously controlled. Teachers should encourage students to identify experimental controls and consider the relationships between the variables under study and the factors held under control.

Key Concepts

The Activities in this book are organized within the context of the unifying geological theory of plate tectonics, which encompasses the following four key concepts:

Key Concept I:	Geological patterns and lithospheric plates
Key Concept II:	Movement of plates
Key Concept III:	Geological phenomena and plate tectonics
Key Concept IV:	Rocks and minerals

Key Concept I deals with the fact that Earth's surface, the lithosphere, is comprised of individual lithospheric plates. Key Concept II is that the plates move or "ride" atop the solid but plastic asthenosphere. Key Concept III is concerned with the fact that many geological events and features occurring on Earth's surface, such as earthquakes, volcanic eruptions, volcanoes, and mountain ranges, are directly related to plate tectonic activity. Key Concept IV has to do with the rocks and minerals that comprise such features, which are produced over time by complex, cyclical geological processes.

Project Earth Science: Geology and the *National Science Education Standards*

An organizational matrix for the Activities in *Project Earth Science: Geology, Revised 2nd Edition,* appears on pages xvi–xvii. The categories listed along the x-axis of the matrix, listed below, correspond to the categories of performing and understanding scientific activity identified as appropriate by the National Research Council's (NRC's) 1996 *National Science Education Standards*.

Subject and Content: Specifies the topic covered by an Activity.

Scientific Inquiry: Identifies the "process of science" (i.e., scientific reasoning, critical thinking, conducting investigations, formulating hypotheses) employed by an Activity.

Unifying Concepts: Links an Activity's specific subject topic with "the big picture" of scientific ideas (i.e., how data collection techniques inform interpretation and analysis).

Technology: Establishes a connection between the natural and designed worlds.

Personal/Social Perspectives: Locates the specific geology topic covered by an Activity within a framework that relates directly to students' lives.

Historical Context: Portrays scientific endeavor as an ongoing human enterprise by linking an Activity's topic with the evolution of its underlying principle.

Project Earth Science: Geology hopes to address the need for making science—in this case, geology—something students do, not something that is done to students. The standards organizational matrix on the following pages provides a tool to assist teachers in realizing this goal.

Safety in the Classroom Practices

The teaching and learning of science today through hands-on, process, and inquiry-based activities make classroom and laboratory experiences effective. Addressing potential safety issues is critical to securing this success. Although total safety cannot be guaranteed, teachers can make science safer by adopting, implementing, and enforcing legal standards and best professional practices in the science classroom and laboratory. Safety in the Classroom Practices includes both basic safety practices and resources specific to the Project Earth Science series. It is designed to help teachers and students become aware of relevant standards and practices that will help make activities safer.

1. When working with glassware, wires, projectiles, or other solid hazards, students should use appropriate personal protective equipment, including safety glasses or goggles, gloves, and aprons.
2. When working with hazardous liquids, indirectly vented chemical splash goggles, gloves, and aprons must be used.
3. Always review Material Safety Data Sheets (MSDSs) with students relative to safety precautions when working with hazardous chemicals.
4. When dealing with hazardous chemicals, an eyewash station within 10-seconds access is required because of the possibility of a splash accident in the eyes. If there is potential for a body splash, an emergency shower is required with 10-seconds access.
5. Make sure appropriate laboratory ventilation is used when working with hazardous vapors or fumes.
6. When heating liquids other than water, use only heat-resistant glassware (Pyrex- or Kimax-type equipment). Remember that glass labware is never to be placed directly on heating surfaces. Also remember that hot containers are potential hazards. Water may be heated in glassware, but teapots or other types of pans also may be used.
7. When heating liquids on electrical equipment such as hot plates, use ground-fault-protected circuits (GFI).
8. Always remind students of heat and burn hazards when working with heat sources such as hot plates for melting wax, heating water, and more. Remember that it takes time for the hot plate and the objects heated on the hot plate to cool.
9. Use caution in working with scissors, plastic knives, pocket pencil sharpeners, rocks, or other sharp objects—cut or puncture hazards.
10. If a relatively harmless liquid (e.g., water, dilute chemical) is spilled on the floor, always wipe it up immediately to prevent slip and fall hazards. However, if a spilled liquid (e.g., concentrated acid) is causing, or has the potential to produce, toxic fumes, the classroom or lab must be vacated and appropriate emergency authorities called immediately. Teachers must know in advance what to do in this type of emergency.
11. Never consume food or drink that has been either brought into or used in the laboratory.
12. Teachers should always model appropriate techniques before requiring students to cut, puncture, or dissect, and so on.
13. Wash hands with soap and water after doing activities dealing with hazardous chemicals.
14. Use caution when working with hot water—it can burn skin.
15. Use caution when working with flammables—keep away from ignition or spark sources.
16. Markers can have volatile organic compounds (VOCs) that can irritate the eyes, nose, and throat. Use in well-ventilated areas, or use only low VOC markers.

17. Lighted bulbs can get hot and burn skin. Handle with care.
18. Make sure that all food is disposed of properly so that it does not attract rodents and insects in the lab or classroom.
19. Work with care when placing boards on the floor—they can be a trip and fall hazard.
20. When using a vise, be careful not to place fingers in the vise—a pinch hazard. It can break or damage skin.

For additional safety regulations and best professional practices, go to
NSTA: Safety in the Science Classroom: *www.nsta.org/pdfs/SafetyInTheScienceClassroom.pdf*

NSTA Safety Portal: *www.nsta.org/portals/safety.aspx*

Standards Organizational Matrix

Activity	Subject Matter and Content	Scientific Inquiry	Unifying Concepts and Processes
Activity 1 GeoPatterns	Global earthquake distribution	Analyzing data	Explaining nature's spatial patterns
Activity 2 Volcanoes and Plates	Where volcanoes form	Plotting and analyzing data	Using a theory to explain data
Activity 3 Volcanoes and Hot Spots	Chains of volcanoes	Modeling to understand trends	Explaining data and predicting
Activity 4 All Cracked Up	Earth's layers, models	Modeling, visualizing	Representing data with a model
Activity 5 Seafloor Spreading	Divergent plate boundaries, ocean floor patterns	Modeling	Modeling to explicate a process
Activity 6 Mapping the Seafloor	Seafloor and ocean depths	Measuring and graphing data	Collecting data strategically
Activity 7 Rocks Tell a Story	Characterizing rocks	Observing, describing	Inferring processes of change
Activity 8 The Rock Cycle	Rock cycle: formation and change	Modeling change	Change within open systems
Activity 9 Solid or Liquid?	Properties of rock in the asthenosphere	Experimenting	Change and rate of applied stress
Activity 10 Edible Plate Tectonics	Plate tectonics: interaction	Modeling, visualizing	Influence of physical properties on change
Activity 11 Convection	Heat transfer within Earth's mantle	Experimenting	Density differences and heat transfer
Activity 12 A Voyage Through Time	Breakup of Pangaea	Modeling, predicting	Evolution of landmasses
Activity 13 Magma and Volcanoes	Volcanic eruption	Modeling	Modeling to illustrate a process
Activity 14 Shake It Up	Earthquakes' effects on structures	Experimenting	Rapid energy transfer
Activity 15 Study Your Sandwich	Deforming rocks	Visualizing in 3-D	Analyzing models of rock structures

Technology	Personal/Social Perspectives	Historical Context	Key Concept
	Natural hazards	Evidence supporting a new paradigm	I, III
	Natural hazards	Evidence supporting a new paradigm	I, III
	Natural hazards	Evidence supporting a new paradigm	I, II, III
		Changing knowledge of Earth's interior	I, II
Adapting technology for science	Teamwork	Evolving theories	I, II, III
Method of measurement	Group decision of priorities	Historical methods of science	I, III
	Scientific perspective of deep time	Inferring history from rocks	III, IV
	Natural resources	Changing understanding of rock origins	III, IV
			II
		Evolving theories	I, II
Convection in technology		Evolving theories	I, II
Animation		History of Earth	I, II, III
	Cultural interpretation of volcanic events		I, III
Design of structures	Natural hazards	Analyzing historical earthquakes	I, III
		Chronology of rock formation and deformation	I, III, IV

Activities at a Glance

Activity	Pages	Subject and Content	Objective	Materials
Activity 1 GeoPatterns	1–15	Global earthquake distribution	Study earthquake distribution around the world and look for patterns of earthquake distribution.	Each student or group will need: all five panels of the strip map, scissors, glue (or clear tape), map of the ocean floor, colored pencils (optional), atlas, indirectly vented chemical splash goggles (if glue is used)
Activity 2 Volcanoes and Plates	17–29	Where volcanoes form	Investigate the relationship between volcanic activity and plate boundaries, and also explore how the kind of rock that is formed at volcanoes depends on the type of plate boundary.	Each student or group will need: colored pencils
Activity 3 Volcanoes and Hot Spots	31–39	Chains of volcanoes	Study volcanoes formed over hot spots, and investigate how plate movement is related to a pattern of volcanic island formation.	Each group will need: a box with clear sides, such as a plastic shoe box or an aquarium, if done as a demonstration; a small dropping bottle with a narrow neck; red food coloring; hot tap water; cold tap water; a Styrofoam "tectonic" plate; gloves and aprons
Activity 4 All Cracked Up	41–52	Earth's layers, models	Use models to understand some of Earth's interior features and evaluate the realism of various models.	For your demonstration: several hard-boiled eggs, preferably brown or dyed; one small kitchen knife (or cut eggs in half at home and wrap tightly to keep moist and shell in place); narrow- and broad-tipped markers For each student group: at least three other objects to serve as Earth models
Activity 5 Seafloor Spreading	55–63	Divergent plate boundaries, ocean floor patterns	Construct a paper model to illustrate why seafloor is newest or youngest at mid-ocean ridges, and is relatively old at and near trenches.	Each group will need: one copy of the seafloor spreading model; scissors; tape; orange-, yellow-, green-, and blue-colored pencils or crayons
Activity 6 Mapping the Seafloor	65–74	Seafloor and ocean depths	Map a simulated seafloor and create a profile of it. Practice teamwork and learn about possible effects of limited data and financial limitations on projects.	Each group of four or more will need: masking tape, permanent marker, graph paper and pencil, data sheets, meter stick The class will need: objects in container to represent seafloor; a large trash can or bucket, kiddie pool, or aquarium with sides covered; hardware cloth or other wire screen to cover water container; water-soluble paint, food coloring, or ink; water; strings long enough to reach bottom, with weights on ends

Time	Vocabulary	Key Concepts	Margin Features
45 minutes	Earthquake	I, III	Safety Alert!, What Can I Do?, Fast Fact, Connections, Resources
50 minutes	Lithosphere, Lithospheric plates, Lava, Igneous rock, Convergent boundary, Divergent boundary, Mid-ocean ridge, Transform boundary	I, III	What Can I Do?, Fast Fact, Connections, Resources
30 minutes	Hot spot, Seamount	I, II, III	Fast Fact, Safety Alert!, What Can I Do?, Connections, Resources
30 minutes	Crust, Plates, Mantle, Asthenosphere, Core	I, II	Safety Alert!, Fast Fact, Connections
50 minutes or less	Plate tectonics, Seafloor spreading, Trenches	I, II, III	Fast Fact, What Can I Do?, Connections
50 minutes	Sounding lines, Terrain, Topography	I, III	Fast Fact, Safety Alert!, What Can I Do?, Connections, Resources

Activity	Pages	Subject and Content	Objective	Materials
Activity 7 Rocks Tell a Story	77–84	Characterizing rocks	Observe characteristics of rock specimens and learn their significance.	Rock-sample set containing gabbro and basalt, shale and slate, granite and gneiss, sandstone and conglomerate, limestone and marble
Activity 8 The Rock Cycle	87–96	Rock cycle: formation and change	Investigate processes that form and alter rocks, and see how rocks change over time.	Each student will need: indirectly vented chemical splash goggles, a lab apron, a pocket pencil sharpener, scrap paper Each lab group will need: eight wax crayons, tongs, two pieces of lumber about 2.5 × 12.5 × 20 cm, hot plate, aluminum foil, four envelopes, newspaper, vise (optional)
Activity 9 Solid or Liquid?	99–108	Properties of rock in the asthenosphere	Investigate and observe how a substance can, under certain conditions, behave like a solid and, under other conditions, behave like a liquid.	**Part 1—**Data tables for all: **BLM 9.1** **Part 2—**Each group will need: Silly Putty, hammer, data tables for all: **BLM 9.2**, board, safety glasses for all, lab aprons **Part 3—**Each person will need: Mystery Substance X, towels for cleanup
Activity 10 Edible Plate Tectonics	111–119	Plate tectonics: interaction	Investigate how plates move on Earth's surface, and observe how some geologic features form as a result of this movement.	Each student will need: one Milky Way bar or similar type of product, towels for cleanup
Activity 11 Convection	121–132	Heat transfer within Earth's mantle	Investigate and observe how material moves within a convection cell, and consider how your observations might pertain to Earth's interior.	Each group will need: indirectly vented chemical splash goggles, aprons, and gloves for each student; room-temperature water; hot water (about 70°C); towels for water spills; food coloring in small containers; basin or sink for used water; plastic pan, pipette or medicine dropper; four foam cups; one cup lid; two sheets of white paper; data sheets for each student
Activity 12 A Voyage Through Time	135–146	Breakup of Pangaea	Model the breakup of the supercontinent Pangaea and the subsequent movement of continents.	Each student will need: a copy of the three map sheets, colored pencils or crayons (red, orange, yellow, green, blue, purple, tan), scissors, a current world map showing terrain such as mountains and seafloor (this could be on display only)

Time	Vocabulary	Key Concepts	Margin Features
50 minutes	Igneous, Sedimentary, Metamorphic	III, IV	Fast Fact, Safety Alert!, What Can I Do?, Connections
Approximately 150 minutes	Igneous rock, Weathering, Erosion, Sediment, Sedimentary rock, Metamorphic rock, Rock cycle	III, IV	Fast Fact, Safety Alert!, What Can I Do?, Connections
50 minutes or less	Glaciers	II	Safety Alert!, Fast Fact, What Can I Do?, Connections
15 minutes		I, II	Safety Alert!, Fast Fact, Connections
50 minutes	Convection, Experiment, Density	I, II	Safety Alert!, What Can I Do?, Fast Fact, Connections, Resources
50 minutes	Supercontinent	I, II, III	Fast Fact, What Can I Do?, Connections, Resources

Activity	Pages	Subject and Content	Objective	Materials
Activity 13 Magma and Volcanoes	149-156	Volcanic eruption	Create a model of a volcano with magma that rises to Earth's surface.	For each volcano model, students will require: two wax crayons, 25 cm of string, beaker (50–100 mL), scissors, paper cup (300 mL), plaster of paris (100–150 mL), hot plate, wire gauze, spoon, pan to boil water, water, tongs, indirectly vented chemical splash goggles, aprons, and gloves
Activity 14 Shake It Up	159–171	Earthquakes' effects on structures	Compare how well various construction designs withstand the effects of an earthquake.	Each group will need: two books (same size), one shoe box lid or tray, 20 sugar cubes, pencil or crayon, ruler, Student Worksheet
Activity 15 Study Your Sandwich	173–186	Deforming rocks	Investigate core sampling techniques geologists use to collect information about rock formations and their relative ages, and geologic structures.	Each group will need: one slice white bread, one slice whole wheat bread, one slice dark rye bread, two table-spoons jelly, two tablespoons soy—not peanut or almond—butter mixed with raisins, two paper plates, plastic knife, measuring spoon, clear plastic straws

Time	Vocabulary	Key Concepts	Margin Features
100 minutes	Tephra, Magma, Viscous	I, III	Fast Fact, Safety Alert!, What Can I Do?, Connections
50 minutes		I, III	Safety Alert!, What Can I Do?, Fast Fact, Connections, Resources
50 minutes	Sedimentary rock, Rock formation, Core sampling	I, III, IV	Safety Alert!, Fast Fact, What Can I Do?, Connections

Activity 9 Planner

Activity 9 Summary
Students explore the physical properties of Silly Putty and a slurry of cornstarch and water. These substances are a physical model of rocks in the asthenosphere, solid rocks that flow slowly—or deform plastically.

Activity	Subject and Content	Objective	Materials
Solid or Liquid?	Properties of rock in the asthenosphere	Investigate and observe how a substance can, under certain conditions, behave like a solid and, under other conditions, behave like a liquid.	**Part 1—**Data tables for all: **BLM 9.1** **Part 2—**Each group will need: Silly Putty, hammer, data tables for all: **BLM 9.2**, board, safety glasses for all, lab aprons **Part 3—**Each person will need: Mystery Substance X, towels for cleanup

Time	Vocabulary	Key Concepts	Margin Features
50 minutes or less	Glaciers	II: Movement of plates	Safety Alert!, Fast Fact, What Can I Do?, Connections

Scientific Inquiry	Unifying Concepts and Processes
Experimenting	Change and rate of applied stress

Solid or Liquid?

Activity 9

Rock Behavior Within Earth

Background

What is a solid, and how does it behave? Let's consider a common solid—ice made from water. Anyone who has ever dropped an ice cube on a floor likely discovered that ice is a rigid and brittle solid, meaning that it is stiff (not flexible) and that it breaks easily. But, ice changes its behavior or properties under different conditions. Valley **glaciers** are "rivers of ice" that flow downhill slowly because of gravity. If you were to walk onto a glacier and examine the ice, you would observe that it is rigid and brittle, like ice in a refrigerator. However, if you could go at least 50 m below the surface of the ice, you would find that it is no longer rigid and brittle. Because of the pressure of the ice above, ice below approximately 50 m is flexible and nonbrittle—this behavior is sometimes called plastic. This plastic ice even flows very slowly, typically a few tens of meters each year. For emphasis, let's repeat this: Ice is a solid, but under pressure it can flow.

The ability of a solid to flow under certain conditions is not limited to ice. Solid rock that makes up lithospheric plates that cover Earth is rigid and brittle. But, under the lithosphere, solid rock of the asthenosphere is hot and at high pressure. Because of these conditions, this rock is not rigid and not brittle. Like ice that is under pressure, the asthenosphere rock is flexible and plastic—and it flows.

The word *fluid* sometimes confuses people. In common usage, *fluid* often is a synonym for *liquid*. However, fluid simply means

Vocabulary

Glacier: A slowly flowing river of ice or a huge sheet of ice (e.g., continental glacier).

Objective

Investigate and observe how a substance can, under certain conditions, behave like a solid and, under other conditions, behave like a liquid.

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Topic: phases of matter
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something that is able to flow. Liquids certainly flow, but so do gases, as well as solids under certain conditions. Thus, we could describe the asthenosphere as being fluid because it flows and, strictly speaking, this word usage is correct. Because people sometimes think a fluid must be a liquid, it is a good idea to try to make it clear that the asthenosphere is solid rock (except for a very small amount of molten rock that is present at some locations) (**Figure 9.1**).

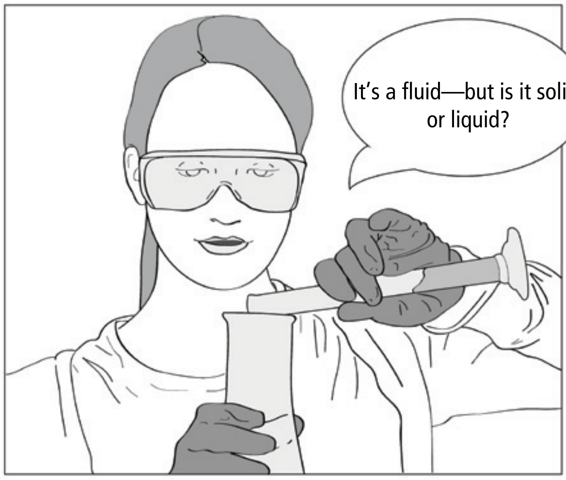

Figure 9.1
Trying to determine if a fluid is solid or liquid

Misuse of the word *fluid* illustrates the importance of using words correctly. If you use a word incorrectly or inconsistently, you can be confusing to others.

In this Activity, you will learn about two unusual substances—Silly Putty and Mystery Substance X—to help you understand the behavior of rocks at Earth's surface and below the surface.

Materials

Part 1
- data tables for all: **BLM 9.1**

Part 2
Each group will need
- Silly Putty
- hammer
- data tables for all: **BLM 9.2**
- board
- safety glasses for all
- lab aprons

Part 3
Each person will need
- Mystery Substance X
- towels for cleanup

Time

50 minutes or less

Procedure

Part 1

1. Think about the following solids: rocks, books, and shoes. What characteristics do they share? From your group's discussion, complete the Typical Solid section of the table in **BLM 9.1**.
2. Now, think about the following typical liquids: water, pancake syrup, and motor oil. What characteristics do they share? From your group's discussion, complete the Typical Liquid section of the table in **BLM 9.1**.

Part 2

3. Send a member from the group to pick up the materials for this Activity.
4. Roll the Silly Putty into a ball and bounce it off the table. Pull it, stretch it, mash it. Record your observations on **BLM 9.2**. Does the Silly Putty display qualities more like a solid or a liquid?
5. Roll the Silly Putty into a ball and place it on top of your board. Place the board on the floor, in an open area away from your desks and chairs. You are about to test some of Silly Putty's other qualities.

6. Before continuing, have everyone in your group (and nearby) put on safety glasses and lab aprons. Select one person to use the hammer. The tester should kneel by the Silly Putty ball and wait for the group's signal.
7. When everyone in the group is safely out of range of the hammer and ready to observe, the group should signal the tester to strike the Silly Putty with one hard swing of the hammer. What happened to the Silly Putty? Record your observations on **BLM 9.2**.
8. The tester should peel the Silly Putty off the board, roll it back into a ball, and repeat the experiment several times using different amounts of force each time. Before each trial, be sure everyone is at a safe distance from the tester and hammer. Record your observations on **BLM 9.2** after each trial.
9. After several trials, the tester should peel the Silly Putty off the board, roll it back into a ball, and place it on a piece of paper. Set the paper and Silly Putty in a place where it can rest undisturbed for at least 30 min. Someone in the group should carefully make a circle on the paper to document the ball's circumference. Record the time. (Note: Any source of gentle heat will speed up the change that you should observe; a lighted lamp with its bulb close enough to the Silly Putty to provide some warmth usually works well.)
10. Leave the Silly Putty undisturbed for 30 min. While waiting, return the other materials to your teacher and go on to Part 3.

Part 3

11. Obtain a small amount of Mystery Substance X. Examine this material—work it in your hands. What are its qualities? When does it have qualities typical of solids? When does it have qualities typical of liquids? Describe the qualities of Mystery Substance X on **BLM 9.2**.
12. Roll Mystery Substance X into a ball, and then break the ball apart. Let each piece of the ball rest in one hand. Describe the qualities of Mystery Substance X on **BLM 9.2**.
13. When you are sure you have fully investigated Mystery Substance X's qualities, dispose of it according to your teacher's instructions. Be sure to wash your hands and clean your lab area.
14. Check the time elapsed in the Silly Putty experiment in Part 2. After 30 min., observe the Silly Putty. Has its shape changed? To help answer this question, make a second circle around the Silly Putty. Handle the Silly Putty to learn if other qualities you observed earlier have changed. Record your observations on **BLM 9.2**. Discuss the changes you observe (if there are any) with members of your group. Is Silly Putty a solid or a liquid?

SAFETY ALERT

1. Safety glasses and lab aprons should be worn throughout the Activity.

2. The person using the hammer must be careful that no one is too close when the hammer is raised in order to swing and strike the test material.

3. Wash hands with soap and water upon completing the lab.

Fast Fact

Astronauts supposedly used Silly Putty on the *Apollo 8* mission, the first manned mission to orbit Earth's Moon. The story is that its adhesive properties helped them keep tools from floating around the capsule. There are many non-NASA links that make this claim, including one by the company that makes Silly Putty.

What Can I Do?

Glaciers exist in Alaska and the contiguous United States. You could research where you can still see them and plan a trip—real or hypothetical—to see a glacier. Where would you go? Have the glaciers there changed in size in recent years? How have they changed? How would you get there? Who would you take with you on this adventure?

Questions and Conclusions

1. When you bounced, mashed, and struck the Silly Putty with a hammer, did it react like a typical solid or like a typical liquid? Explain your answer.
2. When left undisturbed for 30 min., what happened to the ball of Silly Putty? Is this reaction typical of a solid or a liquid? Explain your answer.
3. How is Silly Putty different than typical solids, such as rocks, books, and shoes?
4. When you worked Mystery Substance X with your hands, what did you observe? Explain why this might have occurred.
5. How is Mystery Substance X different from a liquid such as water, pancake syrup, or motor oil?
6. Apply your understanding of Silly Putty and Mystery Substance X to Earth's asthenosphere. How can knowing that solids are not always rigid and brittle help you understand plate tectonics?
7. If Silly Putty or Mystery Substance X were used to model Earth's asthenosphere, what would be the strengths and weaknesses of each?

Date________________________________ Activity 9: Solid or Liquid?

Typical Solid	Characteristics
Rocks	
Books	
Shoes	
Typical Liquid	**Characteristics**
Water	
Syrup	
Motor Oil	

BLM 9.2: Observations of Characteristics of Silly Putty and Mystery Substance X

Date________________________________ Activity 9: Solid or Liquid?

Silly Putty—Student Observations:
Mystery Substance X—Student Observations:

Solid or Liquid?

Rock Behavior Within Earth

What Is Happening?

The behavior of seismic or earthquake waves demonstrates that both lithosphere and asthenosphere are almost entirely solid rock, as is the mantle below the asthenosphere. Only at the depth of the mantle-core boundary, about 2,900 km below Earth's surface, is there a layer of molten material.

Just below the lithospheric plates, in an area called the low velocity zone (LVZ), there is a very small amount of dispersed molten material, perhaps as little as 1% of the volume of the rock. The LVZ is characterized by unusually low seismic wave velocity. Even though the asthenosphere is mostly solid rock, its high temperature makes the rock weak and soft, or flexible (nonrigid) and plastic-like (nonbrittle); therefore, it flows very slowly. (It is the weakness of the rock that slows the seismic waves.) This fluid behavior of the asthenosphere is markedly different from that observed for the rigid and brittle rock that makes up lithospheric plates at and near Earth's surface. The plastic asthenosphere below the lithospheric plates may be what allows the plates to move.

Any rock will melt if its temperature is raised to a high enough temperature. However, the melting point of a rock is also a function of the pressure on the rock. The temperature of the rock that makes up the asthenosphere is just below the melting temperature for this rock. This causes the rock to have its unusual plastic-like quality, allowing it to flow. In general, as pressure increases on a material, its melting temperature increases.

How Do We Know This?

How do we know whether Earth's interior is solid, liquid, or both?

Earthquake or seismic waves, and waves created by explosions, are used to tell if places deep within Earth are solid or liquid. There are different kinds of seismic waves, including P-waves and S-waves. P-waves can travel through any kind of material; S-waves travel only through solids. If an earthquake occurs on one side of Earth, the P-waves reach the opposite side of Earth, but the S-waves do not. This means that part of Earth's interior must be liquid. Detailed studies of these waves have shown that Earth is almost entirely solid from the surface to the outer core, and that the outer core is liquid, but the inner core is solid.

Objective

Investigate and observe how a substance can, under certain conditions, behave like a solid and, under other conditions, behave like a liquid.

Key Concept

II: Movement of plates

Materials

Part 1
- data tables for all: **BLM 9.1**

Part 2
Each group will need
- Silly Putty
- hammer
- data tables for all: **BLM 9.2**
- board
- safety glasses for all
- lab aprons

Part 3
Each person will need
- Mystery Substance X
- towels for cleanup

Time

50 minutes or less

Preconceptions

Ask students, "What does 'fluid' mean to you?"

- Except for the rocky crust, Earth is molten.
- Earth is completely solid.
- Molten rock or magma comes from a molten layer just below Earth's crust.
- Molten rock that forms volcanoes comes from Earth's core.
- Magma forms when rock is subjected to great pressure deep within Earth.
- Continents move on top of molten rock.
- Liquids can flow, but solids cannot.
- All fluids are liquid.

What Students Need to Understand

- Earth's plates are rigid, brittle, and solid rock that moves on the top of the asthenosphere.
- The asthenosphere is not liquid molten rock. It is almost entirely hot solid rock.
- The solid rock of the asthenosphere is flexible and plastic-like, causing it to flow very slowly.
- Some solids have qualities or behaviors similar to those usually shown by liquids; some liquids have qualities or behaviors similar to those usually shown by solids.
- Using careful and precise language can be very important in science, as well as in many other disciplines and activities.

Time Management

Students can do this Activity, including setup and cleanup, in 50 minutes or less. However, they will need a 30-min. interval for Part 2 of the procedure.

SAFETY ALERT !

1. Safety glasses and lab aprons should be worn throughout the Activity.

2. The person using the hammer must be careful that no one is too close when the hammer is raised in order to swing and strike the test material.

3. Wash hands with soap and water upon completing the lab.

Preparation and Procedure

You will need to assemble materials and mix Mystery Substance X before class. Mystery Substance X is a slurry of water and cornstarch in a ratio of two or three parts cornstarch to one part water. You are trying to create a very thick sludge.

Try the Activity before having students do it to ensure that you know what to expect. The experience will help you address safety concerns and prevent mishaps.

Extended Learning

- Students usually enjoy opportunities to experiment with variations of this Activity. Many recipes are available for "slimes"—substances exhibiting qualities typical of both solids and liquids.
- Place a mound of Mystery Substance X on a table or lab bench, and put two blocks of wood side by side on top of it. As the cornstarch begins to flow, the two blocks of wood will move apart, carried along by the moving cornstarch underneath. Using this demonstration, students can explore how the rigid plates that make up Earth's surface can be carried about by material flowing underneath.
- Encourage students to seek information about other substances that mix qualities typical of both solids and liquids. Suggest that they investigate *thixotropic* substances (fluid materials that are liquid when stirred or shaken but become semisolid or solid when allowed to stand).
- Earth gets hotter going from surface to core. Have students look for information about why Earth's interior is so hot. And, if it is so hot, why isn't everything in Earth's interior molten?

Interdisciplinary Study

- Have students research and read the poem "Earthquake" by Kokan Shiren. Ask them to describe how Shiren's earthquake resulted in things similar to or different than what they have observed about solids and liquids. Also, ask them to describe the mood of the poem. Have them investigate liquefaction, a phenomenon that sometimes occurs during earthquakes and always occurs when you tap your foot on wet sand at the edge of the ocean.
- Have students think and write about how they feel when substances and objects exhibit unexpected qualities and characteristics, and when events take unexpected turns.
- Glass is another material with some unusual properties. Ask students to investigate what glass is and how it is made. Have them make a list of different ways in which glass is used.
- Ask students to think about a time when they or someone with them incorrectly used a word when speaking with someone, and that misused word caused some type of problem. Did the misuse cause a disaster? Was it funny? Was it sad? Or, was it just an inconvenience? Explain what happened.

Differentiated Learning

- Scientifically inclined students can investigate non-Newtonian fluids, of which Silly Putty is an example.
- Other students might benefit from a review of the properties of solids, liquids, and gases.

Connections

This Activity uses glaciers as examples of solids that flow slowly, like the rocks in the asthenosphere. Glaciologists study the distribution and size of glaciers, and measure the rate at which they flow. Many glaciers are flowing faster than they did during the last century, and yet the ends of these glaciers are receding (i.e., the glaciers are becoming shorter or smaller). (Note: Glacial ice always flows toward the end of the glacier, but the position of the end changes as climate changes—colder, more ice, and larger glacier; warmer, less ice, and smaller glacier.) Have students investigate the relationship among climate change, periods of glaciation, and amounts of glacial ice.

Answers to Student Questions

1. When bounced, pulled, and stretched, Silly Putty behaves largely as a typical solid. If left alone, it changes its shape without breaking, which is a quality typical of liquids. When hammered, Silly Putty fractures or breaks, as would a typical solid.
2. When left undisturbed for 30 min., Silly Putty slowly flows and spreads out. The bottom of the ball flattens. This fluidity is a quality typical of liquids.
3. Typical solids do not exhibit the fluid qualities of Silly Putty; they cannot easily be stretched.
4. When worked vigorously by hand, Mystery Substance X reacts more like a typical solid than a typical liquid. It crumbles, rolls into a ball, and can be broken in half. In this instance, Mystery Substance X reacts like a typical solid.
5. Mystery Substance X exhibits qualities of a typical solid under certain conditions. When worked vigorously it exhibits qualities of a typical solid, but when left alone it exhibits qualities of a typical liquid.
6. Earth's asthenosphere is an atypical solid: it flows. Most geologists believe a flowing asthenosphere allows or causes overlying lithosphere plates to move.
7. Answers will vary. Of course, the asthenosphere or mantle is not made of either Silly Putty or Mystery Substance X. Students should recognize that the environment within Earth's asthenosphere is quite different than that of the classroom, or Earth's surface in general. Also, flow within the asthenosphere is extremely slow—much slower than the flow observed for either of these substances.

Assessment

- For a summative assessment, you can grade answers to questions.
- You can also ask students to create a concept map based on what they have learned about solids, liquids, gases, and fluids.

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