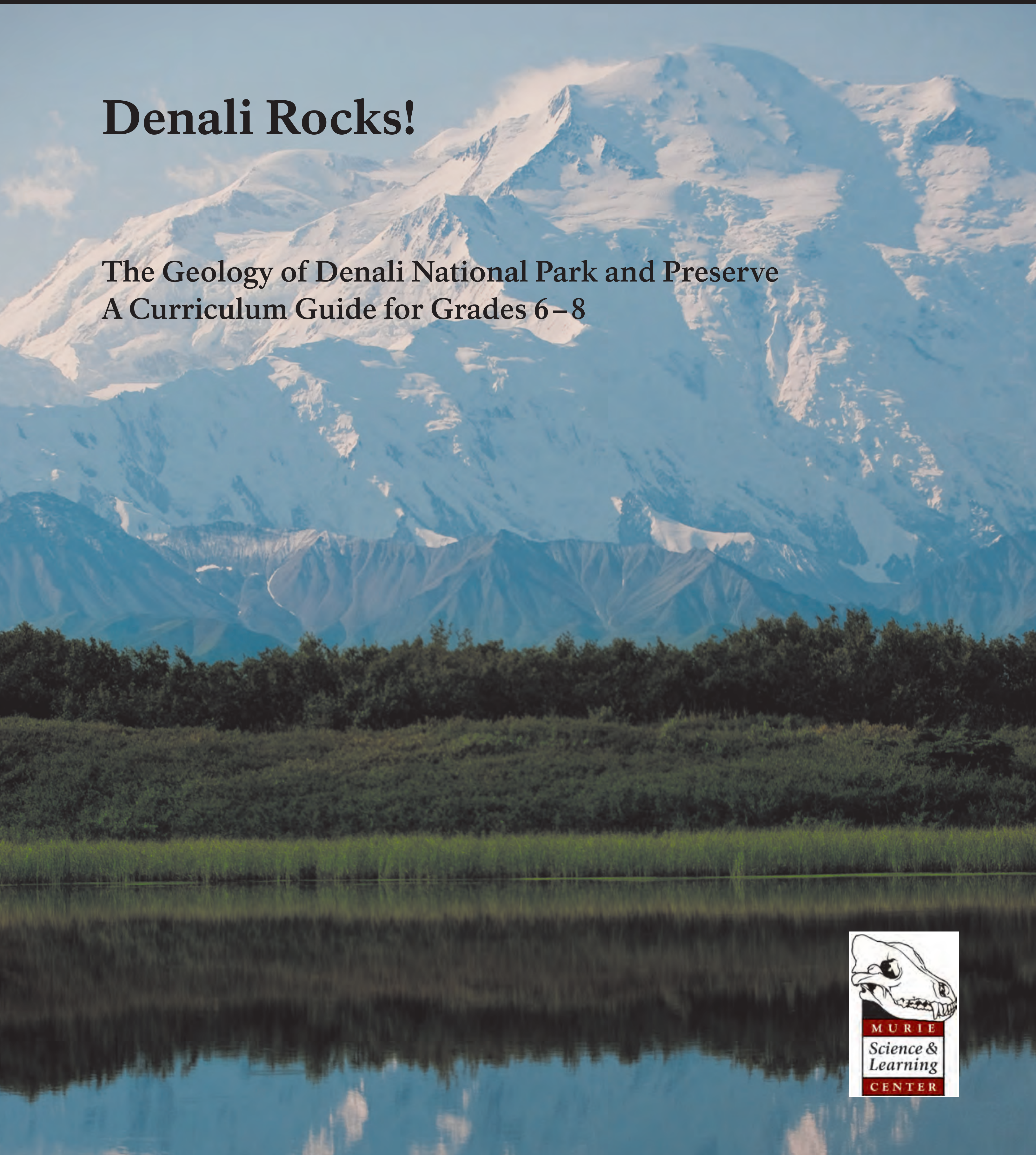
Denali National Park and Preserve

National Park Service
U.S. Department of Interior

Denali Rocks!

The Geology of Denali National Park and Preserve
A Curriculum Guide for Grades 6–8



MURIE Science & Learning CENTER

Denali Rocks!
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A Curriculum Guide for Grades 6–8

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NPS Cover Photo by Kent Miller

Acknowledgements

Denali Rocks! is based on Denali National Park and Preserve's curriculum *Denali: A Living Classroom* by Howard Carbone and Ed O'Connor (2002).

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National Park Service

Murie Science and Learning Center

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Teacher Introduction

Note to Teachers

Denali National Park and Preserve is one of more than 390 public "classrooms" that comprise our National Park System. Our parks serve as living classrooms where students can see natural processes at work, explore the lives of ancient cultures, and stand in the footsteps of our nation's history. Denali's landscape is full of lessons for an inquiring mind, and it offers teachers a way to spark interest in topics such as geology, biology, and native cultures. Teachers have long used Denali to inspire students and to make learning an adventure. This curriculum is designed to give teachers the resources they need to provide their 6th to 8th grade students with a learning adventure through the discovery of the geology behind North America's highest peak and the park surrounding it.

Denali Rocks! The Geology of Denali National Park and Preserve is based on Alaska State Standards for 6th through 8th grade science. The eight lessons in this guide are designed to be used as a unit, but individual lessons can be pulled out and incorporated into other geology units. The lessons are generally broken into three parts: lesson plans for the teacher, student handout pages, and an answer key for the student handout pages. Each lesson introduces new vocabulary, and you may find it helpful to have your students create a vocabulary journal to keep track of all the new words and terms.

Beyond the lessons, the curriculum contains background information on the National Park System, Denali National Park and Preserve, and geology, as well as a recommended reading list and glossary. The curriculum also has its own web pages for teachers and students, providing electronic materials, links to other web resources, and ideas for continuing *Denali Rocks!* in your classroom.

A wonderful continuation of this curriculum is an in-person or virtual visit to Denali National Park and Preserve with your class. The park's Murie Science and Learning Center offers teacher training, education programs, videoconferencing opportunities, and interaction with researchers. Please visit the curriculum web page to find information on contacting the park to arrange an in-person or virtual ranger visit to your school. We hope that you will take advantage of our living classroom to inspire students to discover the wonders of Denali.

There are some web pages and associated addresses referenced within this curriculum. The internet changes frequently and over time the web pages referenced in the curriculum may change or be unavailable. If this happens, using a search engine with applicable key words may help you to relocate the web page.

Note: Local teachers in Nenana, Anderson, Healy, Trapper Creek, Talkeetna, or Willow, may borrow a trunk that contains equipment used for the *Denali Rocks!* activities. For more information, please visit the curriculum web page.

> The curriculum web page can be found at:
> http://murieslc.org/static/1065/educator-resources

Evaluation Process

We need your help! Since this guide was designed for your use, only your feedback will make it work. Following the teacher introduction is a pre-addressed evaluation form. Please complete, fold in thirds, affix postage, and drop in the mailbox. All teachers returning evaluations will be entered into an annual drawing for a $100 gift certificate for all Murie Science and Learning Center evaluations. In addition to the evaluation forms, we encourage other types of feedback. Please send any of the following items from your students:

1. Video or photos of students engaging in *Denali Rocks!* projects.
2. Any completed classroom projects or photographs of projects.
3. Other ways of illustrating student feedback.

Please indicate if these items need to be returned. We will use them to create a project library to highlight classroom efforts on our website and in Park publications, and to complete evaluations of student outcomes.

Email: dena_education@nps.gov

Send to: National Park Service
Denali National Park and Preserve
Murie Science and Learning Center
Attn: MSLC Education Coordinator
P.O. Box 9
Denali Park, AK 99755

A mountain with two names?

Some call it Denali and others call it Mount McKinley, but which name is correct? The name Denali means "The Tall One" in the language of the Koyukon Athabaskans who have lived on the north side of the Alaska Range for thousands of years. In 1896 a gold prospector renamed the mountain for presidential candidate William McKinley. The name stuck and was officially adopted by the federal government. Since the Athabaskans do not name places after people, there is a certain cultural irony in the Denali/McKinley name issue. Most Alaskans and climbers prefer the name Denali, and it is still the official name in Alaska. Both names are used within this curriculum.

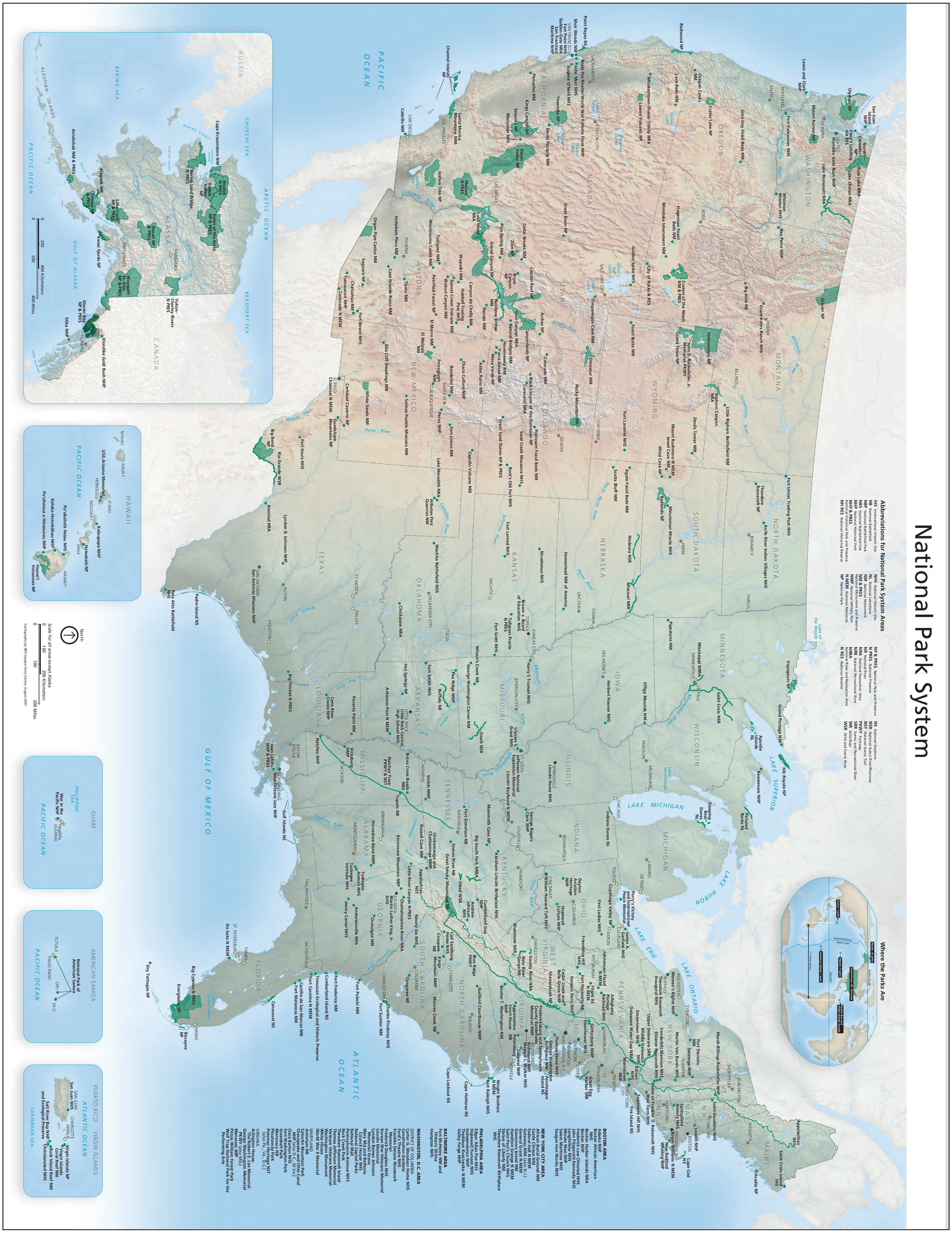
Meeting Alaska Standards

This curriculum was designed to help teachers meet Alaska state content standards for middle school students, as well as Alaskan science performance standards for grades 6-8. In this section, the Alaskan content standards in all subject areas and the Alaskan performance science standards/GLE's are listed for each lesson.

The broad Alaska content standards are explicated by performance standards (also called "Grade Level Expectations" or GLE's). Performance standards indicate which skills a student should master at a given grade level, and are bulleted in the row below the content standard in the table below. For a complete look at the Alaskan standards and GLE's, including descriptions, visit http://www.eed.state.ak.us/standards/.

National content standards that apply to each lesson are found in the resources section.

Alaska Content Standards and GLE's								
	Lesson 1	**Lesson 2**	**Lesson 3**	**Lesson 4**	**Lesson 5**	**Lesson 6**	**Lesson 7**	**Lesson 8**
Geography A1	X	X						
Geography C1			X	X		X	X	X
Geography C2			X	X		X	X	
Cultural E2	X	X	X	X	X	X	X	X
Science A1					X	X	X	X
• [6, 7, 8] SA1.1					X	X	X	X
Science A3			X					
• [6] SA3.1			X	X				
Science B1						X	X	X
• [6] SB1.1						X	X	X
Science D1			X	X	X	X	X	X
• [6, 7] SD1.1				X	X			
• [8] SD1.1					X			
• [7, 8] SD1.2						X	X	X
Science D2		X	X	X	X	X	X	X
• [8] SD2.1		X						
• [6] SD2.2			X	X	X			
• [7] SD2.2			X	X	X			
• [8] SD2.2			X	X				
• [6] SD2.3						X	X	X


National Park System

What is the National Park System?

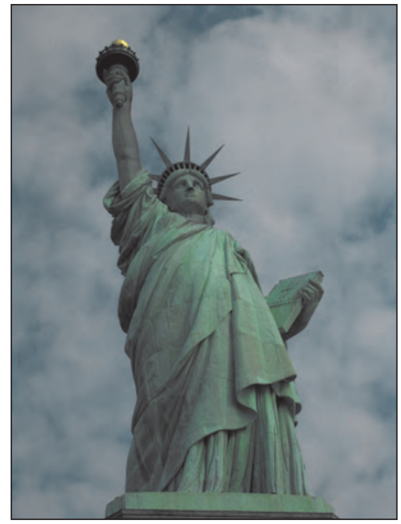
"In 1872, America did something unprecedented proclaiming Yellowstone the world's first national park setting aside more than one million acres of wilderness as a 'public park', not for the privileged, but for the benefit and enjoyment of all people.

For more than 100 years American citizens have continued this work of transforming the great landscapes of our country and the important sites from our history into an extraordinary public treasure. Today, because of their vision and action, each of us is a shared owner in nearly 400 national park sites spanning 18 million acres and including high mountain peaks, deep valleys, sacred battlefields, celebrated monuments, picturesque seashores, extraordinary museum collections... and that is just the beginning! We are truly owners of the world's greatest collection of nature, history and culture.

Our parks remind us who we were with when we first saw bison, an eagle or a bear cub in the wild. They share the stories of our past in the places where they happened and introduce us to larger than life figures from Abraham Lincoln to Martin Luther King, Jr., to Sacagawea. They are the places that inspire us, refresh us and connect us so proudly as Americans.

There is so much to discover in our national parks!"

—Kurt Repanshek, *America's National Parks Owners Guide*



The Statue of Liberty National Monument greets United States citizens, new immigrants, and foreign visitors alike, standing as an ambassador of freedom and democracy. Learn more by visiting www.nps.gov/stli. NPS photo by Kevin Daley.

During the Civil War, Antietam National Battlefield was the site of the bloodiest one-day battle in American history. This battle was important in changing the course of the Civil War, ultimately helping the Union forces to win the war and thereby freeing over four million African Americans from slavery. Learn more by visiting www.nps.gov/anti. NPS photo by Keith Snyder.

Bison and elk are some of the wildlife that call Yellowstone National Park home. Learn more by visiting www.nps.gov/yell. NPS photo by D.L. Cole, 1962.

By preserving our heritage, the National Park System of the United States helps us to answer the question "What does it mean to be American?" In the spring of 2010, the system comprises 392 units covering more than 88 million acres in 49 states, the District of Columbia, American Samoa, Guam, Puerto Rico, Saipan, and the Virgin Islands. Although not all the units are as well known as the Grand Canyon and Yellowstone, all are areas of such national significance that they have been included in the National Park System—ancient ruins, battlefields, birthplaces, memorials, recreation areas, seashores, and countless other wonders.

Visitors to Point Reyes National Seashore can experience the powerful force of ocean waves crashing against its rocky headlands and sandy beaches. There are over 1000 plants and animals to be discovered, as well as the stories of several cultures of people that have called the seashore home over thousands of years. Learn more by visiting www.nps.gov/pore. NPS photo by Christie Anastasia.

Who cares for these national treasures? Since President Woodrow Wilson signed the Organic Act of 1916, the National Park Service has served as the federal bureau in the Department of the Interior responsible for protecting the 40 national parks and monuments then in existence and those that have been established since.

Following the direction laid out in the Organic Act, the mission of the National Park Service is as follows: "The National Park Service preserves unimpaired the natural and cultural resources and values of the national park system for the enjoyment, education, and inspiration of this and future generations. The Park Service cooperates with partners to extend the benefits of natural and cultural resource conservation and outdoor recreation throughout this country and the world."

The National Park Service has the responsibility of protecting and helping people understand the meanings, values, and natural and cultural resources (objects, systems, and practices) of the sites within the National Park System. Each part of the system represents a part of the American story, and preservation of individual sites and the entire system will ensure that the legacies and traditions of the United States remain to be discovered and known by us and future generations.

You can learn more about the National Park Service by visiting www.nps.gov/aboutus.

Grand Canyon National Park's geologic wonders provide visitors with awe-inspiring hikes. Many trails descend through one vertical mile of multi-colored rocks to reach the Colorado River, passing through four eras of geologic time and introducing hikers to the resilient plants and animal residents. Learn more by visiting www.nps.gov/grca. NPS photo.

During World War II, the United States government ordered more than 110,000 Japanese American citizens and resident Japanese aliens to leave their homes to be detained in remote military style camps. Manzanar War Relocation Center was one of ten camps where the men, women, and children were interned. Learn more by visiting www.nps.gov/manz. NPS photo by Ansel Adams.

Getting to Know Denali National Park and Preserve

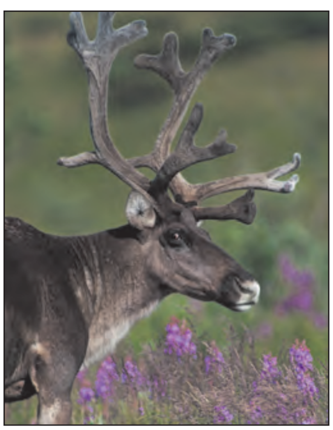
Historically, Athapaskans (Native Alaskans of the region) lived seasonally on the land now known as Denali National Park and Preserve, gathering plants and hunting animals. In the early 1900s, discovery of gold in Kantishna led to an influx of prospectors looking to find their fortunes, and needing food to do so. Commercial hunters saw an opportunity to cash in on the wealth by harvesting large quantities of local wildlife to sell to the miners and other residents of the territory.

A backpacker pauses to take in the view of Mount McKinley, before setting out to explore Denali's wilderness. NPS photo by Kent Miller.

By spending their summers in high rocky areas, Dall sheep are able to avoid most of their predators. NPS photo by Nate Kostegian.

Charles Sheldon, a hunter and naturalist, came to the Denali area in 1906 to study Dall sheep. Seeing the need to protect this area and the Dall sheep from unsustainable levels of commercial hunting, Sheldon lobbied Congress to set the area aside as a national park. Congress agreed with Sheldon, and on February 26, 1917, Mount McKinley National Park was established as a "game refuge" to "set apart as a public park for the benefit and enjoyment of the people . . . for recreation purposes by the public and for the preservation of animals, birds, and fish and for the preservation of the natural curiosities and scenic beauties thereof. . ." The size of the original park totaled about two million acres, and it included Mount McKinley, the highest point in North America.

> "The whole vast north face of Denali was mutilated by avalanches, exposing the underlying black rock. The great mountain rose above me desolate, magnificent, overpowering. The lower ranges were white, while below, nothing could be seen but fog, which took on the appearance of thick clouds. I felt, as never before, completely alone in the presence of this mighty mountain; no words can describe my feelings."
>
> —Charles Sheldon, *The Wilderness of Denali*



Caribou exhibit seasonal migrations within the park, spending summers in the tundra habitat and winters in the boreal forest. NPS photo by Kent Miller.

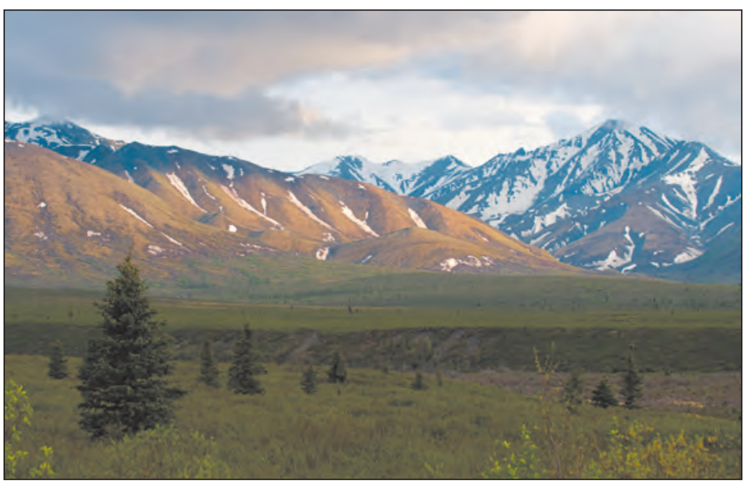
In 1980, through the Alaska National Interest Lands Conservation Act, Congress changed the park's name and tripled its acreage, so that today Denali National Park and Preserve covers more than 6 million acres. The purposes of the expansion were to protect and interpret the entire mountain massif and the additional scenic mountain peaks and formations; to protect habitat for, and populations of fish and wildlife; and to provide continued opportunities for mountain climbing and other wilderness recreation activities. Over 2 million acres are designated a wilderness area.

What is Denali wilderness? It is a place where you can look in all directions and see no signs of humans, like roads or buildings. It is where there is enough room for a caribou herd to roam freely and for wolves to hunt, without human interference. The wilderness of Denali is an intact ecosystem, a natural, wild home to over 1350 species of plants and over 230 species of animals that are interdependent upon one another. It also includes trace fossils, old volcanoes, newly forming mountains, and water in the form of glaciers, rivers, and lakes.

Grizzly bears spend the summer eating in order to put on the layer of fat needed to survive hibernation during Denali's long winters. NPS photo by Nate Kostegian.

Today, more than 350,000 people visit Denali each year to experience the interconnected subartic worlds of taiga forest, tundra, and ice. To learn more about visiting the park, visit http://www.nps.gov/dena.

> "The history of Denali National Park is the history of human effort to set aside a wild place and preserve its wildlife, wilderness, and history so that present and future generations can touch this land and find their heritage whole. Denali's wilderness and its history are inextricably woven together, and through them both runs a team of sled dogs."
>
> —Karen Fortier, *Sled Dogs of Denali National Park*



Once pollinated, low bush cranberry blossoms like these will grow into berries fed on by many animals in Denali. NPS photo by Robbie Hannawacker.

As the elevation increases in Denali spruce trees of the boreal forest become fewer and fewer, yielding to the small plants of the treeless tundra. NPS photo by Kent Miller.

> "Lofty Mount McKinley is so remote and grand it hardly needs protection. It rises higher from its base than any other mountain in the world, about 18,000 feet, and is the highest mountain on the North American continent. Even without this dominating feature, McKinley Park would be outstanding because of its alpine scenery, its arctic vegetation, and its wildlife. I have walked over the green, flowering slopes in the rain, when the fog hid the landscape beyond a few hundred yards, and felt that the white mountain avens, the purple rhododendrons, and the delicate white bells of heather at my feet were alone worthy of our efforts."
>
> —Adolph Murie, *A Naturalist in Alaska*

Evaluation Form

Please help us develop and improve our programs by taking a few minutes to complete this form. All teachers returning evaluations will be entered into an annual drawing for a $100 gift certificate for all Murie Science and Learning Center evaluations.

This evaluation form is preaddressed, but needs to be folded in thirds and provided with postage. If you prefer to fill the form out online, please visit: http://murieslc.org/static/2052/denali-rocks-for-teachers.

Name:
School Name:
School Address: **City:** **State:** **Zip Code:**
School Phone: **School Fax:**
Email: **Class Size:** **Grade:**

Lesson Specific Feedback

Please circle the number that represents how you feel about the statements below.

The lesson was effective. Strongly Disagree → Strongly Agree

Lesson 1	Did not use this lesson	1	2	3	4	5	6	7
Lesson 2	Did not use this lesson	1	2	3	4	5	6	7
Lesson 3	Did not use this lesson	1	2	3	4	5	6	7
Lesson 4	Did not use this lesson	1	2	3	4	5	6	7
Lesson 5	Did not use this lesson	1	2	3	4	5	6	7
Lesson 6	Did not use this lesson	1	2	3	4	5	6	7
Lesson 7	Did not use this lesson	1	2	3	4	5	6	7
Lesson 8	Did not use this lesson	1	2	3	4	5	6	7

The lesson was grade appropriate. Strongly Disagree → Strongly Agree

Lesson 1	Did not use this lesson	1	2	3	4	5	6	7
Lesson 2	Did not use this lesson	1	2	3	4	5	6	7
Lesson 3	Did not use this lesson	1	2	3	4	5	6	7
Lesson 4	Did not use this lesson	1	2	3	4	5	6	7
Lesson 5	Did not use this lesson	1	2	3	4	5	6	7
Lesson 6	Did not use this lesson	1	2	3	4	5	6	7
Lesson 7	Did not use this lesson	1	2	3	4	5	6	7
Lesson 8	Did not use this lesson	1	2	3	4	5	6	7

The lesson was relevant to your students and curriculum. Strongly Disagree → Strongly Agree

Lesson 1	Did not use this lesson	1	2	3	4	5	6	7
Lesson 2	Did not use this lesson	1	2	3	4	5	6	7
Lesson 3	Did not use this lesson	1	2	3	4	5	6	7
Lesson 4	Did not use this lesson	1	2	3	4	5	6	7
Lesson 5	Did not use this lesson	1	2	3	4	5	6	7
Lesson 6	Did not use this lesson	1	2	3	4	5	6	7
Lesson 7	Did not use this lesson	1	2	3	4	5	6	7
Lesson 8	Did not use this lesson	1	2	3	4	5	6	7

How do these lessons fit into Alaska/National Standards and your personal education program?

General Feedback

Based on your observations of your students' learning experiences during the lessons, please circle the number that represents how you feel about the statements below.

The students discovered the geologic forces that have created and continue to create the landscape of Denali.	1	2	3	4	5	6	7
The students discovered the destructive geologic forces that shape the landscape of Denali.	1	2	3	4	5	6	7
The students understood the geologic forces that have created and continue to create the landscape of Denali.	1	2	3	4	5	6	7
The students understood the destructive geologic forces that shape the landscape of Denali.	1	2	3	4	5	6	7

Overall, how would you respond if a colleague asked about this program?
Please circle your response.

Not recommend	Recommend with some qualifications	Recommend	Highly recommend

Suggestions for improvement:

Optional Questions

Please rate your interest in the following ways that *Denali Rocks!* could be continued in your classroom:

Short ranger talk using a Polycom:	Not interested	Somewhat interested	Very interested	Not applicable
Short ranger talk using Skype:	Not interested	Somewhat interested	Very interested	Not applicable
Viewing podcasts about geology:	Not interested	Somewhat interested	Very interested	Not applicable
Field trip to the park:	Not interested	Somewhat interested	Very interested	Not applicable

National Park Service
Denali National Park and Preserve
Murie Science and Learning Center
Attn: MSLC Education Coordinator
P.O. Box 9
Denali Park, AK 99755

Lessons

Lesson 1
Fire and Ice: Geology of Denali National Park and Preserve

Mount McKinley, standing at 20,320 feet, towers above its neighboring mountain peaks. NPS photo by Kent Miller.

Overview:

Students are introduced to geology and to Denali National Park and Preserve through a reading, a brainstorm of geologic features, and a brochure and movie about the park.

Objectives:

Students will:
- Define geology and list geologic landforms and forces.
- Describe landforms and other features of Denali National Park and Preserve.

Duration:

60 minutes

Vocabulary:

Denali National Park and Preserve, geology, landforms

Materials:

- Computers with internet access
- List of web addresses for Denali National Park and Preserve pages
- Park Film "Heartbeats of Denali" and equipment needed to show the film

  Note: A 17-minute version of the film can be accessed via the internet at http://www.nps.gov/dena/photosmultimedia/movies.htm. A 28-minute long DVD version of the movie with additional narration may be purchased from Alaska Geographic at http://www.alaskageographic.org/store.

Background:

Refer to the "Teacher Background: The Geology of Denali National Park and Preserve" section of this lesson, and the "Getting to Know Denali National Park and Preserve" section in the Teacher Introduction.

Preparation:

1. Read the background information.
2. Prepare to show "Heartbeats of Denali."

Procedure:

1. Read and discuss with the class the reading on the student worksheet.
2. Have students brainstorm a list of geologic features and forces with which they are already familiar and write these on the board or a large sheet of paper e.g. landforms like mountains, rivers, valleys, mesas, deserts, glaciers; events and forces like volcanic eruptions, earthquakes, plate tectonics, erosion; kinds of rocks, etc.
3. Have the students go online to look at the Denali National Park and Preserve website (http://www.nps.gov/dena). Ask individual or pairs of students to find and read information about the land, history, geology, and wildlife together and then discuss this information as a class. Ask the students to read the Denali Education Packet (download at http://www.nps.gov/dena/planyourvisit/justforkids.htm). Take time to look at and discuss the map as well (found on the Denali park brochure which can be downloaded at http://www.nps.gov/dena/parknews/newspaper.htm).
4. View the park film "Heartbeats of Denali." Tell students to look for landforms as they watch. Although it does not focus on the geology of the park, the movie will orient the students to the park and, hopefully, inspire them to want to learn more about its landscape.
5. After watching, ask students to tell about the kinds of landforms and other interesting features of Denali National Park and Preserve they saw in the movie. Ask them, "Why do you think this area was made into a national park? What makes it special?"

Assessment:

Being an introductory lesson, keep the assessment informal. Encourage students to participate in the activities, and give positive reinforcement to those who do.

Extensions:

1. Have students look for pictures of geologic features and landforms in magazines. *National Geographic* or *Alaska* magazines would be excellent sources. Have them cut out pictures and make collages. Each student could make their own collage of mixed landforms or students could pool pictures and make several theme-based collages of one landform (a collage of mountains, one of glaciers, river valleys, etc.).
2. Have students choose a geologic feature or landform to research. Have them make a poster with a picture and short description of their landform.

Teacher Background: The Geology of Denali National Park and Preserve

The Alaska Range is a 600-mile long arc of mountains that stretches from the Alaska-Canada border all the way to the Alaska Peninsula. The range is highest at its midsection, a vast region of towering peaks and massive glaciers that lies within Denali National Park and Preserve. Denali is a region of great geologic activity and complexity, and scientists are only beginning to piece together its puzzling past. It has rock formations that have been carried there from thousands of miles away, fossils of ancient creatures that have been plowed up from ocean depths, new rocks born of the Earth's internal fire, and some of the oldest rocks in Alaska. The range's height and distance from the equator combine to make it a place of eternal winter, and deep snows compress to form glaciers (creeping rivers of ice which continuously grind away at the still-rising peaks). It would be considered one of the world's great geologic showcases, even if it didn't contain the highest peak in North America.

Denali (Mount McKinley)

Denali (Mount McKinley) is one of the most striking features on the entire planet. At 20,320 feet, it is the crowning peak of the Alaska Range and the highest mountain on the continent. It towers three and one-half vertical miles above its base, making it a mile taller from base to summit than Mt. Everest. (Denali starts at about 2000 feet and rises over three and one-half miles to its 20,320 foot summit. Everest begins on a 14,000-foot high plain, then summits at 29,028 feet.) Its icy north face—the Wickersham Wall—is one of the world's highest continuous mountain faces, rising 14,000 feet from the Peters Glacier to the North Peak. Permanent snow and ice cover over 75 percent of the mountain, and enormous glaciers, up to 45 miles long and 3,700 feet thick, spider out from its base in every direction. It is home to some of the world's coldest and most violent weather, where winds of over 150 miles per hour and temperatures of -93˚F. have been recorded. At times it is the most dangerous and inhospitable place on Earth, but at other times it is a place of astounding beauty and peace.

Land of Eternal Winter

Many consider Denali to be the world's coldest mountain because of its combination of high elevation and its subarctic location at 63 degrees north latitude. After Denali, the next furthest 20,000-foot mountain from the equator is at 43 degrees north, the same latitude as Detroit, Chicago, and Boston. Mount Everest (29,028 feet) is the world's highest point above sea level, but it is at the same latitude (28 degrees north) as Florida's Walt Disney World. Denali sits 2,400 miles further north. This makes an enormous difference in temperature.

> *"On the South Col of Mount Everest (26,200 feet) in late October, the lowest temperature we recorded in 1981 was 17 below zero (˚F). On Denali, this would be a rather warm night at only 14,300 feet in May and June. Temperatures between the high camp (17,200 feet) and the summit, even in the middle of the summer, are routinely 20˚ to 40˚ below (˚F) and even lower at night. This combination of extreme weather and temperatures pummels the unprepared."*
>
> —Peter H. Hackett, M.D.

Denali is so massive that it generates its own weather systems, much the way a huge boulder submerged in a river makes whitewater rapids. All mountains deflect air masses and influence local conditions, but Denali rises so abruptly and so high that this effect is more dramatic here than perhaps anywhere else on Earth. Storms barrel in from the Gulf of Alaska and the Bering Sea and collide with Denali's towering mass. Weather can quickly change from sunny and clear to blizzard conditions with fierce winds, intense cold, and heavy snowfall. Climbers must understand and pay close attention to warning signs of changing weather, and use their observations to plan when to climb, when to retreat, and when to dig in.

The Birth of a Mountain Range

The spectacular mountains we see today are a result of millions of years of rock formation, uplift, and erosion. Before we discuss the processes that created today's Alaska Range, let's review some basics about rocks and their origins.

Three major types of rocks make up the earth.

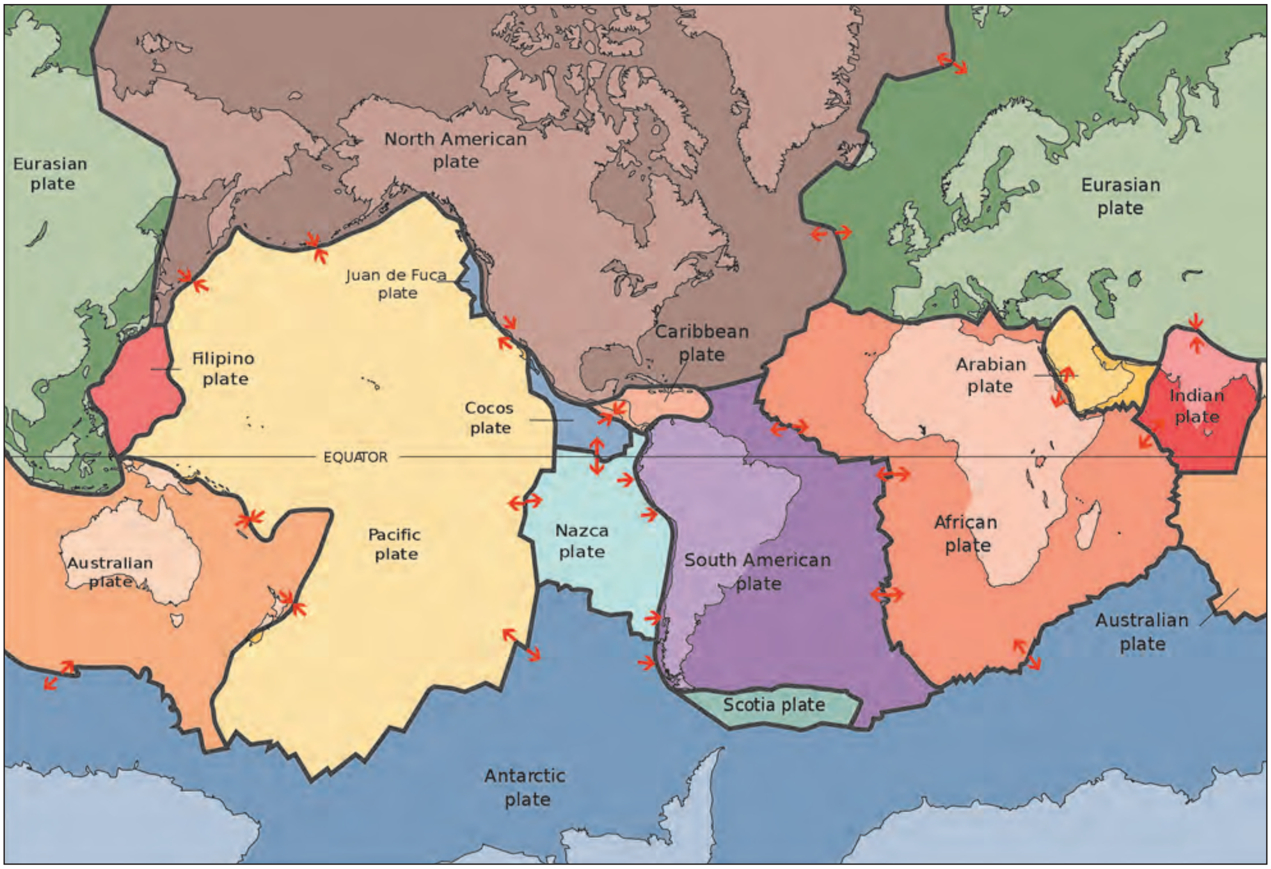
Igneous rocks are formed when molten rock (magma or lava) solidifies. Igneous rocks can be plutonic or volcanic. Plutonic rocks, such as granite, form when magma cools slowly in the depths of the earth. Volcanic rocks, such as basalt, rhyolite, and andesite form when lava cools rapidly on the surface.

Sedimentary rocks are derived, as the name implies, from sediments (particles composed of mineral and organic material) that have been deposited by water or wind. Most commonly, sediments are carried by rivers and deposited under lakes and seas, which accounts for the fossilized shells often found in sedimentary rocks. These sediments are buried and compressed into rock strata. Typical sedimentary rocks include sandstone, limestone, shale, and chert.

Metamorphic rocks are rocks that were once sedimentary or igneous, but have changed due to intense heat and/or pressure deep within the earth without completely melting. After rocks are squeezed and baked beneath the earth's surface, the minerals recrystallize in an altered form, often characterized by deformed or folded layers that may be interlaced with bands of new minerals such as quartz. Typical metamorphic rocks around Denali include schist, slate, quartzite, and marble.

How Did Ocean Rocks Get Way Up There?

The Alaska Range consists mostly of oceanic sedimentary rock, but has a great variety of other rock types, including many forms of each of these three main types. The mountains rise because the rock is uplifted by the collision of two massive pieces of the Earth's crust. One such tectonic plate, known as the Pacific Plate, forms the floor of the Pacific Ocean. It is slowly moving northward at about the rate that your fingernails grow. It subducts, or dives underneath, the Alaska mainland that is part of the North American



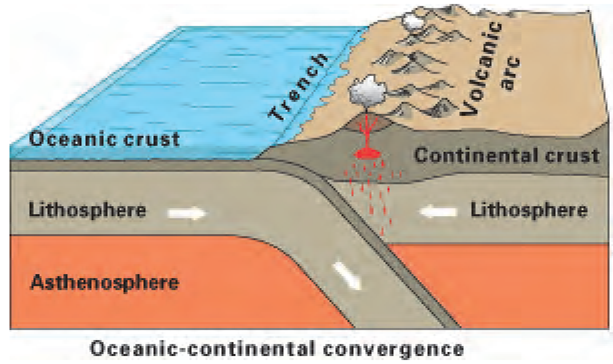
Oceanic plates are heavier causing them to subduct when they meet lighter continental plates. Image courtesy of the U.S. Geological Survey.

Plate. The build-up and sudden release of tension as these plates slip past one another causes earthquakes. As it moves northward, the Pacific Plate carries chunks of land and pieces of other plates, some carried from thousands of miles away.

To illustrate this, picture the Pacific Plate as the conveyer belt at a supermarket checkout. The conveyer belt carries groceries to the end, where a metal strip gathers them together. Likewise, the Pacific Plate carries chunks of land to the south coast of Alaska, where they are jammed together and added on to the Alaska mainland. Alaska is actually composed of about 50 of these “groceries” that have been rafted here from elsewhere and scraped off on the edge of the North American Plate. Thus, there are many types of rock in the Alaska Range, including ocean sediments and rock formations carried here from south of the equator.

The force of the Pacific Plate pushing northward causes the uplifting of mountain ranges, as well as the formation of still more types of rock. The coastal ranges are plowed up, and more uplift continues far inland, causing the Alaska Range to rise, much the way the hood of a car buckles under the force of a collision.

A Land Born of Fire



Oceanic plates are heavier causing them to subduct when they meet lighter continental plates. Image courtesy of the U.S. Geological Survey.

As the Pacific Plate subducts down into the hot, molten mantle of the Earth, moisture and certain minerals are cooked off and "sweat" up towards the surface. Some of this material erupts explosively at the surface to form volcanoes. As the Alaska Range rose the molten rock erupted and much of it also extruded, oozing up to the surface through cracks in the uplifting rock. Here it hardened quickly, forming basalt, rhyolite and andesite, the colorful volcanic rocks that can be seen in Denali National Park and Preserve around Polychrome Pass. These rocks are heavy and soft, and erode quickly, limiting the size of those mountains to around 5,000-7,000 feet.

So How Did the Big Mountain Get So Big?

At the same time that magma was extruding to form volcanic rocks, several kilometers beneath the earth's surface, more magma intruded between existing rock, forming a huge pool of magma. There it cooled very slowly, allowing the minerals to crystallize into hard igneous rock. Rock that forms from intrusive magma that cools beneath the earth's surface is called a pluton. The pluton that we now know as Denali (or "the High One") formed from a magma that intruded 56 million years ago, cooled into granite, and has been uplifted in the last 6 million years along with the rest of the range. Part of the reason that Denali is taller than its neighboring mountains may be due to its granite nature, making it a hard rock that is not eroded as easily as the sedimentary rock that makes up many of the other mountains in the Alaska Range. The main reason it is so tall, however, is because of the geometry of a very large active fault located on the north side of the mountain. This fault, appropriately referred to as the Denali Fault, is oriented northeast-southwest. Rocks south of the fault move to the west relative to those to the north at a rate of about 1 centimeter per year. There is a large bend in the fault directly north of Denali that causes rocks to bunch up inside the bend in the fault, and this causes Denali to be so tall. Denali sits on a large 'thrust fault,' a type of fault where rocks on one are pushed on top of those on the other. The forces that caused the uplift of Denali continue today, and scientists have determined that Denali rises at a rate of one half of a millimeter per year. That may not seem like much, but at that rate it will rise one kilometer in the next two million years - a brief period in geologic time.

The Power to Move Mountains

Even as the uplift of the Alaska Range continues, weathering and erosion are constantly tearing it down. Weather and water, in the form of wind, rain, frost, streams, rivers and glaciers, have the power to turn mountains into molehills. First the weathering process disintegrates rocks and minerals. Then erosion via moving water, wind, glaciers, or gravity physically removes the weathered rock, often transporting it long distances. Following is a look at the processes of weathering and erosion in more detail.

Just as trees fall, iron tools rust and ancient cities crumble, rocks also disintegrate over time due to conditions of the Earth's physical and chemical environment. Weathering occurs due to two different processes. Mechanical weathering is the physical disintegration of rocks into smaller and smaller pieces without altering their composition and mineral content. The grinding of glaciers, tumbling of rocks in rivers, abrasion by windblown particles, frost action and expansion of growing roots are all agents of mechanical weathering. Chemical weathering occurs when water and air react with rocks to change the chemical composition of the minerals within the rock. Evidence of this process can be seen by visiting an old cemetery and noting the deterioration of older headstones, with limestone and marble headstones eroding the fastest. Oxygen, water, and carbon dioxide all react with different minerals, as do acids and bases that are dissolved in water. Normally, rain is slightly acidic, but industrial pollution has increased the acidity of rain up to 1000 times that of natural levels. It is widely known that acid rain kills trees and fish; stunts crops; corrodes paint, steel bridges, textiles, and other materials; and damages the health of humans, livestock, and wildlife. It also increases the chemical weathering of rock, especially marble and limestone, and has caused widespread weathering of ancient carvings and sculptures.

A Land Sculpted by Ice

In the high, frozen regions of the range, little or no melting occurs. The snow accumulates deeper and deeper, year after year, until it is so thick that it compresses down into ice under its own weight. Gravity causes this ice to flow down out of the range, but it is continuously fed up high by more snow and ice. What results is a glacier, a river of ice flowing from the high, cold mountains down to the valleys where it will melt. Glaciers flow at rates ranging from several feet per year to several feet per day, grinding away at their beds with tremendous force. Much of the rock is ground to a fine powder called silt, which is released into glacier-fed rivers. It is washed out to the ocean, where it settles onto the ocean floor. Over time it becomes sedimentary rock, which eventually gets subducted and melted or uplifted to form new mountains. And the cycle continues…

Mount McKinley from base camp at 7000 feet on the southeast fork of the Kahiltna Glacier. NPS photo.

The glaciers we see today in the park are mere shadows of their former selves, but all around us we can see evidence of when they dominated the landscape. During past ice ages, most recently about 10,000 years ago, glaciers covered the Alaska Range and much of Alaska in ice. All of Southcentral Alaska has been buried in ice numerous times, and the shape of the land in this area comes from the carving forces of glaciers and the debris they leave behind. The rocks embedded in glacial ice grind away at bedrock, forming the jagged ridges and deep U-shaped valleys found in the range. Rocks that melt out of the end or sides of a glacier form ridges or hills called moraines. Large blocks of ice can be stranded in the moraines left behind by retreating glaciers. When they finally melt, a water-filled depression known as a kettle lake develops. The carving action of ice forms many of the elongated lakes in the upper Susitna Valley to the south of Denali, and examination of a map reveals that they are all oriented in the direction that the ice was moving.

Life in the Valley Below

Wildlife, forests, farms and gardens all depend on healthy soil. It provides minerals, nutrients, water and a substrate upon which plants can grow. Soil consists mainly of weathered rock, but also contains organic matter from decomposed organisms, which gives soil the ability to conserve and regulate moisture and nutrients. Soil is home to large numbers of invertebrates such as insects, earthworms, roundworms, millipedes and centipedes, and microorganisms such as bacteria, fungi, algae and protozoa. All are vital to the fertility of the soil. These organisms decompose plant material, producing nutrients, which are used by living plants. They also produce carbon dioxide, which combines with soil moisture to break down minerals into forms that are usable by plants. The plants, in turn, hold the soil in place, preventing erosion.

In places in Alaska where agriculture takes place, the soil is relatively young, about 10,000 years old or less. Since a full soil profile develops in about 2,000 years here, soils in the valley's south of Denali have still had plenty of time to develop fertility. These fertile soils combine with long summer days and the occasional fertilization by nutrient-rich volcanic ash. One can easily understand why the lands near Denali support such lush vegetation and abundant wildlife.

In Conclusion

Most people in Alaska live in cities and towns where they can occasionally stop to see Denali looming on the horizon, marvel at the storms that ravage its slopes, and fish the rivers that carry away the Alaska Range piece-by-piece. We also feel the jolt of earthquakes and are showered by the ash of volcanoes, testaments to the powerful forces at work within the Earth. Despite the persistent erosion that tears it down, the range is still young and the mountains continue to rise ever higher. Denali will always be a magnet for climbers, explorers, artists, scientists, and those who want no more than to be awestruck by the sight of one of the world's biggest, coldest and most beautiful mountains.

Name: ______________________________

Date: ______________________________

Class: ______________________________

Student Worksheet

Lesson 1
Fire and Ice: Geology of Denali National Park and Preserve

Mount McKinley, standing at 20,320 feet, towers above its neighboring mountain peaks. NPS photo by Kent Miller.

The Alaska Range is a 600-mile long arc of mountains that stretches from the Alaska Peninsula in the west across the state to the Canadian border in the east. The range is highest at its midsection, a vast area of towering peaks and massive glaciers that lies within **Denali National Park and Preserve**.

This is a region of great geologic activity and complexity, and scientists are only beginning to piece together its puzzling past. It has rock formations that have been carried there from thousands of miles away, fossils of ancient creatures that have been plowed up from ocean depths, new rocks made deep within the earth's core, and some of the oldest rocks in Alaska.

The earth's mountain-building forces have created spectacular peaks in the Alaska Range. At 20,320 feet, Denali (Mount McKinley) is the crowning peak and the highest mountain on the North American continent. The height of the range and its distance from the equator combine to make it a place of eternal winter. Deep snows compress to form glaciers, creeping rivers of ice which continually grind away at the still-rising peaks.

Mt McKinley National Park, established in 1917, was enlarged to become Denali National Park and Preserve in 1980. In addition to the mountain range, the park has large areas of tundra and taiga forests, and it is home to numerous birds and mammals. Denali attracts mountaineers from around the world who hope for the chance to stand atop the highest peak in North America. Many other people visit Denali National Park and Preserve each year, drawn by its scenic beauty and wildlife, and by the chance of catching a glimpse of Denali and other peaks in the Alaska Range.

At the park visitors are taken in by another of its attractions, its complex geology with a myriad of rocks, faults, and folds. Coming from the Greek *geo* (earth), **geology** is the science that deals with the origin, composition, structure, and history of the earth.

Geologists study forces that shape Earth's surface: earthquakes, volcanoes, glaciers, and drifting continents; and they study **landforms**, features of the earth's surface. The landscape of Denali National Park and Preserve provides geologists with a countless variety of features to study and questions to answer. How are mountains born? What are they made of? Why is Denali so big? How do glaciers form? Why are there so many different kinds of rocks in Denali National Park and Preserve?

These are the kinds of questions we will explore in *Denali Rocks!* But to understand the answers it will help to become familiar with some basics of physical geology including the structure of the earth and the geologic processes that change the earth's surface. There are still many unanswered questions about this complex geologic showcase, but what is known is fascinating, and what remains unknown provides the kind of challenge that draws geologists and others to Denali National Park and Preserve.

Vocabulary:

Denali National Park and Preserve, geology, landforms

Lesson 2
Steep Terrain on Flat Maps: Topography of Denali National Park and Preserve

NPS photo.

Overview:

Students will use contour lines to read topographic maps, and look for landforms in Denali National Park and Preserve on a topographic map.

Objectives:

Students will:

- Use contour lines on a topographic map to visualize the three-dimensional features of a landscape.
- Identify some landforms (e.g. ridge, peak, valley and pass) on a topographical map of the Denali Park area.

Duration:

60 minutes

Vocabulary:

topography, topographic map, elevation, contour lines, contour interval

Materials:

Lesson section	Materials needed
Activities 2.2 and 2.3	USGS 1:250000 topographic maps of the Denali National Park and Preserve (5 maps, or the number needed to break students into small groups)
Activity 2.2	Copy of contest sheet for each group
Activity 2.2	Small prize for each member of the winning group

Background:

This lesson assumes that students have the following basic working knowledge of maps.

- It is not possible to put all information about a place on one map, so there can be many different maps of the same place, each showing certain types of information.
- Different maps highlight different natural and manmade features of a particular location depending on the intended use of the map. Examples of types of maps include political, physical, road, weather, population, natural resources, shaded relief, and topographical maps.
- Mapmakers use north, south, east and west to describe direction, and usually orient their maps to show north at the top, indicated by a compass rose. A key or legend tells what symbols on the map represent.
- The relationship between the distance on the map and the corresponding distance on the ground is known as scale. Using scale, it is possible to determine the actual distance on the ground between two points shown on a map. A large-scale map shows a small area of land in great detail; a small-scale map shows a larger land area in less detail.

Preparation:

1. Read through the student worksheet information and decide how much background about maps you will need to incorporate.
2. For Activity 2.2
   - Make copies of the contest sheet (at the back of this lesson).
   - Gather small prizes for winning group members. (This could be pencils, stickers, cookies—whatever you have around and like to use.)
   - Decide if you are going to require that the landforms come from anywhere on the topographic map or if they must come from within the park boundaries.

Procedure:

1. Review basic map concepts with your students as needed (see "Background") and discuss the different types of maps and their use.
2. Tell them that they are going to learn about a specific type of map—the topographic map. Write the word "topographic" on the board and tell them the word is derived from two Greek words: "topo" meaning place and "graphos" meaning drawn or written.
3. Read and discuss with the class the concepts and vocabulary on the student worksheet.
4. Help students work through Activity 2.1.

5. For the contest in Activity 2.2:
   - Have students look at the landforms listed in their worksheets under Activity 2.2, and tell them they will be working in groups to search for particular examples of these landforms on a topographic map of Denali National Park and Preserve.
   - Show students one of the topographic maps. If you have decided their examples must come from within the National Park Boundary, explain this to them now and have them how to find the boundary.
   - Divide students into groups (the number of groups will depend on the number of topographic maps you have).
   - Hand out the contest list of landforms and explain that they will have 7 minutes to look for examples of each on the map. They should write the name of a particular landform next to that item on the list. For example, next to "Glacier" they might write "Kahiltna Glacier." Explain that the group that has the most names wins.
   - Hand out the maps and tell them to begin. After 7 minutes, call time.
   - Have students count their total; they can share names if you think there is time. Ask if any groups found landforms that were not in the original list.
   - Give a small reward to the members of the winning group.
6. Have students answer the questions on their worksheets for Activity 2.3 to get further practice reading contour lines.

Assessment:

Correct the work from Activities 2.1 and 2.3 for completeness and accuracy.

Extensions:

1. Have student groups use Activity 2.3 as a model to write their own questions about contour lines on the Denali National Park and Preserve topographic map then have them exchange questions with another group.
2. Bring in topographic maps of your area (or other areas) for students to explore. One option would be to have them work in groups to create Scavenger Hunt like the one in Activity 2.2 then have groups exchange and do each other's hunts.
3. If you have time, have students create 3-dimensional models of hills from a topographic map. Use the very simple contour map from Activity 2.1 or find an area from another map to use. Project the contours on a wall at whatever scale you want. Trace each contour onto a piece of cardboard or foam board, one layer for each contour interval, and cut them out. Stack the sheets to make the landform. You can find more detailed plans for this activity on the internet.

Name: ____________________

Date: ____________________

Class: ____________________

Student Worksheet

Lesson 2
Steep Terrain on Flat Maps: Topography of Denali National Park and Preserve

NPS photo.

The landscape of Denali National Park and Preserve includes many varied landforms and geologic features. To visualize an area's physical features, or **topography**, such as mountains, valleys and other landforms, geologists and others use a special kind of map. A **topographic map**, or contour map, is a representation of a three-dimensional landscape on a flat piece of paper. These maps show the actual **elevation**, or height above sea level, of the land.

The Alaska Range is an area of extreme terrain, and elevation changes are often quite dramatic. Knowing how to read topographic maps can help you visualize the shape of the land. On topographic maps, elevation is shown by **contour lines** that join points of equal elevation. If you walked along a contour line, you would stay at the same height above sea level; by crossing contour lines you gain or lose elevation. The closer together the contour lines appear on the map, the steeper the slope; the farther apart the lines, the flatter the terrain. To make it easier to read topographic maps, every fifth contour line is darker and is labeled with the actual elevation above sea level to serve as a reference.

The difference in elevation between adjacent contour lines is called a **contour interval**. Different maps use different intervals depending on the steepness of the terrain and the size of the land area being shown. A contour map of a relatively flat region could use a smaller contour interval, for example, 20-foot intervals. But to show 20,320-foot-high Denali in this detail would make the map far too complicated and difficult to read. The steep landforms in the Alaska Range would be better shown by 200-foot intervals. The size of the area being mapped also determines how large the contour intervals should be. A map showing a small land area in great detail uses smaller contour intervals to show more detail in elevation changes. But on a map showing a larger land area in less detail, larger contour intervals are used.

Patterns of contour lines on a topographic map show the shape of the land. In this lesson, we will explore topographic maps to become familiar with how to read them and to find ridges, valleys, peaks and passes and other landforms in the Alaska Range. In later lessons, knowing how to read contours will facilitate a closer look at the area's landforms, mountains and glaciers.

Besides geologists and other scientists, topographic maps are used in Denali National Park and Preserve by hikers, climbers, and other visitors to figure out where they are and to navigate routes. Perhaps some day you will carry a "topo map" in your backpack to hike Denali's back country or climb one of the peaks in the Alaska Range's—or to explore a wilderness area closer to your home.

Vocabulary:

topography, topographic map, elevation, contour lines, contour interval

Activity 2.1 Three Dimensions on a Two-Dimensional Map

Contour lines show the shape and elevation of land; they can help you visualize the elevation, or height, of the hills. Contour lines on a topographic map add the third dimension—height—to a two-dimensional (flat) map. Each line joins points of equal elevation. You could think of a contour line as an imaginary line on the ground that takes any path necessary to maintain a constant elevation.

Here are a topographic map and a drawing of two hills.

Look at the side view of the hills (bottom of diagram).

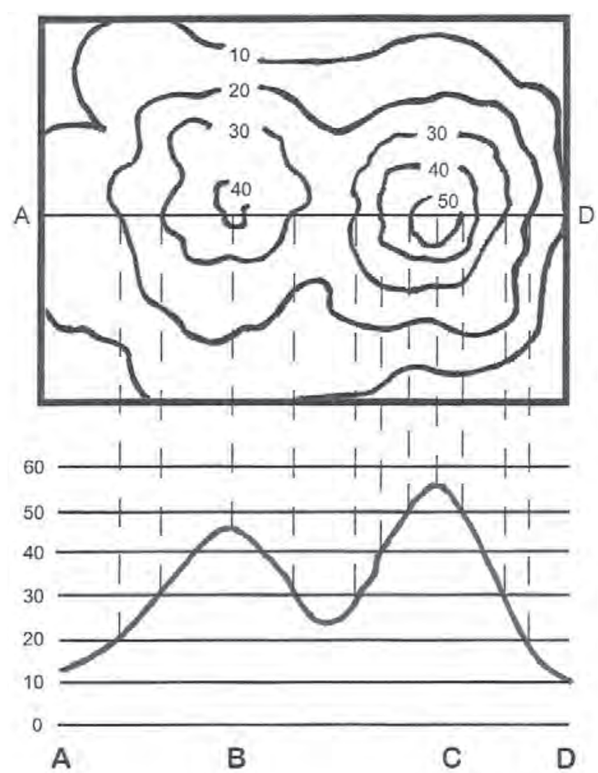
1. Which hill is higher, Hill B or Hill C?

2. Which hill is steeper, Hill B or Hill C?

3. Now look at the topographic map of the hills (top of diagram). With your finger, trace around the 40-foot contour lines on the map; then do the same on around the 20-foot contour line.

4. What is the contour interval on the map (feet of elevation between lines)?

5. How high is Hill B?



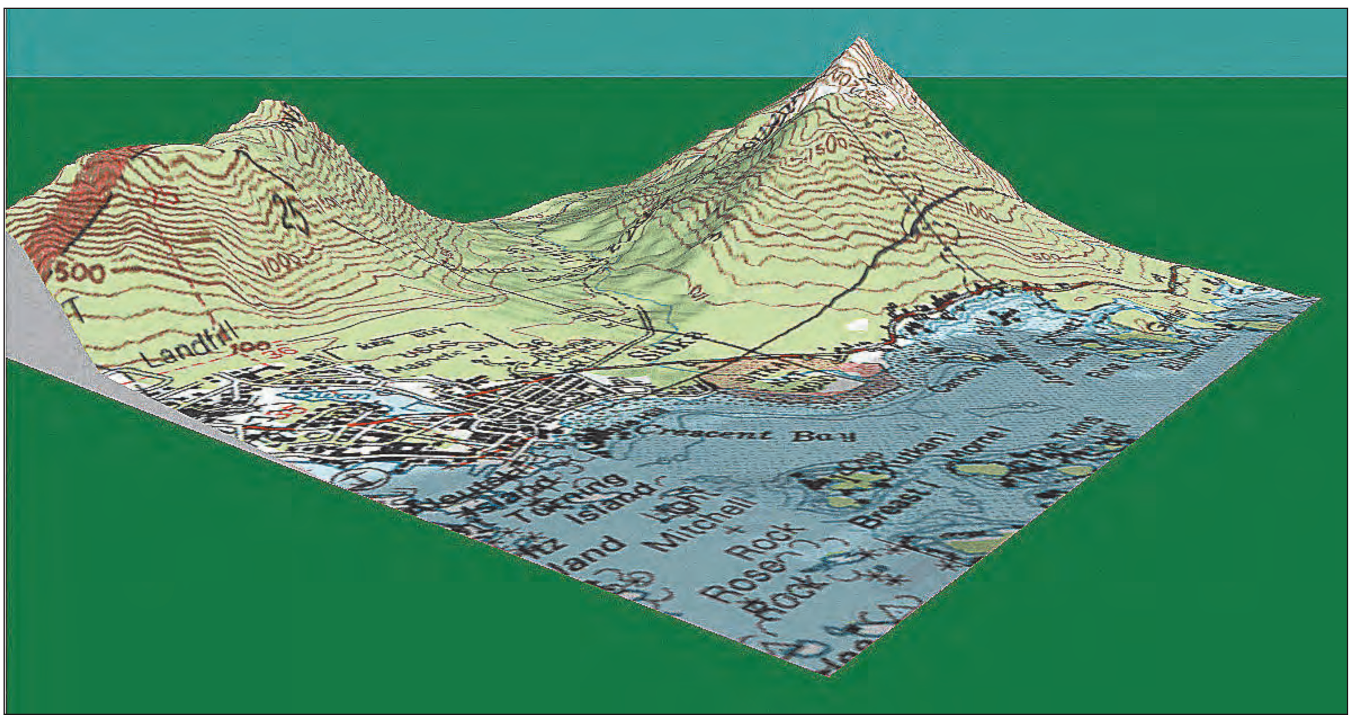
NPS illustration.

6. How high is Hill C?

7. Are the contour lines closer together on Hill B or Hill C?

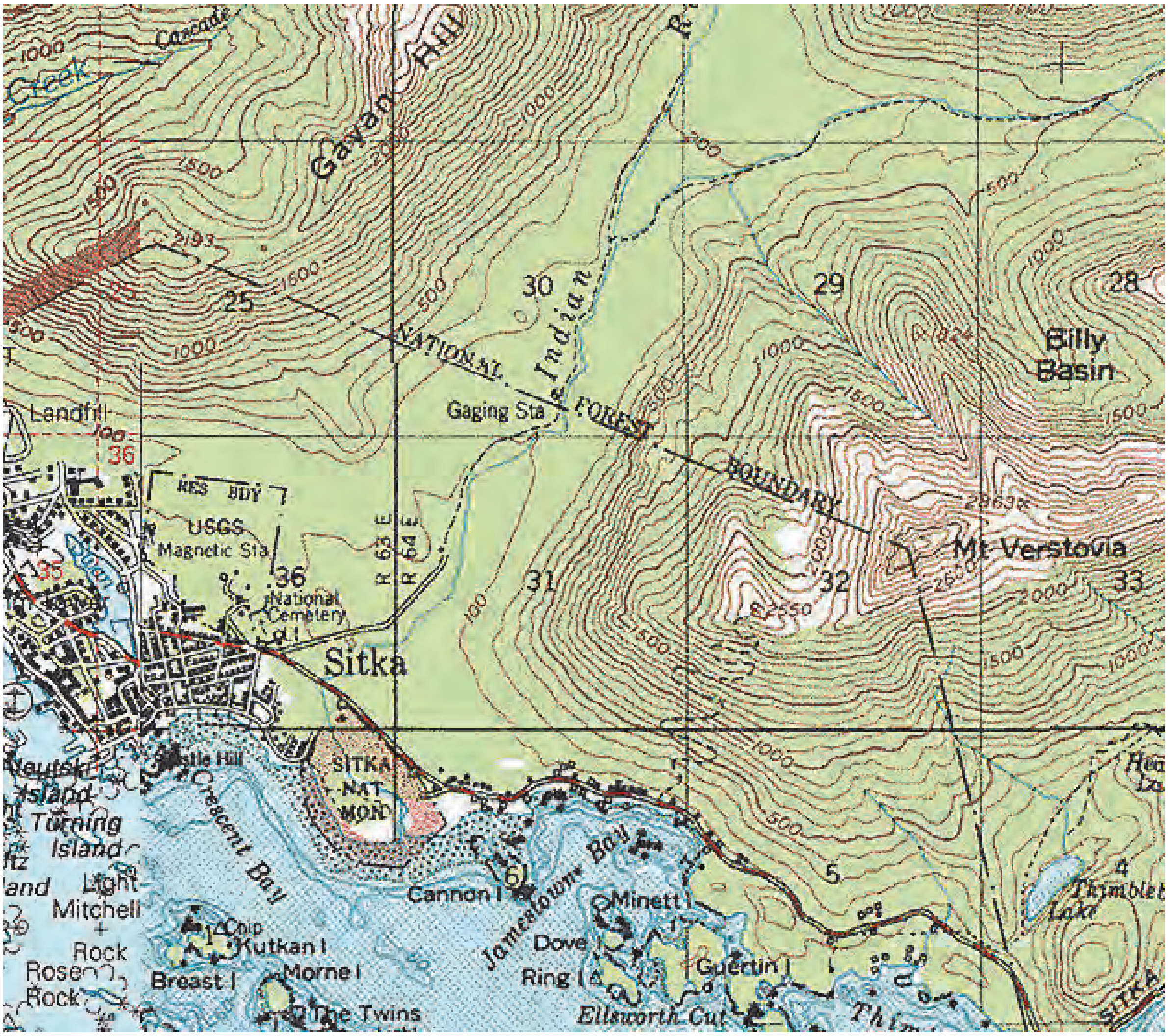
8. As you read earlier, the steeper the slope of the hill that is being mapped, the closer together the contour lines on the map will be. Find the place on the map that shows the steepest slope.
9. Now look at the pass (low spot) between the two hills. This would be a good route to go if you were hiking in these hills. What is the elevation of this pass?

Here are an image and a topographic map of Sitka, Alaska.



1. Look at the illustration. It shows the town of Sitka and some nearby mountains. Circle these features on the picture:
   - A river valley
   - An island
   - A steep mountain capped in snow
   - A trail
   - A road

Look at this topographic map of Sitka and the nearby mountains.



1. Find Sitka National Monument. The contour interval on this map is 100 feet. Since there are no contour lines on the monument land, it must be less than 100 feet in elevation.
2. Find Mount Verstovia. What is the elevation of the contour line at the highest point of the mountain?

3. Find the river then locate where it flows into the ocean. Draw a pencil line down that river and put an X where the river joins the ocean. On a real topographic map, streams are shown in blue and contour lines in brown. (To see the color version of the topographic map, visit the Denali Rocks! web page at http://murieslc.org/static/1065/educator-resources and click on the student page link.)
4. Find the two trails on the map. Circle the trail that would be easier to hike. (Remember that when the contour lines are close together, the ground is very steep making for more difficult hiking.)

Activity 2.2 Landform Scavenger Hunt CONTEST!

With your group, you will look for examples of each of these landform types on the topographic map of Denali National Park and Preserve. ***Your teacher will give your group a handout*** and, for each landform you find, write the name of the particular example you found. The group that finds the most in 7 minutes wins!

Basin	Gorge	Ridge
Buttress	Hills	River
Canyon	Lake	Rocks
Col	Mountain	Spire
Creek	Notch	Spur
Dome	Pass	Valley
Gap	Peak	Wall
Glacier		

Activity 2.3 Looking at Contour Lines

Directions: Use the topographic map of Denali National Park and Preserve to answer these questions.

Inset Map: Find the Park Entrance and Headquarters Area inset at the bottom right-hand corner of the map. Answer the first five questions using the inset map.

1. What is the contour interval of the inset?

2. What is the elevation of the Headquarters?

3. At what elevation would you be if you hiked to the top of Little Creek?

4. What is the highest point on the inset map?

5. What is the name of the highest point on the inset map?
(**Hint:** the name is not on the Inset Map!)

Main Map: Use the main part of the contour map to answer the remaining questions.

1. What is the contour interval of the map?

2. Broad Pass is the lowest point between the north and south sides of the Alaska Range. What is its elevation? (Hint: it is marked by a small triangle southwest of Summit Lake.)

3. Between the east end of the Muldrow Glacier and the West Fork Glacier is Anderson Pass. What is its elevation?

4. Find the summit of Mount McKinley (it's not easy!). How high is it?

5. Compared to Mount McKinley, the flattest parts of the map have very few contour lines. Name two rivers that flow through the flattest parts of Denali National Park and Preserve.

6. Between the Tokositna Glacier and the Ruth Glacier are the Tokosha Mountains. What is the highest point in the Tokoshas?

7. How do contour lines change when they cross a snowfield or glacier?

Name: ______________________________

Date: ______________________________

Class: ______________________________

Answer Key

Lesson 2
Steep Terrain on Flat Maps: Topography of Denali National Park and Preserve

NPS photo.

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Here are a topographic map and a drawing of two hills.

Look at the side view of the hills (bottom of diagram).

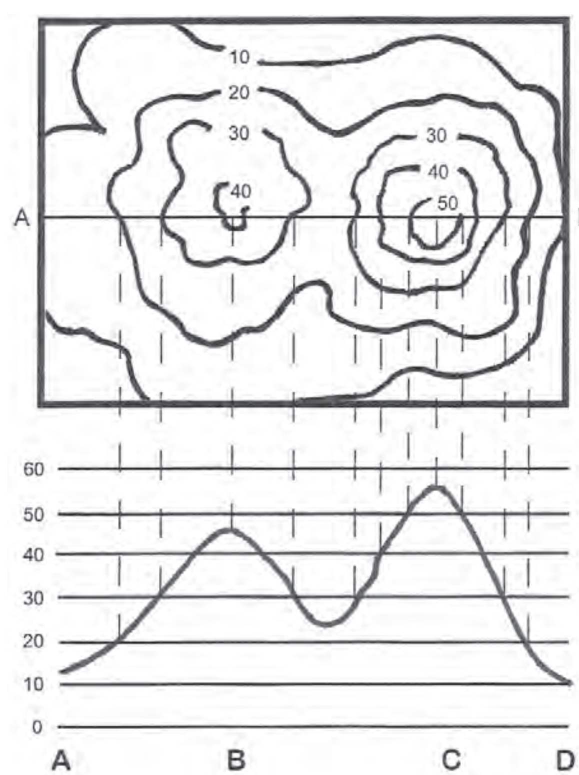
1. Which hill is higher, Hill B or Hill C?
   Hill C is higher.

2. Which hill is steeper, Hill B or Hill C?
   Hill C is steeper.

3. Now look at the topographic map of the hills (top of diagram). With your finger, trace around the 40-foot contour lines on the map; then do the same on around the 20-foot contour line.

4. What is the contour interval on the map (feet of elevation between lines)?
   The contour interval is 10 feet.

5. How high is Hill B?



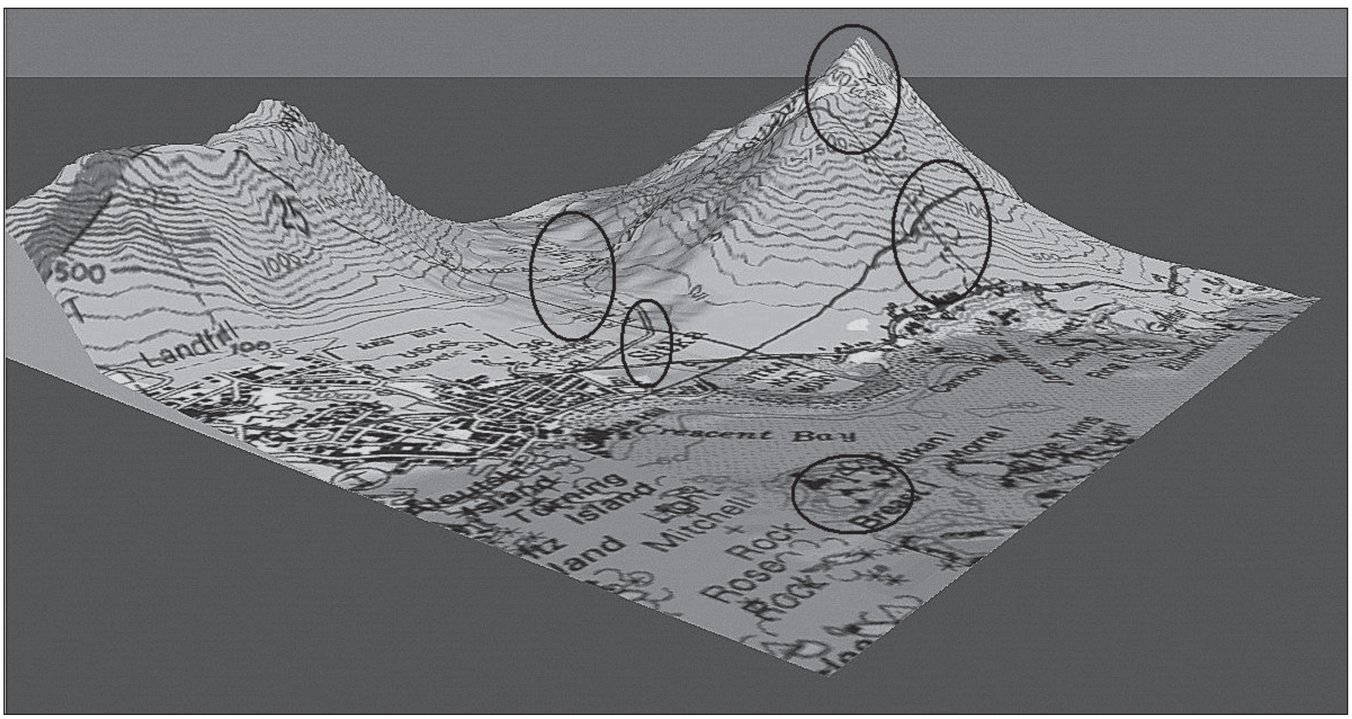
NPS illustration.

6. How high is Hill C?
   Hill C is about 54 feet high.

7. Are the contour lines closer together on Hill B or Hill C?
   The contour lines are closer together on Hill C.

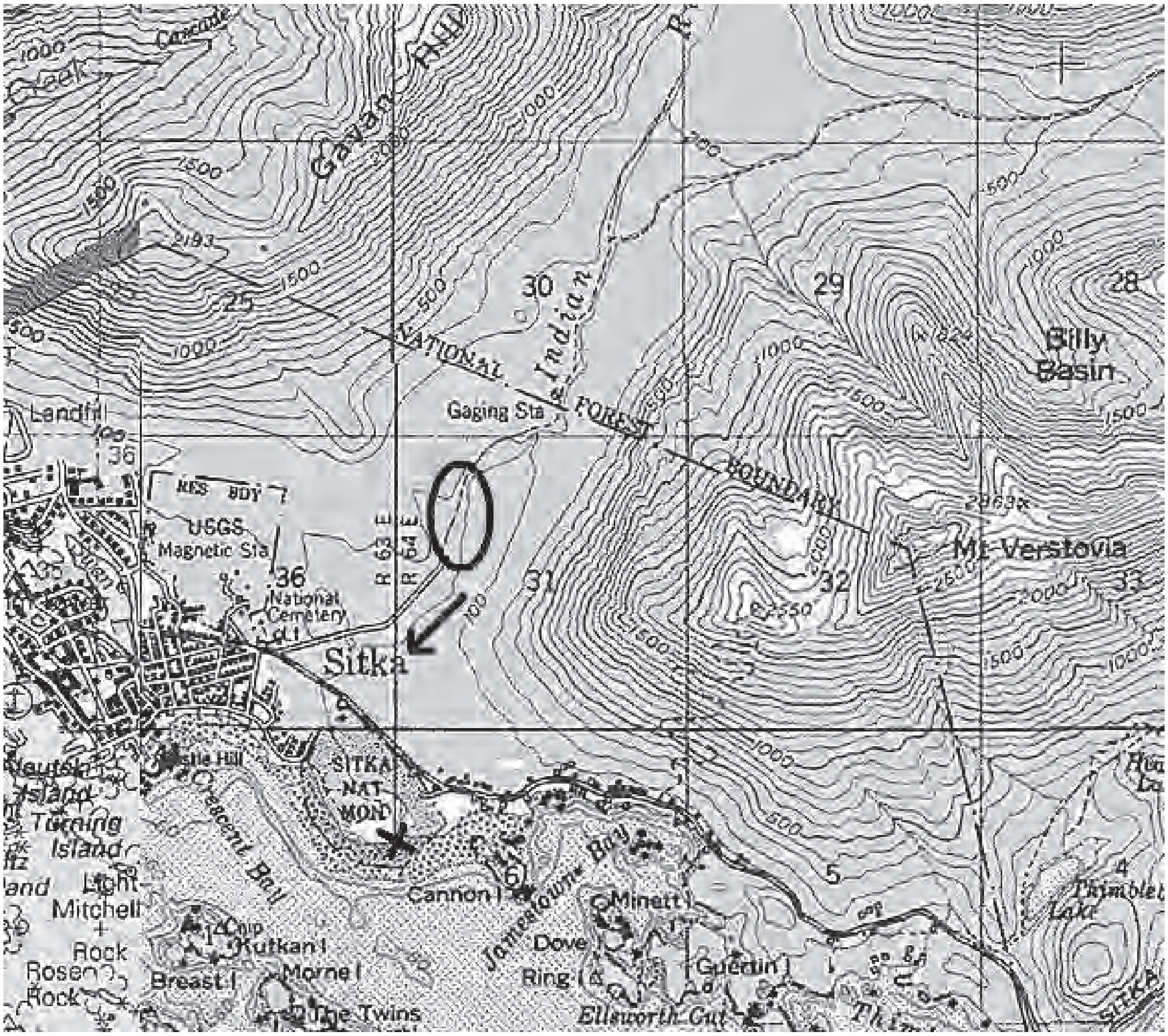
8. As you read earlier, the steeper the slope of the hill that is being mapped, the closer together the contour lines on the map will be. Find the place on the map that shows the steepest slope.
9. Now look at the pass (low spot) between the two hills. This would be a good route to go if you were hiking in these hills. What is the elevation of this pass?
   The pass is 30 feet high.

Here are an image and a topographic map of Sitka, Alaska.



1. Look at the illustration. It shows the town of Sitka and some nearby mountains. Circle these features on the picture:
   - A river valley
   - An island
   - A steep mountain capped in snow
   - A trail
   - A road

Look at this topographic map of Sitka and the nearby mountains.



1. Find Sitka National Monument. The contour interval on this map is 100 feet. Since there are no contour lines on the monument land, it must be less than 100 feet in elevation.
2. Find Mount Verstovia. What is the elevation of the contour line at the highest point of the mountain?

   3200 feet
3. Find the river then locate where it flows into the ocean. Draw a pencil line down that river and put an X where the river joins the ocean. On a real topographic map, streams are shown in blue and contour lines in brown. (To see the color version of the topographic map, visit the Denali Rocks! web page at http://murieslc.org/static/1065/educator-resources and click on the student page link.)
4. Find the two trails on the map. Circle the trail that would be easier to hike. (Remember that when the contour lines are close together, the ground is very steep making for more difficult hiking.)

   The trail along Indian River would be easier to hike than the trail leading up to Mount Verstovia.

Activity 2.2 Landform Scavenger Hunt CONTEST!

With your group, you will look for examples of each of these landform types on the topographic map of Denali National Park and Preserve. ***Your teacher will give your group a handout*** and, for each landform you find, write the name of the particular example you found. The group that finds the most in 7 minutes wins!

Answers will vary because for most of these, there are several examples on the map.

Basin	Gorge	Ridge
Buttress	Hills	River
Canyon	Lake	Rocks
Col	Mountain	Spire
Creek	Notch	Spur
Dome	Pass	Valley
Gap	Peak	Wall
Glacier		

Activity 2.3 Looking at Contour Lines

Directions: Use the topographic map of Denali National Park and Preserve to answer these questions.

Inset Map: Find the Park Entrance and Headquarters Area inset at the bottom right-hand corner of the map. Answer the first five questions using the inset map.

1. What is the contour interval of the inset?
   100 feet

2. What is the elevation of the Headquarters?
   Approximately 2000 feet

3. At what elevation would you be if you hiked to the top of Little Creek?
   Approximately 3,400 feet

4. What is the highest point on the inset map?
   Approximately 5,800 feet

5. What is the name of the highest point on the inset map?
   (**Hint:** the name is not on the Inset Map!)
   Mount Healy

Main Map: Use the main part of the contour map to answer the remaining questions.

1. What is the contour interval of the map?
   200 feet

2. Broad Pass is the lowest point between the north and south sides of the Alaska Range. What is its elevation? (Hint: it is marked by a small triangle southwest of Summit Lake.)
   2,345 feet

3. Between the east end of the Muldrow Glacier and the West Fork Glacier is Anderson Pass. What is its elevation?
   Approximately 5,400 feet

4. Find the summit of Mount McKinley (it's not easy!). How high is it?
   20,320 feet

5. Compared to Mount McKinley, the flattest parts of the map have very few contour lines. Name two rivers that flow through the flattest parts of Denali National Park and Preserve.
   The Foraker River, McKinley River, and Herron River all flow through the flatter northwest area of the park.

6. Between the Tokositna Glacier and the Ruth Glacier are the Tokosha Mountains. What is the highest point in the Tokoshas?
   6,148 feet

7. How do contour lines change when they cross a snowfield or glacier?
   They change color from brown to light blue.

Group Members' Names

____

____

____

Lesson 2

LANDFORMS HUNT CONTEST!

Basin ______________________________

Buttress ______________________________

Canyon ______________________________

Col ______________________________

Creek ______________________________

Dome ______________________________

Gap ______________________________

Glacier ______________________________

Gorge ______________________________

Hills ______________________________

Lake ______________________________

Mountain ______________________________

Notch ______________________________

Pass ______________________________

Peak ______________________________

Ridge ______________________________

River ______________________________

Rocks ______________________________

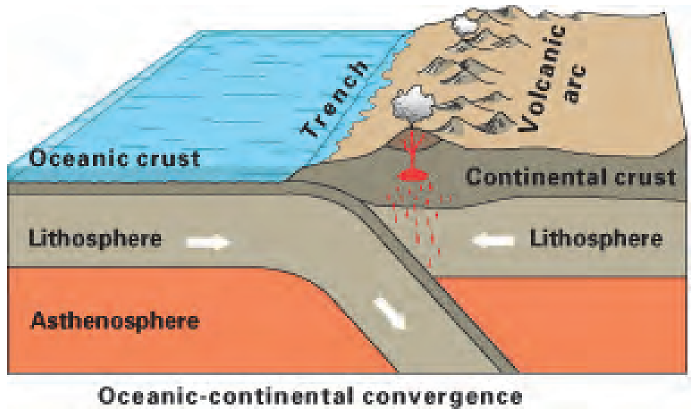
Spire ______________________________

Spur ______________________________

Wall ______________________________

If you find any landforms not on this list, write them here:

Lesson 3
Kitchen Geology: How Mountains Grow



Oceanic plates are heavier causing them to subduct when they meet lighter continental plates. Image courtesy of the U.S. Geological Survey.

Overview:

Through teacher demonstrations and hands-on activities using food, students learn about plate tectonics and how the Alaska Range, Denali, and Alaska's earthquakes are explained by movements of the earth's crust.

Objectives:

Students will:

- Diagram a cross section of the earth.
- Describe oceanic and continental tectonic plates.
- Label a diagram of tectonic features including plate boundaries and convection currents.
- Model what happens where plates move apart at spreading centers.
- Describe what happens where plates collide at subduction zones.

Duration:

60 minutes

Vocabulary:

plate tectonics, tectonic plates, convection current, divergent boundary, convergent boundary, transform boundary, spreading center, subduction zone, fault, core, mantle, crust, magma, uplift, terrane

Materials:

Lesson Section	Materials needed
Activity 3.1	Egg - hard-boiled for 10 minutes Knife
Activity 3.2	Clear container full of warm water (12 ounce water glass or larger) Ice cubes colored with food coloring Lava lamp (optional)
Activity 3.3	World map showing tectonic platesa Package of Oreo-type cookies
Activity 3.4	Three slices of bread Jar of chunky peanut butter Box of raisins Package of crackers (Pilot Bread Crackers/Pilot Biscuits work best)

[a] An electronic version of the map can be linked to from the *Denali Rocks!* Teacher page.

Background:

Refer to the "How did ocean rocks get way up there" section in the "Teacher Background: The Geology of Denali National Park and Preserve" from Lesson 1. Excellent information on plate tectonics (including animations of plate movement and collisions) can be found on the websites listed under "Geology" in the web resources section. The USGS sites are particularly good.

Note: This activity is adapted from *North Cascades National Park: A Living Classroom*.

Preparation:

1. For Activity 3.1, hard boil an egg; sketch the continents on it with a marker.
2. For Activity 3.2, the day before teaching this lesson, make a set of ice cubes with a few drops of food coloring in each one. Using a few different colors gives a nice effect. Just prior to the demonstration, fill the clear container nearly full of hot tap water.
3. For Activity 3.3, Oreos and peanut butter work best when warm. Heat them just prior to the demonstration.
4. All activities in this lesson are teacher-led demonstrations, so have all materials handy.

Procedure:

1. Read and discuss with the class the introduction and concepts on the student worksheet.
2. Do the following demonstrations and hands-on activities. At the end of each, have students do the related work on their worksheets. This work should reinforce the concepts modeled in the activities.

Activity 3.1 The world is an egg. Earth's three layers

1. Show students the egg (with the continents drawn on it). Explain how the earth's crust is like the eggshell, because (crack the egg shell) it's broken into "plates" that move very slowly over the earth's surface. Solicit ideas of how the egg is like Earth in other ways, too.
2. Cut the egg in half at the "equator" to show student the cross section and identify the layers of the earth: in the center is the solid **core** (yolk), surrounded by the liquid **mantle** (white), and on the outside is the thin **crust** (shell). Write the three terms on the board.
3. Explain that the mantle is composed of a hot, liquid called magma and that the crust consists of plates that make up the continents and ocean floors; inform students that you will talk more about these concepts in a few minutes.
4. Using the egg as a model, have students draw a diagram of the earth's cross section and label the three layers (on their worksheets, Activity 3.1). Sketch a diagram on the board as a model if you think it is needed.

Activity 3.2 Why do the plates move? Earth's heat engine

1. Introduce the concept of convection in the earth's interior. Most students have seen a lava lamp (perhaps a student or colleague has one), so it could be used as a model. As the light bulb heats the material, it becomes less dense than the surrounding medium and rises; at the top, it cools, becomes denser again and sinks.
2. Explain that, similarly, the earth is hottest at the core so the molten (liquid) material, or **magma,** deep in the mantle is heated up and rises; as it approaches the crust, it cools and sinks again. This movement which is caused by differences in temperature is called a **convection current**. The continuous rising and sinking of magma creates convection currents in the mantle and the plates floating on the mantle above move as a result.
3. Demonstrate convection currents. Fill the clear container close to the top with hot tap water. Put the colored ice cube in the glass and use a pencil to hold it near the side of the container; the cold dense colored liquid will sink to the bottom. As it warms, it will move back up to the top. If you have one, put a hot plate under the container to simulate the earth's core and speed up the currents.
4. Sketch or project a diagram of a pair of the earth's convection currents on the board. Draw it like the example on the student worksheet answer key for Lesson 3. Students should copy the diagram on their worksheets (Activity 3.2).

Activity 3.3 World map with ocean floor ridges and spreading centers

1. Show students the world map with tectonic plates and point out the spreading center in the mid-Atlantic Ocean. Ask what they notice about the shorelines east and west of these spreading centers. Tell them the two coastlines are parallel to the mid-Atlantic ridge because these continents were once joined there.
2. Warm the chocolate sandwich cookies. Hand out a cookie to each student, but instruct them not to eat it yet. Give them the following instructions: Twist your cookie apart so it separates with all of the cream on one wafer. Break the clean wafer in half. Place the two pieces back on the frosted wafer, leaving one-quarter inch of space between the two pieces. Press down on the pieces so that the warm cream squeezes up from between the two halves.
3. Explain that this illustrates what happens at a **spreading center** like the mid-Atlantic Ridge, where two plates pull apart and upwelling magma hardens to form new crust.
4. Continuing with the drawing you made of the convection currents, sketch or project the diagram of a spreading center on the board for students to copy on their worksheets (Activity 3.3).

Activity 3.4 Peanut butter and subduction sandwich

1. Refer to the world map again and have students find the spreading centers. Point out that if new crust is always forming at these sites, but the earth stays the same size, then it must be disappearing somewhere, too. Ask if they can tell where this happens on the world map. Help them find **subduction zones**, areas where continental and oceanic plates collide, and focus in on the zone where the Pacific Plate meets the North American Plate along the Aleutian Trench and south of mainland Alaska.
2. Demonstrate what happens at subduction zones where two **tectonic plates** collide. Use a slice of bread to represent a continental plate. These plates are thick and relatively light since they are made of lighter material, silica, and contain fewer heavy elements compared to oceanic plates. Use a cracker as an oceanic plate. These plates are thinner but heavier because they are more dense.
3. Spread a cracker with some peanut butter to represent the accumulated sediments on the ocean floor, and top it with raisins representing islands (this works best if the peanut butter is warm). Place the cracker on a table next to some bread. Remind the students that oceanic plates are very heavy and dense, and ask them to predict what will happen when the two collide.
4. Slide the two "plates" together and discuss three results:
   - The oceanic plate is subducted, or slides underneath, the continental plate; this may **uplift** part of the coastline (bread) to a higher elevation, building mountains.
   - The land (bread) might buckle and elevate further in from the edge, showing how uplift can also occur far from the subduction zone (like a car hood in a collision); this is one reason why the Alaska Range continues to rise even though it is far inland.

- The ocean sediments and islands (peanut butter and raisins) get scraped off to form what geologists call **terranes**, foreign rocks carried by a colliding plate and attached to a continent. The coast of Alaska used to be just north of where the Alaska Range is now but over the ages, the lands south of it (the Mat-Su Valley, Kenai Peninsula, and Chugach Mountains) have been created by terranes.

5. While the bread is out, you may want to show what happens when two continental plates collide. Since neither plate is heavy enough to subduct under the other, the collision will cause major uplift and buckling. This is what formed the Himalayas: India headed north and collided with Asia.

Assessment:

Check that students' work is complete and accurate.

Extensions:

1. Have students go to the USGS and other sites on the internet to explore plate tectonics and look at animations of plate movement and collisions.
2. Create a half-sphere model of the earth that correctly shows the relative thickness of the Earth's layers in cross-section. Show continents and plate boundaries, and use arrows to show direction of plate movement.

Name: ______________________________

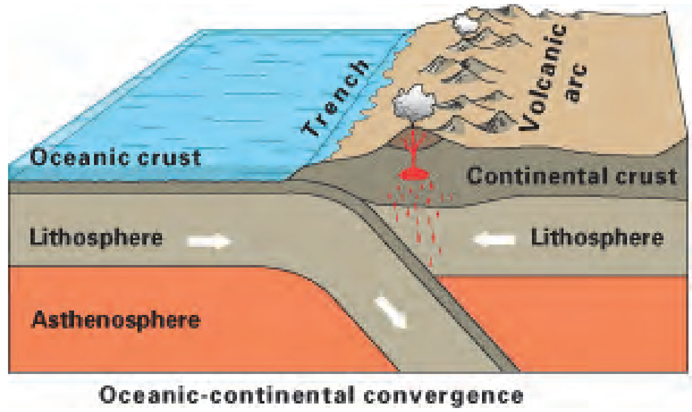
Date: ______________________________

Class: ______________________________

Student Worksheet

Lesson 3

Kitchen Geology: How Mountains Grow

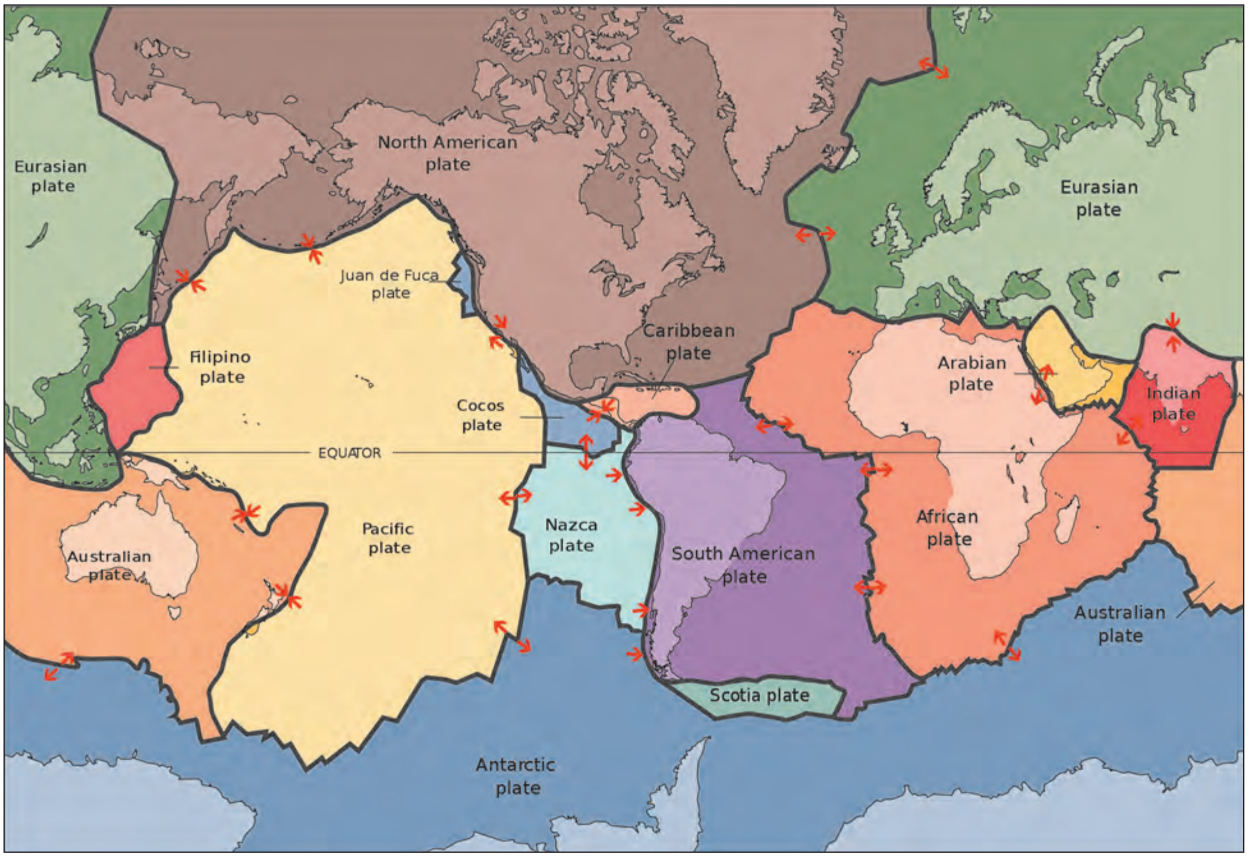


Oceanic plates are heavier causing them to subduct when they meet lighter continental plates. Image courtesy of the U.S. Geological Survey.

In the Introduction, we learned that geology is the study of Earth's history. Geologists study the earth by looking at rocks and landforms, and by exploring the forces that shape the earth. Learning about the composition of the earth and the forces that constantly act upon it will help you understand the richness of Denali's geologic history.

Once the world was mapped, scientists noticed that the continents seem to fit together like pieces of a puzzle, but few believed that continents could move. In 1912, Alfred Wegener proposed the theory of continental drift and evidence began to build to support it. Matching rocks were found on both the coast of Brazil and the coast of West Africa, and fossils of uncommon species were found in these same two places but nowhere else. After World War II when submarines began to map the floor of the Atlantic Ocean, further evidence was found. Corresponding bands of submerged ridges on either side of **spreading centers** showed where plates were moving apart. Some years later, deep-ocean exploration showed that molten lava could be found welling up inside the spreading centers.

Geologists now understand that Earth's surface is covered by large irregular plates that move due to forces acting upon them from deep within the planet's interior. The theory of **plate tectonics** explains this movement and what happens at boundaries where plates collide, move apart or slide past each other. We are all familiar with instant and sometimes catastrophic geologic events like earthquakes and volcanoes that shifting plates can cause. But most changes to Earth's landforms are less apparent, happening slowly over long periods of time.



The earth's crust is broken into tectonic plates. Image courtesy of the U.S. Geological Survey.

Plate tectonics helps explain the origin of mountains, volcanoes and earthquakes. Using some familiar items from the kitchen, we will look at what happens deep within the earth to begin figuring out how the Alaska Range, including Denali, formed. Here are some of the concepts we will examine. If some of the terms are unfamiliar to you, the activities in this and later lessons will help you understand them.

- The earth's **crust** is broken up into a number of rigid irregular slabs called **tectonic plates** (continental and oceanic) which slowly move in relation to each other.
- Plate movement is driven by **convection currents** caused by the continuous movement of heated **magma** deep within the earth that rises, cools and sinks again.
- Magma wells up and hardens to form new crust at **spreading centers** of **divergent boundaries** where two plates pulling apart to separate from each other.
- **Convergent boundaries** are areas where two plates move toward one another and collide.
- **Subduction zones** occur at **convergent boundaries** where an oceanic plate moves toward and collides with a continental plate or a lighter oceanic plate, causing earthquakes, volcanoes and **uplifted** mountain building.
- Where two plates neither separate nor collide but slide past each other at **transform boundaries**, fractures and **faults** cause a lot of earthquake activity.

Vocabulary:

plate tectonics, tectonic plates, convection current, divergent boundary, convergent boundary, transform boundary, spreading center, subduction zone, fault, core, mantle, crust, magma, uplift, terrane

Activity 3.1 The world in an egg! Earth's three layers

Draw a cross section of the earth. Label its three layers:

Activity 3.2 Why do the plates move? The earth's heat engine

Sketch a diagram of a pair of convection currents in the earth's interior.

Activity 3.3 World map with ocean floor ridges and spreading centers

Draw a diagram of a spreading center over the convection currents you drew on the previous page. Indicate with arrows the direction each plate is moving. Put a little upwelling magma between the two plates.

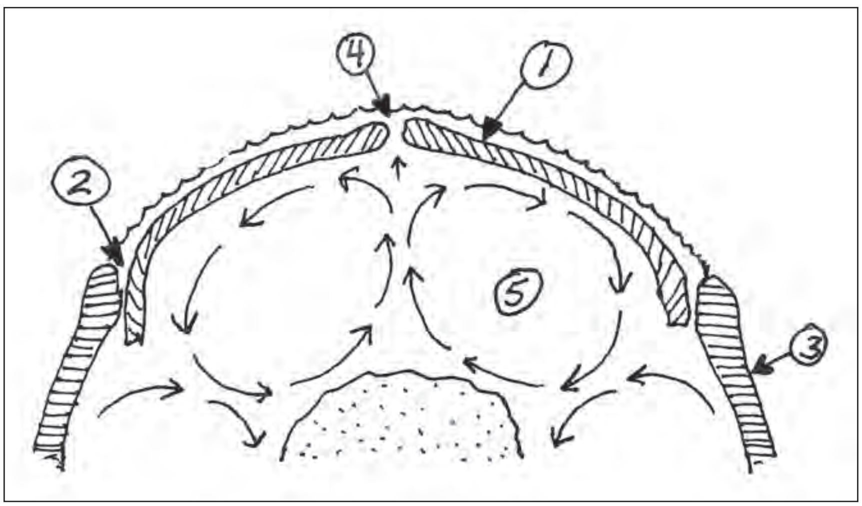
Activity 3.4 Peanut butter and subduction sandwich

1. How is the bread like a continental plate?

2. How is the cracker like an oceanic plate?

3. Draw a cross-section of the peanut-butter-and-raisin-covered cracker meeting the bread. Show what happened. Where did the cracker go? What happened to the bread? What happened to the raisins? Under your drawing, name three geologic events that happen where an oceanic plate is subducted under a continental plate.

4. For each numbered item in the diagram below, write the name of the item on the line with the same number. Items that have more than one answer have more than one line. Choose words from the following list: continental plate, oceanic plate, divergent boundary, convergent boundary, spreading center, subduction zone, magma .



NPS illustration by Doug Smith.

1. ______________________________

2. ______________________________

   ____

3. ______________________________

4. ______________________________

   ____

5. ______________________________

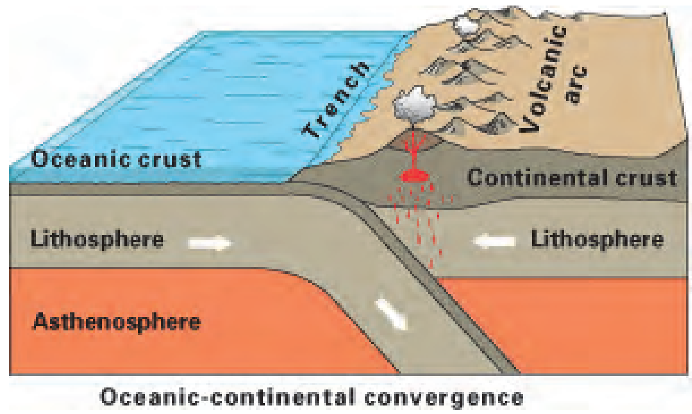
Name: ______________________________

Date: ______________________________

Class: ______________________________

Answer Key

Lesson 3
Kitchen Geology: How Mountains Grow



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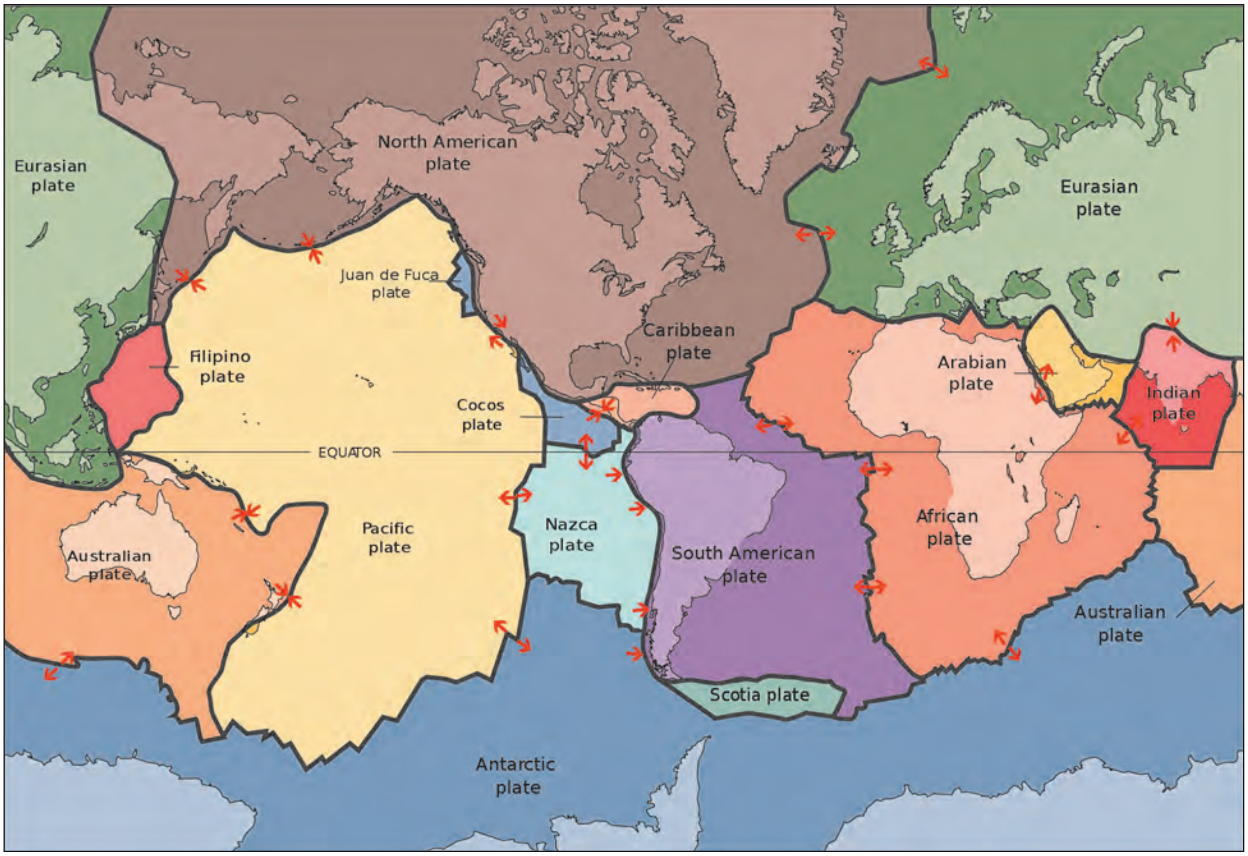
Geologists now understand that Earth's surface is covered by large irregular plates that move due to forces acting upon them from deep within the planet's interior. The theory of **plate tectonics** explains this movement and what happens at boundaries where plates collide, move apart or slide past each other. We are all familiar with instant and sometimes catastrophic geologic events like earthquakes and volcanoes that shifting plates can cause. But most changes to Earth's landforms are less apparent, happening slowly over long periods of time.



The earth's crust is broken into tectonic plates. Image courtesy of the U.S. Geological Survey.

Plate tectonics helps explain the origin of mountains, volcanoes and earthquakes. Using some familiar items from the kitchen, we will look at what happens deep within the earth to begin figuring out how the Alaska Range, including Denali, formed. Here are some of the concepts we will examine. If some of the terms are unfamiliar to you, the activities in this and later lessons will help you understand them.

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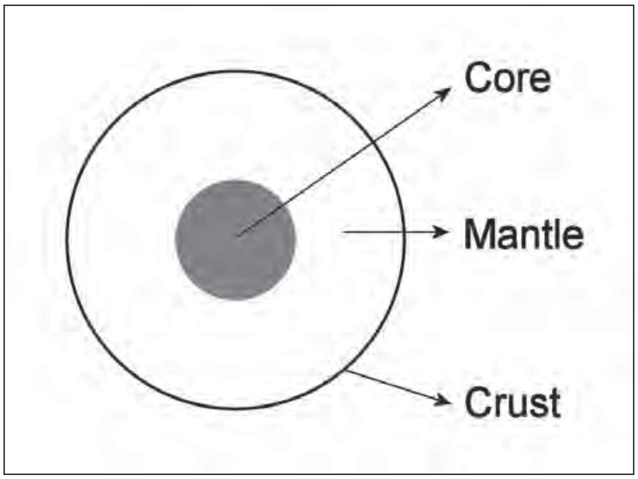
Vocabulary:

plate tectonics, tectonic plates, convection current, divergent boundary, convergent boundary, transform boundary, spreading center, subduction zone, fault, core, mantle, crust, magma, uplift, terrane

Activity 3.1 The world in an egg! Earth's three layers

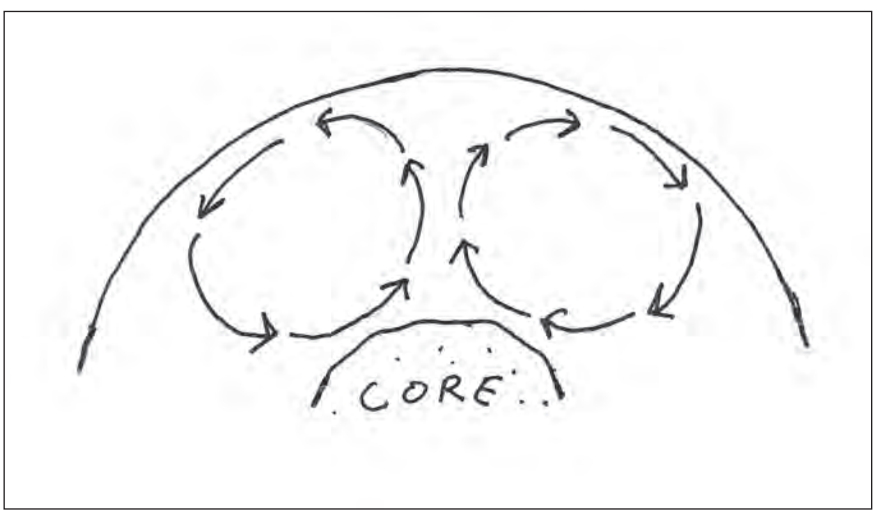
Draw a cross section of the earth. Label its three layers:



NPS illustration

Activity 3.2 Why do the plates move? The earth's heat engine

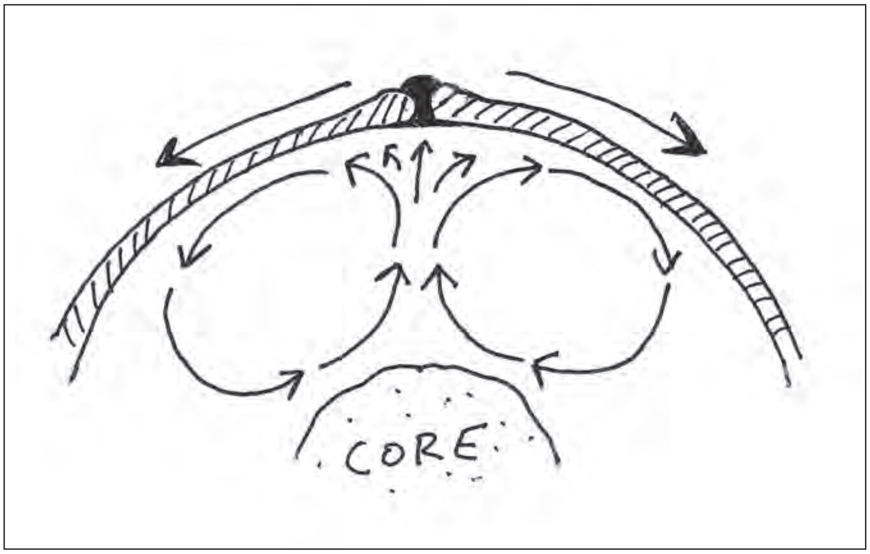
Sketch a diagram of a pair of convection currents in the earth's interior.



NPS illustration by Doug Smith.

Activity 3.3 World map with ocean floor ridges and spreading centers

Draw a diagram of a spreading center over the convection currents you drew on the previous page. Indicate with arrows the direction each plate is moving. Put a little upwelling magma between the two plates.



NPS illustration by Doug Smith.

Activity 3.4 Peanut butter and subduction sandwich

1. How is the bread like a continental plate?
   It is thick and full of air (less dense than the cracker).

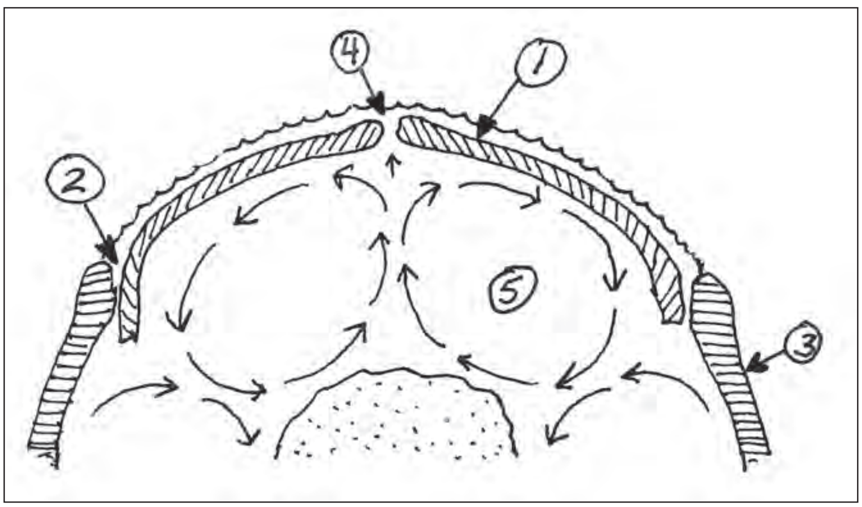
2. How is the cracker like an oceanic plate?
   It is thinner than the bread (continental plate) and denser.

3. Draw a cross-section of the peanut-butter-and-raisin-covered cracker meeting the bread. Show what happened. Where did the cracker go? What happened to the bread? What happened to the raisins? Under your drawing, name three geologic events that happen where an oceanic plate is subducted under a continental plate.

   Drawings will vary, but should show the cracker subducting, terranes attached to the bread, and the bread being uplifted.

   Three events that happen in a subduction zone include earthquakes, volcanoes, and mountain-building. Ocean trenches are another possible answer.

4. For each numbered item in the diagram below, write the name of the item on the line with the same number. Items that have more than one answer have more than one line. Choose words from the following list: continental plate, oceanic plate, divergent boundary, convergent boundary, spreading center, subduction zone, magma .



NPS illustration by Doug Smith.

1. *oceanic plate*
2. subduction zone
   convergent boundary
3. *continental plate*
4. divergent boundary
   spreading center
5. *magma*

Lesson 4
Denali has its Faults (and Volcanoes)

The colorful rocks of Polychrome Pass originated from volcanic activity.
NPS photo by Tim Rains.

Overview:

Students use the internet and maps and make a geologic timeline to learn about volcanism and faults and how they have shaped the land in Denali National Park and Preserve.

Objectives:

Students will:

- Explain two ways molten rock forms igneous rock: intrusion (plutons) and extrusion (volcanoes).
- Identify examples of intruded and extruded features of Denali's landscape.
- Locate the Denali Fault and point out evidence of its movement.
- Demonstrate that geologic events take place on a long time scale.

Duration:

Two 60-minute periods

Vocabulary:

volcanism, trench, igneous rock, intrusion, pluton, batholith, lava, volcano, extrusion, Pacific Ring of Fire, Aleutian Trench, strike-slip fault, Denali Fault

Materials:

Activity 4.1	Computers with internet access (for student-centered activity) or computer and a digital projector (teacher-led activity)
Activity 4.2	3-D plastic raised relief map of Denali National Park and Preserve Computers with internet access to look at the online Denali National Park and Preserve brochure map linked to off of the Denali Rocks! Teacher and Student Pages Topographic map of Denali National Park and Preserve Ruler Calculator (not required; the calculations are simple)
Activity 4.3	100-foot tape (most physical education teachers have one) or 100 feet of string and a yardstick or tape measure

Background:

Refer to the “Three major types of rocks make up the earth”, “A land born of fire”, and “So how did the big mountain get so big” sections in the “Teacher Background: The Geology of Denali National Park and Preserve” from Lesson 1.

Preparation:

1. Decide on an approach that would work best for your class size and computer availability. There are three activities in this lesson: an internet website visit, a “tour” of the 3-D plastic raised relief map of Denali National Park and Preserve, and a geologic timeline. The geologic timeline is a whole-class activity; the other two activities could be done simultaneously with the class working in two groups that would flip-flop between activities, or as teacher-directed whole-class activities.
2. For Activity 4.1, preview the Alaska Volcano Observatory website (http://www.avo.alaska.edu). You can get there by searching for “Alaska Volcano Observatory” on Google. Once there, click on “Volcano Information,” and then click on “Interactive Map.”
3. For Activity 4.3, gather materials for the geologic timeline.

Procedure:

1. Read and discuss with the class the reading on the student worksheet.
2. Go over directions and have students begin the internet search. If you are splitting the class into two groups, give directions for the map tour as well (allow 30 minutes).
3. On the second day, have the class do the map tour (or switch groups).
4. Gather the class together to do the geologic timeline as a whole group.

Activity 4.1 Exploring Alaska's Volcanoes on the Net

1. Direct students to the Alaska Volcano Observatory website (http://www.avo.alaska.edu). (Or search for "Alaska Volcano Observatory" on Google). Click on "Volcano Information," then click on "Interactive Map."
2. Have students tour the site as directed on the student worksheet. Students can do this individually, or you can project the site in front of the classroom and tour it together. Students will record information on their worksheets as they tour the site.

Activity 4.2 Tour of the Park

Students will record information on their worksheets as they take the Denali map tour.

Activity 4.3 Denali Geologic Time Line

This activity helps students to comprehend the scale of geologic time.

1. Explain to students that they are going to construct a geologic timeline. In this particular timeline, the scale will be: 1 inch = 1 million years.
2. Assign a student (or pair of students) to each event; there are 14 events on this time line. Have the students make signs for their events by writing down the geological event and the time at which it took place on a piece of paper.
3. Show students how to figure out where they will stand on the time line. It may help for the teacher to model this calculation on the board. Convert the number of millions of years to inches (e.g. 200 million years = 200 inches). Then divide by 12 to get feet. It helps to do this without calculators because the remainders are the "leftover" inches, whereas calculators would show decimal parts of feet. Have the students write their distance from the present day on their signs so they will remember them.

   Note: Calculations for the first two events on the time line occurred less than 1 million years ago so the math is slightly more difficult.
4. If you are using string instead of a 100' tape, have a group that gets done early mark off 10' intervals on the string with a marker or tape to make later measurements easier.
5. Go outside, or use the gym or hallway. Starting with the present day, have students go to their places on the time line as you say each event. There won't be enough string for the last event!

Assessment:

Go over the worksheet answers for accuracy and completeness. Discuss with the class any answers that seem to need clarification.

Name: ______________________________

Date: ______________________________

Class: ______________________________

Student Worksheet

Lesson 4
Denali has its Faults (and Volcanoes)

The colorful rocks of Polychrome Pass originated from volcanic activity. NPS photo by Tim Rains.

In Lesson 3, we learned about three kinds of plate boundaries: convergent (colliding), divergent (spreading), and transform (sliding). Subduction occurs where an oceanic plate collides with a continental plate and causes earthquakes, uplifting and addition of terranes to the land. In this lesson, we will look at two other results of subducting plates, trenches and volcanoes, and how they have affected the landscape in Denali Park. We will also learn about a transform boundary that runs through the Alaska Range, and investigate what happens in Denali where subducting and sliding plates meet.

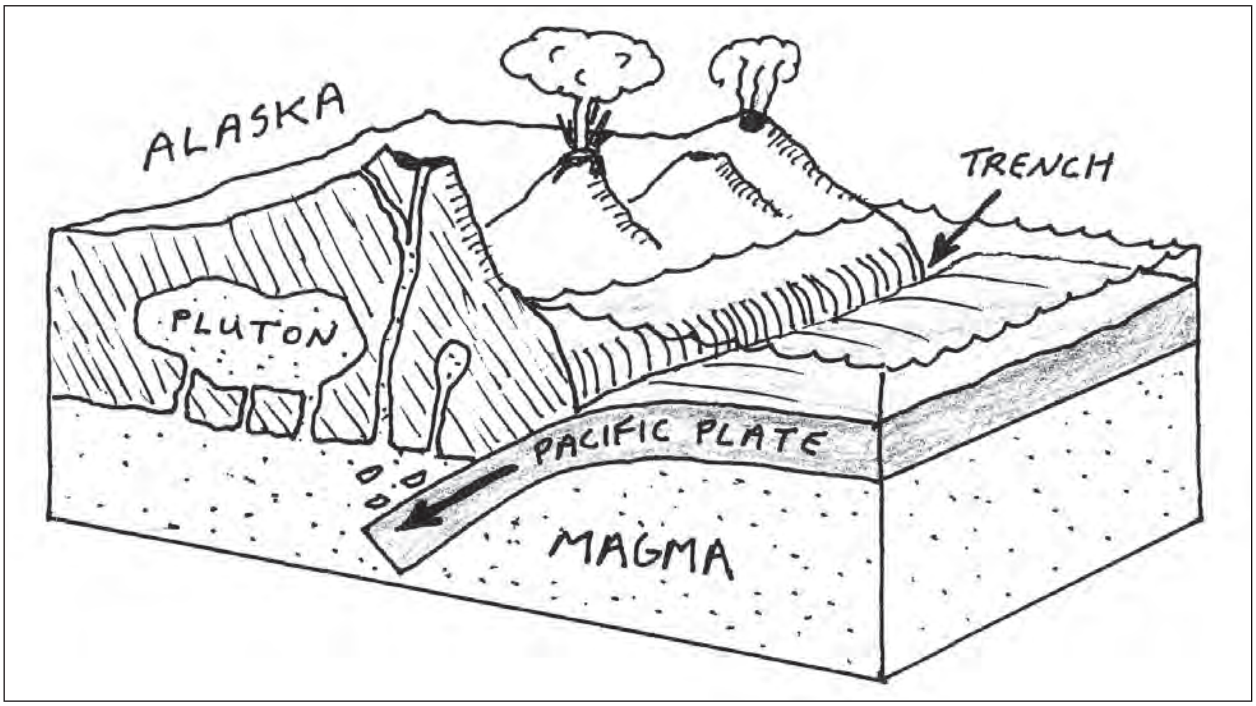
Volcanism

Volcanism deals with the movement of molten rock inside the earth or on the earth's surface. When an ocean plate dives under a continental plate, a **trench**, or deep steep-sided canyon is formed on the ocean floor at the edge of the continent. As the plate descends it melts, and the lighter molten material and gasses float up into cracks in the overlying continental plate, forming **igneous rock**.

Sometimes magma fills underground cracks or chambers and hardens below the surface of the earth to form an **intrusion** or **pluton** (named for Pluto, the Roman god of the underworld). The large mountains of the Alaska Range were formed in this way. A very large pluton like Denali is called a **batholith**. Plutons can only be seen if they are uplifted and the rocks covering them get eroded away. Denali formed inside the earth 56 million years ago but wasn't pushed up out of the earth until about 6 million years ago. Around Denali's summit, there are still some rocks from the old sea bottom under which the pluton formed!

If the magma reaches the earth's surface to harden, it is called **lava**. Lava finds its way to the surface either through long fissures or cracks, or through vents to form a **volcano** (named for Vulcan, the Roman god of fire). Either way, rock formed from hardened lava, called **extrusions**, can cover hundreds of square miles and be thousands of feet deep. While there are no active volcanoes in Denali National Park and Preserve today, there have been in the past; there is evidence of extensive volcanic activity 37 million and 56 million years ago, and of minor eruptions as recently as 3000 years ago.

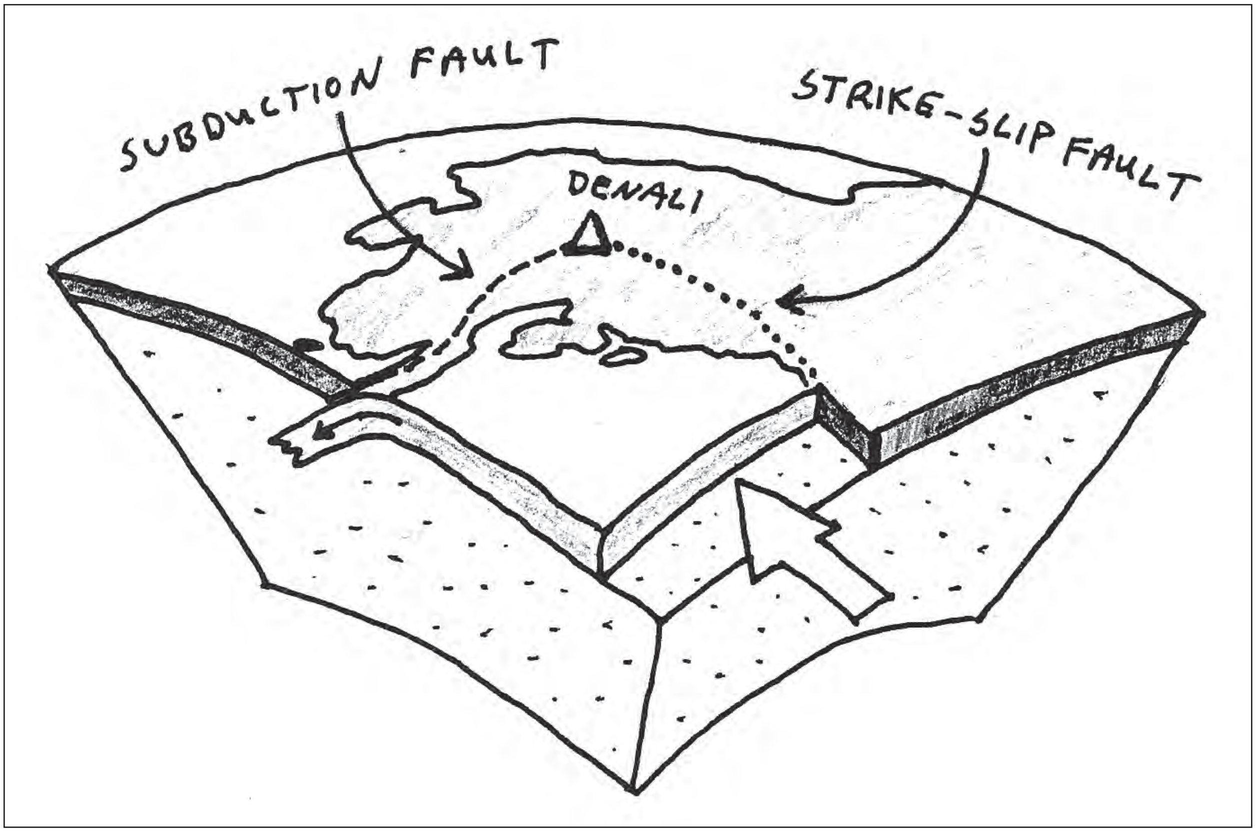
Trenches, volcanoes and earthquakes occur all around the **Pacific Ring of Fire** where the Pacific Plate subducts under the continents surrounding it (North and South America, New Zealand and Oceania, and Asia). Its northern portion lies along the **Aleutian Trench**. A string of active volcanoes runs through Aleutian Islands and continues up the Alaska Peninsula. North of the Alaska Peninsula this string of active volcanoes mysteriously stops at what geologists call the "Denali Gap," a break that runs about 200 miles east through Denali Park, then it reappears to the southeast with the active volcanoes in the Wrangell-St. Elias Range.



NPS illustration by Doug Smith.

The Denali Fault

The plates covering the earth's surface do more than diverge, and collide or subduct. Sometimes they slide past each other along a transform boundary creating a **strike-slip fault**. About 75 million years ago, the Pacific Plate was moving northwards, subducting under Alaska and piling up terranes against the coastline which was then located north of the Alaska Range. Around 65 million years ago, for reasons not yet understood by geologists, the Pacific Plate changed direction to start moving more toward the west. As a result, the plate now slides along the coast of North America and Alaska, then subducts under Cook Inlet and the Alaska Peninsula.



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Notice right at the corner where the strike-slip fault turns into a subduction zone? There's Denali! It has been piled up, bunched up and scrunched up into the highest vertical relief in the world right against the corner of the ancient North American shoreline.

Once you know it's there, this strike-slip fault, called the **Denali Fault** in Alaska, is so obvious that you can even see it from space! If you look at a map you can see evidence that the Alaska Range has moved to the west in relation to the land north of it. Of course it's moving too slowly to see, only about 1 ½ inches per year, but that adds up over geologic time. In Denali Park, there is plenty of evidence that mountains and glaciers south of the fault are moving west compared to those on the north side of it.

This same fault extends southward from the Alaska Range at Denali through Southeast Alaska and all the way to California where it's called the San Andreas Fault. Yes, California is slowly moving toward Alaska! Slowly, but not smoothly. In the last lesson, we saw how plates don't slide smoothly past one another; instead they "jump" and make earthquakes. This fault has produced lots of big ones. In 1906, the plates along it jumped almost 20 feet near San Francisco and leveled the town. In 1958, an earthquake measuring 8.0 on the Richter scale caused a whole mountainside to fall into Lituya Bay in Southeast Alaska, creating a splash that cleared trees off the mountains 1500 feet above the bay—the tallest wave in history! And in November 2002, the Denali Fault jumped 24 feet in the Alaskan Range, causing a magnitude 7.9 earthquake. Trenches, earthquakes, volcanoes, plutons, faults, subducting and uplifting: Denali is in the center of some major tectonic action!

Vocabulary:

volcanism, trench, igneous rock, intrusion, pluton, batholith, lava, volcano, extrusion, Pacific Ring of Fire, Aleutian Trench, strike-slip fault, Denali Fault

Activity 4.1 Exploring Alaska's Volcanoes on the Net

1. On the internet, go to http://www.google.com and search "Alaska Volcano Observatory." Click on the Alaska Volcano Observatory website (http://www.avo.alaska.edu), click on "Volcano Information," and then click on "Interactive Map."

   Now that you're on the interactive map, click on "Hybrid" on the upper right corner of the map to get the view from space combined with the map.

   Start in the ocean. Find the Aleutian Trench south of the Aleutian Islands. What is forming the trench?

2. How far does the trench extend to the west?

3. Click on "Monitored Volcanoes," "Other Volcanoes," and "Recent Earthquakes." What do volcanoes, earthquakes, and trenches have in common?

4. Note how the volcanoes stop south of Denali National Park and Preserve, and start up again past it, even though the plate is still subducting under Denali. No one knows why; it's a mystery geologists call "The Denali Gap." Now you've seen it!

5. Wait a minute: there ***are*** two volcanoes near Denali. What are their names, and how long ago did they erupt? (You'll have to cruise around the site to find this out.)

6. What is the largest recent earthquake you can find? How deep below the earth did the slipping occur?

7. How good are your eyes? If they're good, you'll be able to see the Denali Fault from space. It looks like a line drawn by dragging a gigantic stick through the mountains. Start where the fault curves over the north side of the Alaska Range. Follow it in an arc across the north side of the Wrangell-St. Elias Mountains, and through a gap in the snowfields to Haines, then through Chatham Strait to the Pacific Ocean. Can you see it? (If you're really astute, you can follow the fault under the ocean all the way down to California).

8. While you're in the ocean, let's go to Hawaii. Remember how the Denali Fault started when the Pacific Ocean Plate changed its direction 65 million years ago? Hawaii makes the change real obvious. Hawaii sits over a "hot spot" in the mantle which makes a volcano right in the middle of the Pacific Ocean. As the plate moves north, the old volcano moves away from the hot spot, and a new volcanic island is born over the hot spot south of the previous volcano. Over time, this makes a chain of volcanic islands, with the oldest ones to the north eroding back under the sea. Starting at the newest volcano (the "Big Island" of Hawaii), follow this chain of present and ancient Hawaiian Islands. How far north do they go?

9. There's an argument over the tropical plant fossils found in Alaska: did it used to be hot and humid here, or did the plants move here from somewhere else? Which side of the argument does the Hawaiian Island chain support?

10. Can you see the place where the chain changes direction? Draw what it looks like below. How is this evidence that Pacific Ocean Plate has changed direction?

11. Before you move on, take a quick "trench" tour around the entire "Pacific Rim of Fire." The trenches in the western Pacific are the deepest places on earth.

Activity 4.2 Tour of the Park

For this activity, you will need a ruler, the 3-D plastic raised relief map of Denali National Park and Preserve, and the map of the park found in the online Denali brochure linked to from the *Denali Rocks!* student page.

The Volcano Tour

1. Find Polychrome Pass just west of the Toklat River. Imagine yourself here 56 million years ago, when lava was pouring out of cracks in the earth, layer upon layer. (Under your feet, this molten rock is hardening into the McKinley Pluton). Look at the mountains to the south of Polychrome Pass; they consist of many thousands of feet of this many-colored (poly-chrome) hardened lava extrusion.
2. Find Mt. Galen and Mt. Eielson close to the Muldrow Glacier terminus. They were both formed in the second big period of volcanism here 38 million years ago. Mt. Eielson was an intrusion (a pluton, like Denali) while Mt. Galen was formed by a volcanic eruption above ground.

Fault-finding tour

1. It's time to find the Denali Fault, the boundary where two plates are sliding past each other. On the east side of the map, start where Schist Creek flows into the Nenana River, follow the valley below the words "ALASKA RANGE," over Anderson Pass, along the Muldrow Glacier and past the north sides of Denali and Mount Foraker. Put your head close to the map and look along the fault from its west or east end. Cool! South of the fault, the plate is moving the whole range to the west.
2. Find Mt. Foraker south of the fault and McGonagall Mountain by the Muldrow Glacier north of the fault. These two mountains are parts of the same pluton, magma that hardened underground about 37 million years ago. It split along the fault and moved apart. How far has Foraker moved away from McGonagall since then? (1 inch = 4 miles on the map).
3. The park boundary is 35 miles west of Denali. If the land south of the fault continues moving at the same rate, about how long will it take for Denali to move out of its own park?

4. Look at the glaciers on the north side of the range, starting on the west side of the map. Cut off by the edge of the 3-D plastic raised relief map of Denali National Park and Preserve is the Chedotlothna Glacier behind Mt. Russell (it is on the online park brochure map, though), followed by the Heron, Foraker, Straightaway, Peters, and Muldrow Glaciers. What general shape do they ***all*** have in common as you follow them from where they start to where they end? Draw it below.

5. Glaciers like to travel in a straight path, but in every one of these glaciers, it looks like the south ends have been moved to the west, and the north ends have been moved to the east, making a big zigzag. How can you explain this?

6. The plate south of the fault isn't just sliding to the west, it's rising up as well. (This makes the Denali Fault a "thrust fault" as well as a "slip-strike fault.") Compare the mountains north of the fault to those south of the fault near Denali. How are they different?

7. The Wickersham Wall is evidence of the light granite pluton at the north edge of the plate being pushed up vertically. While land on the north side of the fault continues to erode, land on the south side of the fault (especially the light granite) is popping up like a cork. Besides the Wickersham Wall, what other evidence can you see for uplifting south of the fault?

Lesson 4

Activity 4.3 Denali Geologic Time Line

This activity helps students to comprehend the scale of geologic time.

1. Explain to students that they are going to construct a geologic time line. In this particular time line, the scale will be: 1 inch = 1 million years.
2. There are 14 events on this time line (see back of this page). Assign a student (or pair of students) to each event. Have the students make signs for their events by writing down the geological event and the time at which it took place on a piece of paper.
3. Next, they should figure out where they'll be standing on the time line. It may help for the teacher to model this calculation on the board. Convert the number of millions of years to inches (200 million years = 200 inches). Then divide by 12 to get feet. It helps to do this by hand because their remainders are the "leftover" inches, whereas calculators would show remainders as decimal parts of feet. Have the students write their distance from the present day on their signs. (Note: Calculations for the first two events on the time line will require slight modification.)
4. If you are using string instead of a 100 foot tape, have a group that gets done early mark off 10 foot intervals on the string with a marker to make later measurements easier.
5. Go outside (or use the gym or hallway). Starting with the present day, have students go to their places on the time line as you say each event. There isn't enough string for the last event!
6. The students' signs could be put up in the classroom using the same (or smaller) scale to create a geologic timeline for display. Students could illustrate each event.

Students on the timeline represent:

- The present day
- **10,000 years ago —** The end of the most recent glacial advance.
- **14,000 years ago —** The first people arrive in Alaska, living alongside mammoths, saber-tooth cats, camels, and bear-sized beavers.
- **1.8 million years ago —** First human-like hominids (*Homo erectus*) in Africa.
- **5 million years ago —** Denali is around 10,000 feet high, half its present height. The Alaska Range is a group of low hills.
- **6 million years ago —** Denali is pushed up out of the sedimentary rocks covering it.
- **30 million years ago —** Lush forests create present-day coal beds (Usabelli Mines).
- **37 million years ago —** Mt. Foraker pluton is formed in the earth's crust.
- **56 million years ago —** Cracks formed in the crust by the collision lets upwelling magma form the park's volcanic rocks on the surface and the McKinley pluton in the earth's crust.
- **65 million years ago —** A huge cluster of islands (the Talkeetna Superterrane) collides with the Alaska mainland to form Southcentral Alaska.
- **75 million years ago —** The ocean shore was just north of Denali. A shallow sea filling with sediment was trapped between it and the "Talkeetna Superterrane" approaching from the south.
- **225 million years ago —** Dinosaurs were the world's predominant land animals and many lived in Alaska, which was then located near the equator!
- **1 billion years ago —** The oldest rocks found in Denali National Park and Preserve were formed.
- **4.4 billion years ago —** The oldest rocks ever found on Earth were formed.

Name: ______________________________

Date: ______________________________

Class: ______________________________

Answer Key

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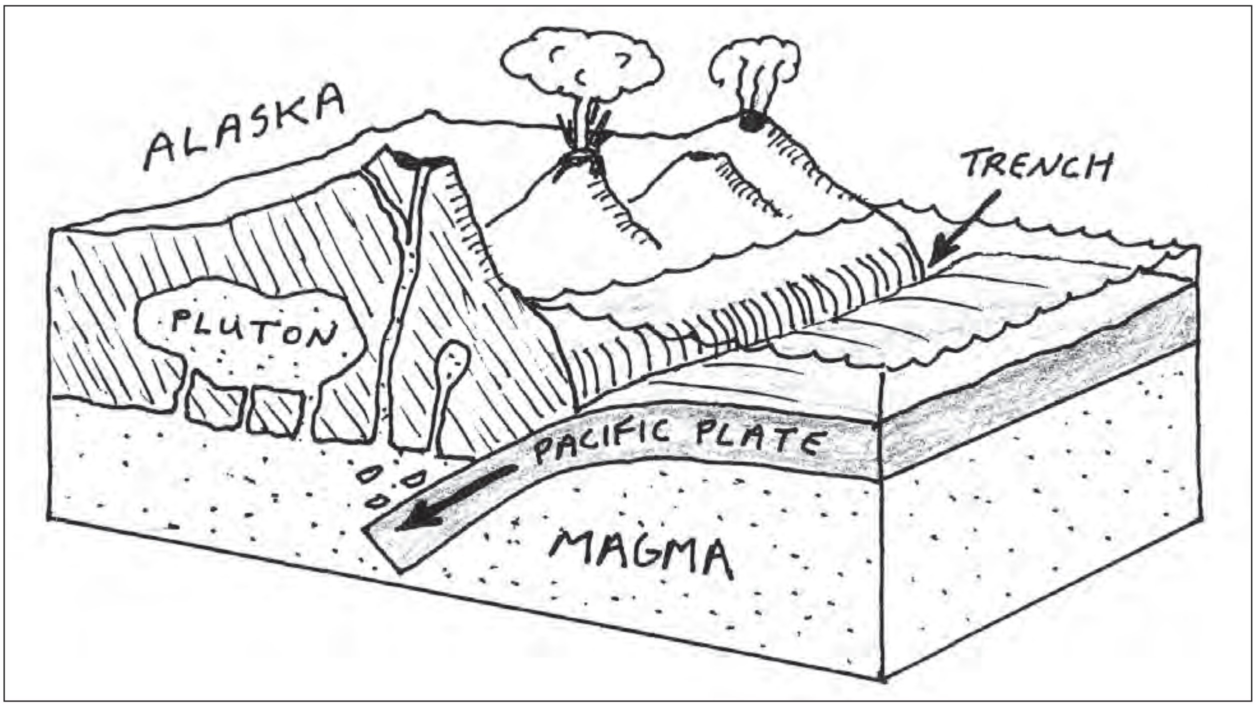

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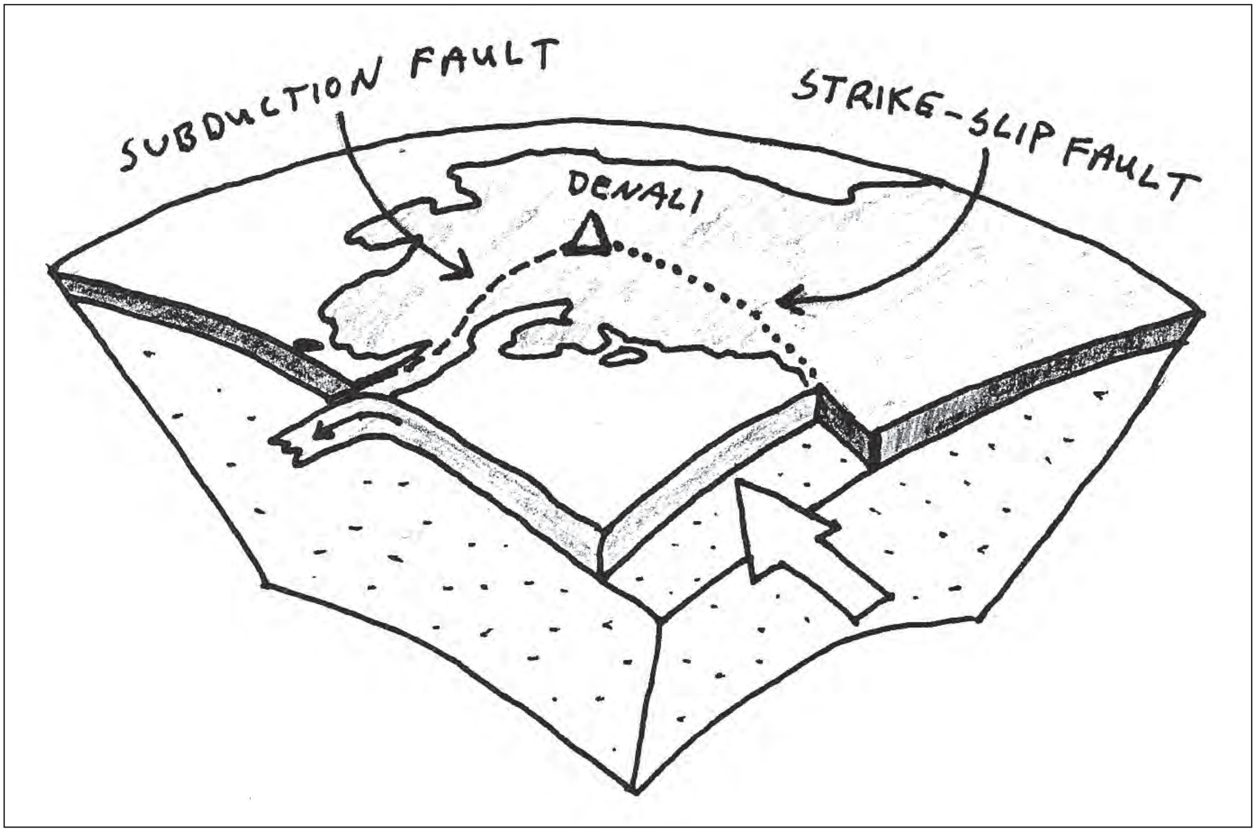

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1. On the internet, go to http://www.google.com and search "Alaska Volcano Observatory." Click on the Alaska Volcano Observatory website (http://www.avo.alaska.edu), click on "Volcano Information," and then click on "Interactive Map."

   Now that you're on the interactive map, click on "Hybrid" on the upper right corner of the map to get the view from space combined with the map.

   Start in the ocean. Find the Aleutian Trench south of the Aleutian Islands. What is forming the trench?

   The subducting Pacific Plate is causing the trench as it goes under the North American plate.

2. How far does the trench extend to the west?

   All the way to Russia on the Kamchatka Peninsula.

3. Click on "Monitored Volcanoes," "Other Volcanoes," and "Recent Earthquakes." What do volcanoes, earthquakes, and trenches have in common?

   They all occur in the same place: a subduction zone.

4. Note how the volcanoes stop south of Denali National Park and Preserve, and start up again past it, even though the plate is still subducting under Denali. No one knows why; it's a mystery geologists call "The Denali Gap." Now you've seen it!

5. Wait a minute: there ***are*** two volcanoes near Denali. What are their names, and how long ago did they erupt? (You'll have to cruise around the site to find this out.)

   Jumbo Dome; erupted about 1.2 million years ago
   Buzzard Creek erupted just 3,000 years ago.

6. What is the largest recent earthquake you can find? How deep below the earth did the slipping occur?

   Answers will vary; the site is updated frequently.

7. How good are your eyes? If they're good, you'll be able to see the Denali Fault from space. It looks like a line drawn by dragging a gigantic stick through the mountains. Start where the fault curves over the north side of the Alaska Range. Follow it in an arc across the north side of the Wrangell-St. Elias Mountains, and through a gap in the snowfields to Haines, then through Chatham Strait to the Pacific Ocean. Can you see it? (If you're really astute, you can follow the fault under the ocean all the way down to California).

   Students should be able to follow the fault all the way to southern California. It is very obvious in Alaska!

8. While you're in the ocean, let's go to Hawaii. Remember how the Denali Fault started when the Pacific Ocean Plate changed its direction 65 million years ago? Hawaii makes the change real obvious. Hawaii sits over a "hot spot" in the mantle which makes a volcano right in the middle of the Pacific Ocean. As the plate moves north, the old volcano moves away from the hot spot, and a new volcanic island is born over the hot spot south of the previous volcano. Over time, this makes a chain of volcanic islands, with the oldest ones to the north eroding back under the sea. Starting at the newest volcano (the "Big Island" of Hawaii), follow this chain of present and ancient Hawaiian Islands. How far north do they go?

   They extend all the way to Alaska!

9. There's an argument over the tropical plant fossils found in Alaska: did it used to be hot and humid here, or did the plants move here from somewhere else? Which side of the argument does the Hawaiian Island chain support?

   The fact that the chain extends to Alaska supports the idea that the fossils were brought here (which is what most geologists believe).

10. Can you see the place where the chain changes direction? Draw what it looks like below. How is this evidence that Pacific Ocean Plate has changed direction?

    The track of the Hawaiian hot spot runs straight south from Alaska, and then takes a quick turn to the southeast. This suggests that the plate was moving due north, and then suddenly started moving in a northwesterly direction (about 65 million years ago). (You can demonstrate this by holding up your left index finger (the "hot spot") and moving your right hand (the Pacific plate) over it to make a similarly-shaped track: it will move away from you, and then veer left).

11. Before you move on, take a quick "trench" tour around the entire "Pacific Rim of Fire." The trenches in the western Pacific are the deepest places on earth.

Activity 4.2 Tour of the Park

For this activity, you will need a ruler, the 3-D plastic raised relief map of Denali National Park and Preserve, and the map of the park found in the online Denali brochure linked to from the *Denali Rocks!* student page.

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2. Find Mt. Foraker south of the fault and McGonagall Mountain by the Muldrow Glacier north of the fault. These two mountains are parts of the same pluton, magma that hardened underground about 37 million years ago. It split along the fault and moved apart. How far has Foraker moved away from McGonagall since then? (1 inch = 4 miles on the map).

   4 miles/inch X 6.5 inches = 26 miles

3. The park boundary is 35 miles west of Denali. If the land south of the fault continues moving at the same rate, about how long will it take for Denali to move out of its own park?

   It should take about 50 million years (there is evidence that the fault is slowing down, however, so it will probably take longer).

4. Look at the glaciers on the north side of the range, starting on the west side of the map. Cut off by the edge of the 3-D plastic raised relief map of Denali National Park and Preserve is the Chedotlothna Glacier behind Mt. Russell (it is on the online park brochure map, though), followed by the Heron, Foraker, Straightaway, Peters, and Muldrow Glaciers. What general shape do they ***all*** have in common as you follow them from where they start to where they end? Draw it below.

   The glaciers start northward, then are deflected to the east, then continue northward again.

5. Glaciers like to travel in a straight path, but in every one of these glaciers, it looks like the south ends have been moved to the west, and the north ends have been moved to the east, making a big zigzag. How can you explain this?

   The glaciers are all moving to the north across the fault, so they are stretched laterally where they cross it, making a west-to-east zigzag.

6. The plate south of the fault isn't just sliding to the west, it's rising up as well. (This makes the Denali Fault a "thrust fault" as well as a "slip-strike fault.") Compare the mountains north of the fault to those south of the fault near Denali. How are they different?

   The mountains to the south are far higher and rise more dramatically.

7. The Wickersham Wall is evidence of the light granite pluton at the north edge of the plate being pushed up vertically. While land on the north side of the fault continues to erode, land on the south side of the fault (especially the light granite) is popping up like a cork. Besides the Wickersham Wall, what other evidence can you see for uplifting south of the fault?

   The dramatic rise from Mt. Mather in the east past Mt. Foraker in the west is the result of this uplifting.

Lesson 4

Activity 4.3 Denali Geologic Time Line

This activity helps students to comprehend the scale of geologic time.

1. Explain to students that they are going to construct a geologic time line. In this particular time line, the scale will be: 1 inch = 1 million years.
2. There are 14 events on this time line (see back of this page). Assign a student (or pair of students) to each event. Have the students make signs for their events by writing down the geological event and the time at which it took place on a piece of paper.
3. Next, they should figure out where they'll be standing on the time line. It may help for the teacher to model this calculation on the board. Convert the number of millions of years to inches (200 million years = 200 inches). Then divide by 12 to get feet. It helps to do this by hand because their remainders are the "leftover" inches, whereas calculators would show remainders as decimal parts of feet. Have the students write their distance from the present day on their signs. (Note: Calculations for the first two events on the time line will require slight modification.)
4. If you are using string instead of a 100 foot tape, have a group that gets done early mark off 10 foot intervals on the string with a marker to make later measurements easier.
5. Go outside (or use the gym or hallway). Starting with the present day, have students go to their places on the time line as you say each event. There isn't enough string for the last event!
6. The students' signs could be put up in the classroom using the same (or smaller) scale to create a geologic timeline for display. Students could illustrate each event.

Students on the timeline represent:

- The present day
- **10,000 years ago —** The end of the most recent glacial advance.
  (0.01 in)
- **14,000 years ago —** The first people arrive in Alaska, living alongside mammoths, saber-tooth cats, camels, and bear-sized beavers.
  (0.14 in, or about 1/8 inch)
- **1.8 million years ago —** First human-like hominids (*Homo erectus*) in Africa.
  (1.8 in, or about 3/4 inch)
- **5 million years ago —** Denali is around 10,000 feet high, half its present height. The Alaska Range is a group of low hills.
  (5 in)
- **6 million years ago —** Denali is pushed up out of the sedimentary rocks covering it.
  (6 in)
- **30 million years ago —** Lush forests create present-day coal beds (Usabelli Mines).
  (30 in, or 2 ft 6 in)
- **37 million years ago —** Mt. Foraker pluton is formed in the earth's crust.
  (38 in, or 3 ft 2 in)
- **56 million years ago —** Cracks formed in the crust by the collision lets upwelling magma form the park's volcanic rocks on the surface and the McKinley pluton in the earth's crust.
  (56 in, or 4 ft 8 in)
- **65 million years ago —** A huge cluster of islands (the Talkeetna Superterrane) collides with the Alaska mainland to form Southcentral Alaska.
  (65 in, or 5 ft 5 in)
- **75 million years ago —** The ocean shore was just north of Denali. A shallow sea filling with sediment was trapped between it and the "Talkeetna Superterrane" approaching from the south.
  (75 in, or 6 ft 3 in)
- **225 million years ago —** Dinosaurs were the world's predominant land animals and many lived in Alaska, which was then located near the equator!
  (225 in, or 18 ft 9 in)
- **1 billion years ago —** The oldest rocks found in Denali National Park and Preserve were formed.
  (1000 in, or 83 ft 4 in)
- **4.4 billion years ago —** The oldest rocks ever found on Earth were formed.
  (4,400 in, or 367 ft)

Lesson 5
Denali Rocks! How the Mountain Got so BIG

The Athapaskan people (Native Alaskans of the region) called the mountain Denali or "The High One." NPS photo by Kent Miller.

Overview:

Students rotate through three stations to investigate rock types, rock hardness, and rock density. By comparing rocks that make up Denali (granite) to the rocks that make up lesser peaks in the Alaska Range (sedimentary), they will understand that Denali is higher because it gets pushed up more easily and erodes more slowly than rocks in surrounding mountains.

Objectives:

Students will:

- Identify samples of the three basic types of rock and describe the origin of each type.
- Use physical characteristics that geologists use to classify rocks: appearance, hardness and density.
- Give two reasons why Denali is higher than other peaks in the Alaska Range.

Duration:

60 minutes (two class periods)

Vocabulary:

gravel bar, igneous rock, sedimentary rock, metamorphic rock, density, Mohs' Hardness Scale

Materials:

Lesson Section	Materials needed
Activity 5.1	2 specimens each of sedimentary rock, igneous rock (granite), and metamorphic rock (schist) 1 blindfold
Activity 5.2	10 each of igneous (granite) and sedimentary rocks 10 iron nails 10 pre-1982 copper pennies (newer pennies won't work) Mohs' scale of Hardness rock collection
Activity 5.3	Graduated cylinder (in Archimedes Balance kit)[a] 1 each of igneous (granite) and sedimentary rock[a] Calculator Scale (electronic or triple-beam balance) Water (sink, or a large cup or pitcher of water)

Note: additional cylinders and rocks will allow multiple groups to do the activity at the same time.

Background:

Refer to the "So How Did the Big Mountain Get So Big" and "The Birth of a Mountain Range" sections in the "Teacher Background: The Geology of Denali National Park and Preserve" from Lesson 1.

Preparation:

1. Prepare rocks for Activity 5.1 by numbering them as follows: igneous rocks = 1 and 5; sedimentary rocks = 2 and 3; metamorphic rocks = 4 and 6.
2. This lesson will probably require two class periods; decide how you will handle this. One possible option: Day 1, do steps 1-4 and one station/group; Day 2, do two more stations/group and steps 6-8.
3. Set up the three stations. There should be no more than four students at each station; if you have more than 12 students in your class, divide the class in half and make two sets of the three stations.
4. Make a table on the board for students to record group results from Rock Density measurements so class data can be compared (step 3 for this station on the worksheet). Make two columns: sedimentary rocks and igneous rocks.

Procedure:

1. Read and discuss with the class the introduction on the student worksheet.
2. Follow up on the final bullet under "To summarize" by having students hypothesize why Denali is so much higher than the surrounding mountains in the Alaska Range.
3. Tell class they will do experiments with rocks to discover why Denali is so tall.

4. Explain the procedure at each of the three stations. Have students follow along on their student worksheet directions while you go over the procedure for each station.
   - The Rock Types and Rock Hardness stations are relatively easy to do, so explain them first.
   - Emphasize that the Rock Density station requires careful measuring to get good results since the rock samples are small. Show students how to read a graduated cylinder, and demonstrate how to slide, not drop, the sample into the cylinder. Also show them where to record their density data on the board.
5. Make groups and send students off to work in stations. They will need 15 - 20 minutes at each station, so tell them how many they will complete this period and how many they will do tomorrow.
6. After all groups have completed the labs, discuss the results from each station. Refer to the table of class data for Rock Density to eliminate outliers and average reasonable results.
7. Return to the question of why Denali is so much higher than the surrounding mountain peaks.
   - Discuss the formation of the Alaska Range, building on what they learned about plate tectonics. Denali is made of granite, an igneous rock formed from an underground pool of magma, and on top of Denali is a layer of sedimentary rock. Most of the rest of the Alaska Range is made of uplifted sedimentary rock.
   - Lead students to the conclusion that Denali is higher because it is made of granite, while its neighbors are mostly made of sedimentary rock; since granite is less dense it is more easily lifted to the surface (Denali keeps rising) and since it is harder it is much less susceptible to erosion.
8. Have students answer the last question on their worksheets independently.

Assessment:

Collect worksheets. Check lab results for accuracy and final question for understanding.

Extensions:

1. View a photo of a granite sculpture (Mount Rushmore) at http://www.NPS.gov/moru/
2. Read the book, *Everybody Needs a Rock*, by Byrd Baylor and have students find their very own rock.
3. Collect other rocks locally (see the previous extension). Have each student identify which type of rock theirs is, and test their rock for hardness and density.

Name: ______________________________

Date: ______________________________

Class: ______________________________

Student Worksheet

Lesson 5

Denali Rocks! How the Mountain Got so BIG

The Athapaskan people (Native Alaskans of the region) called the mountain Denali or "The High One." NPS photo by Kent Miller.

Denali is a geologic marvel, soaring higher above its base than even Mt. Everest. Denali starts at about 2000 feet and rises over three and one-half miles to its 20,320 foot summit. Everest begins on a 14,000-foot high plain, then summits at 29,028 feet. In the Alaska Range, most other peaks are "only" 4,000 to 7,000 feet high. How did Denali get so much higher than its neighbors? The answer is in the rocks.

Do you have a rock collection? Have you ever marveled at the diversity of colors, patterns, shapes and sizes of rocks on a **gravel bar**? There are a great many different kinds of rocks in Denali National Park and Preserve; knowing about them helps you begin to sense the complex events that formed these mountains. This area has been the site of a coastline and shallow sediment-filled sea, volcanoes, trenches, and a subducting plate that has carried terranes (large chunks of rock) from far away. No wonder there are so many rock types here!

Identifying rocks is the first step in figuring out the geologic history of an area. Rocks are classified into three main types based on how they were formed: igneous, metamorphic, and sedimentary. **Igneous** (like the word "ignite") **rocks** are formed by the cooling of molten rock. **Sedimentary rocks** come from sediments deposited by water, wind or glaciers that have been buried and compressed to form rock. **Metamorphic rocks** are igneous or sedimentary rocks that have changed form by intense heat and pressure deep within the earth (like a butterfly changes form when it undergoes metamorphosis).

Geologists measure the hardness of rocks to help identify unknown samples. Hardness can be tested through scratching. A harder mineral can scratch a softer one but a softer mineral can never scratch a harder one. The **Mohs' Hardness Scale** is used by geologists around the world. It uses ten common minerals and arranges them into a 10-point scale of increasing hardness, with "1" being the softest (talc) and "10" being the hardest (diamond).

In order to compare the heaviness of rocks, scientists don't simply measure their weight. What is heavier, wood or gold? A tree weighs more than a gold nugget, but a tree floats and a nugget sinks in water. To compare heaviness you must find the **density**: the weight (mass) of a given volume of the material. A certain volume of gold weighs more than the same volume of wood so it is said to be more dense. To find the density of an object, you must know its weight (which measures its mass) and its volume. Dividing the mass by the volume gives you density.

To summarize:

- There are three types of rocks: igneous, sedimentary and metamorphic.
- Hardness of rocks is measured using Mohs' Hardness Scale.
- Density is the mass (weight) of an object divided by its volume.
- Scientists use these and other techniques to determine the geologic make up and history of Denali and the Alaska Range, and to understand why Denali is higher than neighboring peaks.

Vocabulary:

gravel bar, igneous rock, sedimentary rock, metamorphic rock, density,
Mohs' Hardness Scale

Activity 5.1 Rock Types Station

In this lab, you will observe and identify the three rock types.

Materials:

2 sedimentary rocks

2 metamorphic rocks

2 igneous rocks

Blindfold

Key to the Three Rock Types

Igneous rocks

- **Origin:** Formed by the cooling of molten rock (magma or lava).
- **Examples:** Granite, basalt, pumice, obsidian.
- **Appearance:** Made up of crystals that form as the magma cools. Crystals may be large, like in granite, or small and granular, like in basalt. Does not break apart in layers. May be glassy and smooth, like obsidian.

Sedimentary rocks

- **Origin:** Formed from sediments that have been deposited on the surface by wind or water, and are then buried and compressed to become rock.
- **Examples:** Sandstone, shale, conglomerate, limestone.
- **Appearance:** Can look like pebbles that have been cemented together, like conglomerate, or fine-grained, like sandstone. Often looks like many thin layers and breaks apart along layers. May contain fossils.

Metamorphic rocks

- **Origin:** Formed when sedimentary or igneous rocks are changed by intense heat and pressure deep within the earth. Metamorphic rocks can also be changed by intense heat and pressure to form other metamorphic rocks.
- **Examples:** Schist, slate, gneiss (pronounced nice) from mudstone; marble from limestone.
- **Appearance:** After rocks are squeezed and baked beneath the earth's surface, the minerals recrystallize in an altered form, often showing deformed or folded layers interlaced with white layers of quartz. Look for bands or for layers that aren't flat.

Procedure:

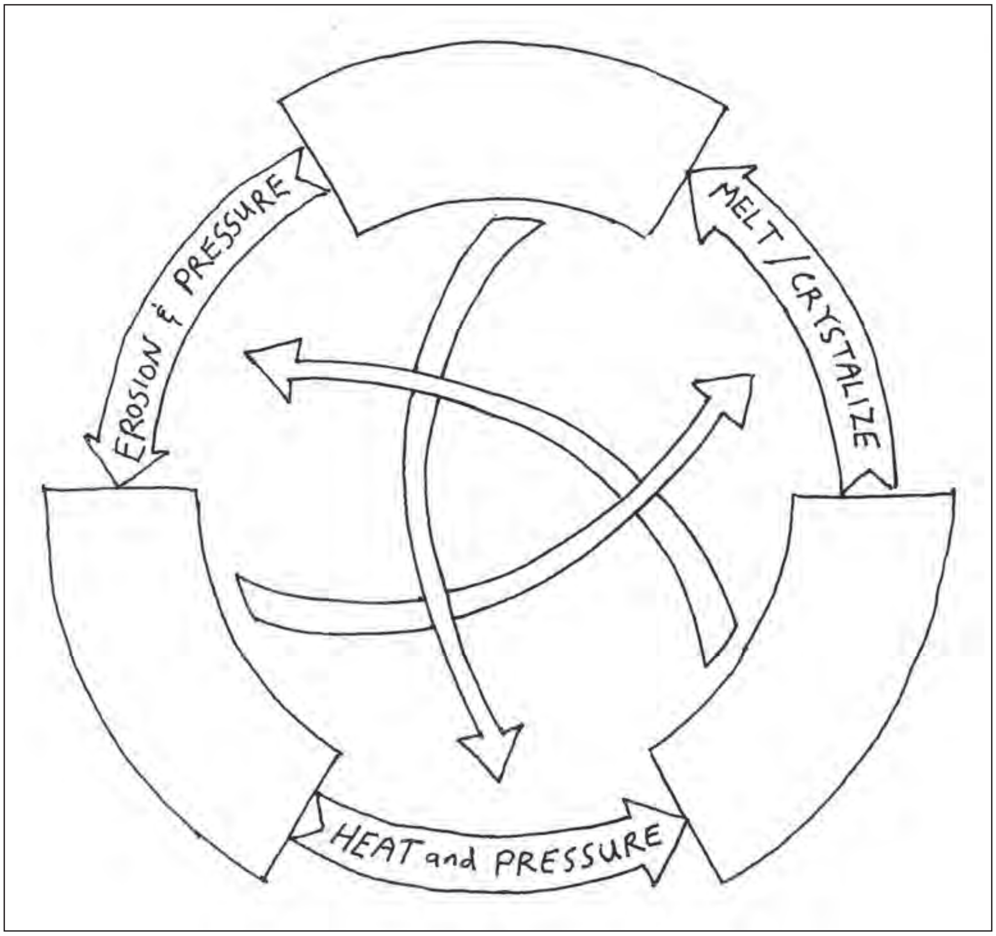
1. Working with your partners, use the key to figure out the type of each of the six rocks. Record your results below.

Rock Number	1	2	3	4	5	6
Rock Type (I, S, M)						

2. Choose a student to select one of the six rocks. Give them 30 seconds to become familiar with its weight, texture and shape. Then blindfold that student, mix up the rocks, and give him or her 60 seconds to find the rock.
3. Repeat until each student has succeeded in finding his or her rock.
4. Read the following description of the rock cycle

   In nature, many things run in cycles including rocks. For billions of years, the earth has been changing one type of rock into another. New **igneous rocks** form where magma breaks through the surface of the earth, like a volcano. Mountains are constantly worn away by the erosive forces of weather, glaciers, and wind, and silty rivers wash the sediment out to sea. There it settles, and over time cements together to form new **sedimentary rocks**. The pressure of colliding plates squeezes and heats these sedimentary rocks, forming new **metamorphic rocks**. These rocks get dragged down into the earth and re-melted into magma, and the cycle continues...

5. Label the diagram below by writing **igneous**, **sedimentary** or **metamorphic** next to the arrow that shows where each kind of rock is being formed.



NPS illustration by Doug Smith.

Activity 5.2 Rock Hardness Station

In this lab, you will determine the hardness of two different types of rock by trying to scratch them with materials of known hardness: a nail, a penny and several rocks from a Mohs' Hardness kit.

Materials:

10 pieces of igneous rock (granite)
10 pieces of sedimentary rock
iron nails
pennies (pre-1981; solid copper)
Mohs' Hardness Scale collection (red box)

Procedure:

1. Test the two kinds of rocks with the nail.
   - Select a fresh clean surface on one of the sample sedimentary rocks.
   - Put the sample on the table and try to scratch it with the nail. If the nail is harder, you will feel a definite "bite" into the rock sample.
   - Wipe away the dust trail on the rock sample and inspect it for an etched line. If you are unsure of your result, repeat the test again in a different spot on the rock.
   - Determine whether the nail is harder than the rock (scratched it) or softer (no scratch).
   - Record your results on the table below. If the nail scratched the rock, put an "H" (for harder) under "nail" in the row for Sedimentary Rock. Put an "S" (for softer) if it did not.
   - Repeat the nail test with the igneous rock sample, and mark the data table.
2. Test both kinds of rock with the penny.
   - Use the pointed end of a sample rock, and try to scratch the penny with it.
   - Determine whether the penny is harder than the rock (not scratched) or softer (scratched).
   - Record results in the table . Put "H" if the is penny harder or "S" if the penny is softer.
3. Test the rocks using the rocks from the Mohs' Hardness Scale kit.
   - Using rocks from the Mohs' Scale collection, scratch the sample rocks until you have determined the hardness of each of your two samples. Note: It works better to use a Mohs' Scale rock to scratch the sample rock rather than using the sample to scratch the Mohs' Scale rock.
   - For each test, record whether the Mohs' rock was harder ("H") or softer ("S") than the sample.
4. Determine the hardness of your two samples. The hardness of your rock sample will fall between an "H" (harder rocks to the right) and an "S" (softer rocks to the left) in the data table.
5. Answer the questions below the table.

Mohs' Hardness	1	2	3	penny (3.5)	4	5	nail (5.5)	6	7	8	9
Sedimentary Rock											
Igneous Rock (Granite)											

Questions:

1. What is the Mohs' Hardness of your two sample rocks?

   Sedimentary rock: ____________________ Igneous rock: ____________________

2. Wind, rain, glaciers, freezing and thawing all wear down rocks. Which of your two sample rocks do you think would erode more easily and why?

3. All the mountains in the Alaska Range are being uplifted at about the same rate. Denali is made of granite, while most of the rest of the range is made of sedimentary rock. Explain why the other mountains are smaller.

Activity 5.3 Rock Density Station

In this lab, you will compare two types of rock to see which is denser. Record your results below.

Materials:

Scale

Sedimentary and igneous (granite) rocks: 1 of each

Graduated cylinder with directions

Procedure:

1. Measure Mass.
   - Weigh one of each rock type.
   - Record the results below.

	Sedimentary Rock	Igneous Rock
Mass of the rock:	___________ grams (g)	___________ grams (g)

2. Measure volume. Finding the volume of irregularly-shaped objects is easy—just see how much water they displace. Here's how:
   - Fill the graduated cylinder around half-full with water. Record the water level on the first line below.
   - Tilt the cylinder so you can slide a rock into the water (if you drop it straight in, water drops can splash out and you'll have to start over).
   - Slide the sedimentary rock into the water, set the cylinder upright and record the new water level on the second line.
   - Subtract your first reading from the second reading.; the difference is the volume of the rock. Record the rocks' volumes on the third line.
   - Repeat this process with the igneous rock.

	Sedimentary Rock	**Igneous Rock**
Water volume (no rock)	________________ ml	________________ ml
Water volume (with rock)	________________ ml	________________ ml
Volume of rock (subtract)	________________ ml	________________ ml

3. Calculate density:
   - Divide the rock's mass (step 1) by its volume (step 2).
   - Record the density below. Then record it in the table on the board so we can compare class data.

   Density:

   Sedimentary Rock ______________ g/ml Igneous Rock ______________ g/ml

4. How *did* the mountain get so BIG?

   Wait until your class has discussed the results from all these stations. Then answer this question:
   - Based on what you have learned, give two reasons why Denali is so much higher than the other mountains in the Alaska Range.

Name: ______________________________

Date: ______________________________

Class: ______________________________

Answer Key

Lesson 5
Denali Rocks! How the Mountain Got so BIG

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Vocabulary:

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Mohs' Hardness Scale

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2 metamorphic rocks

2 igneous rocks

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- **Examples:** Schist, slate, gneiss (pronounced nice) from mudstone; marble from limestone.
- **Appearance:** After rocks are squeezed and baked beneath the earth's surface, the minerals recrystallize in an altered form, often showing deformed or folded layers interlaced with white layers of quartz. Look for bands or for layers that aren't flat.

Procedure:

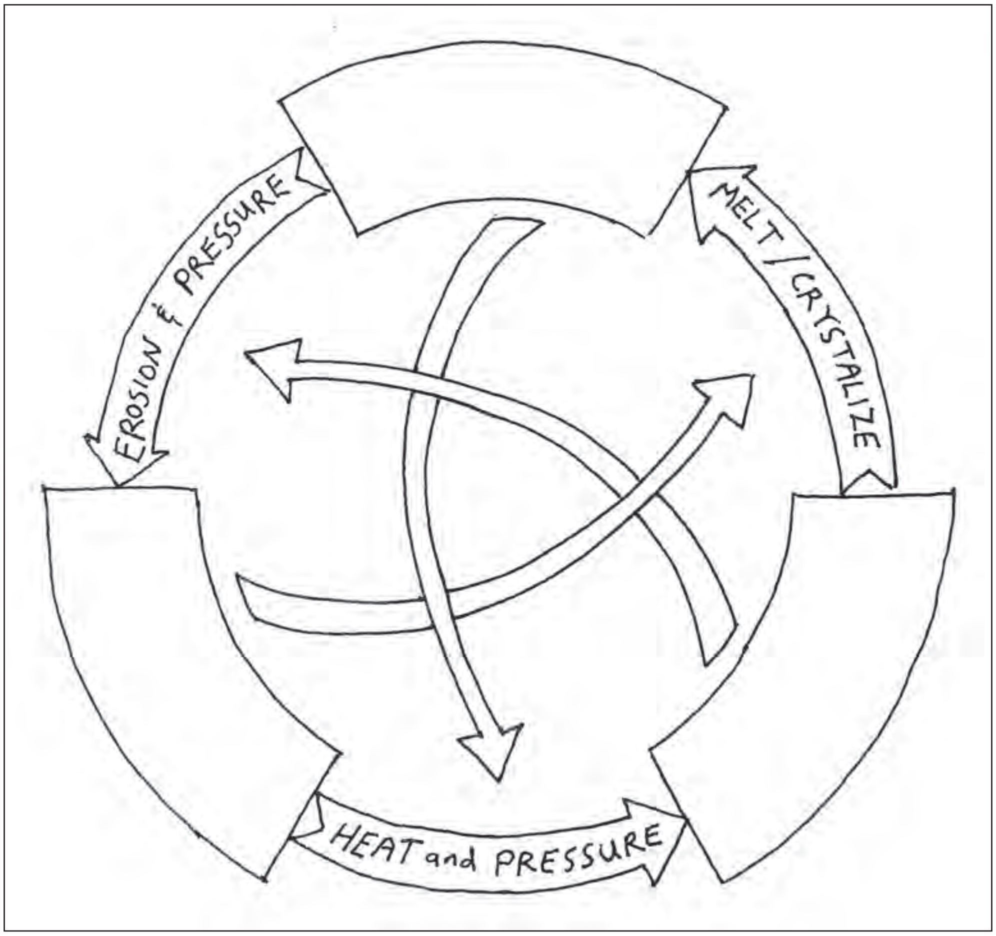
1. Working with your partners, use the key to figure out the type of each of the six rocks. Record your results below.

Rock Number	1	2	3	4	5	6
Rock Type (I, S, M)	*I*	*S*	*S*	*M*	*I*	*M*

2. Choose a student to select one of the six rocks. Give them 30 seconds to become familiar with its weight, texture and shape. Then blindfold that student, mix up the rocks, and give him or her 60 seconds to find the rock.
3. Repeat until each student has succeeded in finding his or her rock.
4. Read the following description of the rock cycle

   In nature, many things run in cycles including rocks. For billions of years, the earth has been changing one type of rock into another. New **igneous rocks** form where magma breaks through the surface of the earth, like a volcano. Mountains are constantly worn away by the erosive forces of weather, glaciers, and wind, and silty rivers wash the sediment out to sea. There it settles, and over time cements together to form new **sedimentary rocks**. The pressure of colliding plates squeezes and heats these sedimentary rocks, forming new **metamorphic rocks**. These rocks get dragged down into the earth and re-melted into magma, and the cycle continues...

5. Label the diagram below by writing **igneous**, **sedimentary** or **metamorphic** next to the arrow that shows where each kind of rock is being formed.



NPS illustration by Doug Smith.

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Materials:

10 pieces of igneous rock (granite)
10 pieces of sedimentary rock
iron nails
pennies (pre-1981; solid copper)
Mohs' Hardness Scale collection (red box)

Procedure:

1. Test the two kinds of rocks with the nail.
   - Select a fresh clean surface on one of the sample sedimentary rocks.
   - Put the sample on the table and try to scratch it with the nail. If the nail is harder, you will feel a definite "bite" into the rock sample.
   - Wipe away the dust trail on the rock sample and inspect it for an etched line. If you are unsure of your result, repeat the test again in a different spot on the rock.
   - Determine whether the nail is harder than the rock (scratched it) or softer (no scratch).
   - Record your results on the table below. If the nail scratched the rock, put an "H" (for harder) under "nail" in the row for Sedimentary Rock. Put an "S" (for softer) if it did not.
   - Repeat the nail test with the igneous rock sample, and mark the data table.
2. Test both kinds of rock with the penny.
   - Use the pointed end of a sample rock, and try to scratch the penny with it.
   - Determine whether the penny is harder than the rock (not scratched) or softer (scratched).
   - Record results in the table . Put "H" if the is penny harder or "S" if the penny is softer.
3. Test the rocks using the rocks from the Mohs' Hardness Scale kit.
   - Using rocks from the Mohs' Scale collection, scratch the sample rocks until you have determined the hardness of each of your two samples. Note: It works better to use a Mohs' Scale rock to scratch the sample rock rather than using the sample to scratch the Mohs' Scale rock.
   - For each test, record whether the Mohs' rock was harder ("H") or softer ("S") than the sample.
4. Determine the hardness of your two samples. The hardness of your rock sample will fall between an "H" (harder rocks to the right) and an "S" (softer rocks to the left) in the data table.
5. Answer the questions below the table.

Mohs' Hardness	1	2	3	penny (3.5)	4	5	nail (5.5)	6	7	8	9
Sedimentary Rock	*S*	*S*	*H*	*H*	*H*	*H*	*H*	*H*	*H*	*H*	*H*
Igneous Rock (Granite)	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S*	*S or H*	*H*	*H*

Questions:

1. What is the Mohs' Hardness of your two sample rocks?

   Sedimentary rock: *2-3*   Igneous rock: *7*

2. Wind, rain, glaciers, freezing and thawing all wear down rocks. Which of your two sample rocks do you think would erode more easily and why?

   The sedimentary rock will erode more easily, because it is softer.

3. All the mountains in the Alaska Range are being uplifted at about the same rate. Denali is made of granite, while most of the rest of the range is made of sedimentary rock. Explain why the other mountains are smaller.

   For the sedimentary rock, the rate of erosion is faster than the rate of uplift. For Denali, the rate of erosion is less than the rate of uplift.

Activity 5.3 Rock Density Station

In this lab, you will compare two types of rock to see which is denser. Record your results below.

Materials:

Scale

Sedimentary and igneous (granite) rocks: 1 of each

Graduated cylinder with directions

Procedure:

1. Measure Mass.
   - Weigh one of each rock type.
   - Record the results below.

	Sedimentary Rock	Igneous Rock
Mass of the rock:	___________ grams (g)	___________ grams (g)

Answers will vary in parts 1 and 2 of this lab, depending on which of the sample rocks the students measure. They should all get the same densities in part 3.

2. Measure volume. Finding the volume of irregularly-shaped objects is easy—just see how much water they displace. Here's how:
   - Fill the graduated cylinder around half-full with water. Record the water level on the first line below.
   - Tilt the cylinder so you can slide a rock into the water (if you drop it straight in, water drops can splash out and you'll have to start over).
   - Slide the sedimentary rock into the water, set the cylinder upright and record the new water level on the second line.
   - Subtract your first reading from the second reading.; the difference is the volume of the rock. Record the rocks' volumes on the third line.
   - Repeat this process with the igneous rock.

	Sedimentary Rock	Igneous Rock
Water volume (no rock)	________________ ml	________________ ml
Water volume (with rock)	________________ ml	________________ ml
Volume of rock (subtract)	________________ ml	________________ ml

Answers will vary in parts 1 and 2 of this lab, depending on which of the sample rocks the students measure. They should all get the same densities in part 3.

3. Calculate density:
   - Divide the rock's mass (step 1) by its volume (step 2).
   - Record the density below. Then record it in the table on the board so we can compare class data.

   Density:

   Sedimentary Rock *3.1* g/ml Igneous Rock *2.4* g/ml

*Because the rock samples are so small, expect large variations in the results here. It helps to put students' density results on the board: throw out the "outliers" and average the rest to get results close to these. It could be instructive to discuss sources of error (most likely in measuring volume). **NOTE:** Your densities may differ from the answers above based on your particular rock samples. Do the density measurement beforehand to determine the answers for your rock samples.*

4. How *did* the mountain get so BIG?

   Wait until your class has discussed the results from all these stations. Then answer this question:
   - Based on what you have learned, give two reasons why Denali is so much higher than the other mountains in the Alaska Range.

It is less dense so it is uplifted easily (some say that it "floats" above the other denser rocks like a cork). It is also harder, so it doesn't erode as rapidly as the surrounding mountains.

Lesson 6
A Land of Glaciers


The Muldrow Glacier flows from the summit of Mount McKinley.
NPS photo.

Overview:

Students will learn about glacial landscapes through reading, looking at maps, and exploring internet sites.

Objectives:

Students will:

- Identify and label features of glaciers and effects of glaciers on a landscape.
- Locate glaciers and features of the glacial landscape on maps of Denali National Park and Preserve.
- Search for pictures of glacial features on the internet.

Duration:

60-90 minutes

Vocabulary:

glacier, cirque, arête, col, horn, U-shaped valley, crevasse, icefall, till, moraine (lateral, medial, terminal), terminus, kettle lake, hanging valley, erratic

Materials:

Lesson Section	Materials needed
Activity 6.2	3-D plastic raised relief map of Denali National Park and Preserve Computers with internet access to look at the online Denali National Park and Preserve brochure map linked to off of the Denali Rocks! Teacher and Student Pages
Activity 6.3	Computers with internet access List of internet sites for glacier research (on Lesson 6 student worksheet)

Background:

Refer to the "The Power to Move Mountains" and "A Land Sculpted by Ice" sections in the "Teacher Background: The Geology of Denali National Park and Preserve" from Lesson 1.

Preparation:

1. Determine the best approach for delivering this lesson given your class size, technology resources and computer access. There are three activities: reading and labeling a diagram, finding features on maps, and looking for images on the internet; each will take approximately 15 minutes (the internet search could be extended). If you have computers in your classroom, you can set up three stations for student groups to rotate through. If the computers are in a school lab or if you prefer to project pictures in front of the class, you can do that as a whole group and split into two groups for the reading and maps. Of if your class is small enough, you can do everything as one group.
2. To set up three stations: Designate an area for the reading and diagram work on the student worksheet (Activity 6.1), place the 3-D plastic raised relief map of Denali National Park and Preserve on a table next to computers with internet access so that students can look at the online park brochure map or project the map onto a screen for the entire group to look at (Activity 6.2), and have computers ready for the internet search (Activity 6.3). Make three student groups.

Procedure:

1. Review the geology of mountain building from Lessons 3 – 5, and make a transition by telling students that the next three lessons will be about glaciers and their role in wearing mountains down through erosion.
2. If you are using the stations approach, briefly explain the directions for each station (refer to student worksheet), indicate where each station is located, and make groups.
3. If you will work as a whole group, begin with the worksheet reading and Activity 6.1.

Activity 6.1 The Glacial Landscape

Students read background material and label a diagram.

1. Have students read the background reading on the student worksheet.
2. Students then label the diagram and answer the questions on their worksheets.
3. Or, do this activity as a class. Read the background together and fill in the diagram together (you might project it in front of the classroom).

Activity 6.2 Denali's Glaciers

Students look for features on the online park brochure maps and 3-D plastic raised relief map of Denali National Park and Preserve.

1. Have students peruse the maps, looking for glacial features.
2. Students then use the map to answer questions on the student worksheet.
3. Or as a whole class, project the online Denali brochure map so all the students can see it. Students can work around the 3-D plastic raised relief map of Denali National Park and Preserve on a centrally-placed table.

Activity 6.3 Picture This

Students will search the internet for pictures of glacial features (see vocabulary list).

1. Send students alone or in pairs to a computer with internet access.
2. Give students time to search for pictures of the various features listed on the student worksheet. Remind them to check the features off as they find them.
3. Students then answer the questions on their worksheets.
4. Have students save as a "favorite" the best glacier picture from their search. Depending on your technological capabilities, these could be saved to a class folder for everyone to view, presented as a "slideshow," printed to make a classroom display, or shared among individual students at their computers.
5. This activity can also be done by the class going to the computer lab for student internet search, or with you projecting images for the whole class to see.
6. While on the computer, a trip to Denali National Park and Preserve on Google Earth is a must. Tilt the earth so it looks like you are flying. Explore the glacier valleys, cols and mountains in the range. Try to identify as many of the glaciers and peaks as you can.

Assessment:

Follow up the three activities by going over the answers to the questions on the worksheets. Look at student's worksheets to make sure students understand the terms presented in this lesson. Give students time to share their favorite internet images.

Extensions:

1. Invite a climber to your classroom. They can make this unit come alive with stories, slide shows, equipment and know-how.
2. For a look at how the coastal Alaskan town of Yakutat is being threatened by the advancing Hubbard Glacier, go to http://www.glacierresearch.com. You can see what the glacier is doing daily thanks to a laser rangefinder that scientists installed to measure the glacier's advance.

Name: ______________________________

Date: ______________________________

Class: ______________________________

Student Worksheet

Lesson 6
A Land of Glaciers

The Muldrow Glacier flows from the summit of Mount McKinley. NPS photo.

While colliding plates have uplifted the Alaska Range, other forces have been tearing it down. Wind, rain, rivers and glaciers are all doing their part in breaking the mountains into pieces and carrying them back to the ocean. In Denali Park and Preserve, glaciers play a major role; there are more than 20 glaciers over five miles long, and six of these are over 25 miles long. There have been numerous times in the past when the lands south of the park have been completely covered by glaciers that were miles thick. Their effects can be seen almost everywhere in southern Alaska.

Glaciers are moving rivers of ice, formed where the amount of snow that falls in winter is greater than the amount that melts in the summer. In these accumulation zones, the immense weight of the piled-up snow compresses it into ice which then slowly flows downhill. A look at a map shows huge ice fields and numerous glaciers on the south side of the Alaska Range, while only a few individual glaciers run down the north side. (Of the six glaciers over 25 miles long, only the Muldrow is on the north side.) This is because a lot more snow accumulates on the south side. The Alaska Range acts as a barrier to the moisture-laden air sweeping north off the Pacific Ocean. When this air hits the range, it is pushed up and cooled, causing the moisture to be dropped on the south side, mostly in the form of snow. The amount of snow that accumulates can be enormous. The Ruth Glacier in the Great Gorge is 3,800 feet thick – 380 stories high!

At the upper ends of Denali's glaciers are steep-walled semicircular basins called **cirques**. These are caused by the freezing and thawing of meltwater in the rocks above the glacier, and by scouring action under the glacier. As cirques on the opposite sides of a ridge are cut deeper and deeper into the divide, they form a narrow serrated ridge called an **arête**. As the arête is worn away, the low point between cirques is called a **col** (or if it is large, a pass) – a good route for mountain climbers! When three or more cirques cut back into a mountain, a spire-like peak called a **horn** is formed.

Glacier ice flows downhill following old streambeds and filling valleys wall to wall with ice. The V-shaped valleys cut by rivers are enlarged to broad **U-shaped valleys** by the glaciers. The tops of glaciers are covered with **crevasses**, cracks in the brittle top layer of a glacier. They are most prevalent where a glacier bends around a corner or down a steep incline, where an **icefall** is formed. As glaciers move down the mountainside, they transport **till** (clay, sand, dirt, rocks and boulders). Over time, the glacial river pushes the till to the glacier's side, forming **lateral moraines**, or to the glacier's front end, forming **terminal moraines**. Where two glaciers meet, their lateral moraines merge together in the middle to form a **medial moraine**.

Eventually, the glacier flows far enough off the mountain that it melts faster than it grows. This area where the glacier is shrinking is called an ablation zone, which ends at the glacier's **terminus**. The large hills and broad valleys found throughout south-central Alaska consist of till from old glacial moraines. The landscape is filled with **kettle lakes** formed by melted chunks of ice left behind by a retreating glacier. A cirque basin left by a retreated glacier can form a **hanging valley**, often the source of a spectacular waterfall. Large, smooth house-sized rocks called **erratics** can be deposited far from their point of origin by former glaciers, and seem totally out of place, as their name implies. A huge erratic is found 4,200 feet high on the summit of Mount Fellows near Denali Park.

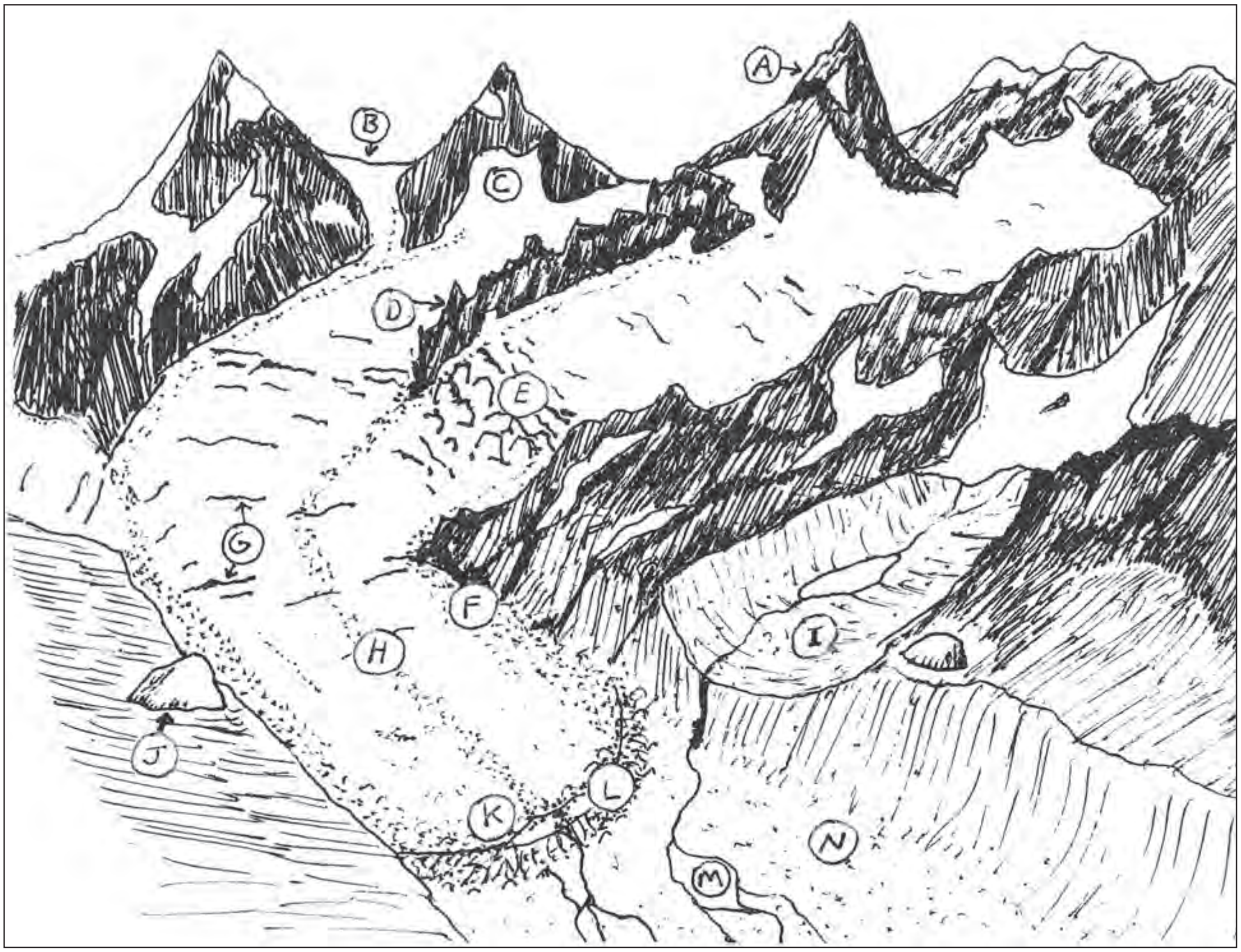
Glacial erratics like these are rocks that have been carried far away from the mountain they were part of by glaciers that eventually drop the rocks upon retreat. NPS photo.

Vocabulary:

glacier, cirque, arête, col, horn, U-shaped valley, crevasse, icefall, till, moraine (lateral, medial, terminal), terminus, kettle lake, hanging valley, erratic

Activity 6.1 The Glacial Landscape

Directions: Label the lettered features above, using the vocabulary terms (in bold) in the preceding reading. (Use all words except glacier and till.)



NPS illustration by Doug Smith.

A.

B.

C.

D.

E.

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M.

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Activity 6.2 Denali's Glaciers

Directions: Answer the following questions while you look at the maps of Denali National Park and Preserve.

1. List the six largest glaciers in Denali National Park and Preserve. Circle the largest.

2. Compare the glaciers on the north side of the range with those across the divide on the south side. In general, which side has bigger glaciers?

3. Name four glaciers that feed the Chulitna River.

4. All the rivers that begin on the south side of the Alaska Range continue flowing south except one: the Nenana. It's glacier cut a shortcut through the range 70,000 years ago. Find this cut (north of Cantwell). Name 4 creeks that enter the Nenana on its trip north.

5. Find Mount Fellows a few miles east of the park entrance. On top of it is an erratic that a glacier dropped there 10,000 years ago.

   Can you see a glacier around there now?

   From which direction do you think the glacier came (hint: is there a river nearby?)

6. As you enter the park on the road, you'll come to a valley to the north by Mount Margaret that the Savage River has eroded. In this valley are the oldest rocks in the park: 1 billion years old! Find this site: it is on the original shoreline of Alaska! All the land to the south has been tacked on by a subducting plate depositing terranes onto this ancient shore.

7. The broad valley that the park road follows to the Teklanika River is an old glacier moraine.

   How many kettle lakes can you find in the valley?

   Where do you find the most kettle lakes in the park?

8. How many cirques were cut by past glaciations at the headwaters of the Sanctuary River?

9. In the Don Sheldon Amphitheatre is a mountain that has been eroded by cirques on all sides.

   What is this kind of mountain called?

   What is the name of the mountain?

10. Find an example of another horn named on the map.

11. This area was unmapped when Belmore Brown's expedition climbed the mountain to within 100 feet of the summit in 1912. They crossed the range from the south by going up the Ohio River valley. It was a tough crossing. Describe two easier routes to cross the range.

12. What evidence do you see in landforms that suggest that the Toklat River and the Sanctuary River were once covered with glaciers?

Activity 6.3 Picture This!

Directions: Search the internet for pictures of the glacial features introduced in this lesson.

1. The following web sites have good pictures of glaciers.
   - http://pubs.usgs.gov/of/2004/1216/glaciertypes/glaciertypes.html
     This is the best: a glacier glossary that includes pictures of every defined term, and lots more besides. The place to start!
   - http://nsidc.org/glaciers
     This is an excellent site including pictures, glossary, data, facts, and more.
   - http://www.glaciers.er.usgs.gov/gl_slide/
     This site has scans of color slides of glaciers you can download.
   - http://www.usgs.gov/features/glaciers2.html
     This site has loads of pictures of Alaskan glaciers, and links to other good sites.
2. Check off each feature as you and your partner find them. Save the location (in "favorites") and write down the web address of the picture that shows the most examples of the listed words: the best picture in the class wins a bonus!

_____ arête	_____ hanging valley	_____ medial moraine
_____ cirque	_____ horn	_____ terminal moraine
_____ col	_____ icefall	_____ terminus
_____ crevasse	_____ kettle lake	_____ U-shaped valley
_____ erratic	_____ lateral moraine	

3. Best picture site (address): ____
4. Underline each word above that is in your best picture.
5. If you have time left over, you can get on Google Earth and take a virtual plane ride over the Alaska Range. Tilt the earth so you're flying low, then proceed up the Ruth Glacier, over Denali's summit, and down the Muldrow Glacier.

Name: ______________________________

Date: ______________________________

Class: ______________________________

Answer Key

Lesson 6
A Land of Glaciers

The Muldrow Glacier flows from the summit of Mount McKinley. NPS photo.

While colliding plates have uplifted the Alaska Range, other forces have been tearing it down. Wind, rain, rivers and glaciers are all doing their part in breaking the mountains into pieces and carrying them back to the ocean. In Denali Park and Preserve, glaciers play a major role; there are more than 20 glaciers over five miles long, and six of these are over 25 miles long. There have been numerous times in the past when the lands south of the park have been completely covered by glaciers that were miles thick. Their effects can be seen almost everywhere in southern Alaska.

Glaciers are moving rivers of ice, formed where the amount of snow that falls in winter is greater than the amount that melts in the summer. In these accumulation zones, the immense weight of the piled-up snow compresses it into ice which then slowly flows downhill. A look at a map shows huge ice fields and numerous glaciers on the south side of the Alaska Range, while only a few individual glaciers run down the north side. (Of the six glaciers over 25 miles long, only the Muldrow is on the north side.) This is because a lot more snow accumulates on the south side. The Alaska Range acts as a barrier to the moisture-laden air sweeping north off the Pacific Ocean. When this air hits the range, it is pushed up and cooled, causing the moisture to be dropped on the south side, mostly in the form of snow. The amount of snow that accumulates can be enormous. The Ruth Glacier in the Great Gorge is 3,800 feet thick – 380 stories high!

At the upper ends of Denali's glaciers are steep-walled semicircular basins called **cirques**. These are caused by the freezing and thawing of meltwater in the rocks above the glacier, and by scouring action under the glacier. As cirques on the opposite sides of a ridge are cut deeper and deeper into the divide, they form a narrow serrated ridge called an **arête**. As the arête is worn away, the low point between cirques is called a **col** (or if it is large, a pass) – a good route for mountain climbers! When three or more cirques cut back into a mountain, a spire-like peak called a **horn** is formed.

Glacier ice flows downhill following old streambeds and filling valleys wall to wall with ice. The V-shaped valleys cut by rivers are enlarged to broad **U-shaped valleys** by the glaciers. The tops of glaciers are covered with **crevasses**, cracks in the brittle top layer of a glacier. They are most prevalent where a glacier bends around a corner or down a steep incline, where an **icefall** is formed. As glaciers move down the mountainside, they transport **till** (clay, sand, dirt, rocks and boulders). Over time, the glacial river pushes the till to the glacier's side, forming **lateral moraines**, or to the glacier's front end, forming **terminal moraines**. Where two glaciers meet, their lateral moraines merge together in the middle to form a **medial moraine**.

Eventually, the glacier flows far enough off the mountain that it melts faster than it grows. This area where the glacier is shrinking is called an ablation zone, which ends at the glacier's **terminus**. The large hills and broad valleys found throughout south-central Alaska consist of till from old glacial moraines. The landscape is filled with **kettle lakes** formed by melted chunks of ice left behind by a retreating glacier. A cirque basin left by a retreated glacier can form a **hanging valley**, often the source of a spectacular waterfall. Large, smooth house-sized rocks called **erratics** can be deposited far from their point of origin by former glaciers, and seem totally out of place, as their name implies. A huge erratic is found 4,200 feet high on the summit of Mount Fellows near Denali Park.

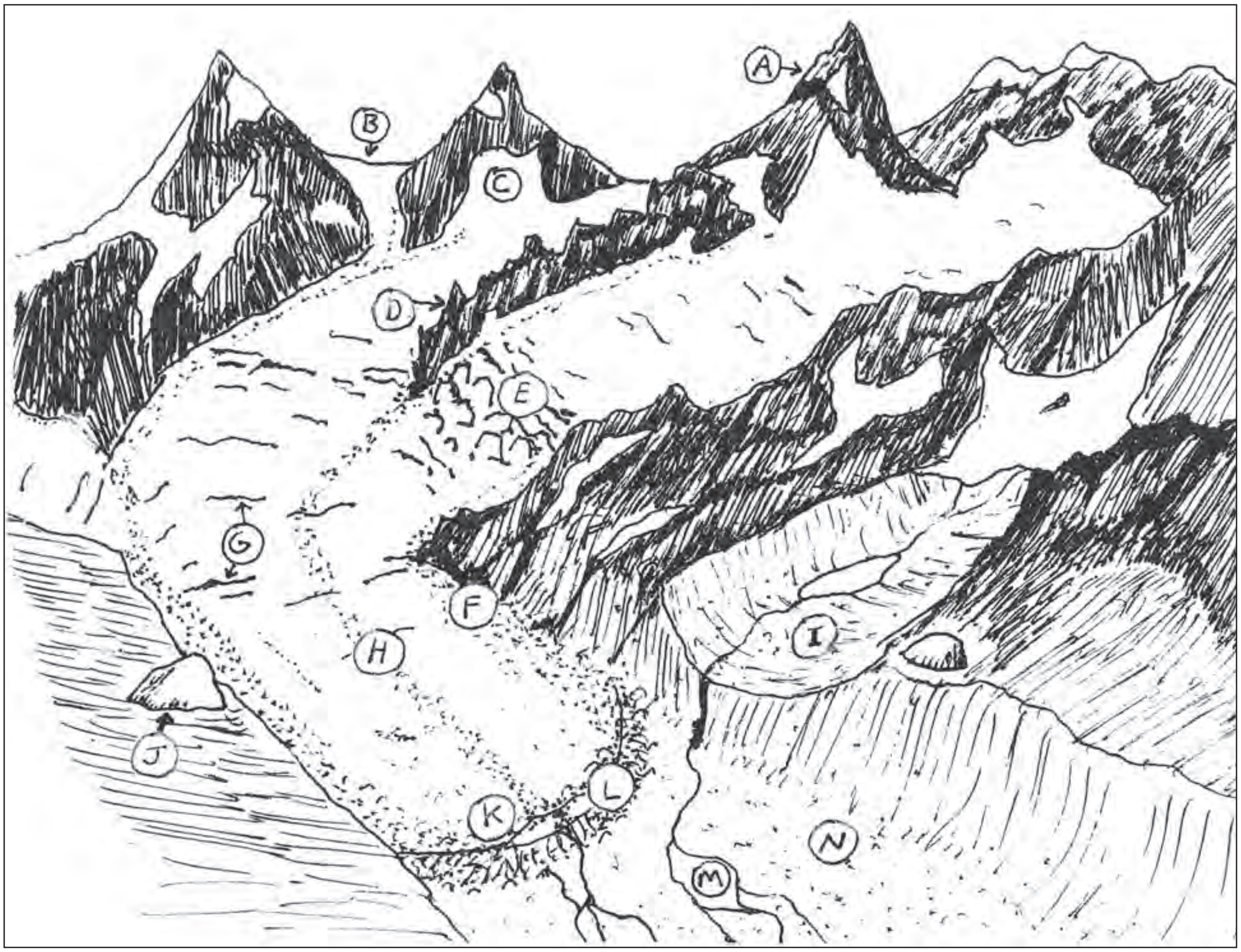
Glacial erratics like these are rocks that have been carried far away from the mountain they were part of by glaciers that eventually drop the rocks upon retreat. NPS photo.

Vocabulary:

glacier, cirque, arête, col, horn, U-shaped valley, crevasse, icefall, till, moraine (lateral, medial, terminal), terminus, kettle lake, hanging valley, erratic

Activity 6.1 The Glacial Landscape

Directions: Label the lettered features above, using the vocabulary terms (in bold) in the preceding reading. (Use all words except glacier and till.)



NPS illustration by Doug Smith.

A. *horn*

B. *col*

C. *cirque*

D. *arête*

E. *icefall*

F. *lateral moraine*

G. *crevasse*

H. *medial moraine*

I. *hanging valley*

J. *erratic*

K. *terminus*

L. *terminal moraine*

M. *kettle lake*

N. *U-shaped valley*

Activity 6.2 Denali's Glaciers

Directions: Answer the following questions while you look at the maps of Denali National Park and Preserve.

1. List the six largest glaciers in Denali National Park and Preserve. Circle the largest.
   Kahiltna (the largest; 43 miles), Muldrow (40 miles), Ruth (35 miles), Yetna-Lacuna (32 miles), Eldridge (30 miles) and Tokositna (25 miles).

2. Compare the glaciers on the north side of the range with those across the divide on the south side. In general, which side has bigger glaciers?
   South

3. Name four glaciers that feed the Chulitna River.
   Eldridge, Buckskin, Ruth, Tokositna

4. All the rivers that begin on the south side of the Alaska Range continue flowing south except one: the Nenana. It's glacier cut a shortcut through the range 70,000 years ago. Find this cut (north of Cantwell). Name 4 creeks that enter the Nenana on its trip north.
   Windy, Riley, Yanert, Hines, Healy

5. Find Mount Fellows a few miles east of the park entrance. On top of it is an erratic that a glacier dropped there 10,000 years ago.

   Can you see a glacier around there now?
   No

   From which direction do you think the glacier came (hint: is there a river nearby?)
   The glacier came down the valley to the east that the Yanert Fork now comes down (from the now-small Yanert Glacier).

6. As you enter the park on the road, you'll come to a valley to the north by Mount Margaret that the Savage River has eroded. In this valley are the oldest rocks in the park: 1 billion years old! Find this site: it is on the original shoreline of Alaska! All the land to the south has been tacked on by a subducting plate depositing terranes onto this ancient shore.

7. The broad valley that the park road follows to the Teklanika River is an old glacier moraine.

   How many kettle lakes can you find in the valley?
   The map shows the six largest.

   Where do you find the most kettle lakes in the park?
   The most kettle lakes are found west of here in the McKinley River Valley which used to be covered by a glacier.

8. How many cirques were cut by past glaciations at the headwaters of the Sanctuary River?
   There are four old cirques there.

9. In the Don Sheldon Amphitheatre is a mountain that has been eroded by cirques on all sides.

   What is this kind of mountain called?
   horn

   What is the name of the mountain?
   Mount Dan Beard

10. Find an example of another horn named on the map.
    Answers will vary; there are many!

11. This area was unmapped when Belmore Brown's expedition climbed the mountain to within 100 feet of the summit in 1912. They crossed the range from the south by going up the Ohio River valley. It was a tough crossing. Describe two easier routes to cross the range.
    Anderson Pass at the head of the West Fork of the Chulitna River and the Nenana River Valley

12. What evidence do you see in landforms that suggest that the Toklat River and the Sanctuary River were once covered with glaciers?
    Broad U-shaped valleys, kettle lakes, and cirques at their headwaters

Activity 6.3 Picture This!

Directions: Search the internet for pictures of the glacial features introduced in this lesson.

1. The following web sites have good pictures of glaciers.
   - http://pubs.usgs.gov/of/2004/1216/glaciertypes/glaciertypes.html
     This is the best: a glacier glossary that includes pictures of every defined term, and lots more besides. The place to start!
   - http://nsidc.org/glaciers
     This is an excellent site including pictures, glossary, data, facts, and more.
   - http://www.glaciers.er.usgs.gov/gl_slide/
     This site has scans of color slides of glaciers you can download.
   - http://www.usgs.gov/features/glaciers2.html
     This site has loads of pictures of Alaskan glaciers, and links to other good sites.
2. Check off each feature as you and your partner find them. Save the location (in "favorites") and write down the web address of the picture that shows the most examples of the listed words: the best picture in the class wins a bonus!
   Answers will vary.

_____ arête	_____ hanging valley	_____ medial moraine
_____ cirque	_____ horn	_____ terminal moraine
_____ col	_____ icefall	_____ terminus
_____ crevasse	_____ kettle lake	_____ U-shaped valley
_____ erratic	_____ lateral moraine	

3. Best picture site (address): ____
4. Underline each word above that is in your best picture.
5. If you have time left over, you can get on Google Earth and take a virtual plane ride over the Alaska Range. Tilt the earth so you're flying low, then proceed up the Ruth Glacier, over Denali's summit, and down the Muldrow Glacier.

Lesson 7
Glaciers: Rivers of Ice

Glaciers cover one million acres, or one-sixth, of Denali National Park. NPS photo.

Overview:

Through reading, a hands-on activity and experiments, students will learn about the properties of ice that help explain how glaciers move.

Objectives:

Students will:
- Describe how ice is both like a solid and like a liquid.
- Identify gravity as the basic force that causes glaciers to move.
- Explain two properties of ice under pressure that help glaciers move: basal slide and plasticity.

Duration:

60 minutes on the first day (can be broken up into separate, shorter demonstrations)

5 – 10 minutes daily for several days to collect data for Activities 7.1 and 7.2

Vocabulary:

melting point, basal slide, surge, plasticity, plastic flow

Materials:

Lesson Section	Materials needed
Introduction	Snickers® bar
Activity 7.1	1 bread pan (or similar long narrow pan) and water 2 tall (10 inch) wood blocks, cans, or equivalent supports 1 large cookie sheet, cake pan or similar flat pan to hold the set-up Approximately 2 feet of thin wire (28 gauge) A weight (1 pound or heavier) Freezer to make ice and hold the set-up for a few days
Activity 7.2	1 bread pan (as above) and water 2 blocks or other supports 1 cookie sheet (or similar) to hold the set-up 1 weight (approximately 2 pounds) Freezer to make ice and hold the set-up for a few days
Activity 7.3	1 box of cornstarch Water Large mixing bowl Enough small containers (bowls or paper cups) for 1/2 cup of oobleck per group 1 box aluminum foil

Background:

Refer to the "The Power to Move Mountains" and "A Land Sculpted by Ice" sections in the "Teacher Background: The Geology of Denali National Park and Preserve" from Lesson 1.

Preparation:

For Activities 7.1 and 7.2, make ice at least one day ahead. For Activity 7.1 make a long, thick cube (4 inches of water in a bread pan). For Activity 7.2, make a thinner version (1/2 inch of water in a bread pan).

For Activity 7.3:

- Figure out how many groups of students there will be and prepare aluminum foil for each group to use in building a model mountain. Each group will need 2 pieces about a foot long.
- Mix the "oobleck" before class. First put one cup of water into the bowl then slowly mix in a box of cornstarch. It should be thick enough to hold and handle. It can be stored for many days but you might have to add water. It thickens as it sits.
- Have paper cups ready for giving oobleck to each group. It's better not to fill the cups ahead because you might have to adjust the consistency of the oobleck just before you pass it out to groups. Note: If you'll be doing this with more than one class, the oobleck can be collected in the large bowl at the end of class, then adjusted for reuse.
- Warning: if you haven't worked with students and oobleck before, it is really messy—but really fun. It does clean up easily.

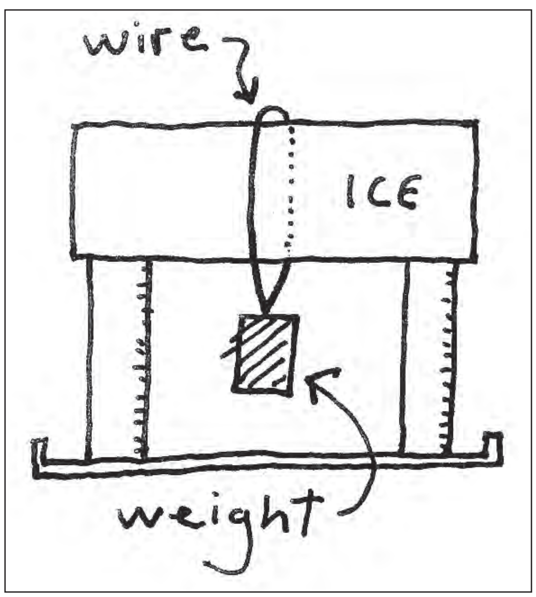
Procedure:

1. Read and discuss with the class the reading for this lesson on the student worksheet.
2. Use the Snickers bar to illustrate plasticity and the formation of crevasses. Bend the Snickers bar in an arch. Explain that the bendable nougat inside of the candy represents the plasticity of the deeper layer of a glacier. Point out the cracks that form on the outer chocolate surface layer and explain that these are like crevasses that form on the upper layer of glaciers. (The peanuts inside the candy bar can represent the rocks a glacier picks up; showing that glaciers aren't just pure ice.)
3. Explain that the class will be setting up two experiments today that will demonstrate basal slide and the plasticity of ice, and that they will observe and record data from these for several days.
4. Begin Activities 7.1 and 7.2 with the class. Get the set-ups into the freezer before they melt too much.
5. Do the oobleck activity, allowing time for students to experiment with it, clean up and answer the questions on their worksheets.

Activity 7.1 Ice under pressure

This activity shows how ice can melt under pressure then refreeze, which explains how glaciers are able to travel over the land at their base (basal slide).

1. Retrieve the frozen block of ice that you prepared for this activity.
2. Remove the block and support it between the two cans on the cookie sheet.
3. Tie the wire around the ice and suspend the weight by the wire.



NPS illustration by Doug Smith.

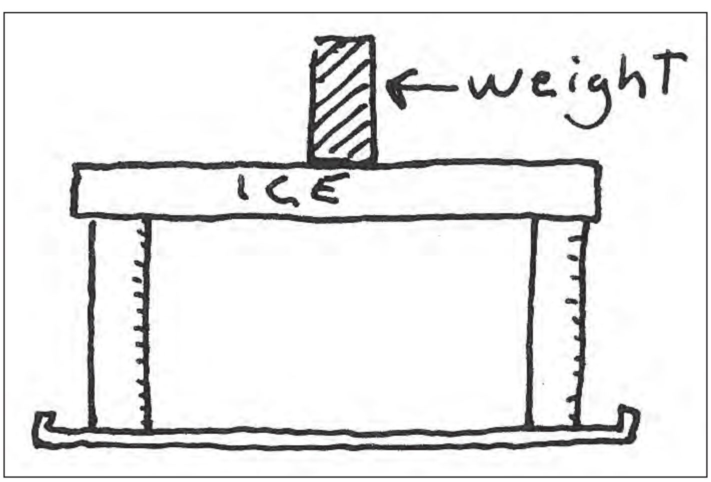
4. Put the set-up in the freezer.

5. Have students hypothesize what they think will happen and write their predictions on their student worksheets. Will the wire just sit on the ice block and not move? Will the wire cut the block in two? If so, how long will it take? (Note: What will happen is that the ice under the wire, being under pressure, will melt and the wire will move downward. The liquid water above the wire is not under pressure, so it will refreeze. The rate of travel depends on the temperature and the pressure—the thickness of the wire and the weight attached.)
6. Have the students make daily observations and record them on their student worksheets. Encourage them to continue to make predictions. For example, after recording how far the wire moved in a 24-hour period, predict how long will it take for the wire to move all the way through the block.
7. There is space for 3 days' worth of data in the chart, but you could have students add space to the chart if you want to extend the activity.
8. Variation: The same principle can be demonstrated by placing the ice on a cake cooling rack (instead of using the wire). Put a weight on the ice block to add pressure and put the set up in the freezer. The ice will move through the wire rack.

Activity 7.2 Plastic Ice

This simple activity demonstrates how ice bends under pressure.

1. Put a couple of blocks on a cookie sheet
2. Take the long, thin ice block out of its pan and place it so that it spans the two blocks.
3. Place the weight in the center of the ice block.
4. Have students draw the set-up on their student worksheet. Have someone measure the height of the ice above the cookie sheet; students then record this data for "Day 0" on the worksheet.
5. Put the set-up in a freezer.



NPS illustration by Doug Smith.

6. Check the ice daily. Record how far it is being deformed by measuring the distance between the ice and the cookie sheet under it. (Note: The ice can be deformed faster by putting a larger weight on it or by keeping the ice at a temperature closer to freezing. Do this by putting it in the refrigerator section for a few hours daily.)
7. After the first 24-hour period, students could make a prediction about how far the ice will deform by the end of the experiment.

Activity 7.3 Solid or liquid?

"Oobleck" is made from cornstarch and water and, similar to glacier ice, exhibits properties of both liquids and solids.

1. Explain to students that they will be working in groups to explore "oobleck" because it has properties similar to the properties of ice in glaciers.
2. Show how to begin a model mountain using aluminum foil. Loosely ball up a wad of aluminum foil for a base. Then shape another sheet of aluminum foil over that to make a mountain that includes some features they have learned about.
3. Let students know they will have a task to do with the oobleck (build a mountain and watch oobleck move), but they will also have time to explore the oobleck afterwards.
4. Give them directions:
    - Build a model mountain out of aluminum foil. Build in features that we studied in the last lesson; be sure to have a U-shaped valley, arête, and cirque at least.
    - Place a large blob of oobleck on top of the model mountain to simulate a glacier.
    - Observe and discuss the behavior of the oobleck. Notice how it follows a path of least resistance (flows through valleys).
    - Experiment with the oobleck, looking for properties of solids and liquids. Every group member should handle it: try packing it into a ball, breaking it, letting it drip and flow—have fun!
5. Divide class into groups and give them aluminum foil to begin their mountain model. As they work, adjust the consistency of the oobleck and put some in a small container for each group.
6. Allow about 20 minutes for the mountain experiment and oobleck exploration, then clean up and regroup the class.
7. Discuss how ice, like oobleck, has properties of both liquids and solids. In the top layers of glaciers, the ice is like a solid—retains it shape and is hard and brittle. In deeper layers of glaciers where ice is under great pressure, it is like a liquid because it becomes plastic—able to be shaped and to flow.
8. Have students answer the questions for Activity 7.1 on their worksheets.

Extensions:

- If you have climbers in your area, invite one to come in and show pictures of climbing on glaciers. He/she could show students equipment, and rope them up as if they were traveling on a glacier.
- For Activity 7.1 - If your students loved oobleck and you can tolerate the mess, search the internet to find oobleck web sites for more ideas and lesson plans.
- For Activity 7.2 - Students are typically fascinated by this demonstration, and their questions make many extensions possible. How would the results change if a thicker or thinner wire were used? Does string work? How would it change if a lighter or heavier weight were used? If the weight were twice as heavy, would it move through twice as fast? If your school has a walk-in freezer that the cook will let you use (or a cold winter), you could set up a number of these activities simultaneously. Have different groups of kids tackle individual questions they have. Graphing their data is a logical math application. Finish with an "Ice Science Convention" where they report their findings.

Name: ______________________________

Date: ______________________________

Class: ______________________________

Student Worksheet

Lesson 7
Glaciers: Rivers of Ice

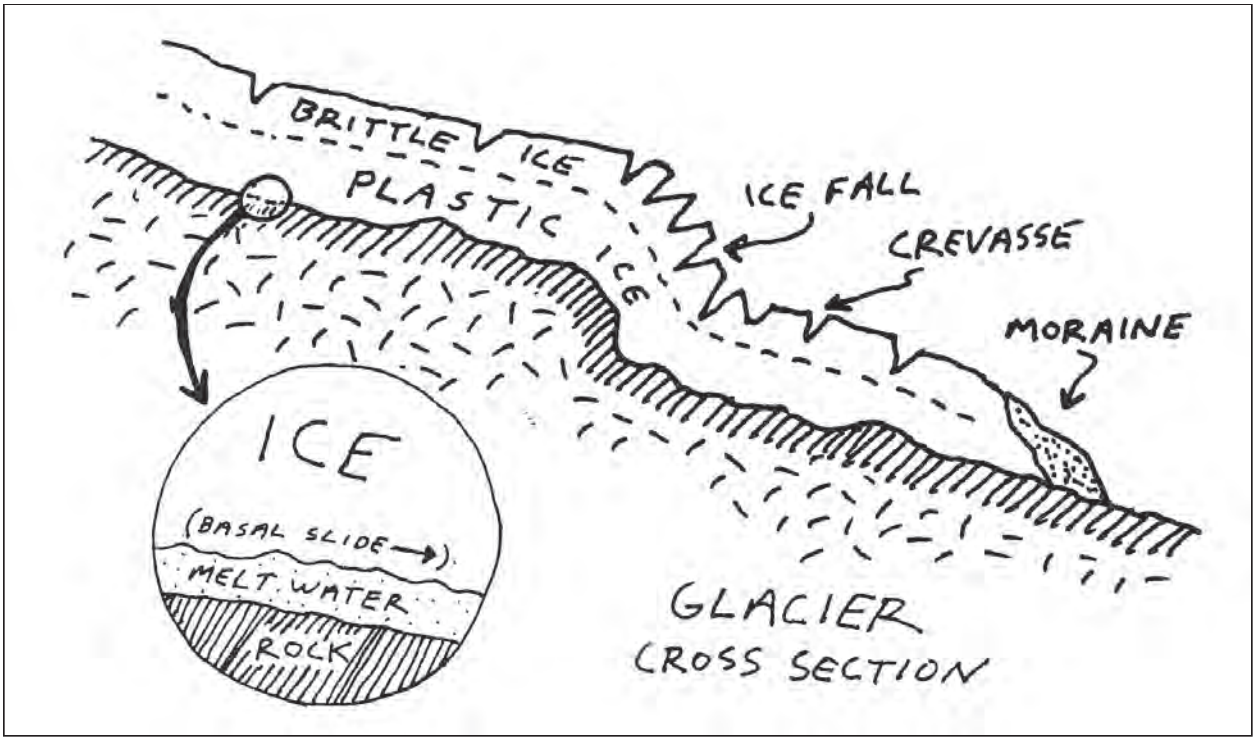
Glaciers cover one million acres, or one-sixth, of Denali National Park. NPS photo.

Unlike a snow field, glaciers move. They do this for two reasons: both reasons are related to pressure. As you know from the last lesson, glaciers are very thick—up to thousands of feet thick. All this ice is heavy and creates a great deal of pressure on the ice deep inside the glacier.

Pressure lowers the **melting point** of water. At the base of a glacier where the ice meets the ground, the pressure is so great that it lowers the melting point and causes the ice to melt. Because of this, the glacier rides on a thin layer of water which lubricates it and helps it move. This is called **basal sliding**. This same thing happens under ice skates—you are really skating on water! Warmer summer temperatures can increase basal slide. Glaciers usually move quite slowly (a few inches a day) but at times the amount of water under a glacier can increase and cause a glacier to **surge** or speed up. In 1956-57, Denali Park's Muldrow Glacier moved 1150 feet in a day, 100 times its normal speed! The Peters Glacier surged in 1986, moving 350 feet a day over a distance of three miles.

Another reason glaciers move is that the compressed ice crystals deep inside a glacier deform and slide past each other. We are used to ice that behaves like an easily-breaking solid that cracks and shatters like glass. But when it is over 160 feet thick, the compressed ice deep in a glacier is no longer brittle but becomes bendable. This property of ice that makes it be flexible and deform under pressure is called **plasticity**. Glacier ice is formed in layers with weak bonds between them and these layers move over the top of each other like an out-of-control lasagna. This is called **plastic flow**.

This property of glacial ice also explains the formation of crevasses. Since the overall motion of the layers adds up from the bottom, the still-brittle top layer of a glacier is the fastest moving part. The center part of this layer moves faster than the sides, which are slowed by friction where the glacier rubs against the mountains around it. Instead of bending around corners and steep terrain, this brittle ice cracks, forming crevasses. Crevasses can be wide enough to swallow a house or only inches wide, and they can be hundreds of feet deep. They are a major hazard to mountain climbers.



NPS illustration by Doug Smith.

Vocabulary:

melting point, basal slide, surge, plasticity, plastic flow

Activity 7.1 Ice under pressure

Directions:
When this experiment is first set up, write a prediction of what you think will happen (Question 1). Each day when the set up is checked, write the data in the chart (Question 2). At the end of the experiment, answer Questions 3 – 5.

1. What do you think will happen to the wire around the block of ice? Be specific.

2. Record your daily observations here for the duration of the experiment.

	Distance wire traveled (cm)	Observations
Day 0 (start)		
Day 1		
Day 2		
Day 3		

3. How would you explain what happened?

4. How is this like a glacier?

5. What do you think would happen if you used:
   - a thinner wire?
   - a heavier weight?
   - Do you think the wire would travel twice as fast if you doubled the weight? Try it to find out!

Activity 7.2 Plastic ice

Directions: Draw the set up, make a prediction, and record the data for Day 0 in the chart. As the class observes the experiment each day, continue to record the data in the chart. Finally, answer the final two questions about how you would explain the data.

1. Draw the set up of the experiment.

2. What do you think will happen?

3. Record the distance between the ice and the cookie sheet and all daily observations here:

Day	Distance (cm)
0	______________
1	______________
2	______________
3	______________
4	______________

4. How can you explain what happened?

5. How is this like a glacier?

Activity 7.3 Solid or liquid?

Directions: Think about what you learned from experimenting with the oobleck to answer these questions.

1. How is oobleck like a solid?

2. How is oobleck like a liquid?

3. How is oobleck like ice?

4. List two ways that the oobleck's path on the mountain model is similar to a glacier's path in the Alaska Range.

Name: ______________________________

Date: ______________________________

Class: ______________________________

Answer Key

Lesson 7

Glaciers: Rivers of Ice

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Unlike a snow field, glaciers move. They do this for two reasons: both reasons are related to pressure. As you know from the last lesson, glaciers are very thick—up to thousands of feet thick. All this ice is heavy and creates a great deal of pressure on the ice deep inside the glacier.

Pressure lowers the **melting point** of water. At the base of a glacier where the ice meets the ground, the pressure is so great that it lowers the melting point and causes the ice to melt. Because of this, the glacier rides on a thin layer of water which lubricates it and helps it move. This is called **basal sliding**. This same thing happens under ice skates—you are really skating on water! Warmer summer temperatures can increase basal slide. Glaciers usually move quite slowly (a few inches a day) but at times the amount of water under a glacier can increase and cause a glacier to **surge** or speed up. In 1956-57, Denali Park's Muldrow Glacier moved 1150 feet in a day, 100 times its normal speed! The Peters Glacier surged in 1986, moving 350 feet a day over a distance of three miles.

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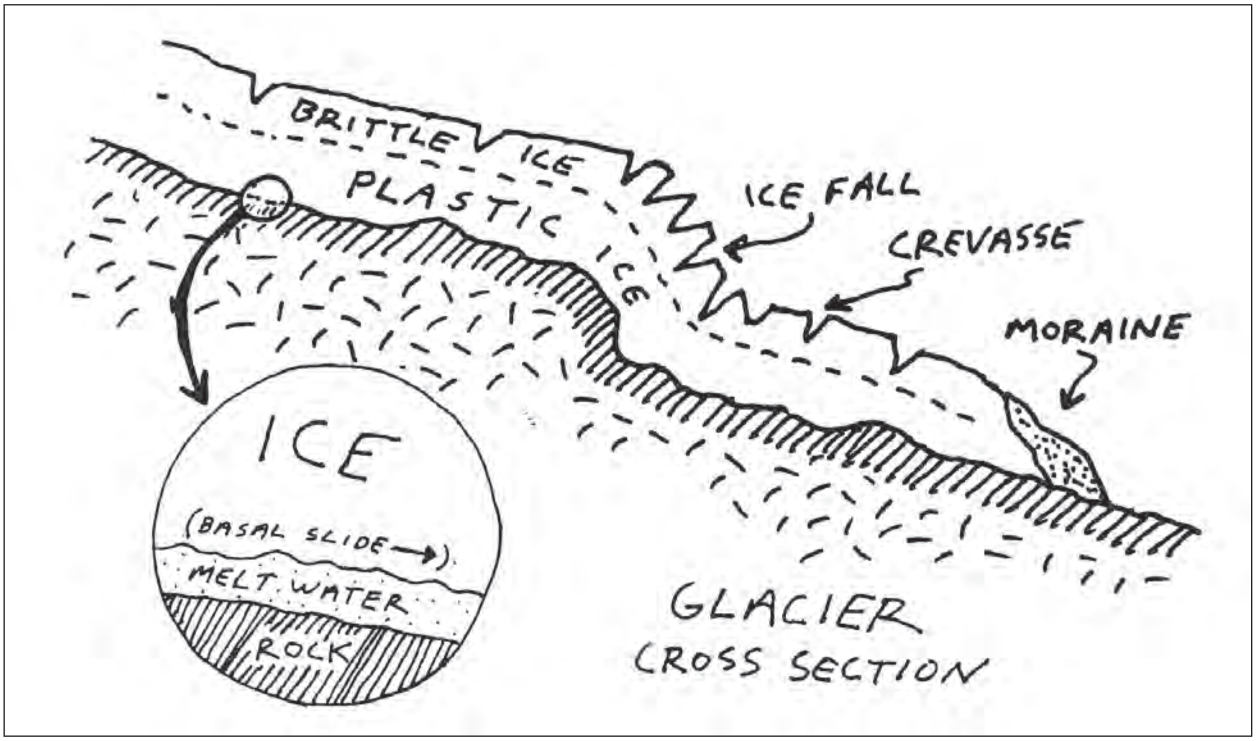

NPS illustration by Doug Smith.

Vocabulary:

melting point, basal slide, surge, plasticity, plastic flow

Activity 7.1 Ice under pressure

Directions:
When this experiment is first set up, write a prediction of what you think will happen (Question 1). Each day when the set up is checked, write the data in the chart (Question 2). At the end of the experiment, answer Questions 3 – 5.

1. What do you think will happen to the wire around the block of ice? Be specific.
   Predictions will vary. Most think the ice will be cut in half.

2. Record your daily observations here for the duration of the experiment.

	Distance wire traveled (cm)	Observations
Day 0 (start)	*0*	
Day 1		*The wire travels through the block of ice.*
Day 2		
Day 3		

3. How would you explain what happened?
   The ice under the wire melts as its melting point is raised by the pressure of the wire. The liquid above the wire is not under pressure so it refreezes.

4. How is this like a glacier?
   The ice under a glacier also melts due to the pressure of the glacier on it.

5. What do you think would happen if you used:
   - a thinner wire?
     More pressure (less area) so it will travel faster.
   - a heavier weight?
     More pressure (more weight) so it will travel faster.
   - Do you think the wire would travel twice as fast if you doubled the weight? Try it to find out!

Activity 7.2 Plastic ice

Directions: Draw the set up, make a prediction, and record the data for Day 0 in the chart. As the class observes the experiment each day, continue to record the data in the chart. Finally, answer the final two questions about how you would explain the data.

1. Draw the set up of the experiment.
   (See the teacher's Procedure section for a diagram.)

2. What do you think will happen?
   Predictions will vary.

3. Record the distance between the ice and the cookie sheet and all daily observations here:
   Answers will vary; the distance decreases

Day	Distance (cm)
0	______________
1	______________
2	______________
3	______________
4	______________

4. How can you explain what happened?
   The ice bent (deformed) under pressure because it is plastic.

5. How is this like a glacier?
   Glacier ice also becomes plastic under pressure and is pulled downhill by gravity.

Activity 7.3 Solid or liquid?

Directions: Think about what you learned from experimenting with the oobleck to answer these questions.

1. How is oobleck like a solid?
   Oobleck is hard when you hit or compress it and it can be "broken."

2. How is oobleck like a liquid?
   Oobleck flows and it can change shape.

3. How is oobleck like ice?
   Ice also shows properties of both solids and liquids.

4. List two ways that the oobleck's path on the mountain model is similar to a glacier's path in the Alaska Range.
   Students should notice that it is slow, flows downhill along a path of least resistance (through valleys). They might also notice its rate slows down on less steep terrain.

Lesson 8
Mountains into Molehills: Erosion

The dark lines of rock within a glacier (moraines) are evidence of the powerful erosion performed by the glacier as it carves away at the mountains it flows through. NPS photo.

Overview:

Students will learn about how glaciers and rivers erode mountains like those in the Alaska Range through demonstrations and hands-on activities.

Objectives:

Students will:

- Describe the breaking up of rocks by ice through frost wedging.
- Explain how glaciers scour the ground beneath them through abrasion.
- Calculate and visualize the immense amount of material eroded by a glacier and carried downstream in glacier-fed rivers.

Duration:

60 minutes, plus 15 minutes for observation the following day

Vocabulary:

erosion, frost wedging, abrasion, outwash, rock flour, sediment

Materials

Lesson Section	Materials needed
Activity 8.1	Plaster of Paris Bowl and spoon for mixing plaster 4 small plastic bowls or milk cartons Wooden matchsticks or knife 3 balloons Water and freezer
Activity 8.2	Two cake pans Sand Water and freezer Aluminum foil Modeling clay and/or a painted board
Activity 8.3	2 bottles of sediment-laden Chulitna River water Rulers Calculators

Background:

Refer to the "The Power to Move Mountains" and "A Land Sculpted by Ice" sections in the "Teacher Background: The Geology of Denali National Park and Preserve" from Lesson 1, as well as the diagrams in the previous two lessons.

Preparation:

1. For Activity 8.1, decide if you will do one or both of these demonstrations, and whether to do them with or without controls.

   Demonstration 1:
   - Mix enough plaster to almost fill two bowls (only one if no control is used).
   - Before the plaster sets, use a wooden match or knife to make an inch-deep groove in the surface of the plaster in both bowls, stopping short of letting the groove touch the sides of the bowl.
   - Set the plaster aside for at least half an hour to harden.

   Demonstration 2:
   - Fill one balloon with water until it is the size of a golf ball or egg; tie it off.
   - Mix plaster and almost fill the two bowls (one if no control is used).
   - Place the water-filled balloon in one container and hold it about one-quarter inch below the surface of the plaster until it begins to set.
   - Put the empty balloon in the other container as a control.
   - Set aside for at least half an hour to harden.

2. For Activity 8.2, make the ice the day before the activities. Cover the bottom of one of the cake pans with a layer of sand. Fill both pans with water and freeze them.
3. For Activity 8.3, do this several days in advance of teaching the lesson. Put one of the two bottles of Chulitna River water aside where nobody will have access to it (so it does not get shaken) so that the sediment settles to the bottom of the bottle.

Procedure:

1. Read and discuss the information on the student worksheet with the class.
2. Explain to the class that today the class will explore the forces of glacier erosion presented in the reading.

Activity 8.1 Frost Wedging: How ice weathers rocks

These two teacher demonstrations show the tremendous force that water exerts when it freezes. You may elect to do just one of the demonstrations.

1. Explain to the students that the two experiments to demonstrate frost wedging will be set up today then continued tomorrow.
2. Get the four bowls of plaster, prepared ahead (two each: experimental and control)
3. Set up the experiments as follows:

Day One

Demonstration 1:

1. Pour water into the inch-deep grove in the experimental bowl of plaster. Put no water into the control bowl.
2. Explain to students that the water represents meltwater that would fill cracks in mountain rocks or boulders, and that these will go in the freezer overnight to simulate the refreezing of the meltwater.
3. Put the bowls in a freezer overnight.

Demonstration 2:

1. Explain to students that you have put a balloon into each of the two bowls of plaster and that the balloon in the control bowl is empty (show them the 3rd balloon empty) while the balloon in the experimental bowl has water in it (fill the 3rd balloon to show them how much water is in the experimental balloon).
2. Explain that, again, the water represents meltwater, but this experiment will simulate what happens when water fills a pocket in a rock boulder then refreezes.
3. Put the bowls in a freezer overnight.

Day 2

1. Remove the containers the next day and observe what has happened.
2. Have students record their observations on their worksheets.

Activity 8.2 Abrasion: How glaciers erode mountains

Students will vividly see and feel how the debris under glaciers causes erosion.

1. Remove the smooth piece of ice you made previously from its cake pan.
2. Have students feel the bottom of the piece of ice and record their observations.
3. Put a piece of aluminum foil on a table and push the piece of ice across the foil. Have a student do it, pushing hard. (The ice will slide smoothly over the foil.)
4. Have students try pushing the ice over other base surfaces such as flattened-out clay or a painted board.
5. Now repeat the process with the ice that has sand in the bottom. (It is rough. The ice will tear up the aluminum foil.)
6. Have students try pushing this sandy ice over other base surfaces as above.
7. Discuss the results so you are sure students know how a glacier erodes the bedrock beneath it. (Glacial ice is too smooth to abrade rock; instead it is the load of rock debris under the glacier that does the eroding.)
8. Have students answer the questions for Activity 8.2 on the student worksheet.
9. Here are two pieces of information you can share with your students:
   - The water at the base of the glacier (studied in Lesson 7) is an extremely important factor. If there's too much water, it can lift the glacier up and prevent erosion. If there's not enough water to remove eroded particles, the base of the glacier can become like a clogged-up file and it will stop eroding.
   - A marble block (to simulate the bedrock) was fixed under a moving glacier in Iceland; measurements showed that 1/8th inch was worn off the block after the glacier moved 30 feet. At the rate this glacier is advancing, it would erode three feet of rock in 200 years.

Activity 8.3 "Rivers of ice" make rivers of sediment

This math-based activity will help students realize that enormous amounts of sediment are carried by glacial rivers, evidence of the immense erosive power of glaciers.

1. Retrieve the first bottle of Chulitna River water that you set aside several days ago. The sediment should have (mostly) settled to the bottom.
2. Shake up the second bottle of water from the Chulitna River. Pass it around the classroom and have students record their observations.
3. Have a student measure the height of sediment in the first, settled bottle, and the total height of the sample. Then have them use these two measurements to calculate what percent of the river is composed of solids.
4. Have students work the math problems on their worksheets to get an idea of the amount of the Alaska Range that is carried out to sea in one river. If you want to have a contest, you could announce a prize to the student who has the closest guess to the correct answer in question 4 (the length of the line of dump trucks).

Extensions:

1. For Activity 8.1: Students may want to carry the first demonstration further and experiment with different depths and shapes of cracks.
2. For Activity 8.3: Look at a map of Denali National Park and Preserve to find the Chulitna River, the source of the sediment it carries, and where it is headed. Look for other glacier-fed rivers on the map as well. Using the data from the original activity, have the students estimate how much sediment is being carried to Cook Inlet by all of the rivers put together.

Name: ______________________________

Date: ______________________________

Class: ______________________________

Student Worksheet

Lesson 8
Mountains into Molehills: Erosion

The dark lines of rock within a glacier (moraines) are evidence of the powerful erosion performed by the glacier as it carves away at the mountains it flows through. NPS photo.

Glaciers, rivers and wind are powerful forces of **erosion**, the breaking down and wearing away of land. The Alaska Range has been sculpted by its many glaciers and the rivers that flow out of them. We have already looked at some of the landforms that glaciers create; now we will look at some of the ways glaciers and ice act on the land.

One way that ice erodes mountains is called **frost wedging.** Meltwater flows into cracks in the rock, then freezes, expands, and breaks the rock into pieces. When this happens in rocks above or to the side of a glacier, the debris becomes the moraines on the glacier's surface or edges and that are carried down the mountain by the glacier. Much of this material will eventually be deposited at terminal moraines. Ancient terminal moraines, leftovers from past glacial periods, form hills all over south-central Alaska. Just south of Denali Park's entrance, the highway cuts through a huge hill that is a moraine left by the Riley Creek Glaciation ten thousand years ago.

A second way that glaciers break down mountains is by abrasion. **Abrasion** is erosion caused by rocks and gravel in the base of glaciers acting like giant sandpaper. As the glacier moves, the embedded debris scrapes and scours the rock beneath, forming sand and rock that is carried as **outwash** by streams of glacial meltwater. The larger fragments get deposited near the glacier's terminus. The bluffs along the Nenana River just north of the entrance to Denali Park expose ancient glacial outwash hundreds of feet deep. Gravel, one of the most important natural resources for many south-central Alaskan communities, was deposited as outwash from the Alaska Range's glaciers.

Much of the outwash is ground into fine dust called **rock flour** (or silt) and carried further downstream by glacier-fed rivers. As **sediment** suspended in rivers, it turns the river water an opaque dark gray or brown—you can't see your hand even a half an inch into this water. The rivers that flow from the Alaska Range carry tremendous amounts of glacial sediment out of the mountains to be deposited in the valleys and deltas below.

The fact that Denali and its neighbors continue to grow in spite of the relentless wearing away by erosion proves that mountain-building forces are also at work in the range. Uplifting caused by the collision of the North American plate with the subducting Pacific Ocean plate builds the mountains up, and erosion caused by ice, wind, and water wears them away. We've come full circle in our exploration of these awe-inspiring mountains.

Vocabulary:

erosion, frost wedging, abrasion, outwash, rock flour, sediment

Activity 8.1 Frost Wedging: How ice weathers rocks

Frost wedging is a major agent of weathering in the Alaska Range, breaking apart rocks during daily and seasonal temperature fluctuations. Glaciers and their rivers then carry the rocks away.

1. What happened to the plaster in the containers with water and without water?

2. Explain why the result was different with and without water.

3. Why did there have to be two bowls for each demonstration?

4. How does this experiment show what happens to mountain rocks when water seeps into cracks and then freezes?

Activity 8.2 Abrasion: How glaciers erode mountains

Glaciers cause erosion through abrasion by rubbing and scraping the base rock underneath. This experiment shows how this occurs.

1. Describe the feel of the first piece of ice.

2. What happened when it was rubbed on the foil?

3. Based on this, does glacier ice cause erosion? Why or why not?

4. What did the bottom of the second piece of ice feel like?

5. What happened when the second piece of ice rubbed on the foil?

6. How do glaciers cause erosion?

Activity 8.3 "Rivers of Ice" make rivers of sediment

The fine dust or rock flour from glacial erosion is carried away from the glaciers by meltwater, eventually ending up in glacier-fed rivers like the Alaska Range's Chulitna River.

1. Describe the water in the bottle from the Chulitna River that was shaken up.

2. Once the sediment has settled out of the water, measure the following:

   a. Height of sediment in bottle (cm): __________

   b. Height of water in bottle (including sediment) (cm): __________

3. What percent of the Chulitna River is sediment? (Divide a by b, and multiply by 100)

4. The Chulitna River carries a lot of melted glacier water off the Alaska Range; the equivalent of a million of your sample bottles flows downstream every second. Over the course of a year, that amounts to 30 million tons of sediment being carried off the mountains by this one river in one year.

   If we put all that sediment into dump trucks and lined them up in a row, how many miles do you think the line of trucks would extend?

   Take a guess: I think the line of trucks would extend __________ miles.

   Now get out a calculator and see how close your guess is!

5. A dump truck holds 5 tons. How many trucks will it take to hold all this sediment?

6. A dump truck is 28 feet long. How many feet long will the line of trucks be?

7. Convert this length to miles by dividing your answer (in feet) by 5280 (the number of feet in a mile).

8. The circumference of the earth is about 24, 900 miles. Would the line of trucks make it all the way around?

   How many times?

9. The Chulitna River is not alone nor is it the largest river—there are dozens of glaciers and their rivers wearing away at the Alaska Range. Why haven't the mountains been completely "trucked away" by now?

Name: ______________________________

Date: ______________________________

Class: ______________________________

Answer Key

Lesson 8
Mountains into Molehills: Erosion

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Frost wedging is a major agent of weathering in the Alaska Range, breaking apart rocks during daily and seasonal temperature fluctuations. Glaciers and their rivers then carry the rocks away.

1. What happened to the plaster in the containers with water and without water?
   The plaster in the bowls with water cracked and broke; without water it remained whole.

2. Explain why the result was different with and without water.
   When water freezes, it expands, so the force of the expanding water caused the plaster to break.

3. Why did there have to be two bowls for each demonstration?
   One acts as a control, so the effect of the water is the only thing that can account for the breaking of the plaster.

4. How does this experiment show what happens to mountain rocks when water seeps into cracks and then freezes?
   Rocks are hard and difficult to break, but expanding ice is strong enough to break them.

Activity 8.2 Abrasion: How glaciers erode mountains

Glaciers cause erosion through abrasion by rubbing and scraping the base rock underneath. This experiment shows how this occurs.

1. Describe the feel of the first piece of ice.
   It was smooth and cold.

2. What happened when it was rubbed on the foil?
   It slid smoothly on the foil.

3. Based on this, does glacier ice cause erosion? Why or why not?
   Not really; it's too smooth to abrade a hard surface like bedrock.

4. What did the bottom of the second piece of ice feel like?
   Rough. Coarse.

5. What happened when the second piece of ice rubbed on the foil?
   It tore the foil.

6. How do glaciers cause erosion?
   Glaciers cause erosion because the sand and rock fragments underneath make them rough so they scrape up (abrade) the base rock underneath.

Activity 8.3 "Rivers of Ice" make rivers of sediment

The fine dust or rock flour from glacial erosion is carried away from the glaciers by meltwater, eventually ending up in glacier-fed rivers like the Alaska Range's Chulitna River.

1. Describe the water in the bottle from the Chulitna River that was shaken up.
   It's gray and milky, with bigger grains of sediment in the bottom.

2. Once the sediment has settled out of the water, measure the following:

   a. Height of sediment in bottle (cm): __________

   b. Height of water in bottle (including sediment) (cm): __________

3. What percent of the Chulitna River is sediment? (Divide a by b, and multiply by 100)
   (Samples vary) The sediment constitutes over 20% of the sample.

4. The Chulitna River carries a lot of melted glacier water off the Alaska Range; the equivalent of a million of your sample bottles flows downstream every second. Over the course of a year, that amounts to 30 million tons of sediment being carried off the mountains by this one river in one year.

   If we put all that sediment into dump trucks and lined them up in a row, how many miles do you think the line of trucks would extend?
   Answers will vary.

   Take a guess: I think the line of trucks would extend __________ miles.

   Now get out a calculator and see how close your guess is!

5. A dump truck holds 5 tons. How many trucks will it take to hold all this sediment?
   30 million tons divided by 5 tons/truck = 6 million trucks

6. A dump truck is 28 feet long. How many feet long will the line of trucks be?
   6 million trucks times 28 feet/truck = 168 million feet

7. Convert this length to miles by dividing your answer (in feet) by 5280 (the number of feet in a mile).
   168 million feet divided by 5280 feet/mile = 31,818 miles

8. The circumference of the earth is about 24, 900 miles. Would the line of trucks make it all the way around?
   YES

   How many times?
   31,818 miles divided by 24,900 = 1.28 times, or once with 6,918 miles of trucks left over.

9. The Chulitna River is not alone nor is it the largest river—there are dozens of glaciers and their rivers wearing away at the Alaska Range. Why haven't the mountains been completely "trucked away" by now?
   The mountains are constantly being uplifted by the collision of the North American plate with the subducting Pacific Ocean plate.

Resources

Recommended Reading

Beckey, F. *Mount McKinley: The Icy Crown of North America*. The Mountaineers Books, 1001 SW Klickitat Way, Suite 201, Seattle, WA 98134. 1993.

Brown, W.E., *Denali: Symbol of the Alaskan Wild*. The Donning Co./Publishers, 184 Business Park Dr., Suite 106, Virginia Beach, VA 23462. Copyrighted with the Alaska Natural History Association, P.O. Box 230, Denali Park, AK 99755. 1993.

Collier, M., *The Geology of Denali National Park*. Alaska Natural History Association, 750 West Second Avenue, Suite 100, Anchorage, AK 99501.

Collier, M., *Sculpted By Ice: Glaciers and the Alaska Landscape*. Alaska Natural History Association, 750 West Second Avenue, Suite 100, Anchorage, AK 99501.

Davidson, A., *Minus 148 Degrees*. W.W. Norton and Co., Inc., New York, NY. 1969.

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Hocker, K. *Frozen in Motion: Alaska's Glaciers*. Alaska Natural History Association, 750 West Second Avenue, Suite 100, Anchorage, AK 99501.

Johannessen, T., W. Scherrer, and S. Weisberg. *North Cascades National Park: A Living Classroom*. North Cascades Institute, 2015 State Route 20, Sedro-Woolley, WA 98284. 1996.

Murie, A., *The Birds of Mount McKinley*. Mount McKinley Natural History Association. 1963.

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Palmer, M., *Denali Curriculum: Climbing America's Highest Peak*. Paws IV Publishing, P.O. Box 2364, Homer, AK 99603. 1996.

Pratt, V. E. and F. G. Pratt. *Wildflowers of Denali National Park*. Alaskakrafts, Inc. 1993.

Renner, J., *Northwest Mountain Weather*. The Mountaineers, 1001 SW Klickitat Way, Suite 201, Seattle, WA 98134. 1992

Sherwonit, B., *To the Top of Denali*. Alaska Northwest Books, 22026 20th Ave. S.E., Bothell, WA 98021.1990.

Stuck, H., *The Ascent of Denali*. Wolfe Publishing Co., Inc., 6471 Airpark Dr., Prescott, AZ 86301. 1988.

Walker, T., *Denali Journal*. Stackpole Books. 1992.

Washburn, B., and D. Roberts, *Mount McKinley: The Conquest of Denali*. Harry N. Abrams, Inc., New York, NY, A Times Mirror Company. 1991.

Maps

The United States Geological Survey (USGS) provides standard topographical maps of Alaska. Visit the USGS website at http://store.usgs.gov/, or call USGS at (907) 786-7000. They are also available in climbing stores and other sites on the web. The map utilized in this curriculum is:

"Denali National Park and Preserve," 1:250,000

Also available from USGS:

"Geologic map of Alaska," 1980. Scale 1:2,500,000. USGS Special Map, prepared in cooperation with State survey. Order from USGS.

"Surficial geology of Alaska," 1964 (compiled in 1960). Scale 1:1,584,000. Map I-357. Order from USGS.

"Talkeetna" D-3 and "Mount McKinley" A-3 show the West Buttress route of Mount McKinley.

Another map source:

Alaska Division of Geological and Geophysical Surveys, 794 University Avenue, Suite 200, Fairbanks, AK 99709-3645. (907) 451-5000.
http://www.trailsillustrated.com

National Geographic Society maps can be ordered from this web page:

http://www.natgeomaps.com/

Under the "Trails and Adventure Maps" category, you can find trail maps of many National Parks (http://www.natgeomaps.com/trailsillustrated).

Under the "US State and Thematic Maps" category, find "The Earth's Fractured Surface" map (http://www.natgeomaps.com/earth_fractured_surface) and "Alaska" map (http://www.natgeomaps.com/alaska_wall).

Under the "World" category, find "World Physical/Ocean Floor" maps (http://www.natgeomaps.com/world_physical_oceanfloor).

Web Resources

Please visit the *Denali Rocks!* Teacher web page at http://murieslc.org/static/1065/educator-resources to find additional web resources for this curriculum.

Meeting National Standards

Denali Rocks! was designed to help teachers meet National Science Content Standards for students in grades 6-8. The lessons focus on the national standards related to geology and "science as inquiry," as well as some physical science topics. Below is a summary of the national standards covered in each lesson. For a look at the complete National Science Standards (National Academy of Science), including Teaching, Program, Assessment, and Content Standards, visit http://www.nap.edu/readingroom/books/nses/.

National Science Content Standards	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5	Lesson 6	Lesson 7	Lesson 8
A1.1					X			
A1.2					X		X	X
A1.3		X			X	X	X	X
A1.4		X	X	X	X	X	X	X
A1.5		X	X	X	X	X	X	X
A1.6			X	X	X	X		
B1.1					X	X	X	
D1.1			X	X				
D1.2			X	X	X			
D1.3	X		X	X	X	X	X	X
D1.4			X	X	X			
D1.5							X	X
D1.6						X	X	X
D2.1			X	X	X	X	X	X

Glossary

abrasion one way glaciers cause erosion; when the glacier moves, sand and rock fragments at it base scour and scrape the bedrock beneath

Aleutian Trench the deep gorge where the Pacific Plate is being subducted by the North American plate, reaching 2000 miles (3400 kilometers) along the Aleutian Chain and southern coast of Alaska

arête a narrow serrated ridge, formed where glaciers cut cirques on the opposite sides of a ridge deeper and deeper into the divide

basal slide the gravity-driven movement of glaciers on a thin layer of lubricating meltwater

batholith the largest intrusive rock formation; a pluton that is at least 40 square miles or 100 square kilometers in size; Denali is a batholith

crevasse cracks in the brittle top layer of a glacier

cirque a steep-walled semicircular basin at the upper end of a glacier, formed by meltwater and the scouring action of the glacier

col a low point in a ridge (like a small pass), formed where glacial cirques on opposite sides of a ridge wear through the divide and meet

contour interval on a topographic map, the difference in elevation represented by two adjacent contour lines

contour lines on a topographic map, the lines that join points of equal elevation

convection current the circulation of material due to differences in density, as when magma near the earth's core is heated causing it to rise, cool and sink again

convergent boundary where two tectonic plates move toward each other and collide

core the dense innermost layer or zone of the earth, including a solid inner core and a liquid outer core, that makes up 30% of Earth's volume

crust the rocky outer layer of the earth that makes up less than 1% of Earth's volume

Denali Fault the strike-slip fault that runs west-to-east through Denali National Park and Preserve, then continues on through Southeast Alaska and eventually turns into the San Andreas Fault in California

Denali National Park and Preserve 6 million acres in Alaska set aside by the Alaska National Interest Lands Conservation Act (ANILCA) in 1980 with three management units including the Denali Wilderness area that comprises most of the original 1917 Mount McKinley National Park

density a measure of mass per unit of volume

divergent boundary where two tectonic plates pull away from each other and separate

elevation the height above sea level of a point on the earth's surface

erosion the breaking down and wearing away of land by wind, water, ice (including glaciers) or humans

erratic a large boulder carried and deposited far from its point of origin by a retreating glacier

extrusion a body of igneous rock that has hardened from a molten magma above the earth's surface; volcanoes are one example

fault a fracture or crack in the earth's crust accompanied by the displacement or movement of one side in relation to the other

frost wedging one way ice causes erosion; when meltwater flows into cracks then freezes, expands and breaks the rock into pieces

geology the science that deals with the origin, composition, structure and history of the earth, and the forces that shape Earth's landforms

glacier a moving river of ice, formed where the amount of snow that falls in winter is greater than the amount that melts in the summer; the immense weight of the piled-up snow compresses into ice which then moves slowly downhill via gravity

gravel bar an elevated region of gravel in a river that has been deposited by the flow of the water.

hanging valley a small, high valley left by a retreating glacier on the side of a lower, broader valley; often the site of spectacular waterfalls

horn a spire-like peak, formed where three or more glacial cirques have cut back into a mountain

icefall a chaotic, crevassed portion of a glacier formed where it steepens and/or narrows

igneous rock rock formed by cooling and hardening from a molten state

intrusion a body of igneous rock that has hardened from a molten magma below the surface of the earth; plutons are one example

kettle lake a deep, round water-filled depression, formed by melted chunks of ice left behind by a retreating glacier

landform a feature of the earth's surface: mountain, valley, mesa, volcano, etc.

lava molten rock that reaches the surface of the earth through fissures or vents then hardens

magma the molten rock material under the earth's surface in the mantle

mantle the highly viscous layer of the earth between the crust and the core that makes up 70% of Earth's volume

melting point the temperature at which a solid becomes liquid; for water under normal atmospheric conditions this would be 32 degrees F or 0 degrees C

metamorphic rock rock that has been changed from its original form by intense heat and pressure deep within the earth

Mohs' Hardness Scale the 10-point scale use by geologists around the world to measure the hardness of rock and to help identify unknown samples

moraine the accumulated till (clay, sand, rocks, boulders) deposited by glaciers; there are three kinds, named for where they occur on the glacier: **lateral** or side; **terminal** or end; and **medial** or middle, formed where two glaciers have joined

outwash eroded sand and rock fragments that are carried away in streams of glacial meltwater

Pacific Ring of Fire an area of trenches, earthquakes and volcanoes encircling the Pacific basin from New Zealand north along the east coast of Asia, then east along the Aleutian Chain and Alaska, then south along the west coasts of North and South America; home to over 75% of the volcanoes and 80% of the earthquakes on Earth

plastic flow the gravity-driven movement of glaciers caused by the deformation of ice crystals under pressure

plasticity the property of ice that makes it flexible and deform under pressure

plate tectonics the theory that the earth's surface is made up of large irregular plates that are driven by convection currents within the mantle below to move continuously, and that interactions among the plates at their boundaries cause most major geologic activity including mountain building, volcanoes and earthquakes

pluton an intrusive igneous rock formed deep below the earth's surface

rock flour glacial outwash that has been ground into fine-grained sediment and carried downstream by glacier-fed rivers

sediment insoluble rock and soil particles that are suspended in river water and eventually deposited

sedimentary rock rock formed from varied-sized fragments (minerals, rocks and organic material) that have been buried and compressed

spreading center an area at divergent boundaries where two plates pulling away from each other forms a fissure that allows upwelling of hot magma to the surface

strike-slip fault a fracture in the earth's crust along which the two sides (may be plates) move sideways to one another

subduction zone an area at convergent boundaries where a dense oceanic plate collides with and is forced under a denser continental plate, producing tectonic activity including earthquakes, volcanoes and mountain building

surge a period of rapid flow in a glacier when it can move up to 100 times faster than normal and advance substantially

tectonic plate one of a number of rigid slabs that are part of Earth's surface and move slowly across the mantle; continental plates are thick and relatively light since they contain dissolved gasses while oceanic plates are thinner but heavier because they are more dense

terminus the face of a glacier; where the glacier ends

terrane an area of rocks with a different geologic history from surrounding rocks; often the result of being carried by a colliding plate and attached to a continent

till the clay, sand, dirt, rocks, and boulders transported and deposited by glaciers

topographic map the representation of a three-dimensional landscape using contour maps lines to show elevation and the relief of the land

topography the physical features of a geographic area including its elevation, contours and landscapes such as mountains, valleys and rivers

transform boundary where two tectonic plates slide past each other with a shearing motion

trench a deep, steep-sided canyon that forms on the ocean floor at the edge of a continent where an oceanic plate is being subducted

uplift to cause part of the earth's surface to move upwards to a higher elevation than surrounding areas, as in the process of mountain building

U-shaped valley a broad glacier valley, formed where glaciers have filled narrower river valleys with wall-to-wall ice and widened them out

volcanism the movement of molten rock inside the earth or on the earth's surface

volcano A vent in the earth's crust where magma, gas and ash erupt; also the cone-shaped mountain that is formed by the eruption