GEOLOGICAL ADVENTURES AT PARASHANT

EXPLORING THE GEOLOGY OF GRAND CANYON-PARASHANT NATIONAL MONUMENT

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Contents

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Module Overview

USING THE MODULE

The module is intended for students in grades 6-9. The primary purpose of the module is to use the diverse and fascinating geologic setting of Grand Canyon-Parashant National Monument (referred to as Parashant throughout the module) as the context to help educators teach fundamental geology concepts and skills. Lessons are engaging and inquiry-based. There are nine lessons, each of which lasts two to three 45-minute class periods. Lessons are designed to be done in cooperative groups and to use a minimum amount of affordable consumable materials and supplies (e.g., lessons 2-6 use the same materials – a one-pound box of four colors of modeling clay). Teachers looking for a four to six-week unit in geology can run through the complete sequence of lessons, while others can choose lessons to suit their needs. The teacher guide for each lesson contains photos of how to set up and run hands-on activities and suggestions for making the lesson more quantitative and challenging for honors, gifted, or higher grade-level students. The student edition can serve as a master to photocopy for students. PowerPoint slide shows with photos from the lessons (and additional photos) are available for each lesson.

LESSON STRUCTURE

Lessons follow the 5E instructional model outlined by Bybee and Trowbridge (1994). Each lesson in the module has five stages: 1. a warm-up question or problem to spark interest (engage), 2. hands-on activity (explore), 3. reading that features comparisons to maps or photographs of rocks, outcrops, landscapes of actual processes that occur (or have occurred) at Parashant (explain), 4. application questions that connect the activity to processes in the monument (elaborate), and 5. an assessment task or reflection questions (evaluate).

LESSON DESCRIPTIONS

1. Exploring Parashant – an Interactive Reading Guide

Students work in pairs or groups of three to explore the Views DVD (or website) on Grand Canyon-Parashant National Monument.

2. Sedimentary Rocks – Exploring the Cliffs at Parashant

Students look at samples of sedimentary rocks and note characteristic features. They then build a sedimentary rock sequence using layers of modeling clay. Each layer of modeling clay stands for a kind of sedimentary rock found in the monument (sandstone, shale, siltstone, limestone). Students then use a piece of dental floss to slice one end of the layers in a manner that is consistent with how rocks weather and erode in canyon walls (i.e., shale will often form gentle slopes, and sandstone, siltstone and limestone will often form cliffs). After the activity, students read about how sedimentary rocks form to learn about the main classification scheme of sedimentary rocks and what sedimentary rocks reveal about depositional environments and Earth's history. Students save their models for use in Lesson 3.

3. Igneous Rocks – Lava Flows at Parashant

Students look at samples of igneous rocks and sort the rocks by texture, color, and then by texture and color. Students then model the flow of lava at Parashant by pouring liquid soap onto the top of their clay models and observing the differences in the speed of the flow (slow, medium, fast) over slopes of different gradients. Students compare their models to surface and aerial photographs of lava flows at Parashant as they read about the main types of igneous rocks (extrusive versus intrusive) and the nature and timing of eruptions at the monument. Students are asked to design and do their own experiment into lava flows using one of six research questions.

4. Metamorphic Rocks – Basement of Parashant

Students begin by conducting thought experiments about how heat and pressure might change rock. They then experiment with their clay models of rock layers by measuring its dimensions, compressing the model, and measuring and calculating how the model changed due to pressure. With this concrete analogy of change due to metamorphic burial and tectonic folding, students read about agents of metamorphism and how metamorphic rocks form the 1.6 to 1.8 billion year old basement rocks beneath Parashant. In the Elaborate activity, students compare samples of metamorphic rocks to common parent rocks to explore the effects of heat and pressure on igneous, sedimentary, and metamorphic rocks.

5. Topography – Landscapes of the Parashant

Students totally mix and reshape their modeling clay into a landform feature. Students place their models in a small transparent plastic container. They mark the sides of the container with 1 cm increments, pour water into the container to the 1-cm line, put the clear plastic cover onto the container, and use a grease pencil or non-permanent marker to outline the edge of the water along the clay. This represents a contour line. Students continue to add water and trace the pattern in one-centimeter increments. Using a scale of 1cm = 100 meters, students label the contour lines on their maps. Students then construct a profile across their contour map to continue developing their understanding of topography. Students read about topography and topographic maps and about the processes that control landscape features at the monument, then interpret topographic maps and construct profiles of different landscape features at Parashant.

6. Geologic Structure and the Parashant Landscape

In this activity, students use modeling clay to simulate and study three kinds of stress that create geologic structures: tensional, compressional, and shear. In Part B of the activity, they apply what they have learned about stress to model the formation of faults, folds, and uplift using their modeling clay. Each group is assigned a different type of structural feature to model. They are given block diagrams to use as a guide to produce a structure, and must create the structure using modeling clay and explain the forces that led to the feature. Each group then presents the structural model to the rest of the class. Students read about the processes of uplift, folding, and faulting in the context of plate tectonic theory and the formation of Parashant's landscape features.

7. Erosion and Deposition– From Washes to Canyons at Parashant

Students interpret a photograph of gravels and cobbles exposed in Whitmore Wash at the monument. They clip an overhead transparency to a photograph of the sidewall of a wash and draw lines through the longest axes of flattened cobbles, and use the overall pattern of lines to infer the direction of stream flow. Students read about the processes of erosion and deposition that are most prevalent on the monument. In an elaboration activity, students return to the photograph of Whitmore Wash to interpret the percentages of various rock types found in the deposit. After building a class data set using representative square-meter areas of the deposit, they draw inferences about the geology of the mountain range that produced the deposit.

8. Copper Calling at Grand Gulch Mine

Students model the mining operation at the Grand Gulch Mine. They mine for pennies in a box of wet sand and must clean, dry, and weigh the pennies, calculate the monetary value of the mined ore, and weigh this against the costs associated with the time it takes to find, remove, clean, and transport the pennies to the point of distribution. Students construct graphs of costs versus gross value for various amounts of copper at several prices per ton to determine what would be required to make the operation profitable. Students read about the actual mining operations.

9. Understanding Time at Parashant

Students examine photographs and schematic diagrams of rock layers, faults, unconformities, dikes, and lava flows from several different locations within the park to learn how to apply the laws of superposition, original horizontality, and cross-cutting relationships in interpreting sequences of geologic events. They read about relative and absolute age dating techniques and the geologic time scale.

BIG IDEAS

This module lays the groundwork for teachers to develop student's understandings about the following ten key ideas in Earth science. (source: Earth Science by Design; http://www.esbd.org/resources/big_ideas.html).

1. The surface of Earth has identifiable major features--land masses (continents), oceans, rivers, lakes, mountains, canyons, and glaciers.
2. Earth's surface is built up and worn down by natural processes, such as rock formation, erosion, and weathering.
3. Physical evidence, such as fossils and radioisotopic dating, provide evidence for the Earth system's evolution and development.
4. The atmosphere exhibits long-term circulation patterns (climate) and short-term patterns known as weather--storms, hurricanes, and tornadoes.
5. Water cycles through the atmosphere, hydrosphere, geosphere, and biosphere.
6. Life appeared early in Earth's history and has been intimately involved in the nature of the Earth--i.e. composition of the atmosphere, weathering, carbon cycle, and rock cycle.

7. Earth scientists use representations and models, such as contour maps and satellite images to help them understand the Earth.
8. Scientists use quantitative, qualitative, experimental and non-experimental methods of scientific inquiry to understand the Earth.
9. Earth scientists make an assumption of uniformitarianism, that the processes that shaped the Earth in the past are the same processes we observe today.
10. As in all scientific disciplines, knowledge in Earth science is subject to revision.

NATIONAL SCIENCE EDUCATION STANDARDS ADDRESSED

Lessons in this module can be used to develop the following understandings and abilities outlined in the National Science Education Standards (NRC, 1996).

Structure of the Earth System

⇒ The solid earth is layered with a lithosphere; hot, convecting mantle; and dense, metallic core.

⇒ Lithospheric plates on the scales of continents and oceans constantly move at rates of centimeters per year in response to movements in the mantle. Major geological events, such as earthquakes, volcanic eruptions, and mountain building, result from these plate motions.

⇒ Landforms are the result of a combination of constructive and destructive forces. Constructive forces include crustal deformation, volcanic eruption, and deposition of sediment, while destructive forces include weathering and erosion.

⇒ Some changes in the solid earth can be described as the "rock cycle." Old rocks at the earth's surface weather, forming sediments that are buried, then compacted, heated, and often recrystallized into new rock. Eventually, those new rocks may be brought to the surface by the forces that drive plate motions, and the rock cycle continues.

⇒ Soil consists of weathered rocks and decomposed organic material from dead plants, animals, and bacteria. Soils are often found in layers, with each having a different chemical composition and texture.

⇒ Water is a solvent. As it passes through the water cycle it dissolves minerals and gases and carries them to the oceans.

⇒ Living organisms have played many roles in the earth system, including affecting the composition of the atmosphere, producing some types of rocks, and contributing to the weathering of rocks.

Earth's History

⇒ The earth processes we see today, including erosion, movement of lithospheric plates, and changes in atmospheric composition, are similar to those that occurred in the past. earth history is also influenced by occasional catastrophes, such as the impact of an asteroid or comet.

⇒ Fossils provide important evidence of how life and environmental conditions have changed.

Abilities Necessary to Do Scientific Inquiry

⇒ Ask a question about objects, organisms, and events in the environment.

⇒ Plan and conduct a simple investigation.

⇒ Employ simple equipments and tools to gather data and extend the senses.

⇒ Use data to construct a reasonable explanation.

⇒ Communicate investigations and explanations.

Understandings About Scientific Inquiry

⇒ Scientific investigations involve asking and answering a question and comparing the answer with what scientists already know about the world.

⇒ Scientists use different kinds of investigations depending on the questions they are trying to answer. Types of investigations include describing objects, events, and organisms; classifying them; and doing a fair test (experimenting).

⇒ Simple instruments, such as magnifiers, thermometers, and rulers, provide more information than scientists obtain using only their senses.

⇒ Scientists develop explanations using observations (evidence) and what they already know about the world (scientific knowledge). Good explanations are based on evidence from investigations.

⇒ Scientists make the results of their investigations public; they describe the investigations in ways that enable others to repeat the investigations.

⇒ Scientists review and ask questions about the results of other scientists' work.

Systems, Order, and Organization

⇒ The natural and designed world is complex; it is too large and complicated to investigate and comprehend all at once. Scientists and students learn to define small portions for the convenience of investigation. The units of investigation can be referred to as "systems." A system is an organized group of related objects or components that form a whole.

⇒ Science assumes that the behavior of the universe is not capricious, that nature is the same everywhere, and that it is understandable and predictable. Students can develop an understanding of regularities in systems, and by extension, the universe; they then can develop understanding of basic laws, theories, and models that explain the world.

⇒ Prediction is the use of knowledge to identify and explain observations, or changes, in advance. The use of mathematics, especially probability, allows for greater or lesser certainty of predictions.

- ⇒ Types and levels of organization provide useful ways of thinking about the world. Types of organization include the periodic table of elements and the classification of organisms. Physical systems can be described at different levels of organization.

Evidence, Models, and Explanation

- ⇒ Evidence consists of observations and data on which to base scientific explanations. Using evidence to understand interactions allows individuals to predict changes in natural and designed systems.
- ⇒ Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power. Models help scientists and engineers understand how things work. Models take many forms, including physical objects, plans, mental constructs, mathematical equations, and computer simulations.
- ⇒ As students develop and understand more science concepts and processes, their explanations should become more sophisticated...frequently reflecting a rich scientific knowledge base, evidence of logic, higher levels of analysis, and greater tolerance of criticism and uncertainty.
- ⇒ Scientific explanations incorporate existing scientific knowledge and new evidence from observations, experiments, or models into internally consistent, logical statements.

Constancy, Change, and Measurement

- ⇒ Most things are in the process of becoming different—changing. Changes might occur, for example, in properties of materials, position of objects, motion, and form and function of systems. Interactions within and among systems result in change. Changes vary in rate, scale, and pattern, including trends and cycles.
- ⇒ Changes in systems can be quantified. Evidence for interactions and subsequent change and the formulation of scientific explanations are often clarified through quantitative distinctions--measurement. Mathematics is essential for accurately measuring change.
- ⇒ Different systems of measurement are used for different purposes. Scientists usually use the metric system.
- ⇒ Rate involves comparing one measured quantity with another measured quantity, for example, 60 meters per second. Rate is also a measure of change for a part relative to the whole, for example, change in birth rate as part of population growth.

LESSON 1: VIEWS OF PARASHANT

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LESSON 1 GUIDE: VIEWS OF PARASHANT

OVERVIEW

This activity is an interactive reading guide to help students explore the "Views of the National Parks" (Views) Virtual Experience for Grand Canyon-Parashant National Monument (Parashant). The guide will help students focus their attention as they interact with the module. Interactive reading guides are excellent strategies to use when assisting students in productive reading. They allow students to find the essential ideas within a text without being distracted by large amounts of information. Students who may find it difficult to differentiate key ideas from the supporting detail benefit from the clues and guidance of reading guides. Essentially, interactive reading guides are developed to assist students with text materials that may be too difficult for independent reading. Students can complete the assignment individually or in pairs at computers.

Objective	After completing this activity, students will have a broad perspective on the natural setting and historical uses of Colorado Plateau and the lands within the Grand Canyon-Parashant National Monument (Parashant).
Concepts	▪ Physical, geological, and ecological settings of the Colorado Plateau. ▪ Historical use of land for farming, hunting, ranching, and mineral production.
Duration	One or two 45-minute class periods, depending upon how many segments of the DVD/web site students are asked to complete:
Audience	Students in grades 6 to 9
Materials	Instructors can download the **Views DVD** to the school's public server, order a free copy, or have students access the Views website via the Internet.
Extensions	**For all students** ▪ Ecology Project - Use the Ecology portion of the DVD or web site to design a research project on the ecology of the monument. From the main menu of Grand Canyon-Parashant National Monument, click on Ecology. Assign groups of students to read, summarize, and report to the class on one of five research areas: Mojave, Transition, Great Basin, Colorado Plateau, and Riparian.

EXPLORE **45 Minutes**

Answers to the questions in the student guide are shown below. In the activity, whenever students see the symbol "∇", they should click on the link or phrase next to it. This activity compliments the National Park Service's Grand Canyon-Parashant National Monument Visitor Center at http://www2.nature.nps.gov/views/

Part A – Introduction to the Monument

Go to the homepage of Views of the National Parks. Click on Visitor Center, then on Virtual Experiences, then on Grand Canyon-Parashant, and then click on Explore Grand Canyon-Parashant.

1. What four things might you hear if you are in the country?

A. birds singing B. dried leaves blowing across the ground

C. running water D. quiet

2. One of the factors that make this monument so special is that it is **far** from centers of **human** occupation. Some people call it **isolated**, even lonely, while others travel great **distances** to experience its **solitude**. Rugged and **secluded**, the monument is one of largest, un-fragmented stretches of **sparsely** developed lands in the contiguous **United States**.

Part B – Visitor Center

∇ Visitor Center

On this page, the three buttons below **Visitor Center** (Facts, Activities, and Preparation) link to the same pages as the three hyperlinks in the text on page 3 of the Visitor Center home page (general facts, popular activities, and how to prepare a successful expedition).

1. The monument's expansive landscape encompasses a chronicle of science, **geology**, cultures, and **history**.

2. Two hours

3. Hiking, primitive camping, hunting, and photographing unobstructed views of interesting landforms and sweeping vistas.

∇ Facts

4. True

5. Elevation at the monument ranges from **1500** feet above sea level near Grand Wash Bay at Lake Mead to over **8000** feet at Mt. Trumbull.

6. The monument is a special land filled with canyons, **mountains**, and deserts.

7. Grand Canyon-Parashant National Monument is under the joint management of the **National Park Service** and the Bureau of Land Management.

8. The monument is located on the Colorado Plateau in northwestern **Arizona**.

9. Grand Canyon National Park is to the **south** and the monument borders the state of **Nevada** to the west.

∇ Activities

10. False

11. There are no developed **campgrounds** within the monument; please camp within previously used, undeveloped **campsites** along primary **roads**.

12. At the monument, you should camp at least **1/4 mile** from any water source or reservoir.

∇ Preparation

13. No

14. Three diseases to be wary of at the monument are **Hantavirus**, **Plague**, and rabies.

15. Each person should bring **one gallon** of water for each day at the monument.

16. A. Have you planned out your trip?; B. Have you left your itinerary with a family member or friend? C. Have you collected the proper equipment?

The Colorado Plateau

∇ Colorado Plateau

1. A. Pennsylvania; B. Ohio; C. New York

2. Ancient **volcanic** mountains, plateaus and **buttes**, deeply carved canyons, and amazing ranges in **color** are the region's major claims to fame.

3. Temperatures vary from winter lows below **zero** and summer highs into the **hundreds**.

4. Grand Canyon-Parashant is in the **southwestern** part of the Colorado Plateau.

∇ Geology

5. Some areas on the Colorado Plateau are famous for the colorful **sedimentary** rocks formed many **millions** of years ago when a vast **ocean** covered Arizona and much of the **western** United States.

6. A. sandstone; B. shale; C. limestone

7. Warped and folded rock layers that form giant “steps” are called **monoclines**.

8. Not all of the **rocks** exposed on the Colorado Plateau were deposited by **water** or wind, however. Numerous **volcanoes** dot the region, adding variety to the **landscape**.

9. The bedrock absorbs the water into cavities. It sinks through the ground and reaches the surface again as springs in lower elevations.

∇ Ecology

10. The great ecological diversity of the Plateau is due to differences in **climate** and landforms.

11. Ponderosa pine, lodgepole pine, Douglas-fir, and aspen

12. False

13. Golden eagles, red-tailed hawks, and falcons

14. Riparian areas that thread throughout the **Plateau** are home to frogs, **toads**, snails, beavers, **dragonflies**, and fish.

∇ History

15. Humans have lived on the Colorado Plateau for **12,000** years. First to arrive were big game **hunters**, followed by the **Archaic** culture (8000 years ago) who hunted small **game** and gathered **food plants**. Later, the Ancestral **Puebloans** (300 A.D. to circa 1250) met the Plateau's challenges, and settled into permanent **homes** to farm.

16. Non-native explorers and trappers ventured onto the Plateau between **1776** and **1847**.

17. The resident population of the Colorado Plateau today exceeds **one million**.

18. Human impacts that have affected the status of Colorado Plateau **ecosystems** include forest management practices, **grazing**, logging, mining, **power** generation, introduction of non-native **species**, dams and water diversion, and fragmentation of **wildlands** by roads and other **construction**.

∇ **Parashant**

19. Grand Canyon Parashant National **Monument** is located in the **southern** portion of the Colorado Plateau called the **Arizona** Strip.

20. 3,200

∇ **how far away**

21. The monument is located 2,367 **miles** from Washington, DC and 445 miles from **Los Angeles**.

Journey Through Time

∇ **Journey Through Time**

∇ **Nampaweap**

1. By pecking flakes from the surface of rock to expose the lighter colored rock underneath.

2. **Archaeologists** have classified rock elements into categories. Some of the elements you will see at Nampaweap are **anthropomorphs** (human-like figures), zoomorphs (**animal-like figures**), and abstract designs. Anthropomorphs typically have **arms** and legs, even fingers and **toes**. Bighorn sheep, **snakes**, and lizards are common **zoomorph** figures. Abstract elements include circles, **spirals**, and various combinations of **lines**.

∇ **points to consider when visiting [QuickTime Player needed]**

Note: QuickTime Player is needed to view a panoramic and interactive image of the Nampaweap site, but the question relates only to the text on the pop-up window.

3. A variety of factors that contribute to the erosion of petroglyphs, including **wind**, rain, extreme temperatures, **plant growth**, and rock type. The most devastating factor however, is **human impact**.

∇ **Sawmill**

4. Large scale and economically significant lumbering of ponderosa pine began at Mt. Trumbull in the **1870's**.

5. Sawmill operations used **steam boilers** and flues to generate power.

6. False

7. To determine how to restore it to pre-settlement condition.

∇ **Schoolhouse**

8. Abraham Bundy

9. A. school, B. church; C. dancehall; D. town meeting site

10. A. corn, B. wheat, C. beans, and D. squash

11. 250

12. A. to stop injury to the public grazing lands; B. to provide orderly use and development; C. to stabilize the livestock industry that was dependent upon the public range.

13. A. 1966; B. 2001

∇ Ranch

14. It is an oasis – a source of abundant water in an arid region

15. A. Paleo-Indian B. Archaic C. Ceramic period

16. A. Navajo; B. Paiute; C. Ute

17. To turn 200 acres of Mojave Desert creosote bush into a cattle range

18. It was made of local rock, not logs, like other homes in the area.

∇ Grand Gulch Mine

19. False

20. Copper proved to be more abundant and was periodically profitable.

21. A group of men from St. George, Utah established an official **claim** on the mine on June 23, **1873**. Profitable exploration of the **ore**, said to be "the richest ever produced by a copper **mine** in the Territory," was hampered by **isolation** and the long **haul** to a railhead. **Mules** initially packed in tools and **supplies** until the early 1870s when a **wagon road** opened to St. George.

22. It was difficult to haul the large amounts of unprocessed ore long distances.

23. 75 to 80

24. In 1906, a **54**-mile long wagon road was constructed, connecting the mine to St. Thomas, **Nevada** (now under **water** at Lake Mead). It took freight teams a **week** to make the round trip. Between eight to twelve **tons** were hauled each trip at a value of **$10.00** a ton. Teams included **six** to **ten** horses, with drivers usually **traveling** in pairs.

25. The drop in copper prices

26. A. bunkhouse; B. adobe smelter

LESSON 1: VIEWS OF PARASHANT

This activity compliments the National Park Service's **Views of the National Parks** (DVD and web site) *Grand Canyon-Parashant National Monument Visitor Center*. http://www2.nature.nps.gov/views/

EXPLORE

In this activity, you will explore Grand Canyon-Parashant National Monument (Parashant) through the Views DVD or website. Whenever you see the ∇ symbol, click on the button or link to the name that follows it. For true/false or yes/no statements, circle the correct answer.

Part A. Introduction to the Monument

Go to the homepage of Views of the National Parks.

∇ **Visitor Center**

∇ **Virtual Experiences**

∇ **Grand Canyon-Parashant**

∇ **Explore Grand Canyon-Parashant.**

1. What four things might you hear if you are in the country?

A.

B.

C.

D.

2. One of the factors that make this monument so special is that it is __________ from centers of _______________ occupation. Some people call it ____________, even lonely, while others travel great ___________ to experience its ____________. Rugged and ___________, the monument is one of largest, un-fragmented stretches of ____________ developed lands in the contiguous _______________.

Part B. Visitor Center

∇ **Visitor Center**

1. The monument's expansive landscape encompasses a chronicle of science, ________________, cultures, and ________________.

2. How long is the drive on a rough dirt road to the monument boundary? _____________

3. List four things the monument provides excellent opportunities to do.

A.

B.

C.

D.

∇ Facts

4. Parashant covers more than one million acres. True False

5. Elevation at the monument ranges from ______ feet above sea level near Grand Wash Bay at Lake Mead to over ______ feet at Mt. Trumbull.

6. The monument is a special land filled with canyons, ____________, and deserts.

7. Grand Canyon-Parashant National Monument is under the joint management of the _______________________ and the Bureau of Land Management.

8. The monument is located on the Colorado Plateau in northwestern _________________.

9. Grand Canyon National Park is to the __________ and the monument borders the state of ______________ to the west.

∇ Activities

10. Fees and permits are required for backcountry camping. True False

11. There are no developed _______________ within the monument; please camp within previously used, undeveloped ________________ along primary ____________.

12. At the monument, you should camp at least ________________from any water source or reservoir.

∇ Preparation

13. Will your cell phone or radio always work in the monument? Yes No

14. Three diseases to be wary of at the monument are ______________, _________________, and rabies.

15. Each person should bring _________________ of water for each day at the monument.

16. The three questions about planning that you should be able to answer "yes" to in order to ensure a safe and enjoyable trip at Parashant are:

A.

B.

C.

Part C. The Colorado Plateau

∇ Colorado Plateau

1. The Colorado Plateau covers an area as large as which three states combined?

A. _______________ B. _________________ C. _____________

2. Ancient _______________ mountains, plateaus and ______________, deeply carved canyons, and amazing ranges in ___________ are the region's major claims to fame.

3. Temperatures vary from winter lows below _______ to summer highs above _________.

4. Grand Canyon-Parashant is in the ______________ part of the Colorado Plateau.

∇ Geology

5. Some areas on the Colorado Plateau are famous for the colorful __________________ rocks formed many ______________ of years ago when a vast ___________ covered Arizona and much of the _______________ United States.

6. List three kinds of sedimentary rocks that formed along the edge of this ancient sea:

A.

B.

C.

7. Warped and folded rock layers that form giant "steps" are called __________________.

8. Not all of the ___________exposed on the Colorado Plateau were deposited by _________ or wind, however. Numerous _____________ dot the region, adding variety to the ______________.

9. Describe what happens to the surface water that falls on the Colorado Plateau.

∇ Ecology

10. The great ecological diversity of the Plateau is due to differences in ________________ and landforms.

11. Forests of what four kinds of trees are found at higher elevations on the Plateau?

A. _______________________ B. _______________________

C. _______________________ D. _______________________

12. Few species of cacti grow throughout the Plateau. True False

13. Name three kinds of birds that soar in the Plateau's skies.

A. _____________ B. _____________ C. ______________

14. Riparian areas that thread throughout the ____________ are home to frogs, ___________, snails, beavers, ____________, and fish.

∇ History

15. Humans have lived on the Colorado Plateau for ___________ years. First to arrive were big game___________, followed by the ___________ culture (8000 years ago) who hunted small ________ and gathered ____________. Later, the Ancestral ___________ (300 A.D. to circa 1250) met the Plateau's challenges, and settled into permanent ________ to farm.

16. Non-native explorers and trappers ventured onto the Plateau between ______ and _______.

17. The resident population of the Colorado Plateau today exceeds _______________.

18. Human impacts that have affected the status of Colorado Plateau _____________ include forest management practices, ____________, logging, mining, __________ generation, introduction of non-native _____________, dams and water diversion, and fragmentation of _______________ by roads and other _______________.

∇ Parashant

19. Grand Canyon-Parashant National ______________ is located in the ___________portion of the Colorado Plateau called the __________ Strip.

20. How many people live in the 14,000 square miles of the Strip? ______

∇ how far away

21. The monument is located 2,367 _________ from Washington, DC and 445 miles from ________________.

Part D. Journey Through Time

∇ Journey Through Time

∇ Nampaweap

1. How were images on the rocks shown in the photo made?

2. ______________ have classified rock elements into categories. Some of the elements you will see at Nampaweap are _______________ (human-like figures), zoomorphs (______________________), and abstract designs. Anthropomorphs typically have _________ and legs, even fingers and _____. Bighorn sheep, __________, and lizards are common ______________ figures. Abstract elements include circles, ___________, and various combinations of _______________.

∇ points to consider when visiting

3. A variety of factors that contribute to the erosion of petroglyphs, including ___________, rain, extreme temperatures, ____________________, and rock type. The most devastating factor however, is ______________________.

∇ Sawmill

4. Large scale and economically significant lumbering of ponderosa pine began at Mt. Trumbull in the ______________.

5. Sawmill operations used _________________ and ________________to generate power.

6. Sawmills were permanent structures and could not be moved. True False

7. What is the Mount Trumbull ponderosa pine forest area being studied for today?

∇ Schoolhouse

8. What family began settling in the Mt. Trumbull area in 1916?

9. List four uses of the Mt. Trumbull Schoolhouse.

A. ________________________

B. ________________________

C. ________________________

D. ________________________

10. What crops did residents grow?

A. ________________________ B. ________________________

C. ________________________ D. ________________________

11. How many people lived in the area in the 1950's? _______________

12. What were the three objectives of the Taylor Grazing Act of 1934?

A.

B.

C.

13. In what year was the schoolhouse closed? In what year was it rededicated after being rebuilt due to fire?

A. Closed in __________ B. Rededicated in __________

∇ **Ranch**

14. Why has Tassi Springs been used or occupied by humans for 11,000 years?

15. Name three early cultures that used Tassi Springs.

A. ________________ B. _________________ C. ________________

16. Continued development of the land in the 1860s led to conflict with which three groups of native people?

A. ________________ B. _________________ C. ________________

17. What did Ed Yates set out to do in 1936?

18. What made Ed Yates' home unique compared to others constructed in the area?

∇ Grand Gulch Mine

19. The Parashant region never experienced a gold rush. True False

20. _______________ proved to be more abundant and was periodically ____________________.

21. A group of men from St. George, Utah established an official ____________ on the mine on June 23, _____________. Profitable exploration of the ________, said to be "the richest ever produced by a copper ___________ in the Territory," was hampered by _______________ and the long ________ to a railhead. ___________ initially packed in tools and ____________ until the early 1870s when a _______________________ opened to St. George.

22. Why was an adobe smelter built at Grand Gulch Mine around 1878?

23. In the early 1900's, how many people were living at the site? ________

24. In 1906, a ______-mile long wagon road was constructed, connecting the mine to St. Thomas, ______________ (now under ___________ at Lake Mead). It took freight teams a __________ to make the round trip. Between eight to twelve _________ were hauled each trip at a value of ____________ a ton. Teams included ________ to _______ horses, with drivers usually _________________ in pairs.

25. What caused the Grand Gulch Mine to shut down for two decades following World War I?

26. Name two relatively complete buildings that still stand at the mine site.

A. ______________________ B. ______________________

LESSON 2: SEDIMENTARY ROCKS – THE CLIFFS AT PARASHANT

GEOLOGICAL ADVENTURES AT PARASHANT

EXPLORING THE GEOLOGY OF GRAND CANYON-PARASHANT NATIONAL MONUMENT

NATIONAL PARK SERVICE

THE GEOLOGICAL SOCIETY OF AMERICA®

SCIENCE • STEWARDSHIP • SERVICE

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

LESSON 2 GUIDE: SEDIMENTARY ROCKS – THE CLIFFS AT PARASHANT

OVERVIEW

Students look at samples of sedimentary rocks and note characteristic features. They then build a sedimentary rock sequence using layers of modeling clay. Each layer of modeling clay stands for a kind of sedimentary rock found in the monument (sandstone, shale, siltstone, limestone). Students then use a piece of dental floss to slice one end of the layers in a manner that is consistent with how rocks weather and erode in canyon walls (i.e., shale will often form gentle slopes, and sandstone, siltstone and limestone will often form cliffs). After the activity, students read about how sedimentary rocks form to learn about the main classification scheme of sedimentary rocks and what sedimentary rocks reveal about depositional environments and Earth's history. Students save their models for use in Lesson 3.

Objectives After observing samples of sedimentary rocks, building a sequence of sedimentary rocks out of modeling clay, carving slopes out of the clay to match rock types, and reading about sedimentary rocks exposed at Grand Canyon-Parashant, students will understand why sedimentary rocks

- often have a layered appearance,
- provide information about past environments, life, and change over time, and
- serve as a natural resource that we depend upon in our daily lives.

Concepts Features and classification of sedimentary rocks; environments of deposition; strata; controls on slope formation; fossils; sedimentary rocks as natural resources.

Duration Two to three 45-minute class periods

Audience Students in grades 6 to 9

Materials **Part A**

- samples of about 9 to 12 assorted sedimentary rocks:
- Clastic: claystone, shale, siltstone, sandstone, conglomerate, breccia
- Chemical: rock gypsum, rock salt, chert, chemical limestone
- Biochemical: fossiliferous limestone, coquina, chalk, lignite, bituminous coal.
- hand lens or magnifying glass

Parts B and C

- 12-oz. box of 4 sticks of modeling clay – blue, green, yellow and red
- sheet of wax paper
- large Styrofoam plate
- 30 cm piece of dental floss
- 12-cm wooden dowel

Extensions **For all students**

- Add samples of local sedimentary rocks to the collection in Explore steps 1-4.
- Arrange for a field trip to view local outcrops of sedimentary rocks.
- Incorporate photographs of local or regional sedimentary rock sequences into a slide show for comparison to sedimentary rocks and sequences at Grand Canyon-Parashant.

For gifted, honors, or higher grade-level students

- In the first part of the activity, provide a sedimentary rock identification key. Have students use the key to describe, identify, and classify each sample of sedimentary rock. A good source is Pamela Gore's *Sedimentary Rock Exercises*: www.gpc.edu/~pgore/geology/historical_lab/sedrockslab.php.

Resources

- See www.gpc.edu/~pgore/geology/historical_lab/sedrocks-exercises.php for the main page with description of how to classify sedimentary rocks.
- See www.gpc.edu/~pgore/geology/historical_lab/sedrocktable.htm for the sedimentary rock identification table.
- Another sedimentary rock identification chart is available at Mike Strickler's site (GeoManiac): jersey.uoregon.edu/~mstrick/MinRockID/RockID/Sedimentary.html

ENGAGE 10 minutes

Figure 2.1 in the student text shows that lithology can control the gradient of a slope. In this case, the easily weathered shale forms a gentler slope, whereas the hard, resistant sandstone forms ridges and cliffs. Students will note a variety of differences, some of which many not be relevant to the investigation.

Ask volunteers to share ideas. Accept all reasonable ideas and write them on the board. Avoid providing the "right" answer – students will learn the names of the rocks in the explore phase of the lesson.

EXPLORE 50 minutes

Part A - Describing Sedimentary Rocks 15 minutes

This activity gives students hands-on experience observing and describing samples of sedimentary rocks. This addresses part of the Engage question – sedimentary rocks look different from one another when made of different minerals or materials and when the grains of the rock are different sizes.

To save time, students work in groups with a set of 8-12 rock samples and divide the samples up so that each student describes 2-3 samples. Students then share and discuss results at their tables, or you can lead a class discussion. If you expect each student to describe and learn to identify all of the rock samples, you will need to budget more time. The activity is designed to help develop observation and recording skills – if you distribute a classification scheme *before* students have made observations and written descriptions, the emphasis of the activity shifts toward rock identification.

1. Have the collection of samples, hand lens/magnifying glasses, and metric rulers available in a container or tray.

2. Check to see if students are addressing the questions in step 2 within their descriptions of sedimentary rocks. Make note of common issues or problems that arise and address them in a discussion in step 3 or 4.

3. Have students share work in their groups or lead a review as a class.

4. See Resources above for sources of sedimentary rock identification charts. Make sure that students record rock names for each description.

Part B. Building a Model of Sedimentary Rock Layers 20 minutes

In this part of the activity, students build layers of sedimentary rock. It's always a good idea to try the activity yourself to identify tips and suggestions that you might want to share with students.

FIGURE 1. Basic setup used to build clay models of sedimentary rock layers.

Figure 1 shows the basic **materials** used to build the models used in this part of the activity (and used for Lessons 3-6 as well).

- A 12-ounce box of *RoseArt* modeling clay has four colors and is available at major discount stores for about a dollar.
- The Styrofoam plate helps with easy clean up and storage, especially in Lesson 3 when students pour liquid soap onto the model to simulate lava flows.
- A wooden dowel (or any smooth cylindrical tube) makes is easy to roll the clay into flat layers. Have several dowels for each group to save time.
- Dental floss is used to slice the layers (wrap around index fingers, just like when flossing) and works quite well.
- It might be helpful to also have a plastic knife on hand for trimming things.
- Wax paper keeps the clay off students' desks, which minimizes cleanup and keeps the materials clean (throw away wax paper after use).

- The colors on the clay will come off in student's hands. If you do not have soap and water available in your room, latex gloves can be used.

1. Have materials available for students on the Styrofoam plates.

2. Students divide blue and green clay so that they get layers of different thickness in their models, and six layers instead of four.

3. The rectangle serves as a guide to keep the layers roughly equal in area.

4. Students may have to do a little trimming to get the clay into a rectangle. A plastic knife helps with trimming. Layers do not have to be perfect rectangles.

5. Students can build stacks in any order, as long as colors alternate. The reason an order is not assigned is that students will create different landscapes in steps 10-12, and produce different sequences which is helpful in lesson 4 on metamorphic rocks (students mangle and fold the layers to simulate metamorphism and try to figure out the sequence in another group's folded sequence). Once students have built up a reasonably level stack of six "rock layers", they can move directly into the last part of the activity.

Although random stacking of layers works for the purposes of these lessons, in the real world, sedimentary rock layering is not so random. Instead, sediments are deposited and sedimentary rock layers build up in particular sequences that yield clues about whether sea level is rising or falling. When the sea encroaches upon the land, the sequence often moves from sandstone (bottom, representing river sediments or sand along the seashore) to siltstone to shale to limestone (top). When the sea recedes, the sequence goes from limestone (bottom) to sandstone (top).

Part C. Carving a Landscape **15 minutes**

The final part of the activity brings the lesson full circle to the Engage question. Another reason that rock layers look different from one another is that they weather and erode differently. In this part of the activity, students carve one end of their models to make a slope. The way that they carve their models is controlled by the type of rock in each layer. An example of what students will create in this part of the activity is shown in Figure 2. Note that the first (top) cut needs to be made about 2-3 cm from the end of the clay.

FIGURE 2 Example of a landscape carved into modeling clay. Note that the blue layers, which represent shale, form slopes, whereas other rock layers form cliffs. Start carving 2 cm from the end.

1. Sandstone forms steep slopes (cliffs) and shale forms gentle slopes (due to differences in the competency of the different rock layers). Keep in mind that this is a general pattern. For example, easily weathered (poorly cemented) sandstones do not form cliffs or steep slopes.
2. If you have tested the activity, you will have found that although carving a steep slope with dental floss is easy, carving the gentle slope can be tricky. If you are concerned about your student's ability to do this, consider demonstrating the procedure in front of the class. Their finished model will look something like Figure 2 above. Blue layers should be sloped and all others vertical. If you are concerned about what students might do with extra pieces of modeling clay, collect the extra pieces as you circulate and save them for other uses.
3. Students should wash their hands after handing modeling clay.

EXPLAIN

Assign for reading, either during class or as homework (even if the entire activity has not yet been completed). You can supplement the explanation phase of the lesson with a discussion or lecture. Photographs of outcrops of sedimentary rocks, sample of rocks, diagrams of environments of deposition, and photographs of how we use sedimentary rocks as natural resources would be most relevant to the lesson. Photographs of local or regional outcrops would increase the relevance to students.

ELABORATE

Address these questions in a class discussion, assign them for group work, or include them as part of a homework assignment.

1. The rocks in the photo look like sedimentary rocks because they are layered.
2. Four rock layers are visible in the photograph.
3. Students' sketches should show two layers of shale (second from top later and the bottom layer) as slope-forming layers and two layers of sandstone (top layer and third from top layer) as the cliff-forming layers.

Challenge Question:

Using what students observed about shale versus sandstone samples, and what they have read about, they should say that sandstone layers would make for better building stone because the sandstone is harder and more resistant to weathering, and the shale would tend to crumble.

EVALUATE

1. The three main types of sedimentary rocks are clastic, chemical, and biochemical.

2. A. Limestone;

B. Yes, limestone forms in a marine environment (seas and oceans), so the region must have been under seawater long ago.

3. A. Scientists can conclude that Antarctica once had a much warmer climate because coal is made from plants that died in swamps.

B. Antarctica used to have swamp plants, whereas now it has very few plants.

4. Yes. The geologist has found a fossil because a footprint is evidence of past life.

5. Answers will vary, but may include statements like using gasoline found in sedimentary rocks to get to school, using electricity that came from a power plant fueled by coal, walking on a sidewalk made from cement that comes from limestone, flavoring food using salt that came from rock salt, and so on.

Challenge Question:

The oil probably comes from deposits in sedimentary rocks, and the power lines may be carrying electricity that comes from burning coal, which is a sedimentary rock.

LESSON 2: SEDIMENTARY ROCKS – THE CLIFFS AT PARASHANT

ENGAGE

Look carefully at Figure 2.1. Write down as many differences between the two rock layers shown in the photo. Explain why they might be different kinds of rocks.

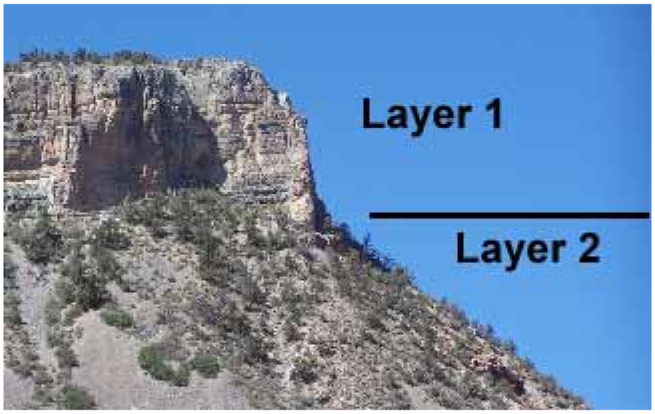


FIGURE 2.1 What differences do you see between these two layers of sedimentary rocks?

EXPLORE

In this activity, you will study samples of sedimentary rocks and make a model of rock layers. In some ways, the rocks will look similar, but if you look closely, you will see key differences. These differences, which are due to how the sedimentary rock formed, give scientists clues about the past. The properties of rocks can also affect the landscapes they form.

Part A. Describing Sedimentary Rocks

1. From your teacher, obtain a collection of sedimentary rocks. Distribute the rocks amongst your group so you each have the same number of rocks.

2. For each rock you have, write a brief but careful description. Use a hand lens or magnifying glass to look closely. Features to observe and record include:

a. What color is it? Be as specific as you can.

b. Is it hard or soft? Can you break off small pieces with your fingernails?

c. Does the rock have grains you can see?

d. Are the grains small or large?

e. Do the grains have sharp edges or are they rounded?

f. Are the grains different colors? If so, what colors can you see?

g. Can you see any fossils? If so, what do they look like?

h. Can you see layers? If so, how thick are they?

3. In your group, take turns presenting your rock descriptions.

4. If an answer key is available, compare your descriptions to the key. Write the names of the sedimentary rocks next to your descriptions.

Part B. Building a Model of Sedimentary Rock Layers

One feature of sedimentary rocks is that they form layers. The layering is somewhat like how you build a stack of pancakes by adding one pancake at a time. In this part of the activity, you will use modeling clay to build a model of layers of sedimentary rocks.

1. From your teacher, obtain a box of four colors of modeling clay, a sheet of wax paper, a metric ruler, a large Styrofoam plate, some dental floss, and a small wooden dowel.

2. Use a piece of floss to cut the blue clay and the green clay in half.

3. Draw a rectangle about 5 cm by 10 cm on the wax paper.

4. Place a piece of clay inside the rectangle on the wax paper. Use the dowel to roll the clay into a flat layer 5 cm wide by 10 cm long.

5. Place the flat layer on the Styrofoam plate. Repeat this process with the rest of the pieces of clay until you have a stack of six layers. You can stack the colors in any order as long as you alternate colors.

Part C. Carving a Landscape

1. Refer back to Figure 2.1. Layer 1 is sandstone, and layer 2 is shale. Use this information to complete this sentence: Harder, more compact rocks like sandstone tend to form [gentle/steep] slopes, while softer, more easily weathered rocks tend to form [gentle/steep] slopes.

2. Table 1 relates a color of modeling clay in your model to a common type of sedimentary rock. On the basis of the information in the table, use dental floss to carve a landscape out of one side of your model.

Table 1. Key to Rock Types

Color of Clay	Rock Type	Nature of Slope Formed
Yellow	Sandstone	Steep (cliffs)
Green	Siltstone	Steep (cliffs)
Blue	Shale	Gentle (gradual slopes)
Red	Limestone	Steep (cliffs)

3. Put away the Styrofoam plate and clay model, then wash your hands.

EXPLAIN

FIGURE 2.2 Layers are a common feature of sedimentary rocks, like these exposed in the Grand Wash Cliffs at Parashant.

Sedimentary rocks at Grand Canyon-Parashant National Monument (Parashant), like those everywhere, began as **sediment** - pieces of older rocks or remains of organisms like shells or coral. Sediments can be carried and deposited by rivers, streams, wind, or glaciers. They can roll down the slope of a mountain. They can be washed along the beach or sink to the bottom of a lagoon or lake. Sediments build up on top of old sediments to form layers called **strata**. Eventually, the layers may get buried deeply enough to be compacted or cemented together to form sedimentary rock. Table 2 lists the basic groups of sedimentary rocks, with examples. Chances are that you have already seen sedimentary rock. They are the most common type of rock at the Earth's surface.

Table 2. Major Types of Sedimentary Rocks

Type	Description	Examples
Clastic	Clastic sedimentary rocks are made up of pieces (clasts) of pre-existing rocks. Pieces of rock are loosened by weathering and transported to some basin or depression where sediment is trapped. If the sediment is buried deeply, it becomes compacted and cemented, forming sedimentary rock. Particles range in size from microscopic clay to huge boulders. Names are based on grain size.	conglomerate breccia sandstone siltstone claystone shale
Chemical	Chemical sedimentary rocks are formed by chemical precipitation. This process begins when water traveling through rock dissolves some of the minerals, carrying them away from their source. Eventually these minerals are redeposited when the water evaporates away or when the water becomes over-saturated.	chert dolomite oolitic limestone rock gypsum rock salt
Biochemical	Biochemical sedimentary rocks form from once-living organisms. They may form from accumulated carbon-rich plant material or from deposits of animal shells.	chalk coquina fossiliferous limestone micrite peat lignite bituminous coal

Source: USGS Geology in the National Parks. geology.wr.usgs.gov/parks/rxmin/rockchart.html

Sedimentary rocks record a history of change over time. Geologists study strata like you might study pages of a history book. The strata tell about past events and climate, where the land and sea were located, and the animals and plants that lived in that region. For example, coal reveals that a region once had vast swamps. Rock salt indicates an ancient arid climate near the sea. The rounded pebbles and cobbles in a conglomerate speak of stones rolling and bouncing along a river bottom. Many layers of limestone can be found at Grand Canyon-Parashant, yet the monument is hundreds of miles form the ocean. As incredible as it may sound, the presence of limestone means that this very arid region once lay beneath a shallow sea!

FIGURE 2.3 Sediments are being deposited along the Colorado River and along slopes of the Grand Canyon, but the layers of sedimentary rock that form much of the canyon's walls are hundreds of millions of years old. They tell a story about change over time in this region.

FIGURE 2.4 Sedimentary rocks exposed in the cliffs at Parashant record millions of years of Earth's history. They provide clues about how life and climate have changed over time.

Sedimentary rocks also reveal how life on Earth has changed over time. Plants and animals that die are sometimes buried in sediment. If that sediment becomes rock, it will contain **fossils**, the remains or evidence (like animal footprints) of living things preserved in rock. Scientists use fossils found in sedimentary rocks to understand the evolution of life and to reconstruct ancient climates and ecosystems. For example, some types of organisms that once lived in shallow seas or on land at Parashant have become extinct (see Figure 2.5).

FIGURE 2.5 The three circular features in this limestone at Parashant are fossil stems of ancient sea lilies called crinoids. Crinoids lived in shallow marine environments.

Sedimentary rocks also provide valuable natural resources that we depend upon every day. Limestone and sandstone are used as building stones, for landscaping, and for road beds. The mineral calcite found in limestone is the key ingredient in cement. Add some sand and gravel to the cement and you have concrete used to make sidewalks, bridges, and roads. Coal provides energy for generating electricity. Most of the world's supply of natural gas and oil comes from deposits trapped in sediments or sedimentary rocks. The salt that we use to season foods or melt ice on sidewalks and roads is mined from layers of rock salt. The wallboard in your home or school is made from rock gypsum, layers of which formed when seawater evaporated long ago (Figure 2.6).

FIGURE 2.6 Sedimentary rocks are an important natural resource. Rock gypsum mined south of St. George, Utah is used for wallboard on homes and offices.

ELABORATE

The questions below relate to Figure 2.7.

1. Do the rocks look like sedimentary rocks? Explain.
2. How many layers of rock are shown?
3. Draw a simple sketch of the rock layers. Based upon what you have learned, label which layers might be sandstone, and which might be shale.

Challenge Question: If you wanted to use these rocks to build a stone home, which layer or layers would you use? Explain.

FIGURE 2.7. A 15-meter thick exposure of sedimentary rocks north of Parashant.

EVALUATE

1. What are the three main types of sedimentary rocks? Give an example of each.
2. Suppose you are hiking in the mountains of northern Arizona and you found a layered rock with fossil coral in it.
   a. What sedimentary rock is it most likely to be?
   b. Can you conclude that this mountain region was once under the sea? Explain.

3. Layers of coal have been found in Antarctica, a continent almost entirely covered with ice. What can you conclude about the following?

a. How has the climate has changed over time in that region?

b. How has life has changed over time in that region?

4. A geologist finds a layer of sedimentary rock with dinosaur footprints in it. She finds no dinosaur bones – just footprints. Has she found a fossil? Explain your answer.

5. Give two examples to show how you have used or depended on resources from sedimentary rocks in the last week.

Challenge Question:

How do the oil rig and power lines shown in Figure 2.8 relate to sedimentary rocks?

FIGURE 2.8. A drilling rig in western Colorado.

Lesson 3: Igneous Rocks – Lava Flows at Parashant

Geological Adventures at Parashant

Exploring the Geology of

Grand Canyon-Parashant National Monument

LESSON 3 GUIDE: IGNEOUS ROCKS – LAVA FLOWS AT PARASHANT

OVERVIEW

Students look at samples of igneous rocks and sort the rocks by texture, color, and then by texture and color. Students then model the flow of lava at Parashant by pouring liquid soap onto the top of their clay models and observing the differences in the speed of the flow (slow, medium, fast) over slopes of different gradients. Students compare their models to surface and aerial photographs of lava flows at Parashant as they read about the main types of igneous rocks (extrusive versus intrusive) and the nature and timing of eruptions at the monument. Students are asked to design and conduct their own experiment into lava flows using one of six research questions.

Objectives After studying samples of igneous rocks, modeling the flow of lava on slopes of different gradients, and reading about the igneous rocks exposed at Grand Canyon-Parashant, students will understand:

- Igneous rocks cool and crystallize from magma.
- The composition of magma determines the chemical and physical properties of the igneous rocks.
- The distribution and thickness of lava depends upon the volume erupted, the topography of the land, and the composition of the magma.

Concepts Properties and types of igneous rocks; magma versus lava; cooling and crystallization; intrusive versus extrusive igneous rocks; gradient.

Duration Two to three 45-minute class periods

Audience Students in grades 6 to 9

Materials **Part A**

- Samples of igneous rocks. The rocks should be labeled with names (or numbered and a key given to students):
  - <u>Intrusive</u>: granite, diorite, gabbro
  - <u>Extrusive</u>: basalt, andesite, rhyolite, scoria, obsidian, pumice, porphyry
- Hand lens or magnifying glass
- Metric ruler
- Worksheet 3.1 – Classifying Igneous Rocks

Part B

- Clay model of rock layers and slopes (see Lesson 2).
- 10 ml of liquid soap
- Eye dropper (or small plastic squeezable dropper bottle filled with liquid soap)
- Stopwatch (or clock with seconds hand)
- Metric ruler
- See the **Elaborate** section of this guide for a description of materials

needed for experimental design activity.

Extensions **For all students**

- Add samples of local or regional igneous rocks to the collection in Explore, Parts A, B, and C.
- Arrange for a field trip to view local outcrops of igneous rocks.
- Incorporate photographs of local or regional igneous rocks into a slide show for comparison to igneous rocks (primarily volcanic rocks) at Parashant.

For gifted, honors, or higher grade-level students

- If you want to focus on identifying igneous rocks, provide students with an identification chart. A good source is Pamela Gore's igneous rock ID chart at gpc.edu/~pgore/geology/physical_lab/igneouschart.htm
- The Elaborate section of the lesson offers many options for tailoring the activity for students of different ability levels and for integrating mathematics (calculating slopes of best-fit lines) and technology (MS Excel). See the suggestions in the appropriate section of this guide.

ENGAGE — 10 minutes

The engage question explores student's observation and description skills, and their initial ideas about igneous rocks. If you have large (hand-sized) samples of granite and basalt, hold them up for comparison as you introduce the question (or put samples of the two rocks at each table – real objects will work better than the photographs). Basalt is a dark-colored, fine-grained igneous rock and granite is a light-colored, course-grained intrusive igneous rock. If you have students record their initial ideas before they discuss with others (i.e., without talking), you will gather more information about their ability to observe and describe.

Observations students might make are that the basalt in the photo is dark in color, does not appear to have crystals, and has holes (vesicles), whereas the granite has different colored crystals (four different colors are visible), the crystals are large enough to see, and the overall color is light. Ask volunteers to share ideas. Accept all reasonable ideas and write them on the board. Avoid providing the "right" answer – students will learn about how to classify igneous rocks in the explore phase of the lesson.

EXPLORE — 60 minutes

Materials for Parts A, B, and C: These three activities involve sorting samples of igneous rocks into groups and should take a total of about 35 minutes. Students can work in pair or groups, depending upon how many rock samples you have available.

- You will need a set of labeled samples of igneous rocks. Students need to have the names of rocks available in order to put rock names in the data tables and to facilitate discussion. If your rock samples lack numbers (with a key that shows the name of each numbered rock), then you can put them in small, labeled trays and ask that students move the trays around the table during the sorting process.

- A few hand lenses or magnifying glasses per group
- A metric ruler for each group (for measuring grain size)
- Photocopy and distribute Worksheet 3.1 – Classifying Igneous Rocks to each student so that they do not have to spend time making up data tables.
- Students begin by observing the texture of igneous rocks. They then move to observing and sorting igneous rocks by color (chemical composition). Finally, they combine the two criteria and sort the rocks by texture and color. Set a timer and give students a set amount of time for each sorting activity. The point is not to memorize the names of rocks, but to focus on the process of classification.

Part A. Sorting Igneous Rocks by Texture **10 minutes**

1. Distribute materials and worksheets to groups at tables. Inform students how much time they have to sort the rocks by texture.

2. Students will have lots of questions about what constitutes coarse texture versus fine texture, what to do with obsidian (Is it one large crystal? Is it a crystal?), and so on. Remind them that they are welcome to make up new categories, so long as they can describe and defend their choices.

3. Save a class discussion of the results of sorting for later (see Part C, question 5). As you circulate, you will see that students will make “mistakes”. Keep in mind that the point is not for them to sort or group rocks as well as geologists do (besides, geologists sometimes argue about how to classify rocks).

Part B. Sorting Igneous Rocks by Color **10 minutes**

1. Inform students how much time they have to complete part B. In this part of the activity, students put the rocks back into the center of the table and focus on a second criterion for sorting igneous rocks – color. It might be helpful to point out to students that “light” and “dark” are relative terms. Dark does not mean black, and light does not mean white. A helpful hint that you can provide students is that an example of mixed color is roughly equal amounts of salt and pepper. You might want to show them a small sample of mixed salt and pepper.

2. As you circulate, review students’ sorting of rocks and remind them that they can make new categories if they wish (and remind them to describe their new categories). Rather than coaching students into making a perfect sorting, encourage group discussion and provide feedback on their ability to defend their choices.

Part C. Classifying Igneous Rocks by Texture and Color 15 minutes

1. Again, it is helpful to set a timer or remind students about time remaining to classify the rocks. At this stage, students are technically classifying the igneous rocks into specific groups using the same two criteria that geoscientists use – texture and composition.
2. Table 3 is very close to a standard igneous rock identification chart. If students wish to use their own chart with their own categories, that's okay. Table 4 in the Explain section provides a scientific classification scheme (but you should avoid pointing Table 4 out to students during the activity to lessen the likelihood that they will simply copy rock names into Table 3).
3. The concept underlying the question is that classification schemes do not exist in nature – they are made by people. It often takes a lot of discussion, debate, and revision to decide where things belong in a classification scheme.
4. The long debate about what constitutes a planet in the solar system is a good analogy to raise in the discussion. In the end, scientists prefer to have a standard classification scheme and appreciate the benefits of grouping similar objects into categories. It is part of defining the order and organization of nature.
5. If you have circulated and monitored student's progress, you should be able to have a brief discussion about the results of Table 3. At this point, you can refer students to Table 4, and ask if they have specific questions about how they classified rocks compared to what is shown in Table 4. Depending upon your district or state standards, discussing the process and benefits of classification schemes may be more important than making sure that every student has the correct rock name in each cell on the data table.
6. It is advisable to have students wash their hands after handling rock samples.

Part D. Modeling Lava Flows 15 Minutes

There are some 213 volcanic vents on the Uinkaret Plateau on or near Parashant that have erupted ash, cinders, and lava during the past 3.6 million years. The most recent eruption on the monument was the Little Springs Volcano near Mt. Trumbull, which erupted less than 1000 years ago. Lava from at least 13 eruptions of various volcanoes flowed into the Grand Canyon. Most common are basalt flows topped by pyroclastic (cinder) cones which blast rock and cinders out during the dying stages of gaseous vents. Many of the basalts at Parashant have inclusions of peridotite (olivine-rich igneous rock), which suggests that the magmas are derived from the upper mantle.

Materials: In this activity, students use their model of sedimentary rock layers and slopes to model the flow of lava across the Earth's surface (see Figure 1). Each group will need:

- The clay model of rock layers on a Styrofoam plate. The Styrofoam plate will prevent soap from running on tables and desks.
- Liquid soap. Choose a liquid soap with some viscosity (not too runny). To get a sense of the viscosity, turn the bottles upside down where you are at the store, and watch how quickly bubbles rise to the surface. The slower the bubbles rise, the more viscous the soap is.
- A small cup (to hold the liquid soap) and an eye dropper (**or** a small squeezable dropper bottle of liquid soap). Dropper bottles work best because they minimize spillage and mess, but a small plastic cup of liquid soap and an eye dropper will work, too.
- Paper towels.
- A metric ruler (to measure the distance lava travels)
- A stopwatch (or clock with seconds hand) to measure how long flows take to stop moving.

FIGURE 1 Clay model showing small lava flow and large lava flow. Have students level the top of the model by gently pressing down on it with a flat object, like a textbook. Drop soap towards one end.

1. Have students read through all of the steps before starting.
2. Students should predict that the larger volume will cover a greater area (flow down the slope). Liquid soap serves as the lava in the model. Point out that in the real world, lava is erupted from vents and fissures from below. Dropping liquid soap onto the model does not simulate the eruption process, just the flow of lava.
3. The activity refers to ml of liquid soap. If you use dropper bottles, measure how many drops of soap there are in 0.5 ml, and provide

students with this number. They can multiply by six to estimate how many drops will be in 3 ml of soap for step 4.

4. It is important the students drop the soap towards the carved end of the model, but not directly on the slope. Students should measure the distance traveled and measure and record how long it takes for the flow to stop moving. Students may have difficulty noting how the steepness of the slope affects the speed of the flow, but if they look carefully, they should see that soap travels faster on the steep slopes (especially if the soap goes over the straight edge of the model, not the carved slope).

5. The greater the volume of lava erupted, the larger the area it covers.

6. Put the models away for use in Lessons 4-6.

EXPLAIN

Assign the reading either during class or as homework (even if the entire activity has not yet been completed). You can supplement the explanation phase of the lesson with a discussion or lecture. Photographs of outcrops of igneous rocks, samples of igneous rocks, diagrams of igneous intrusion structures (batholiths, laccoliths, dikes, sills,), diagrams or photos of types of volcanoes (cinder cones, stratovolcanoes, and shield volcanoes), and photos erupting volcanoes would be most relevant to the lesson. Photographs of local or regional outcrops would increase the relevance to students.

ELABORATE **45 minutes**

In this activity, students design an experiment to investigate a factor that might affect the flow of lava. You can use the description below to create your own worksheet to tailor the activity to the needs of your students and your school or district requirements for writing up laboratory investigations. This would enable you to provide as little or as much structure to experimental design as you think your students require.

Note: Because it requires only simple materials, this activity is well-suited for an at-home assignment to be done with parents or guardians. If you choose the at-home option, have students work on their investigation designs in class to ensure safe and valid procedures.

Materials: For all six of the research questions, students will need liquid soap, dropper bottle(s) or eye droppers, and an overhead transparency of cm-square graph paper. The grid allows them to measure distances (for students who are calculating lava speed) and area (for those doing experiments about surface area covered). Have students use the grid square transparency upside-down so that the squares do not wash away. The transparency is easy to clean up – just rinse and dry gently with a paper towel. Table 1 (next page) shows additional materials needed to test each research question.

Note that each question follows the form "What is the relationship between X and Y?" This allows students to easily identify the independent variable (the "X") and dependent variable (the "Y"), and produce a graph of results (independent variable "X" on the X-axis and dependent variable "Y" on the Y-axis).

Table 1. Guidelines for Designing Experiments Into Lava Flows

Research Question	Suggestions	Additional Materials
1. What is the relationship between the volume of lava erupted and the surface area it covers?	Control the slope angle by doing the tests on a flat surface. Allow students to test multiple volumes simultaneously by dropping soap on different parts of the transparency. Graph volume (cm^3) versus area (cm^2), determine a best-fit line, and calculate the slope of the line.	None
2. What is the relationship between the temperature of magma and the speed of lava flow?	Control the slope angle and volume of liquid soap used in each test. Heat soap in hot water bath, keep one at room temperature, and cool one bottle of soap in ice bath. Use 0.5 ml soap for each test. Graph results as a bar graph with temperature descriptors on X axis: cold, room temperature, warm and speed of the flow in cm/s on the Y axis.	3 dropper bottles of liquid soap at three temperatures Materials for heating soap and cooling soap Clipboard (to attach transparency grid to). Books to make a slope, Stopwatch Calculator
3. What is the relationship between the temperature of magma and the area of a lava flow?	Control the volume of liquid soap "erupted" and control slope by doing tests on a flat surface. Use 2 ml soap for each test Allow students to perform multiple trials simultaneously by dropping different soaps on different parts of the transparency. Graph results as a bar graph with qualitative temperature descriptors on X axis: cold, room temperature, warm, and quantitative data (area in sq. cm) on Y axis.	3 dropper bottles of liquid soap at three temperatures Materials for heating soap and cooling soap

Research Question	Suggestions	Additional Materials
4. What is the relationship between the angle of a slope and the speed of a lava flow?	Control the volume used for each test. Graph results as a bar graph with qualitative temperature descriptors on X axis: cold, room temperature, warm, and quantitative data (speed) on Y axis.	Clipboard (to attach transparency grid to). Books to make a slope, Stopwatch Calculator
5. What is the relationship between the composition of magma and the speed of a lava flow?	Vary composition (which will alter the viscosity) by adding different amounts of water to two of the three bottles of one brand of liquid soap. Create a 50% soap mix (50 parts water to 50 parts soap), a 75% soap mix (75 parts soap to 25 parts water), and a 100% soap (pure). Graph composition as percentage soap on x axis, and speed (cm/s) on Y axis.	Three dropper bottles of liquid soap – 50%, 75%, 100% (pure). Clipboard (to attach transparency grid to). Books to make a slope, Stopwatch Calculator
6. What is the relationship between the composition of magma and the area of a lava flow?	Vary composition (which will alter the viscosity) by adding different amounts of water to two of the three bottles of one brand of liquid soap (OR use three different brands of liquid soap). Create a 50% soap mix (50 parts water to 50 parts soap), a 75% soap mix (75 parts soap to 25 parts water), and a 100% soap. Graph composition (% soap) on x axis, and area covered (sq cm) on Y axis.	Three dropper bottles of liquid soap: 50%, 75%, 100% (or three different brands of soap).

EVALUATE

1.

a. Granite forms slowly underground (coarse crystals) whereas rhyolite forms at the Earth's surface in a volcanic eruption (fine crystals)

b. Both granite and rhyolite are similar in chemical composition (felsic). They are both rich in silica and low in iron and magnesium.

2. A magma that produces rhyolite magma will erupt more explosively than a magma that produces basalt lava because rhyolite has a higher percentage of silica. The higher the silica content, the more explosive the eruption is.

3. The correct order from smallest to largest area covered is c, a, and b. Rhyolite does not flow far due to its high silica content. Basalt flows more easily, and the more basalt that erupts, the greater the area it will cover.

Challenge Question

a. The texture is porphyritic (large-grained crystals surrounded by fine-grained crystals). The chemical composition is mafic because the overall color is dark.

b. The olivine crystals formed underground as the magma began to cool slowly, then a volcanic eruption occurred and made the fine-grained basalt lava with crystals of olivine inside it.

WORKSHEET 3.1 – CLASSIFYING IGNEOUS ROCKS

Table 1. Sorting Igneous Rocks by Texture.

Texture	**Igneous Rocks**
Coarse (crystals > 1mm)	
Fine (crystals < 1mm)	
Mixed (fine and coarse)	
Other – Describe:	
Other – Describe:	

Table 2. Sorting Igneous Rocks by Color (Chemical Composition).

Color	**Igneous Rock Names**
Dark (mostly dark minerals or overall dark color)	
Intermediate (mixed light and dark)	
Light (mostly light minerals or overall light color)	

WORKSHEET 3.1 – CLASSIFYING IGNEOUS ROCKS

Table 3. Classifying Igneous Rocks by Texture and Color

Texture	**Color**		
	Light	**Intermediate**	**Dark**
Fine			
Coarse			
Mixed			
Glassy			
Holes			
Other – Describe:			
Other – Describe:			

LESSON 3: IGNEOUS ROCKS - LAVA FLOWS AT PARASHANT

ENGAGE

Look at the photos of basalt and granite in Figure 3.1.

⇒ What differences do you see between the two rock samples?

Record your ideas, then discuss your answer with a partner.

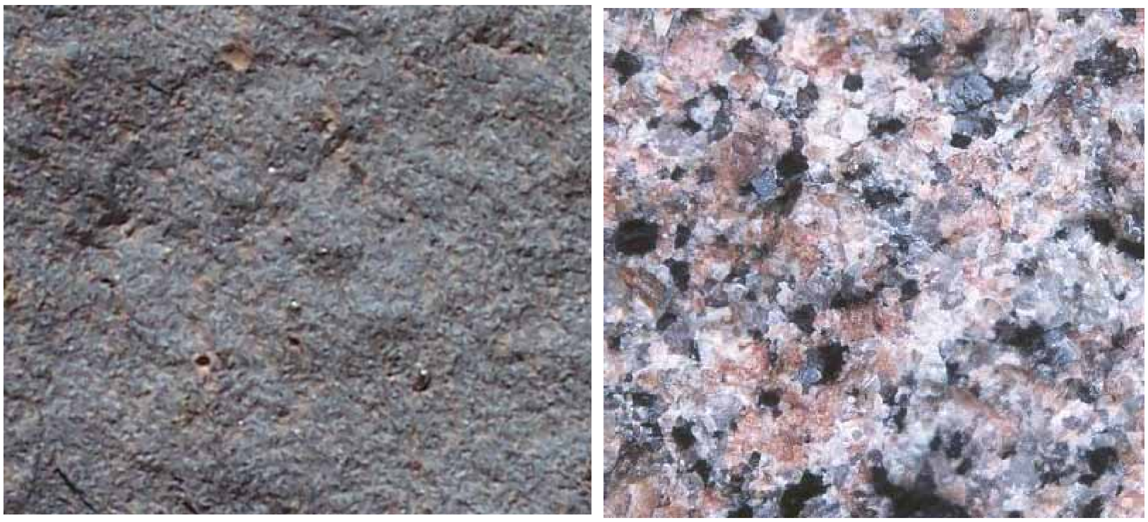


FIGURE 3.1 Left: Basalt, Black Rock Mountain at Parashant. Right: Granite, location unknown (credit: R.A. Busch).

EXPLORE

Igneous rocks are rocks that cool and crystallize from molten rock (**magma**). For now, you can think of magma as being a little like cake batter. What you put into the batter and how hot the oven is controls how your cake turns out. In this activity, you will look at the relationship between magma (batter) and igneous rock (cake). By the end of the lesson, you will understand how igneous rocks form and how lava travels across the landscape.

Part A. Sorting Igneous Rocks by Texture

Can you sort the igneous rocks in your collection by texture? **Texture** refers to the presence, shape, arrangement, and size of mineral crystals in a rock. The texture of an igneous rock reveals whether the magma cooled below ground (slowly) or at the surface (quickly). Large crystals (easily visible to your eye) mean that the magma cooled more slowly.

1. From your teacher, obtain a set of labeled igneous rocks. Put the rocks on the table in front of your group.

2. Using Table 1 as a guide, sort the rocks into groups by texture. If you think that a fourth category of texture will help, add it under “Other” in the table and describe your new category.

3. When your group agrees on the sorting, write the name of each rock where you think it belongs in a copy of **Table 1**.

Table 1. Sorting Igneous Rocks by Texture.

Texture	Igneous Rocks
Coarse (crystals > 1mm)	
Fine (crystals < 1mm)	
Mixed (fine and coarse)	
Other (describe)	

Part B. Sorting Igneous Rocks by Color

Can you sort igneous rocks by their color? Color indicates the **chemical composition** of the igneous rock – the kinds of minerals that make it up. Think again about cake batter. Chocolate has a dark color, so it is no surprise that batter with chocolate in it makes a dark-colored cake. Magma behaves the same way. Magma that has a chemical composition rich in dark-colored minerals will cool to form a dark-colored igneous rock.

1. Put the rocks back into the middle of the table again. This time, sort the rocks by color.

2. When your group agrees on the sorting, write the name of each rock where you think it belongs in a copy of Table 2.

Table 2. Sorting Igneous Rocks by Color (Chemical Composition).

Color	Igneous Rocks
Dark (mostly dark minerals or overall dark color)	
Intermediate (mixed light and dark)	
Light (mostly light minerals or overall light color)	

Part C. Classifying Igneous Rocks by Texture and Color

1. Put the rocks back into the middle of the table for a final sorting. This time, sort the rocks by color and texture.

2. When your group agrees on how to sort the rocks, record your results in a copy of Table 3.

Table 3. Classifying Igneous Rocks by Texture and Color

Texture	Color		
	Light	Intermediate	Dark
Fine			
Coarse			
Mixed			
Glassy			
Holes			
Other (describe):			

3. Describe at least one disagreement that came up during the process of classifying igneous rocks.
4. Was the disagreement resolved? If so, how?
5. Share your group's classification scheme and responses to questions 3 and 4 above in a class discussion.
6. Put the rocks away and wash your hands as instructed by your teacher.

Part D. Modeling Lava Flows

When magma reaches the Earth's surface and flows on the ground, it is called **lava**. Several factors affect how fast the lava flows, how far it travels, and how large of an area it covers. In this part of the lesson, you will model and investigate these factors.

FIGURE 3.2 Eroded cinder cone and lava flow (horizontal ledge in foreground) at Parashant.

1. Place your clay model of sedimentary rock layers onto the Styrofoam plate on your table. Obtain a supply of liquid soap and an eye dropper (or a plastic dropper bottle filled with liquid soap). The liquid soap represents hot lava erupted from a volcano that forms at the top of your sedimentary rock layers.
2. Predict what will happen if you were to pour 0.5 ml of liquid soap (1 full eye dropper) versus 3 ml of liquid soap onto the top of your model. Record your predictions.
3. Pour 0.5 ml of liquid soap onto the top of your model. Measure and record what happens by answering the following questions:

a. How far does the soap travel?

b. How long does it take to stop moving?

4. Pour 3 ml more liquid soap onto the top of your model close to the end that has a slope carved into it. Describe what happens by answering the questions below.

a. How far does the soap travel?

b. How long does it take to stop moving?

c. How does the slope of the rock layers affect how fast the soap moves?

5. Consider how what you have learned might apply to a real volcano by making a prediction. What is the relationship between the volume of lava erupted and the size of the area it covers?

6. Clean up. Wash the soap off the modeling clay and Styrofoam plate, and dry gently with a paper towel. Put the materials away and wash your hands.

EXPLAIN

Just as you could make hundreds of kinds of cakes by changing the ingredients, hundreds of kinds of igneous rocks are possible. Fortunately, scientists have devised a system to put all these different kinds into a few basic groups. The system they use follows what you did in your exploration activity.

Igneous means formed by fire. Igneous rocks form from the cooling and crystallization of molten rock material. Underground molten rock is called **magma**. Rocks that form from magma (beneath the surface) are called **intrusive** igneous rocks (see Figure 3.3). Magma that reaches Earth's surface through a vent or fissure is called **lava**. Igneous rocks that cool and crystallize at the surface are called **extrusive** igneous rocks. Intrusive and extrusive are thus the two basic types of igneous rocks.

FIGURE 3.3 Two different intrusive igneous rocks. The darker granodiorite formed first and was intruded by magma of a different chemical composition, which cooled to form the light-colored pegmatite (credit: Larry Fellows).

Table 4. Basic Classification Scheme for Igneous Rocks

Texture	Composition			
	Felsic	Intermediate	Mafic	Ultramafic
Coarse	Granite	Diorite	Diabase Gabbro	Peridotite
Fine	Rhyolite	Andesite	Basalt	
Porphyritic Coarse – Fine	Porphyritic - Granite Porphyritic Rhyolite	Porphyritic – Diorite Porphyritic – Andesite	Porphyritic - Gabbro Porphyritic - Basalt	Porphyritic – Peridotite --
Vesicular	Pumice	Pumice	Vesicular Basalt Scoria	--
Glassy	Obsidian	--	--	--
Fragmental	Tuff (ash) Volcanic breccia	Tuff (ash) Volcanic breccia	--	
Color Index (% dark minerals)	0-15	20-40	50-60	95-100

(after P. Gore. http://gpc.edu/~pgore/Earth&Space/GPS/Igneous.html)

The rate at which molten rock cools affects the texture of the igneous rock. Intrusive igneous rocks cool slowly beneath the surface where the temperature is high (like letting your cake cool inside the oven). The slower cooling gives crystals time to grow, so intrusive rocks are coarse grained. In contrast, molten rock that reaches the surface cools quickly. Crystals of extrusive igneous rocks have less time to grow and are fine-grained or glassy. Some volcanic rocks have holes (vesicles) due to trapped gases. Others have a fragmental texture because the explosive nature and heat of a volcano can weld together pieces of volcanic rock and ash. Sometimes, magma starts to crystallize underground, and large crystals start to form. Then the magma is erupted in a volcano. The lava cools quickly, producing a rock with coarse crystals surrounded by fine crystals. This texture, a mix of coarse and fine crystals, is called porphyry.

FIGURE 3.4 This igneous intrusion is a volcanic neck - the remains of a conduit that fed a volcano near Pakoon Springs at Parashant.

Now that you know how texture tells you whether a rock formed below or at Earth's surface, let us look at color, the other main property used to group igneous rocks. Color reflects the chemical composition of an igneous rock. If we return to our cake analogy, chocolate cake batter has a dark color and vanilla batter has a light color. The finished cake reflects the "chemical composition" of the batter. Similarly, light-colored igneous rocks have a higher percentage of light colored minerals in them, and dark igneous rocks have a higher percentage of darker minerals.

The minerals that make up all igneous rocks come from a group called **silicates**. Each silicate mineral has a unique percentage of silica in it. In general, minerals rich in silica and low in iron and magnesium are lighter in color than minerals that are low in silica and high in iron and magnesium. We call these compositions **felsic** and **mafic**, respectively. Of course, it is a continuum. A cake batter can be 100% chocolate and 0% vanilla on one end of the continuum, or 100% vanilla and 0% chocolate on the other end, and any combination in-between. Igneous rocks that have close to equal amounts of felsic and mafic minerals in them are intermediate in composition. Table 4 summarizes how to classify igneous rocks by texture and composition. If you find any part of the table confusing, go back and re-read this section.

The chemical composition of magma not only affects the color of the igneous rock, but also affects the nature of volcanic eruptions. The higher the percentage of silica in magma, the more explosive the eruption will be. That is because high silica (felsic) magma forms lavas that are cooler, more viscous (they do not flow freely), and more likely to trap gases. When enough gas pressure builds up behind the viscous magma…boom! A violent eruption occurs. In contrast, low silica (mafic) magmas produce lava that is hotter, flows more easily, and create gentler volcanic eruptions. An analogy is that of old toothpaste being squeezed from a tube (silica-rich magma) versus liquid soap or warm pancake syrup (low-silica lavas). Figure 3.5 shows a recent flow of basalt lava at Parashant. The lava flowed for some distance down a gentle slope.

FIGURE 3.5 Eruption of basaltic lava near Mt. Trumbull at Parashant some 1,000 years ago produced the Little Springs flow (credit: D. Mosby).

FIGURE 3.6. How many of the volcanic centers at Parashant can you find in this photo? (credit: D. Mosby)

The Uinkaret volcanic field at Grand Canyon-Parashant has some 200 volcanic vents. The vents erupted basaltic lava and cinders during the past 3.6 million years (Figure 3.6). On more than 13 occasions in the last one million years, basaltic lavas flowed down canyons that lead to the Grand Canyon. The lava flows built huge dams across the Colorado River. Eventually the dams failed, creating massive outbursts of floodwaters. Evidence shows that some of the floods reached 200 meters above the present level of the Colorado River. Blocks of basalt nearly 40 meters in diameter have been found downstream and traced to these lava dams.

ELABORATE

Design an Experiment into Lava Flows

Some lava flows move more quickly than others. Some flows cover a greater area than others. What causes one flow to behave different than another?

Choose one of the six questions in Table 5 below. Develop a hypothesis, identify the independent and dependent variables, design an experiment (using liquid soap as your lava source), and draw conclusions. Be sure that your design allows you to gather **quantitative data** (numerical data that comes from measuring something) rather than **qualitative data** (e.g., “the liquid soap flowed faster”). Graph your results.

Table 5. Research Questions about Controls on Lava Flows

1. What is the relationship between the volume of lava erupted and the surface area it covers?

2. What is the relationship between the temperature of lava and the speed of a lava flow?

3. What is the relationship between the temperature of lava and the area of a lava flow?

4. What is the relationship between the angle of a slope and the speed of a lava flow?

5. What is the relationship between the composition of lava and the speed of a lava flow?

6. What is the relationship between the composition of lava and the area of a lava flow?

EVALUATE

1. Refer to Table 4 to answer these two questions.

a. Describe the difference between how granite forms versus how rhyolite forms.

b. Describe how granite and rhyolite are similar.

2. Which magma is more likely to form the most violent volcanic eruption – one that produces rhyolite lava or one that produces basalt lava? Why?

3. Three situations that produce lava flows are described below. Put them in order from smallest area covered to largest area covered. Explain.

a. A small volume of basalt magma erupted onto a flat slope

b. A large volume of basalt magma erupted onto a gentle slope

c. A small volume of rhyolite magma erupted onto a flat slope

Challenge Question

Figure 3.7 shows an olivine basalt from Grand Canyon-Parashant. The olivine is visible as large green crystals.

a. Describe the texture and the chemical composition of the rock

b. Explain how the rock formed.

FIGURE 3.7 Olivine basalt from Whitmore Wash at Parashant. The large crystals are olivine, an iron-magnesium silicate mineral.

LESSON 4: METAMORPHIC ROCKS – BASEMENT OF PARASHANT

GEOLOGICAL ADVENTURES AT PARASHANT

EXPLORING THE GEOLOGY OF
GRAND CANYON-PARASHANT NATIONAL MONUMENT

NATIONAL PARK SERVICE

THE GEOLOGICAL SOCIETY OF AMERICA®
SCIENCE • STEWARDSHIP • SERVICE

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

LESSON 4 GUIDE: METAMORPHIC ROCKS – BASEMENT OF PARASHANT

OVERVIEW

Students begin by conducting thought experiments about how heat and pressure might change rock. They then experiment with their clay models of rock layers by measuring its dimensions, compressing the model, and measuring and calculating how the model changed due to pressure. With this concrete analogy of change due to metamorphic burial and tectonic folding, students read about agents of metamorphism and how metamorphic rocks form the 1.6 to 1.8 billion year old basement rocks beneath Parashant. In the Elaborate activity, students compare samples of metamorphic rocks to common parent rocks to explore the effects of heat and pressure on igneous, sedimentary, and metamorphic rocks.

Objectives After comparing metamorphic rocks to their sedimentary and igneous equivalents, making models of metamorphism due to intense folding, and reading about metamorphic rocks at Parashant, students will understand:

- Metamorphism changes one kind of rock into another kind of rock;
- Several ways that heat and pressure change rocks;
- Metamorphic rocks are derived from and related to other rocks;
- Why metamorphic rocks form the basement rocks of Parashant.

Concepts The roles of heat and pressure in metamorphism, regional versus contact metamorphism, changes that occur during metamorphism, common metamorphic rock types, and basement rock.

Duration Two to three 45-minute class periods

Audience Students in grades 6 to 9.

Materials **Explore activity**

- Clay model of rock layers and slopes from prior lesson
- Styrofoam plate
- Metric ruler
- Dental floss

Elaborate activity

- Samples of metamorphic rocks and their parent rocks (shown in parentheses): gneiss, schist, slate (shale or mudstone), marble (limestone), quartzite (sandstone). Note: Some metamorphic rocks can have more than one parent rock. Common examples are used here.
- Hand lens or magnifying glass
- Small, thick glass scratch plate
- <u>Optional:</u> Bottle of dilute hydrochloric acid for testing several rocks. Safety goggles and lab aprons should be used as well.

Extensions **For gifted, honors, or upper-level high school students**

- If you need to emphasize rock identification, substitute metamorphic rock identification for the current activity shown in the Elaborate section. Copy Worksheet 4.1 Metamorphic Rock Identification for each student, or use one of your own.

Resources

- Photographs of metamorphic rocks are available at http://www.soes.soton.ac.uk/resources/collection/minerals/meta-1/index.htm
- A more complete metamorphic rock identification chart is available at http://jersey.uoregon.edu/~mstrick/MinRockID/RockID/MetaClass.html
- An excellent summary of metamorphism and metamorphic rocks that you can use to freshen up your content knowledge on the subject is a page written by Dr. Stephen A. Nelson of Tulane University at http://www.tulane.edu/~sanelson/geol111/metamorphic.htm.

ENGAGE — 10 Minutes

The Engage question uses a familiar event to motivate students to think about metamorphism. When you take freshly powered snow and make a snowball, the volume decreases as some air is driven out, the density increases (because the mass remains the same yet the volume decreases), it becomes harder, and heat from your hands melts some of the snow and makes it recrystallize. Ask volunteers to share ideas. Accept all reasonable ideas and write them on the board.

EXPLORE — 35 Minutes

Part A. Agents of Change: Heat and Pressure

In this part of the activity, students model how rocks respond to heat and pressure within the Earth. In steps 1-5, students run several **thought experiments** about the role of heat in changing rocks into new rocks. The thought experiment uses the clay model of rock layers as a model for what happens to rocks when subjected to heat from magma, lava, or burial within the Earth (**geothermal gradient**). If they are unfamiliar with the idea of a thought experiment, tell them that it is an experiment that you do in your head, like the Engage question about making a snowball. In steps 6-12, students model pressure due to burial in the Earth by flattening and measuring the changes in their clay models, and in steps 13-16, they model pressure due to tectonics by folding their clay models.

Materials: Figure 1 shows the materials needed for the activity, except for a sheet of waxed paper and a book to flatten the clay model.

1. Distribute materials to students. The thought experiments will be easier if they have the clay models in front of them. They also need to see the models to count the layers in step 5.

Figure 1. Materials needed for the activity.

2. The top layer would be affected by super hot liquid soap. This would be like a lava flow baking the top part of the rocks it flows over.

3. Lava from a volcano is most likely to affect the top layer of rock – the layer it flows over.

4. This question makes students think about how the heat from the intrusion of magma affects rocks. The part of the model touching the hot liquid soap will be affected the most.

5. The answer to the question posed is 175^0C. This question asks students to think about how heat within the Earth affects rocks. Students may realize on a general level that the interior of the Earth is hot, but they probably have not thought about it quantitatively. Rocks do not have to be near magma to be heated – they are heated simply due to burial and Earth's geothermal gradient, the increase in temperature with depth in the Earth. If the temperature of rock increases 25^0C for each 1000 meters of rock in the model, which has six layers, the base would be 150^0C warmer, or 175^0C, a temperature warm enough to begin metamorphosing rocks.

6. Students now begin working with their model. Students are asked to slice the end of the model that had the slopes on it to help give the model a more regular shape (a rectangular cube). Working the floss back and forth with a sawing motion and pressing down all the way to the desk will help ensure a complete cut through the model.

Figure 2 Slicing the end of the model to make a clean face. Save scraps for later lessons.

7. Students should measure the length, width, and height of the model to the nearest 0.1 cm. Figure 3 shows the model prior to pressure being applied and how to measure its length, width, and height.

Figure 3 Side view (length), end view (width), and height of clay model prior to it being compressed.

A sample of a completed version of Table 1 is shown below.

Table 1. Changing Dimensions of a Clay Model of Metamorphic Rock

Time	Length (cm)	Width (cm)	Height (cm)
Before Pressure is Applied	6.9	4.0	4.6
After Pressure is Applied	10.8	9.0	1.6
Change (+ or -)	+4.1	+5.0	-3.0

8. Figure 4 shows the wax paper and book on the model after compressing the model. The amount of compression will vary with strength. Students could set the Styrofoam plate and model on the floor and step carefully on the block with one foot. Students can use their desk or lab table to steady themselves while they stand on the block. When they first step on the block, they should put their foot in the middle so the block does not become lopsided. If you choose this option, use a smaller-sized wood block instead of a book, demonstrate how to do so safely, and supervise their efforts as a safeguard.

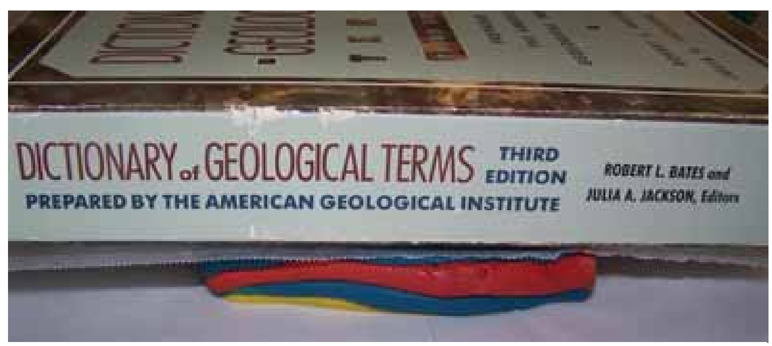


Figure 4 Model after being compressed by a book.

9. Figure 5 shows the length (10.8 cm), width (9.0 cm), and height (1.6 cm) of the model after being compressed. Students must decide where to measure the model (e.g., when measuring width, should they measure at the widest point, the narrowest point, or take an average?). If you want a standard approach used, let students know. The final shape of the model will depend upon how pressure is applied.

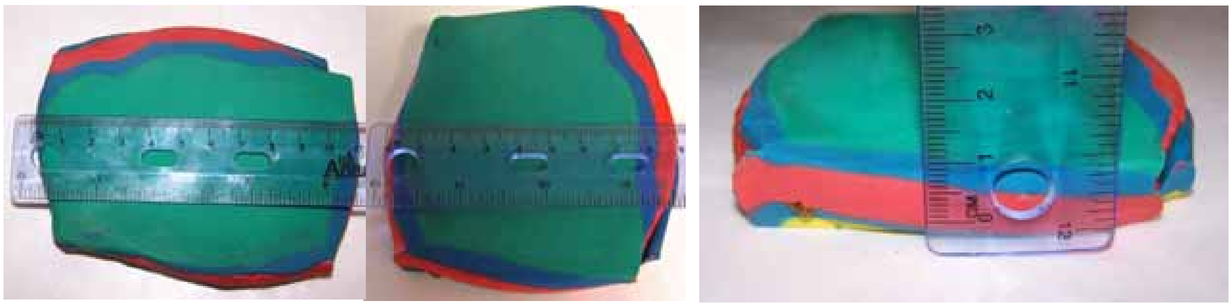


Figure 5 Clay model after being compressed, showing length, width, and height.

10. As shown in the completed copy of Table 1 (previous page), the height of the model decreased due to pressure while the length and width increased. This illustrates that minerals and grains grow in directions perpendicular to the direction in which force is applied. As an extension, you might have students calculate percentage of compression [(change in height ÷ original height) X 100] to see whose model was compressed the most.

11. Answers will vary. In our example, pressure made the model 3.0 cm thinner (1/3 its original thickness), but it increased the length and width of the model.

12. A quick sketch of a side view of the model will enable students to make comparisons after folding the model.

13. Try folding the model so that you know what is involved. Figure 6 shows the kind of fold you want students to make – not a complete folding in half, but a rumpled fold like a mountain. This creates intricate smaller folds within the model, which are even more dramatic when the model is sliced in half (see Figure 7).

Figure 6 Side view of model after folding.

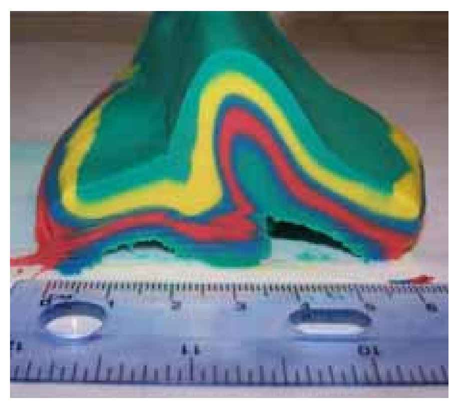


Figure 7 Side view of sliced model after folding.

14. The fold of clay or a rock has an axis that makes a line. The slice should be made at a right angle to the axis of the fold (or parallel to the direction of folding). If students slice down the axis of the fold, they will not see the folded structure. Drawing a diagram on the board of how to slice the model will help guide them. Students draw a second side view of their model. This one shows the folded layers of clay.

15. Note in Figure 7 that the pressure and folding shortens the width of layers to about 6 cm while increasing the thickness of layers, especially those near the center of the fold.

16. Students should wash their hands after handling modeling clay.

EXPLAIN

Assign for reading during class or as homework (even if students have yet to complete the entire activity). You can supplement the explanation phase of the lesson with a discussion or lecture. Photographs of outcrops of metamorphic rocks (see Resources section in this guide), as well as map views and cross-sections of metamorphism that illustrate the differences between contact versus regional metamorphism, would be helpful.

ELABORATE — 45 Minutes

Examining Metamorphic Rocks

This activity takes students from working with clay models and thought experiments to working with rock samples. Questions emphasize the relationships between parent rock (original rock) and metamorphic rock and the changes that occur during metamorphism (e.g., do texture, composition, and other physical properties, like hardness, change?).

Materials you will need for the activity (and consequently, the specific questions from the activity you assign to students) will vary depending on what rocks you have available in your collection. The most basic examples are used in the activity to help students to understand how metamorphism transforms one rock into another. Be sure to emphasize that some metamorphic rocks could have formed from several different kinds of parent rocks. Gneiss can form from metamorphism of schist or granite.

You will need samples of metamorphic rocks and their parent rocks (shown in parentheses). It is helpful if you use rocks of similar color – white sandstone and white quartzite, white to light grey limestone and white marble: gneiss, schist, slate (shale or mudstone), marble (limestone), and quartzite (sandstone). You can also have students compare bituminous coal with anthracite coal, and conglomerate with metaconglomerate.

Students will need a hand lens or magnifying glass to examine texture.

Small, thick glass plate which allows students to test the hardness. This is most useful in comparing marble to quartzite. Quartzite and marble often look alike, but quartzite is made of quartz, a mineral that is harder than glass. Marble is made of calcite or dolomite, both of which are softer than glass. As a result, quartzite scratches glass, while marble does not (and marble reacts with dilute hydrochloric acid). To safely test the hardness of a rock, place the glass plate on a level, hard surface, and firmly press the rock across the glass plate (use plates from science supply companies, not window glass). Use a finger to wipe clean the area on the glass you have tried to scratch. If the rock is harder than the glass, you will see a scratch mark or feel the scratch with your fingernail. If the rock is softer than glass, you will wipe away broken piece of the rock when you wipe the glass clean. Never hold the glass plate in your hand when doing a scratch test. Review and demonstrate these safety precautions with students.

Optional: A bottle of dilute hydrochloric acid for testing several rocks. Have students conduct the acid test under your direct supervision. Have students wear safety goggles and lab aprons while doing or observing the test. Options include waiting until you bring the acid bottle to them, or having groups come to your workspace and doing the test for them (or having them do the test in front of you).

1. Distribute materials after reviewing safety precautions.

2. Compare **limestone** to **marble**.

a. Limestone is fine-grained while marble is coarse-grained and crystalline (shiny surfaces).

b. Marble is non-foliated. The mineral crystals have no preferred orientation and are not in layers.

c. Limestone and marble are one color and are thus made of one kind of mineral.

d. Neither limestone nor marble scratches glass.

e. Marble is made of the same mineral as limestone (same color) and it looks like the grains of the calcite have been changed into large grains or crystals by metamorphism.

f. (Optional): Both rocks fizz when a drop of dilute HCl is applied. The acid liberates carbon dioxide gas from the mineral calcite (calcium carbonate), which makes up both rocks.

3. Compare **shale** (or mudstone) to **slate**

a. Slate is fine-grained. You cannot see individual mineral grains.

b. Slate looks to be foliated because it splits along layers.

c. Shale makes a dull thud sound when struck on a table, while slate rings.

d. Slate would be good for roof tiles or sidewalks because it is hard and can be split into layers to make the right shape needed for these purposes. Students might also note that it looks like water would not soak into slate very easily.

e. Slate looks like shale, only harder (rings when struck against the table, and has a slightly reflective sheen), so it is easy to imagine that metamorphism transformed shale into slate.

4. Compare the **sandstone** to **quartzite**.

a. Both rocks have grains that are large enough to see. Quartzite looks more crystalline or “sugary”.

b. Quartzite is non-foliated.

c. Sandstone and quartzite look like they are made of one mineral (quartz).

d. Sandstone and quartzite scratch glass.

e. Both rocks are made of the same mineral, but while sandstone often feels like sandpaper, quartzite is crystalline, so the mineral grains of the sandstone look like they have been recrystallized into larger grains.

f. (Optional): Neither rock should fizz with acid (unless by chance the cement holding the grains of the sandstone together is calcite, which sometimes happens).

5. Compare **slate** to **schist**

a. Schist has coarser grains.

b. Slate and schist are foliated. They both look like they have layered minerals.

c. As the slate was metamorphosed, the grains recrystallized and grew larger, making schist.

6. Compare **granite** to **gneiss**

a. Granite and gneiss are coarse-grained – you can see the individual mineral grains.

b. Gneiss is color banded. It looks like it has light and dark-colored layers of minerals.

c. Answers will vary between two and four different minerals (colors).

d. Gneiss has the same colors as granite, but it looks like the minerals were moved into layers by the heat and pressure of metamorphism.

7. Review responses in a class discussion. It is important to be flexible and somewhat lenient on some questions because some of the differences between the rocks are subtle.

8. Students should wash their hands after handling rock samples.

EVALUATE

1. Burial pressure comes from the weight of the overlying rocks. Tectonic pressure happens when large sections of Earth's crust collide with one another to form mountains. Tectonic pressure often folds the rocks.

2. Metamorphic rocks are most likely to form below the Earth's surface where high temperatures and great pressures exist. Some metamorphic rocks form at the surface due to contact metamorphism when hot lava flows across rocks.

3. It is difficult to see metamorphic rock at Grand Canyon-Parashant National Monument because the rocks are buried by sedimentary rocks and sediment. They are the basement rocks. In some places, uplift and erosion has brought the metamorphic basement rocks to the surface.

4. The main difference between sandstone and quartzite is texture. Both rocks are made of quartz, but quartzite has a crystalline texture due to metamorphism.

5. When you pushed down on the clay model, the force you applied with your hand is like the force applied to a rock that is buried *(shallowly /* ***deeply****)* in the Earth's crust. The *(****weight*** */ volume)* of the rocks above *(****pushes down*** */ pulls up*) and compresses the rock. As the minerals or grains that make up the rock are squeezed, they tend to line up and grow *(parallel /* ***perpendicular****)* to the force of compression.

6. The geothermal gradient is the rate of increase in temperature with depth in the Earth. It varies from place to place, but averages about 25^{o}C per kilometer. As rocks are buried in the Earth, they are naturally heated due to the geothermal gradient, causing metamorphic rocks to form.

7. It is challenging to interpret the geologic history of metamorphic rocks because heat and pressure can destroy the fossils, cause new minerals to form, and fold and fault the rocks.

Challenge Question.

a. The rock looks like gneiss.

b. Heat and pressure caused the minerals to grow and form colored bands, and then folded the bands.

WORKSHEET 4.1 – METAMORPHIC ROCK IDENTIFICATION

Metamorphic Rock Identification Chart

Texture	Composition; Color, and Miscellaneous Features	Parent Rock Name	Rock Name	Sample Number
Foliated - very fine grained-no visible minerals	Dull; Rings when struck on desk.	Shale or mudstone	Slate	
	Shiny due to increased size of mica minerals (almost see them)	Shale or mudstone	Phyllite	
Foliated - medium to coarse grain	Individual mineral grains visible	Slate	Schist	
Color banded	Alternating layers of light (felsic) and dark (mafic) minerals	Schist	Gneiss	
Non-foliated with non-oriented grains	Calcite; Light; Softer than glass; Reacts with hydrochloric acid	Limestone or Dolomite	Marble	
	Carbon; Dark; Shiny; Breaks with a conchoidal fracture	Bituminous Coal	Anthracite coal	
	Quartz; Light to dark; Harder than glass	Sandstone	Quartzite	

LESSON 4: METAMORPHIC ROCKS: BASEMENT OF PARASHANT

ENGAGE

Describe all the changes that happen to freshly powdered snow when a snowball is made.

EXPLORE

Part A. Agents of Change: Heat and Pressure

1. From your teacher, obtain a model of rock layers (from Lesson 3), a sheet of wax paper, a book, and a piece of dental floss.

2. Start with a thought experiment. Look at your model. Imagine pouring super hot liquid soap onto the top of it to simulate a lava flow.

Which layer of your model would the heat from the soap affect the most – the top, the middle, or the bottom?

3. Next, think about hot (1000°C) lava from a real volcano flowing over the top of rock. Which layer of rock is the heat from the lava most likely to affect?

FIGURE 4.1 Metamorphic rocks form the core of the Virgin Mountains at Parashant.

4. Now, imagine squirting very hot liquid soap into your clay model from below. What would the heat from the model affect the most: the part that the hot liquid soap touches, or the parts that are farther away?

5. Finally, consider how heat within the Earth might affect rocks. Temperature increases with depth at an average rate of 25°C per kilometer. The deeper rocks are buried, the warmer they get. Think of your model as thick layers of rock, with each layer on your model being 1 km of rock in the Earth.

If the temperature was 25°C at the top of your model, how warm would the rocks be at the bottom?

Your thought experiments explored two ways that <u>heat</u> changes rocks: when magma or lava touches rock, and when rock gets buried deeply. You will now work with your model to explore how <u>pressure</u> changes rocks.

6. With a piece of floss, make a vertical slice at the slope end of your clay model. Your model should look like a rectangular box with six flat faces.

7. Measure the length, width, and height of your model, in centimeters. Record your measurements in a data table like Table 1 below. Note: Remove the model from the plate to measure the height accurately.

Table 1. Changing Dimensions of a Clay Model of Metamorphic Rock

Time	Length (cm)	Width (cm)	Height (cm)
Before Pressure is Applied			
After Pressure is Applied			
Change (+ or -)			

8. Put a sheet of wax paper on top of the model. Put a sturdy textbook on top of the waxed paper. If you are able, stand up and push down on the model with two hands. Press straight down as hard as you can to squash the model.
9. Remove the book and the wax paper. Repeat the three measurements. Add the data to your data table.
10. Calculate the change in each of the three measurements. Record this data in your data table. If a measurement increased, indicate this with a plus sign in front of the number. If a measurement decreased, use a negative sign.
11. Summarize how the size of the model changed due to pressure.
12. Draw a side view of your flattened model. Label the colors of each layer on your sketch.
13. Remove the model from the plate. Holding an end in each hand like a sandwich (put your thumbs below the model and your fingers facing each other on the top of the model), fold the model together until it is only 6 cm long. By the time you are done, the layers of clay should have a wavy appearance (see Figure 4.1).
14. Place the model back on the plate. With a piece of dental floss, slice the model in half at a right angle to the line created by the fold. Draw a side view of your folded model, noting the colors.
15. The pressure due to folding decreased the width of the layers to about 6 cm. How did pressure affect the thickness of layers, especially near the center of the large fold?
16. Put the materials away and wash your hands.

Your model showed two reasons why pressure changes rock, and how rocks respond to pressure. Pressure occurs when rocks get buried deeply in the Earth. Pressure can also be applied when large forces fold the rock layers. There are other ways that rocks can be changed. These are too complicated to model using clay, but you will be able to read about examples in the Explain section of the activity.

EXPLAIN

When you make a snowball, snow goes through many changes. As you press down, much of the air gets squeezed out of the snow. As the snowflakes are squeezed into a smaller space, the snow becomes more dense. Heat from your hands also causes the snow to change. Some of the snowflakes re-crystallize. If you work hard enough, the pressure and heat from your hands transform the snow into an icy ball. In a similar way, heat, pressure, and hot chemical fluids inside the Earth can change any kind of rock into **metamorphic rock**.

FIGURE 4.2 Heat and pressure cause minerals to become foliated or banded during metamorphism.

As rock is heated and put under pressure, its texture and its composition can change. First, mineral grains get compacted and the rock gets more dense. You saw this in your clay model when the thickness of clay decreased. The clay minerals in the rock begin to line up, giving the rock a **foliated** texture. Minerals can also recrystallize. When this happens, they grow larger without changing in composition. Sometimes new minerals form. The types of minerals that form leave clues about how deeply the rock was buried and how hot it was.

FIGURE 4.3 How do the folds in this gneiss compare with the folds in your clay model?

Your thought experiments helped you to think about ways that **heat** can change rock. Hot magma or lava can bake nearby rock. This is called **contact metamorphism** (Figure 4.4). Hot magma also interacts with underground water to form hot mineral-rich fluids that circulate through rock. These **hot chemical fluids** change rock by helping minerals to grow and new ones to form. Earth's geothermal gradient also heats rock. The deeper the rocks are buried, the warmer they become.

FIGURE 4.4 The change in color at the top of the red sandstone caused when hot molten lava (now a layer of black basalt) flowed over it is due to contact metamorphism.

Pressure also causes rock to change. Pressure can come from burial or tectonics.

Tectonic pressure happens when huge sections of Earth's crust slowly collide and press into one another. Unlike contact metamorphism, which changes rocks only a few meters to a few kilometers from the magma, burial pressure and tectonic pressure change rock over a large region. Such **regional metamorphism** can also result in intricate folded patterns in the rock. You may have seen this in your clay model.

Table 2. Metamorphic Rock Identification Chart

Texture	Composition; Color, and Features	Parent Rock	Rock Name
Foliated - very fine grained-no visible minerals	Dull; Rings when struck on desk.	Shale or mudstone	Slate
	Shiny due to increased size of mica minerals (almost see them)	Shale or mudstone	Phyllite
Foliated - medium to coarse grain	Individual mineral grains visible	Slate	Schist
Color banded	Alternating layers of light (felsic) and dark (mafic) minerals	Schist	Gneiss
Non-foliated with non-oriented grains	Calcite; Light; Softer than glass; Reacts with hydrochloric acid	Limestone or Dolomite	Marble
	Carbon; Dark; Shiny; Breaks with a conchoidal fracture	Bituminous Coal	Anthracite coal
	Quartz; Light to dark; Harder than glass	Sandstone	Quartzite

Metamorphic Rocks at Parashant

From what you have learned about how metamorphic rocks form, it should not be surprising that it takes special conditions to find them at the Earth's surface. Most metamorphic rocks form deep within the Earth. At Parashant, with the exception of contact metamorphism beneath lava flows, most metamorphic and igneous rocks form **basement rocks** – the rocks deeper in the crust beneath the sedimentary rocks and recent sediments. On the Colorado Plateau (on which Parashant is located), basement rocks formed more than 1.6 billion years ago. In order for the rocks to be seen at the surface, they had to have been uplifted by the forces of tectonics and mountain building. Uplift creates differences in elevation, which allows the overlying rocks to be stripped away. Otherwise, the only way to learn about basement rocks is by finding pieces of them in the lowest sedimentary rocks or drilling deep holes into the Earth.

Fortunately, uplift and the work of the mighty Colorado River (which formed the Grand Canyon) have exposed metamorphic rocks in several places at or near Parashant. Metamorphic rocks form the core of the Virgin Mountains in the western part of the monument. These rocks are at least 1.6 billion years old. Vast forces in the last 100 million years compressed and uplifted the metamorphic and sedimentary rocks to form the Virgin Mountains. Erosion of overlying sedimentary rocks brought the metamorphic rocks of the basement to the surface for us to view and study (see Figure 4.5).

At Parashant, you can also see ancient metamorphic rocks that have been uplifted and then exposed by erosion along the Colorado River. These rocks, like the Precambrian Vishnu Schist, are in the Grand Canyon. They are visible from several overlooks at Parashant. Amazingly, more than one billion years of the rock record from Earth's 4.5 billion-year history is missing at the boundary between the metamorphic basement of Parashant and overlying sedimentary rocks!

FIGURE 4.5 Metamorphic rocks in the Virgin Mountains were exposed by uplift and erosion. Note how the rocks are turned on end.

Metamorphic rocks give us clues about Earth's history, but the clues are harder to detect. Recall from earlier lessons that rocks reveal clues about what the environment of a region was like in the past. Metamorphism obscures these clues because it changes the original rocks. Fossils in sedimentary rocks usually get destroyed and minerals can be changed from one type to another. Metamorphism can happen many times over hundreds of millions of years. This makes interpreting the history very challenging.

The basement rocks of Parashant underwent great changes due to intense heat, pressure, chemical fluids, and folding. This has made it very difficult (but not impossible) for geologists to interpret them to find out what the western edge of North America was like at that time. However, as more and more scientists attack this challenge, the evidence from detailed study and comparison to modern settings has yielded some clues. This evidence suggests that the basement rocks of Parashant and the Colorado Plateau represent the growth of what was then a much smaller continent over a period of some 800 million years. Growth occurred as sections of other plates (sediments and ocean crust) collided with the North America and were plastered onto it, making it larger.

ELABORATE

Examining Metamorphic Rocks

In this activity, you will examine samples of common metamorphic rocks and some of the rocks from which they are derived. Pay careful attention to any safety precautions your teacher provides.

1. From your teacher, obtain a set of metamorphic rocks and parent rocks (the rocks from which the metamorphic rocks are most likely to have formed), a hand lens or magnifying glass, and a glass plate

2. Compare the **limestone** to **marble**.

a. Describe the texture of each rock: fine-grained (individual grains are not visible) or coarse grained (individual grains are visible).

b. Is marble foliated? (are mineral arranged in layers?)

c. Look at the color of the rocks. Color indicates chemical composition. How many different kinds of minerals make up each rock?

d. Do the rocks scratch glass?

e. Summarize the evidence behind the claim that marble is metamorphosed limestone.

f. (Optional – Under your teacher's direct supervision, and when wearing safety goggles and a lab apron): Describe what happens when a drop of dilute hydrochloric acid is placed on each rock.

3. Compare **shale** (or mudstone) to **slate**

a. Describe the texture of slate – is it fine-grained or coarse-grained?

b. Foliated metamorphic rocks have a tendency to split along layered minerals. Is slate foliated?

c. Lightly tap the shale and the slate on the edge of a table. Describe the difference between the sounds they make.

d. Slate has been used for roof tiles, sidewalks, and building stone for centuries. What properties of slate make it useful for this purpose?

e. Summarize the evidence behind the claim that slate is metamorphosed mudstone/shale.

4. Compare the **sandstone** to **quartzite**.

a. Describe the grain size of each rock – can you see individual grains?

b. Is quartzite foliated or non-foliated?

c. Look at the color of each rock. How many different minerals (colors) make up each rock?

d. Do the rocks scratch glass?

e. Summarize the evidence behind the claim that quartzite is metamorphosed sandstone.

f. (Optional – Under your teacher's direct supervision, and when wearing safety goggles and a lab apron): Describe what happens when a drop of dilute hydrochloric acid is placed on each rock.

5. Compare **slate** to **schist**

a. Which rock has coarser grains?

b. Are the rocks foliated or non-foliated? Explain.

c. Schist forms when slate is subjected to even greater pressure and temperature. How does the grain size of schist support the claim that minerals have recrystallized during metamorphism?

FIGURE 4.6 Schist at Parashant. Penny for scale.

6. Compare **granite** to **gneiss**

a. Are the rocks fine-grained or coarse-grained?

b. Which rock has bands of color?

c. How many different kinds of minerals can you see in each rock?

d. Gneiss can form when schist or granite is metamorphosed. Describe any evidence that suggests that granite and gneiss are related.

FIGURE 4.7 Gneiss at Parashant. Penny for scale.

7. Share your results in a class discussion.

8. Put away materials and wash your hands.

EVALUATE

1. Describe the difference between burial pressure and tectonic pressure.

2. Where are metamorphic rocks most likely to form: at or below Earth's surface? Explain.

3. Why is metamorphic rock visible in so few places at Grand Canyon-Parashant National Monument?

4. What is the main difference between sandstone and quartzite: texture or composition? Explain.

5. In the sentences below, choose the correct words to summarize how your work with the clay model demonstrates metamorphism due to burial pressure.

When you pushed down on the clay model, the force you applied with your hand is like the force applied to a rock that is buried *(shallowly / deeply)* in the Earth's crust. The *(weight / volume)* of the rocks above (*pushes down / pulls up*) and compresses the rock. As the minerals or grains that make up the rock are squeezed, they tend to line up and grow *(parallel / perpendicular)* to the force of compression.

6. What is the geothermal gradient and what role does it play in making metamorphic rocks?

7. Describe ways that metamorphism destroys clues or evidence that scientists need to interpret the geologic history (environment, life, etc.) of the parent rock.

Challenge Question

Look at Figure 4.8.

a. What name would you give to this metamorphic rock?

b. Explain how heat and pressure were involved in making the rock look this way.

FIGURE 4.8 Metamorphic rock from the Virgin Mountains at Parashant (penny for scale).

LESSON 5: TOPOGRAPHY – LANDFORMS OF PARASHANT

GEOLOGICAL ADVENTURES AT PARASHANT

EXPLORING THE GEOLOGY OF

GRAND CANYON-PARASHANT NATIONAL MONUMENT

NATIONAL PARK SERVICE

THE GEOLOGICAL SOCIETY OF AMERICA®

SCIENCE • STEWARDSHIP • SERVICE

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

LESSON 5 GUIDE: TOPOGRAPHY – LANDFORMS OF PARASHANT

In Part A, students shape modeling clay into a feature, place it in a transparent container, and add water in increments to make a contour map of the feature. In Part B, they learn how to construct a profile across their contour map. With this concrete, hands-on experience working with maps and profiles, students read about topographic maps and the processes that control the development of landform features, then interpret topographic maps and construct profiles of four different kinds of landscape features at Parashant.

Objectives After constructing a contour map and a topographic profile of a clay model, reading about topographic maps and landscapes at Parashant, and interpreting topographic maps of landscape features at Parashant, students will understand:

- Contour maps and topographic maps are models of the Earth's landscapes
- How to read a topographic map and draw a topographic profile
- How forces and rock materials interact over time to shape the landscape

Concepts Topography, contour interval, contour line, profile, relief, gradient, landscape, landform, controls on landform development, Colorado Plateau.

Duration Three 45-minute class periods

Audience Students in grades 6 to 9

Materials **Part A: Making a Contour Map**

- 12 ounces of modeling clay
- sheet of waxed paper or Styrofoam plate
- clear (transparent) plastic container with clear lid
- metric ruler
- grease pencil or marker
- section of overhead transparency (trimmed to fit lid)
- sheet of white paper
- container of water
- paper towels
- Optional: Colored pencils

Part B: Drawing a Profile

- Contour map (from Part A)
- Thin strip of white paper
- Sheet of graph paper
- Ruler

Elaborate activity (For each pair of students):

- Topographic map and photograph of a Parashant landform (see handouts section)
- Thin strip of white paper (for making profiles)
- Sheet of graph paper
- Magnifying glass
- Optional: Computer to view and magnify pdf's of maps and photographs

Extensions

For all students

- See teacher notes in the **Elaborate** section of the activity for ideas about adapting parts of the activity for various audiences and abilities.
- Provide a local topographic map for students to interpret. Use questions within the activities in this lesson as a guide to making up your own worksheet.

For gifted, honors, or upper level students

- In the **Elaborate** activity, have students do further research to supplement their interpretations of the landform they have been assigned.
- Ask students to plan a hike between points A and B on their topographic map of a Parashant Landform that would be an easier (albeit longer) hike by thinking about gradients along the hike.

Resources

- The USGS guide to topographic map symbols is available at http://erg.usgs.gov/isb/pubs/booklets/symbols/
- TerraServer-USA allows you to access topographic maps as well as aerial photos at http://terraserver-usa.com/
- Michael Ritter of the University of Wisconsin-Stevens Point has made an elegant interactive tutorial about how to draw a topographic profile at http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/manuals/instructor_manual/how_to/topographic_profile.html

ENGAGE **10 minutes**

Figure 5.1 in the student text shows a contour map of a cinder cone volcano at Parashant. The southeast-trending valley on the feature was most likely the place out of which lava flowed. The cinder cone is elevated about 300 feet above the surrounding landscape. Most students will conclude that the feature is a hill, but their explanations may vary. Some students may have difficulty interpreting the lines on the map. Ask volunteers to share ideas. Accept all reasonable ideas with a simple “thank you” and write them on the board. Avoid providing the “right” answer – students will learn how to interpret contour lines in the lesson.

EXPLORE **60 minutes**

Part A. Making a Contour Map **30 minutes**

In this part of the lesson, students form a landscape feature out of clay and make a contour map of the feature. The purpose of the lesson is to give them concrete hands-on experience that relates 2-D maps to 3-D objects. Try the activity before assigning it to students. This will help you to identify potential challenging aspects and obstacles so that you can provide specific advice in advance.

Most of the **materials** needed for the activity are shown in Figure 1 (next page). To save time, prepare kits in advance for quick distribution.

- Use the modeling clay from Lesson 4. Mix thoroughly to make one uniform color (layers will interfere with the activity).
- Save clear plastic containers from the grocery store – the containers used to hold salads, fruit, etc. work just fine. Containers can be any shape or size as long as they are clean and transparent. The larger the container, the more water you will need.
- A grease pencil or marker (note: using a washable marker would allow for reusing transparencies or tops of containers).
- A small piece of overhead transparency – pre-trimmed to the shape of the top of the container (the top is placed on the container with the piece of transparency on top – see Figure 1).

Figure 1 Materials used in Part A of the lesson. Clay used in earlier lessons has been reshaped into a volcanic cone.

- Sheet of white paper (for students to trace their map onto).
- A metric ruler (to measure elevations on the side of the container).
- Optional: colored pencils or crayons (if you want students to color their contour maps).

Figure 2 Side view of container with model and numbered cm marks.

1. Set up materials in advance for students to save time.

2. Students mark the outside of the container. The zero level need not be marked – this is the level before adding water).

3. Encourage students to make any landform shape they would like. The shapes need to be at least three centimeters high so that there is some difference in elevation. The photo shows a different kind of shape than is shown above. It has a tall volcano and a broad hill.

4. The overhead transparency is used when you have multiple classes. If students were to draw directly on the clear plastic top, the next class needs their own containers.

5. It is important that students look straight down on the model when tracing the outside edge of the clay onto the overhead.

6. Pouring water to the 1-cm mark will make water lap up onto the model. The line formed where the water touches the model creates a line connecting points of equal elevation on the model – a contour line.

7. If students have difficulty seeing where the water touches the clay model, have them shine a flashlight into it, place it on a white sheet of paper, and/or add a drop of food coloring to the water.

8. Figure 3 shows container with water filled to the top of the model, and all contour lines drawn.

Figure 3 Model with contour lines drawn on transparency atop the container.

9. At this point students can put some of their materials away and pour out the water. They now have an overhead transparency with unlabeled lines. Tracing the contour map onto a sheet of white paper (in pencil first) will allow them to begin to label the map with the values of contour lines, to color the map, and to add certain features like scale and contour interval.

10. Write values of contour lines parallel to the lines. On most contour maps, only every fifth line is labeled with a value, but when working with such small models, it is okay to label every line.

11. Figure 4 shows two examples of completed contour maps. The contour interval should be added at the bottom of each map.

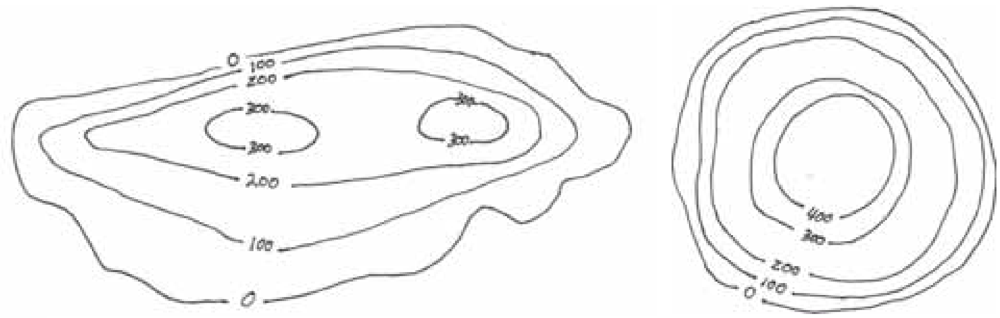


Figure 4 Two examples of contour maps constructed from clay models in water.

12. One aspect of this activity is that contour maps are smaller-scale representations of the real world, but in this case, students produce a scale that is larger than the model.

13. Answers will vary depending on the type of landform feature students modeled. At the very least, they should see that contours form closed loops on hills.

Part B. Drawing a Profile **30 minutes**

In this part of the activity, students construct a profile, that is, a scaled side view of their model. **Materials** needed include the traced contour map, a strip of paper (or a strip of overhead transparency – it allows students to see contour values that might be covered by a paper strip), clear tape, a sheet of graph paper, and a metric ruler.

1. Points A and B should be outside the 0 contour line.

2. The metric ruler is used to draw the line.

3. Taping the ends of the paper down keeps the edge along the line. If students cannot see contour values through the paper strip, that's okay – they can remove the tape in Step 5.

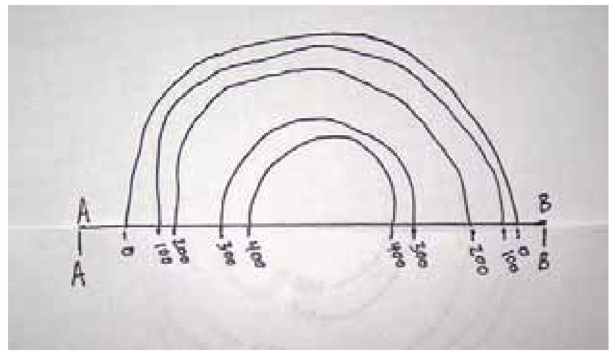


Figure 5 A strip of paper laid along the line that connects points A and B is marked with elevations from the contour map. The strip is used to make a profile (see Figure 6).

4. In this step, students mark the locations of end points of the profile and the points at which contour lines intersect their paper strip.

5. Students should write down the values as shown in Figure 5 above.

6. Taping the strip of paper to a line along the bottom of the graph paper will make it easier for students to transfer the data to the profile (see Figure 6).

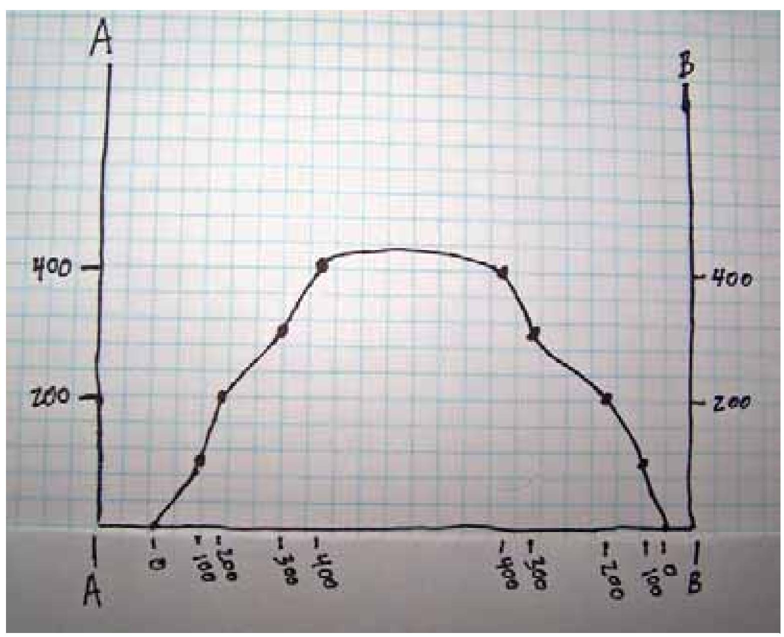


Figure 6 Tape the paper strip with contour values to graph paper as shown. With a ruler, draw a horizontal line between points A and B and then the two vertical axes. Transfer the contour values to the graph paper as dots. Finally, connect the dots with a smooth line.

7. Assume that the horizontal scale of your contour map is 1 cm = 100 m. This means that every one inch on the map is 100 meters on Earth. At points A and B, draw vertical lines upward. Number them to make your vertical scale. Let each centimeter equal 100 meters.

8. Directly above each tic mark on your paper strip, make a small dot on the graph paper at that elevation. Make a small dot for each tic mark on your paper.

9. When you have placed all the elevation dots on the graph paper, connect them with a smooth line. You now have a profile.

EXPLAIN

Assign for reading during class or as homework (even if the activity has not yet been completed). You can supplement the explanation phase of the lesson with a discussion or lecture. Photographs of landforms and a map of landscape regions of the US would be most relevant to the lesson. See the resources section of this guide for web sites that provide photographs that you can use. Photographs of local or regional landforms would increase the relevance to students.

ELABORATE **50 minutes**

In this activity, students interpret a topographic map and a photograph of a landform at Parashant. They should consider the reading and make careful observations of the photograph to hypothesize about how the landscape formed. This activity should be done in pairs (not large groups), with each pair getting a map and photograph. This will allow for multiple interpretations of question 4, which creates a more lively discussion. Note that we refer in the lesson to Grand Canyon-Parashant National Monument as “Parashant” throughout the lesson. One of the landscape features students will study in this section is Parashant Canyon, and we refer to it as such to distinguish it from Parashant the monument.

Keep in mind that this is an interpretation activity. Students will learn more about interpreting landforms after they have completed Lesson 6. Decide how far you think your students can take things (without being frustrated) and what you think they are capable of accomplishing. Above all, remind them that the activity gives them a chance to apply what they have learned and to pose questions and use you as a resource.

Question 4 will be the most challenging. Encourage students to take risks and remind them that it is okay to speculate here. Their responses, questions, and comments should provide rich information that you can use to assess what they learned from the reading, as well as well as their ability to make observations and inferences. If you think that question 4 is too challenging for students, you can wait until students have completed Lesson 6 to assign it, or you can project the maps and photographs with a computer and turn this into a class discussion activity, taking students through the landforms step-by-step.

The **materials** you will need include laminated color copies of the topographic maps and photographs, rulers, small strips of paper and graph paper (for making the profiles), and a magnifying glass (to view maps and photos more easily). As an option, provide the files for the maps and photographs to students to view on a computer so that they can magnify the images (or project them inn the classroom so that students can zoom in when things become difficult to see).

Responses to the questions for each of the four maps and photographs are provided on the following pages.

Map A – Little Springs

2.

a. The contour interval of the map is 40 feet

b. The highest elevation on the map is 7015 feet (marked with an X in the upper left)

c. The lowest elevation on the map is 6120 feet (lower right).

d. The total relief of the map is equal to 7015 feet – 6120 feet = 895 feet.

e. The main type of landform shown on the map is a cinder cone (at least six are visible).

f. Students might note that there is a valley in which there is a lava flow and a wash.

3. For the profile of Little Springs, have students use a vertical scale of one inch = 400 feet, labeling the bottom of the Y axis with 6000 feet and the top of the Y axis 7200 feet. The elevation at point A is 6840 feet, and the elevation of point B is 6220 feet.

4. Answers will vary, but students should refer to eruption of cinders (to form the cinder cones shown in the photograph and the cinder cone shown on the topographic map) and the eruption of lava (shown on both the photograph and topographic map).

Map B – Grand Wash Cliffs

2.

a. The contour interval of the map is 40 feet

b. The highest elevation on the map is 6428 feet (marked with a triangle at Blanco in the upper center part of the map)

c. The lowest elevation on the map is 4480 feet (in the intermittent stream in the lower left, due west of the 4600 foot contour value).

d. The total relief of the map is equal to 6428 feet – 4480 feet = 1948 feet.

e. The main type of landform shown on the map is a cliff.

f. Students might note that there are mountain peaks, buttes, and/or washes.

3. For the profile of Grand Wash Cliffs, have students use a vertical scale of one inch = 500 feet, labeling the bottom of the Y axis with 4500 feet and the top of the Y axis 6500 feet (this makes the profile just under four inches tall). The elevation at point A is 4550 feet, and the elevation of point B is 6000 feet. One tricky aspect to this profile is the vertical cliff on the right side of the profile. Look closely at the contour lines above the 5600 foot contour line ½ inch north of the profile, and you will see the 5800 and 6000 foot contours merge into one. This means that where the profile crosses the 5800 foot contour, it also crosses the 6000 foot contour due to a vertical face.

4. Answers will vary, but students should refer to faulting and uplift (raising the land on one side of the fault and lowering the land on the other side to create a difference in elevation), weathering and erosion of sedimentary rock (seen as layers in the photo, and which falls down the slope), differences in weathering of the rock layers (creating some layers with cliffs/steep slopes and some layers with more gentle slopes).

Map C – Shivwits Plateau

The part of the Shivwits Plateau shown here is just north of the boundary between Parashant and Grand Canyon National Park. The line of the profile runs across the mesa from left to right (the right side of the mesa is in shadow in the photograph).

2.

a. The contour interval of the map is 40 feet

b. The highest elevation on the map is 6520 feet at the bottom center part of the map (three contour lines above the marked 6400 foot contour interval).

c. The lowest elevation on the map is 4320 feet in the upper left corner, two contours below the marked 4600 foot contour interval.

d. The total relief of the map is equal to 6520 feet – 4320 feet = 2200 feet.

e. The main type of landform shown on the map is a mesa.

f. Students might note that there are cliffs on each side of the map, and a few buttes.

3. For the profile of Shivwits, have students use a vertical scale of one inch = 500 feet, labeling the bottom of the Y axis with 5000 feet and the top of the Y axis at 6500 feet. The elevation at point A is 5200 feet, and the elevation of point B is 5400 feet. Note that the 6120 contour interval crosses the profile multiple times along the top of the plateau.

Students can draw a fairly flat mesa top on the left side of the profile. The highest point on the profile appears to be about 6140 feet, which is between two contour lines.

4. Answers will vary, but expect students to refer to uplift of the land (to create differences in elevation), weathering and erosion of rock (to sculpt the cliffs and slopes of the mesa).

Map D – Parashant Canyon

2.

a. The contour interval of the map is 40 feet

b. The highest elevation on the map is about 5523 feet (marked with an X atop a small hill visible in the lower right corner of the map).

c. The lowest elevation on the map is 4360 feet, the last contour line visible in the canyon on the lower right side of the map (the wash crosses the 4360 contour about one inch below the "P" in "PARAS" and is somewhat obscured by the vertical red section line)

d. The total relief of the map is equal to 5523 feet – 4360 feet = 1163 feet.

e. The main type of landform shown on the map is a canyon (a number of side canyons are visible).

f. Students might note that there are a number of buttes, cliffs, and several washes.

3. For the profile of Parashant Canyon, have students use a vertical scale of one inch = 500 feet, labeling the bottom of the Y axis with 4000 feet and the top of the Y axis 5500 feet. The elevation at point A is 5440 feet, and the elevation of point B is 6220 feet. Note that the gradient is very steep near the bottom of the canyon – the 4600 and 4800 contours are very closely spaced, forming near vertical cliffs on either side of the canyon. The mirror image of cliffs on opposite sides of the canyon is mainly due to the presence of the same cliff-forming and slope-forming rock units on either side of the canyon.

4. Answers will vary, but expect students to refer to the importance of weathering and erosion to change the rock layers. Loosen the material, and carve the canyon. Students might also refer to the role of uplift in creating differences in elevation.

EVALUATE

1. The following questions relate to the topographic map shown in Figure 5.7.

a. The wash runs south to southwest

b. The highest elevation shown is 5520 feet

c. The lowest elevation on the map is 4400 feet.

d. The total relief of the map is 5520 feet minus 4400 feet, or 1120 feet.

e. The lower left corner of the map has the steepest gradient because contours are most closely spaced together there.

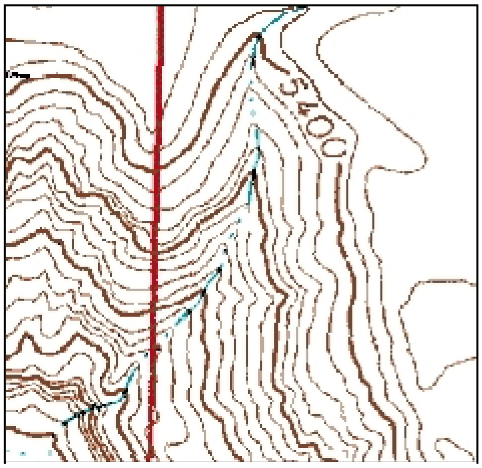


FIGURE 5.7. Part of a topographic map at Parashant. The contour interval is 40 feet. North is towards the top.

2. Relief is important in landform development because the greater the relief, the greater the forces that work to change the landscape. For example, water flows more quickly in areas of high relief, causing faster erosion. Rocks that tumble down slopes have more energy.

3. The arid climate of the Colorado Plateau affects the creation of its landforms because it affects the number of plants on the ground (which act to hold soil and sediment in place, slowing erosion) and also leads to flash floods associated with thunderstorms in the monsoon season.

4. Earth's inner heat has played a role in shaping the landscape at Parashant by 1) causing volcanoes, which build up the land surface, and 2) causing uplift of rock layers to form cliffs and greater relief in general.

WORKSHEET 5.1 – PARASHANT LANDFORMS

Photos for Map A - Little Springs Area Cinder Cones

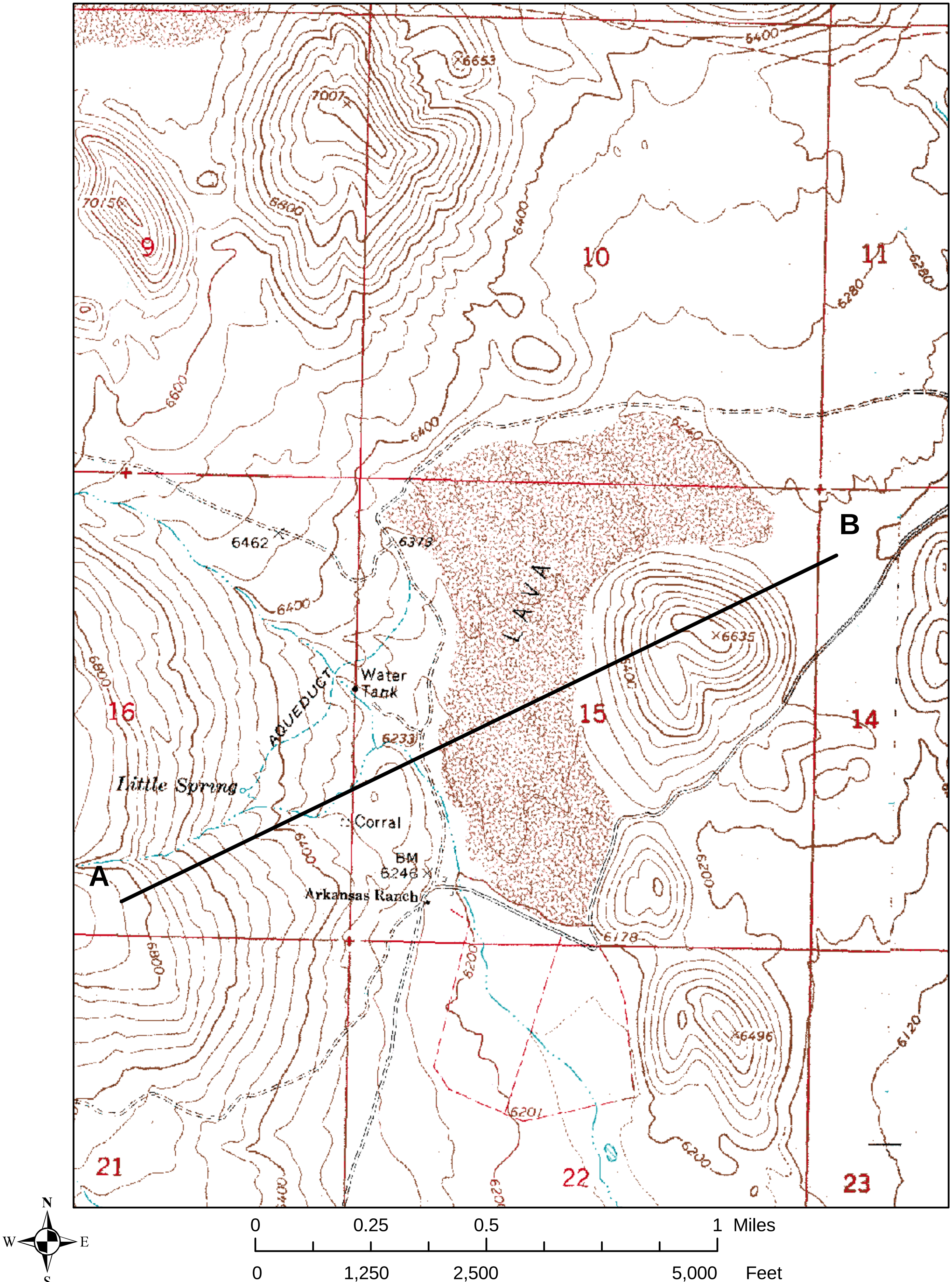
Photo for Map B - Grand Wash Cliffs

Photo for Map C – Shivwits Plateau

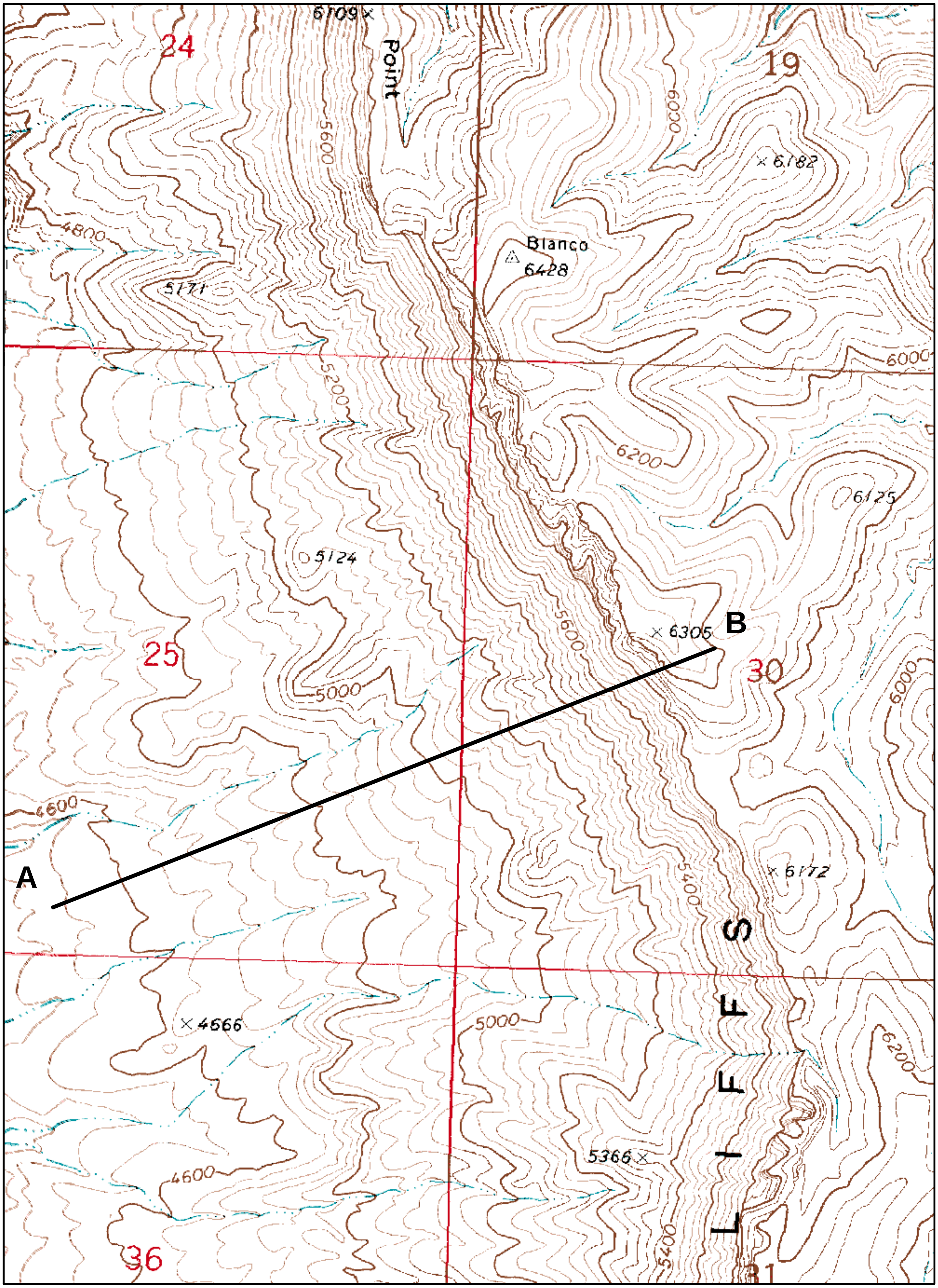
The arrow shows the feature in the topographic map. The line shows the location and orientation of the profile.

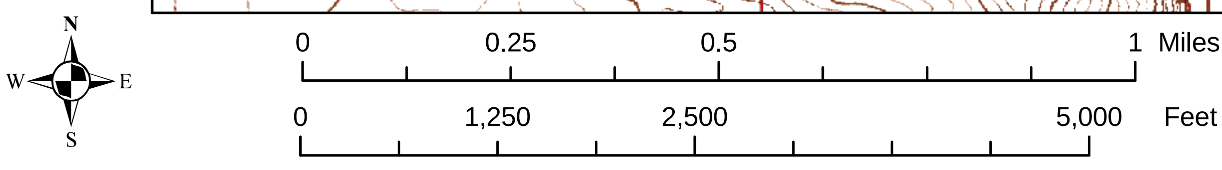
Photo for Map D - Parashant Canyon

Map A - Little Springs

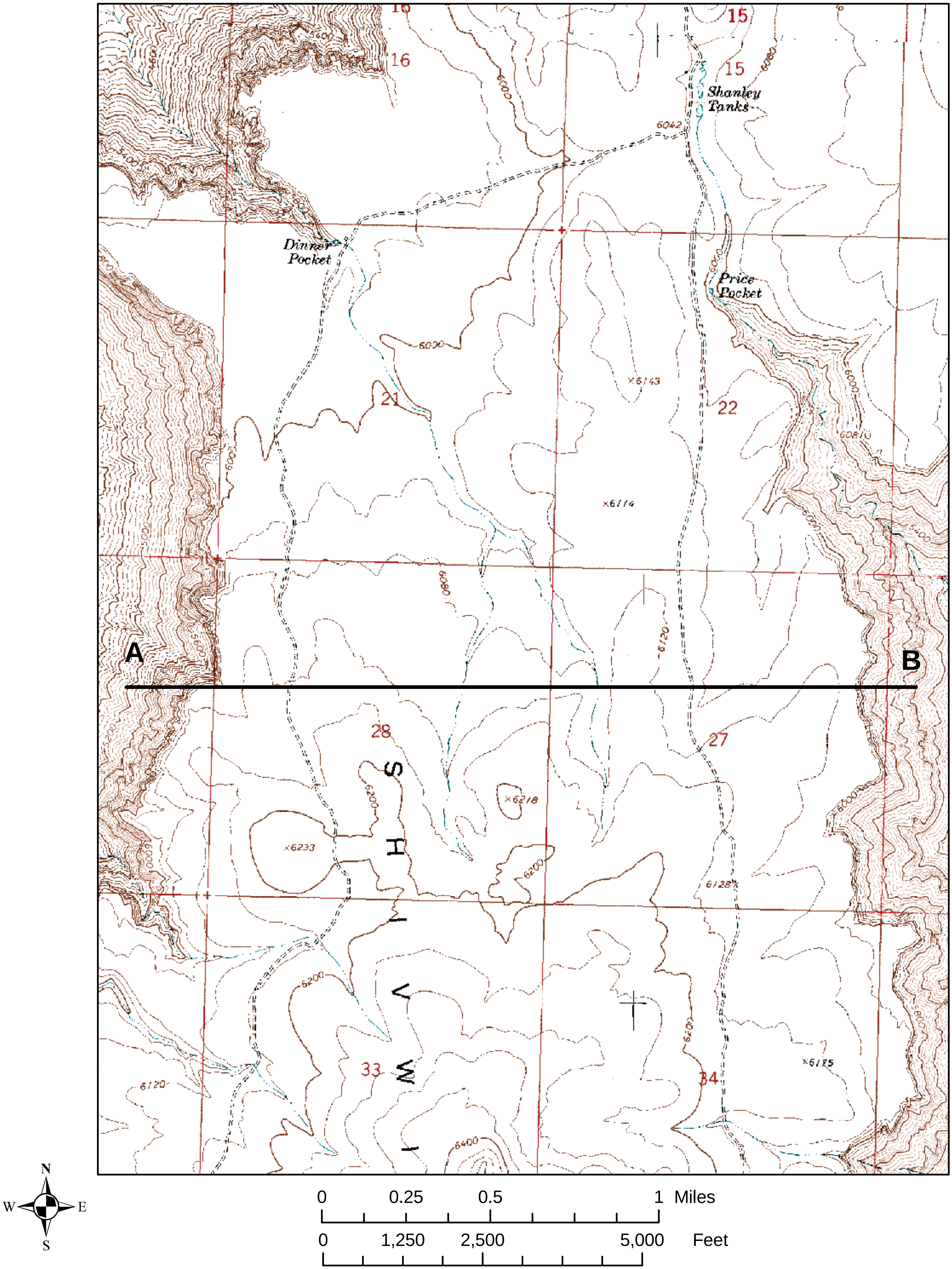


Map B - Grand Wash Cliffs

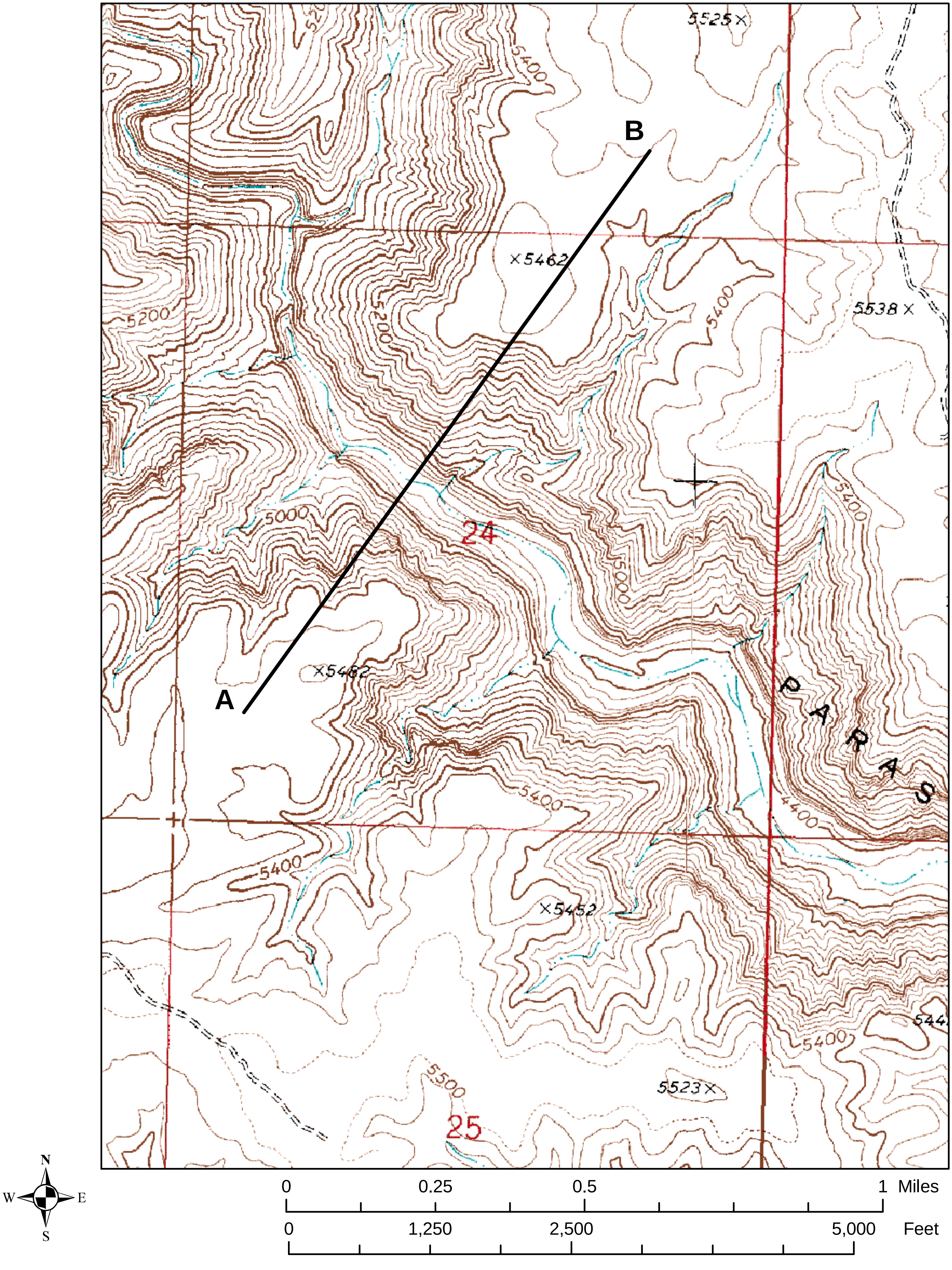




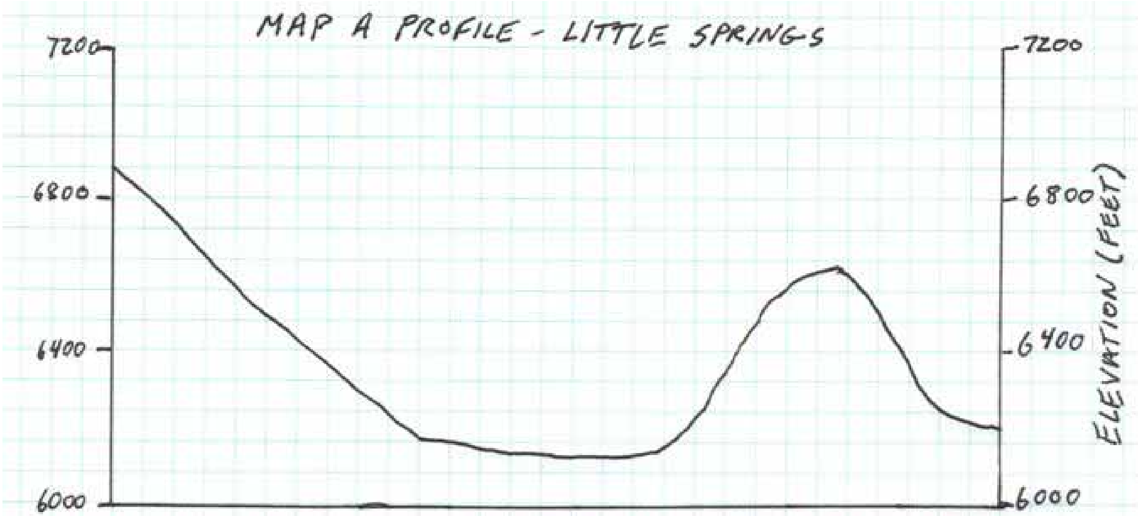
Map C - Shivwits Plateau

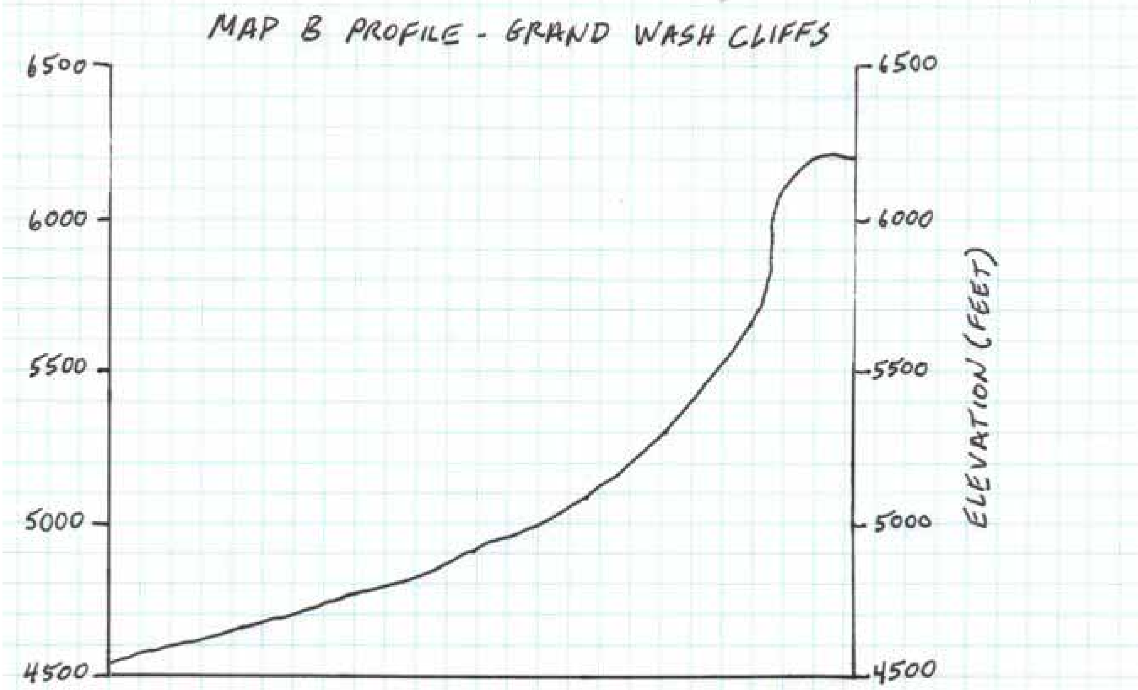


Map D - Parashant Canyon

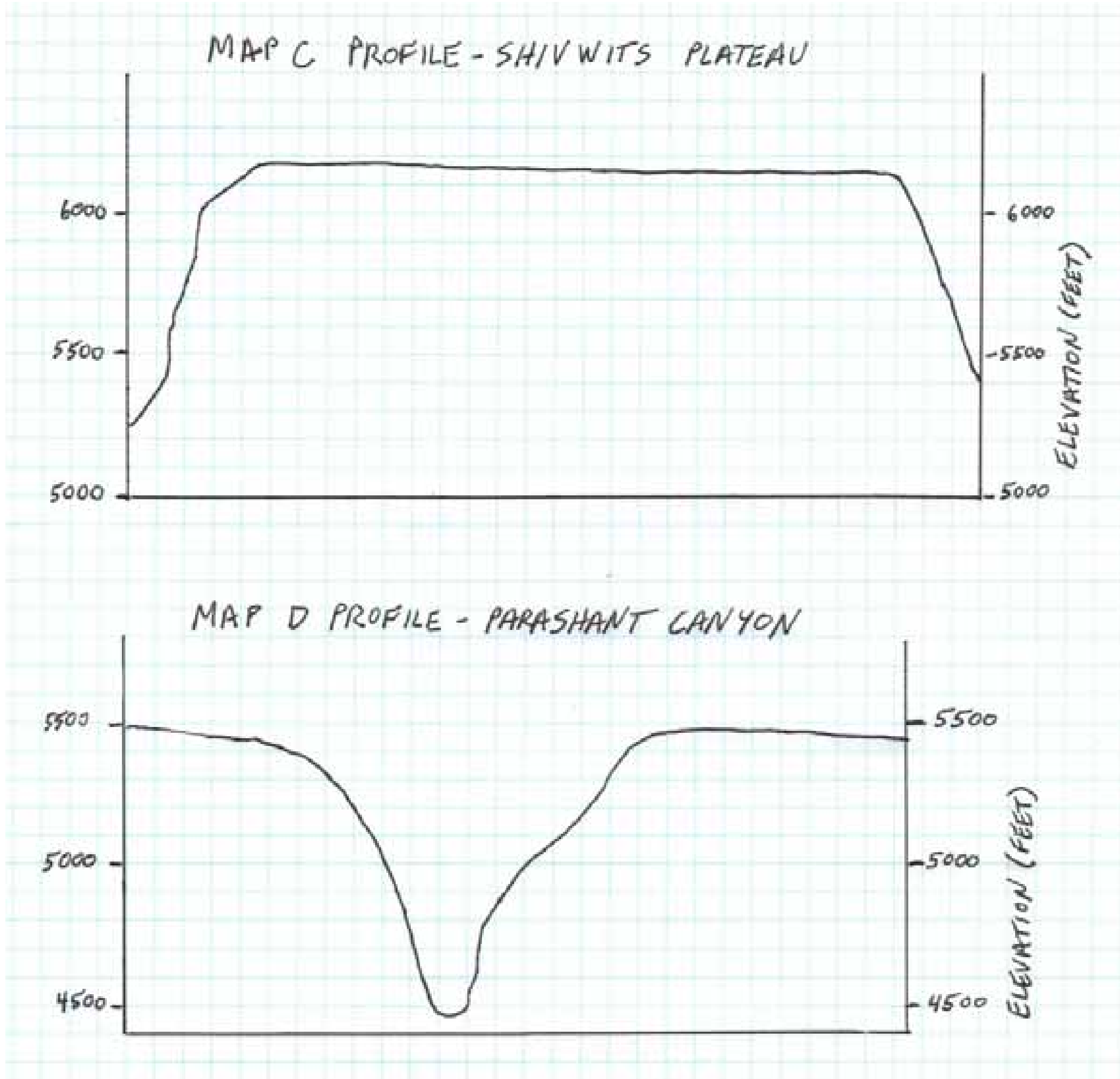


Profiles for Map A (Little Springs) and Map B (Grand Wash Cliffs)





Profiles for Map C (Shivwits Plateau) and Map D (Parashant Canyon)



LESSON 5: TOPOGRAPHY – LANDFORMS OF PARASHANT

ENGAGE

Look at Figure 5.1. What kind of landscape feature do you think the map shows: a hill, a cliff, a depression, or a flat plain? Explain your reasoning.

FIGURE 5.1. Map of a landscape feature at Parashant. Numbers are feet above sea level.

EXPLORE

Part A. Making a Contour Map

1. From your teacher, obtain 12 ounces of modeling clay, a clear plastic container with clear top, a piece of overhead transparency, a grease pencil or nonpermanent marker, a container of water, and a metric ruler.
2. Using the metric ruler, make a mark every one centimeter on the outside of the container from the bottom to the top. Number the lines starting with 1.
3. Form a mountain, volcano, or other landscape feature out of the modeling clay. Place it in the container, as shown in Figure 5.2.
4. Tape the overhead transparency to the top with two small pieces of tape. Put the top on the container.
5. Looking straight down on the model, trace the outside edge of the clay onto the overhead.
6. Pour water into the container until it reaches the 1 cm mark.
7. Place the top on the container, and trace the line made by the water where it laps up onto the clay. This new line will be inside the first one.
8. Keep adding water and tracing the lines until water reaches the top of your model.

FIGURE 5.2 Clay model of a volcano in a transparent container.

9. Remove the transparency. Place it between two sheets of white paper, and trace the map in pencil on the top sheet of paper. You are now ready to label your map with lines of equal elevation, or **contour lines**.

10. Let each centimeter on the model represent 100 meters difference in elevation. Label the outside line "0" by erasing part of the line and writing a zero as shown in Figure 5.3.

11. Label every line (0, 100, 200) until you have labeled every 100 meters on your model.

12. Add a legend. Write "contour interval 100 meters" and "Scale: 1 cm = 100 m" at the bottom of the map.

13. Compare your contour map to the contour map shown at the start of this lesson. Describe the similarities and differences.

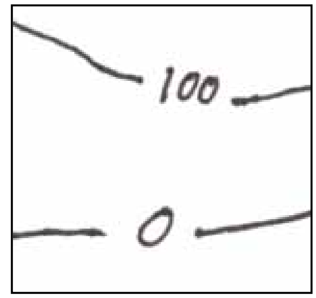


FIGURE 5.3 Write values for contour lines parallel to the lines.

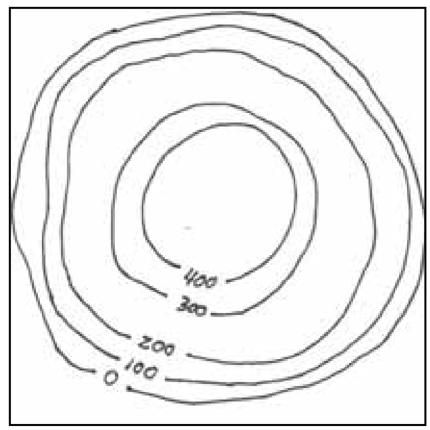


FIGURE 5.4 Sample contour map.

Part B. Drawing a Profile

In this part of the activity, you will draw a side view of your model, called a profile.

1. Pick two points on opposite sides of your contour map. Label them A and B

2. With a ruler and pencil, draw a light, straight line connecting the two points.

3. Lay the edge of a strip of paper along the line you have drawn. Tape the ends of the paper down to keep the edge along the line.

4. Make tic marks at points A and B, and wherever the edge crosses a contour line.

5. Label points A, B, and the other tic marks with the values (see Figure 5.5).

6. Remove the strip of paper and tape it along a line the bottom of a piece of graph paper.

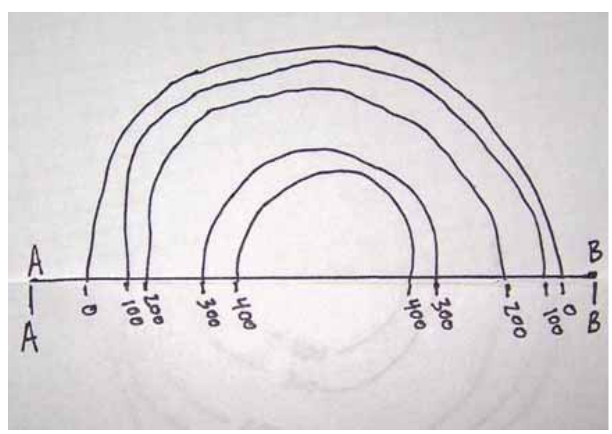


FIGURE 5.5. Tape a strip of paper to your contour map as shown. Mark the locations of A and B on the strip. Then mark and write down the value of each contour line that crosses the strip.

7. Assume that the horizontal scale of your contour map is 1 cm = 100 meters. This means that every one centimeter on the map is 100 meters on Earth. Using a ruler at points A and B, draw vertical lines upward. Number them to make your vertical scale. Let each cm equal 100 meters.
8. Directly above each tic mark on your paper strip, make a small dot on the graph paper at that elevation. Make a small dot for each tic mark on your paper.
9. When you have placed all the elevation dots on the graph paper, connect them with a smooth line. You now have a profile.

EXPLAIN

Contour maps like one you made of a clay model provide information about the shape of the land. The **contour interval** of the map tells the difference in elevation between two adjacent lines. If the contour interval is 100 feet, then adjacent lines will have elevations of 100 feet, 200 feet, and so on. On most contour maps, only every fifth line is labeled with an elevation. These lines are usually thicker and serve as reference points. If the contour interval is 40 feet, then every 200 feet will be labeled (5 X 40).

The highs and lows of the land surface are known as **relief**. Total relief is found by subtracting the lowest elevation from the highest elevation. The total relief of the map shown in Figure 5.5 is 400 meters. The greater the total relief on a map, the greater the contour interval is. The **scale** relates the distance on the map to the distance on the ground. You can use the scale to measure distance between points or estimate the area that a feature covers.

Topography refers to the shape of the land. A **topographic map** is a special kind of contour map. In addition to contour lines, it shows roads, trails, place names, rivers, lakes, buildings, vegetation, and more. The United States Geological Survey (USGS) has prepared topographic maps of the entire country. Knowing just a few basic aspects of topographic maps will help you interpret them, plan hikes, and find your way in a state or national park or monument.

One useful feature to understand about topographic maps is the spacing between contour lines. When slopes are steep, contour lines are more closely spaced. On gentle slopes, contour lines are spread farther apart because the elevation changes gradually. To find the **gradient** of a slope, find the change in elevation between two points (elevation of your starting point minus the elevation of your ending point) and divide it by the distance. For example, suppose you plan to hike 4 miles to the top of a hill at a national monument. If the difference in elevation from where you begin to the top of the hill is 800 feet, then the gradient is 800 feet divided by 4 miles, or 200 feet per mile. Contour lines bend into a V-shape in a stream valley, and the V's point upstream. As you saw in Figure 5.1, contour lines form closed loops around the tops of hills, mountains, or depressions (if the values decrease towards the center of the closed loop, it is a depression). Finally, it is helpful to know that every fifth contour line on a topographic map is usually a thicker, darker line with a labeled elevation.

Landforms at Parashant

In order to understand how Parashant's beautiful scenery came to be, we need to define some key terms and identify several factors that control the shape of the land. A **landform** is a recognizable physical feature on the Earth's surface with a characteristic shape that is produced by natural processes. By natural, we mean that mountains, hills, canyons, and valleys, rather than skyscrapers or baseball parks, which are built by people. A large area of land with a distinct set of landforms is called a **landscape**. Examples of landscape regions include mountains, plateaus, and plains.

Three things work together to create a landform – the material (rock or sediment) it is made of, forces that act on those materials, and time. As you learned in Lesson 2, rocks vary in their ability to resist erosion and changes in shape. For example, water and wind move and shape sediment more easily than rock. Some rocks break down to form gentle slopes, while others tend to form cliffs.

Forces that create landforms can be influenced by climate, Earth's internal heat, and relief. Climate controls the vegetation in a region and the types and rates of weathering and erosion of rock. Climate also changes over time, which affects the rate of landform development. The southwestern US has a hot and dry climate, but was much cooler and wetter during recent ice ages.

Earth's internal heat drives volcanism and moves the crust up and down. Relief is very important - the greater the difference in elevation in a region, the easier it is for rock to move downhill and the faster water can flow and carry rock and sediment away. Finally, it takes time for landforms to develop. Some processes act over periods of hours to days (erosion by floods) whereas others may take millions of years (uplifting of Earth's crust).

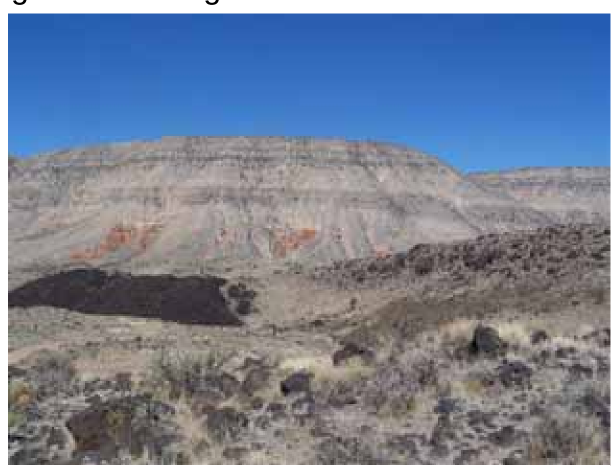


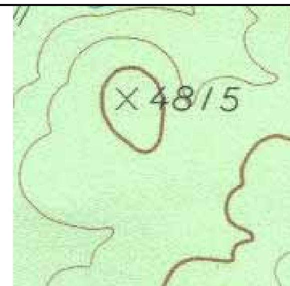
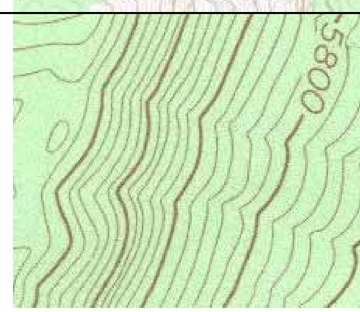
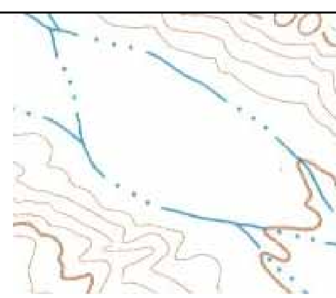
FIGURE 5.6. Earth's internal heat drove two factors that control landform development: the uplift of mountains (background) and the eruption of lava (dark rock in foreground).

Parashant sits on a landscape region that covers parts of four southwestern states called the Colorado Plateau. A **plateau** is a raised landscape confined on one or more sides by a steep boundary. The Colorado Plateau ranges from 4000 to 9000 feet above sea level. It is made up of a series of flat-topped units separated from each other by steep cliffs or steep slopes. Within the plateau are numerous **mesas** (smaller flat-topped mountains that have a steep slope on at least one side), **buttes** (isolated, flat-topped hills with steep slopes), and **pinnacles** (small, slender, pillars of rock).

The western edge of the Colorado Plateau is found in the monument. This western boundary is defined by the Grand Wash Cliffs, which have 2000 feet of elevation change along the Grand Wash Fault (you will learn more about the role of uplift and faulting in shaping the Parashant landscapes in Lesson 6). Rocks are exposed in cliffs and ledges throughout the plateau, which is capped by resistant sedimentary rock units and, in places, topped by volcanoes and lava flows. Two smaller plateaus – the Shivwits and the Uinkaret -- lie upon the Colorado Plateau at Parashant. The Kaibab Limestone caps much of the Shivwits Plateau. The Uinkaret Plateau is dominated by cinder cone volcanoes fed by magma that broke through much older sedimentary rock units within the last nine million years.

Climate helps to shape the landscape of the Colorado Plateau. Much of the Colorado Plateau has an arid climate, which limits the number of plants that grow. Much of the yearly rainfall comes during summer thunderstorms. These heavy rains fill washes (dry channels) with fast-moving water called flash floods. The floods remove sediment not held down by plant roots. This helps to carve spectacular canyons that cut through the raised plateau, exposing thousands of feet of layered geologic strata.

Table 1. Examples of Landscape Features at Parashant.

Description	Photograph	Topographic Map
Cinder cone – Large hill several hundred feet high atop plateaus at Parashant. Formed by the eruption of lava, cinders, and ash. The most recent eruption occurred less than 1000 years ago.		
Butte – A hill that rises abruptly from the surrounding area and which has sloping sides and a flat top. Tops of buttes at Parashant are often capped by resistant sedimentary rock or basalt lava.		
Canyon – Deep gorges that cut into plateaus. Many canyons at Parashant are lined with washes and lead into the Colorado River in the Grand Canyon.		
Cliff – High, steep, overhanging face of rock. The large cliffs at or near Parashant like the Hurricane Cliffs shown here and the Grand Wash Cliffs form along faults. Locally, cliffs are often made of sedimentary rock that is resistant to weathering.		
Wash – The dry bed of a stream that flows only after heavy rains. Often found in the bottom of a canyon. The bottom of a wash is often covered with gravel and sand. Parashant has dozens of washes, but no streams.		

ELABORATE

In this activity, you will interpret a topographic map and a photograph of a landform at Parashant and combine your observations with what you have learned from the reading to speculate about how the landform was made.

1. From your teacher, obtain a topographic map and photograph of a landform at Parashant, a metric ruler, a calculator, a strip of paper, and a sheet of graph paper.

2. Answer the following basic questions about your map.

   a. What is the contour interval of the map?

   b. What is the highest elevation on the map?

   c. What is the lowest elevation on the map?

   d. What is the total relief of the map?

   e. What is the main type of landform shown on the map?

   f. What other types of landforms does the map show, if any?

3. Draw a profile across the map from point A to point B.

4. Study the photograph and the topographic map of your landform carefully. Try to identify some of the processes discussed in the Explain section that might be at work to make this landform. Think about how each of the following might have been involved, then write a few sentences summarizing how you think this landform was made. It is okay to speculate – you will be learning about some of these processes in later lessons, and can come back to revise and improve your interpretation.

   a. Weathering – rock being broken down into smaller pieces and sediment.

   b. Erosion – removal of rock and sediment by gravity, running water, or wind.

   c. Uplift – raising layers of rock upward and causing rocks to break and fracture.

   d. Volcanism – erupting lava and cinders to build up the land.

5. Be prepared to present your map and summary in a class discussion.

EVALUATE

1. The following questions relate to the topographic map shown in Figure 5.7.

a. In what direction does the wash (intermittent stream) flow?

b. What is the highest elevation shown?

c. What is the lowest elevation on the map?

d. What is the total relief of the map?

e. Which part of the map has the steepest gradient: the upper right or the lower left? Explain.

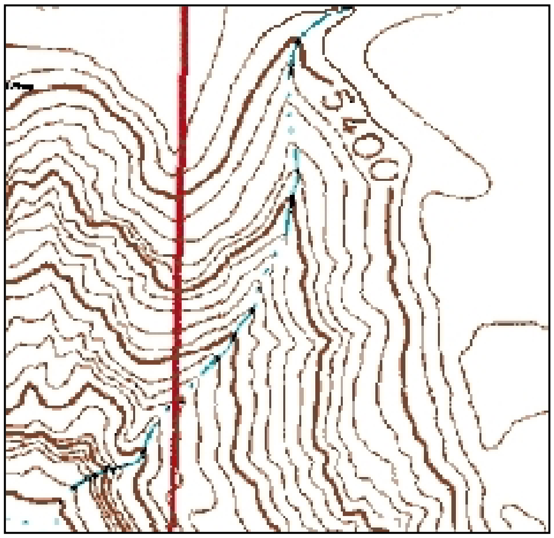


FIGURE 5.7. Part of a topographic map at Parashant. The contour interval is 40 feet. North is towards the top.

2. Why is relief important in landform development?

3. Describe two ways that the arid climate on the Colorado Plateau affects the creation of its landforms.

4. How has Earth's inner heat played a role in shaping the landscape at Parashant National Monument?

LESSON 6: GEOLOGIC STRUCTURE AND THE PARASHANT LANDSCAPE

GEOLOGICAL ADVENTURES AT PARASHANT

EXPLORING THE GEOLOGY OF

GRAND CANYON-PARASHANT NATIONAL MONUMENT

NATIONAL PARK SERVICE

THE GEOLOGICAL SOCIETY OF AMERICA®

SCIENCE • STEWARDSHIP • SERVICE

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

LESSON 6 GUIDE: GEOLOGIC STRUCTURE AND THE PARASHANT LANDSCAPE

OVERVIEW

In this activity, students use modeling clay to simulate and study three kinds of stress that create geologic structures: tensional, compressional, and shear. In Part B of the activity, they apply what they have learned about stress to model the formation of faults, folds, and uplift using their modeling clay. Each group is assigned a different type of structural feature to model. They use instructions to produce a structure using modeling clay, but must use what they have learned to explain the forces that led to the feature. Each group then presents the structural model to the rest of the class. Students read about the processes of uplift, folding, and faulting in the context of plate tectonic theory and the formation of Parashant's landscape features.

Objectives After exploring stresses, folding, and faulting of rocks with modeling clay, reading about the forces that cause folding and faulting at Parashant, and interpreting a cross-section of faulted rocks on the monument, students will understand:

- Three basic types of stress that rocks are subjected to.
- Brittle and ductile deformation
- Folds, faults, and joints are ways that rocks respond to stress
- Common types of folds and faults and the types of stress that produce each
- Large-scale geologic forces have played an important role in shaping the Parashant landscape.

Concepts Stress, strain, ductile versus brittle deformation, jointing, normal, reverse, and strike-slip fault, anticline, syncline, monocline.

Duration Three 45-minute class periods

Audience Students in grades 6 to 9

Materials **Part A: Modeling Stress and Strain**

- clay model of rock layers from prior lesson
- four pieces of colored modeling clay (left over from earlier lessons)
- Styrofoam plate or wax paper
- plastic bottle cap
- metric ruler
- piece of dental floss

Part B: Modeling Folds and Faults

- clay model of rock layers (from prior lessons)
- several pieces of colored modeling clay (left over from prior lessons)
- Styrofoam plate or wax paper
- metric ruler
- dental floss
- small thin wood block or thin textbook (group B only)

- dropper bottle of liquid soap (groups D, E, and F)

Extensions **For honors, gifted, or higher grade-level students**

- Work in the concepts of strike and dip into Part B of **Explore**. This would be useful for students who are expected to work with or interpret geologic maps.
- See Part A, Step 5 of the Explore phase of this teacher guide for ideas about integrating mathematics (ratios and percents) and graphing into the study of stress and deformation.

Resources

- An overview of structural geology written by Dr. James Harwood of Blackhawk State College is available at facweb.bhc.edu/academics/science/harwoodr/Geol101/study/structur.htm
- Most of Parashant has been mapped by George Billingsley (and colleagues) at the USGS Flagstaff. The maps contain reports and overview pamphlets. Some maps include photos and cross-sections. The maps and pamphlets are available as pdf downloads at http://geopubs.wr.usgs.gov/docs/geologic/az/arizona.html.

ENGAGE **10 minutes**

The photo shows folded and faulted sedimentary rocks of the Triassic Moenkopi Formation in a small basin at Parashant known as “Hell’s Hole”. The Hurricane Fault which produced the Hurricane Cliffs that run north-south through northern Arizona runs through this basin. According to a recent geologic map made by the USGS, the Hurricane Fault has a vertical displacement of 610 meters nearby. This is very likely the reason behind the folding and faulting of layers shown in the photo. Responses to the questions (students will probably not provide all this detail – it is more for your knowledge):

1. The rock layers are not lying flat (the photo was taken from above the outcrop rather than ground level, but it should be clear that the layers have been “disturbed.” The layers are tilted – you can see the end of the layers pointing upward.
2. The layers are not continuous. You cannot trace a single layer all the way across the outcrop. Some of this is due to layers being obscured by erosion on slopes, but faulting also controls the lack of continuity.
3. An appropriate response would be that somehow the rocks got squeezed, compressed, tilted, or lifted up in some way by forces inside the Earth.

Ask volunteers to share ideas. Accept all reasonable ideas and write them on the board or on an overhead transparency. Avoid providing the “right” answer – students will learn the names of fold, faults, and stresses on rocks in the explore phase of the lesson.

EXPLORE **60 minutes**

Part A: Modeling Stress and Strain **30 minutes**

In Part A of the Exploration phase, students use clay to model forces that deform rock layers. This part of the lesson gives concrete experience with **stress** (the force applied to rocks) and **strain** (how rocks deform in respond to stress). There are two major types of deformation – **elastic** (objects return to their original shape after stress is removed, like a rubber band or bending a twig) and **plastic** (objects do not return to their original shape after stress is removed, like snapping a twig. Elastic deformation precedes plastic deformation. Students model plastic deformation in the two parts of the Explore phase.

FIGURE1. Materials used in Explore, Part A. The balls of clay are rounded scraps from earlier lessons. Dental floss used in the lesson is not shown.

Try the activity yourself before you teach it so that you can identify potential sticking points for your students. Photographs in this teacher's guide will help you to see how models are set up, but the exact results obtained will vary depending upon thickness of layers, amount of stress applied, and so on.

Materials students will need are shown in Figure 1. Saving scraps of clay when students trimmed clay models in earlier lessons and combining pieces of the same color allows you to use one 12-ounce box of modeling clay per group for lessons 2-6. You need a small water bottle cap for marking circles in the clay. A pencil point or toothpick can be used to draw cross-lines (see below).

You could reduce the time devoted to this activity in half (20 minutes) by eliminating measuring (see step 4 below) and assigning groups to one of the three types of stress (10 minutes), then having them present their results to the class (10 minutes).

1. Gathering materials as "kits" for each group ahead of time will save time.

2. You might model how to roll and shape the clay. It is quite easy once you get the hang of it, but younger students may struggle a bit. Squash the cylinder of clay down to make a rough rectangle, hold it against a metric ruler on the table, working the clay to get the length and widths about right, then slap the clay on the table to flatten the two large surfaces and tap the ends of the clay down on the table to flatten and square off the four smaller ends. Students need not worry about getting the dimensions exactly right, but you can help them appreciate experimental control by discussing why it is better to do the three stress tests with shapes of similar size.

3. Students need only make light marks in the clay so that the circle formed by the bottle cap and the cross-lines are visible. The cross lines should be at about right angles (perpendicular), as shown in Figure 2.

4. If you want to trim some time from this activity, tell students that they should make rough sketches rather than measure the lengths of the lines. Measuring the lines increases the likelihood that they will draw diagrams that closely represent the actual deformation, but since they will not be doing quantitative analysis (e.g., calculating the ratio between the lengths of the axes for each deformation), a simple sketch without measuring lengths will save time.

FIGURE2 Side view of clay model with circle (made with bottle cap) and two perpendicular cross lines.

If you wish to make the lesson even more quantitative, have students label the two axes H for horizontal and V for vertical, calculate the ratio of H to V. For the original shape, the ratio of H to V is 1:1. They can calculate how the ratio changes as a factor of percentage deformation (compression or extension). The percentage deformation would be computed as follows; (new length of the clay [not the circle] divided by the original length of the clay) times 100. Students could then graph the percentage deformation on the X axis versus the ratio of horizontal to vertical ratios on the Y axis to answer a research question like: “What is the relationship between the amount of stress and the amount of deformation of a clay model?” This should work for tensional and compressional stress, but shear stress might be too difficult to measure and quantify with modeling clay.

5. Students can compress the model by holding the model in their hands and pressing inward or by leaving the model on the table and pressing inward. Apply the stress equally and directly to avoid any shearing. Stop when the model is about 50% compressed.

FIGURE 3 Side view of clay model after compressional stress was applied. Note that the clay is about half the original length, and that the circle is deformed, while the cross lines remain perpendicular.

6. Figure 3. shows the results of compressing the clay to about 50% of its original length. Note that the clay is wider top to bottom, shorter side to side, and that even the width of the horizontal cross line increased (it looks wider). A drawing of the compressed model is shown in Figure 6.

7. Students should try to reshape the model to about the same dimensions as the first stress test. Reworking the clay with your hands a few times before reshaping will eliminate traces of the original cross lines and circle. After they make the rectangular shape, they need to remember to do the circle and cross lines.

8. The challenge of modeling tensional stress is to avoid tearing the clay apart. The best way to do this is to hold the model with the thumb and four fingers of each hand (rather than just thumb and one finger) and pull slowly. It is okay to stop and start a few times. Try this yourself to identify tips to give your students.

9. See Figure 4 for the results of a tensional stress applied to clay. The model was stretched to almost 20 cm long without tearing. Figure 6 shows a drawing of the same model shown in Figure 4. Note that cross lines are perpendicular on the model and the drawing. Drawings will reveal how carefully students are observing and measuring the model. Remind students to focus on the shape of the circle, not the whole clay.

FIGURE 4 Side view of clay model after tensional stress was applied. Note that the clay is about twice its original length, and that the circle is deformed. The cross lines remain perpendicular.

10. Students reshape the model for the third and final time in this activity. Again, they should strive to get close to the original dimensions and remember to make the circle and cross lines.

11. When students model shear stress, they focus on a top view because it is easier to model shear stress when the model is lying flat on the table. The

FIGURE 5 Top view of a clay model after shear stress was applied. Note that the circle is highly deformed. The cross lines are no longer perpendicular, but at a lower angle to one another.

top view reveals the strain on the clay.

12. After you have tried the shear stress yourself, decide whether you want to demonstrate this to students. At the very least, you could demonstrate the motion using your hands – pull one hand towards you and move the other away. Shear is like tearing – two forces moving in opposite directions past each other (you might ask if students knew that scissors are also called "shears").

13. Figure 5 shows the results of a shear stress, and Figure 6 shows the drawing of the model shown in Figure 5. The amount and shape of the circle used to show strain will vary depending upon how students stress the clay model (there is no single "right" answer).

14. Students' responses should have elements of the descriptions provided below. You might wish to type this up and leave spaces for them to fill in key words that are underlined below.

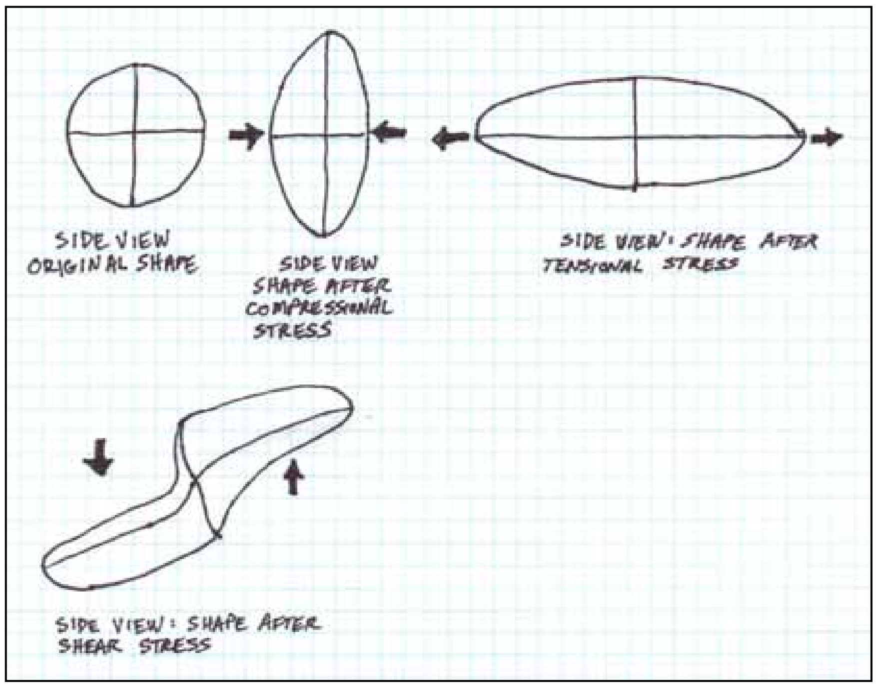


FIGURE 6. Drawings showing the results of stresses applied to the models tested for this guide. Sketches are drawn to scale to each other.

When the clay model is subjected to compressional stress, the model gets shorter parallel to the direction of stress and wider perpendicular to the stress. The cross lines remain perpendicular to one another.

When the clay model is subjected to tensional stress, the model gets longer parallel to the direction of stress, and shorter perpendicular to the direction of stress. The cross lines remain perpendicular to one another.

When the clay model is subjected to shear stress, the model is bent and stretched and longer at a 45 degree angle to the directions of stress.

15. Students should wash their hands with antibacterial soap after handing modeling clay.

Part B: Modeling Folds and Faults **45 minutes**

In this part of the activity, students model geologic structures that results from two different types of plastic deformation: ductile (when rocks bend or **fold** without breaking) and brittle (when rocks break by **faulting** or jointing). Although students will explore the processes separately, folding and faulting are commonly closely associated in nature. For example, monoclines (one-sided folds) on the Colorado Plateau form where sedimentary rocks are draped over deeper basement faults.

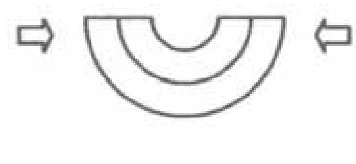
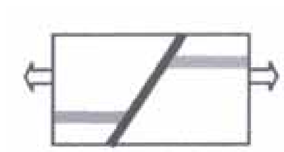
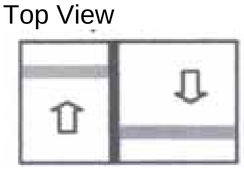
FIGURE 7. Materials used in Part B. Not shown is a wood block (or thin book) used to make the monocline.

Assign each group one type of strain to model. Have them fill in the correct row in Table 1 for their model. Then, have each group demonstrate its model to the class. As presentations are made and ideas and models are discussed, students complete the remainder of Table 1. Use Table 1 as a guide to assign groups to one of the six types of deformations. It helps to think of folds as having a wave-like structure – anticlines are like crests and synclines are like troughs.

Most of the **materials** each group will need for the activity are shown in Figure 7. Clay is simply recycled from the earlier activity. Group B (monocline) will need a thin textbook or wood block. Groups D, E, and F will need to apply a drop or two of liquid soap onto the fault plane of their models to lubricate the surface because clay is sticky and the sides of the fault will not slide past one another without lubrication.

A completed copy of Table 1 is shown on the following page. Photos of what the models should look like and how to arrange materials follow the table. This exercise requires a bit of critical thinking, and students may struggle with some aspects of the cells. Be flexible and encourage discussion, critical thinking, and risk-taking, but be prepared to adjust expectations based upon the needs and abilities of your students.

Table 1. Results of Modeling Stress and Deformation of Rocks

Structure	Stress Compressional, Tensional, or Shear	Deformation Brittle or Ductile	Diagram Label Top or Side View; Use arrows to show directions of stress	Explanation
A. Anticline	Compressional	Ductile	Side View 	Forces compress rock making it bend.
B. Syncline	Compressional	Ductile	Side View 	Forces compress rock making it bend.
C. Monocline	Tensional/Shear	Ductile	Side View 	Forces push upward on one end of rock layers, bending them into a fold with one side.
D. Normal Fault	Tensional	Brittle	Side View 	Forces pull rocks apart, causing them to break. Rocks above the break slide down the break.
E. Reverse Fault	Compressional	Brittle	Side View 	Forces push rocks together until they break. Rocks above the break are pushed up the break.
F. Strike-Slip Fault	Shear	Brittle	Top View 	Rocks are broken by forces that push them past each other horizontally.

A. Anticline

Anticlines are most commonly caused by compressive stress. Compression can arise in a number of ways. Geologists recognize anticlines in the field by 1) seeing strata that dip away from the axis of the fold; 2) noting that erosion eposes progressively older sediments as you move towards the fold axis (students would see the latter relationship if they sliced the clay model horizontally). Cylindrical anticlines (perfectly shaped like the top half of a cylinder lying on its side on a table) are rare in nature. Most anticlines (and synclines) “plunge” into the Earth at and angle.

Students will model the compression by pressing the ends of the clay together. However, the “trick” is to create the fold, not simply repeat the compression stress test from Part A. Therefore, it helps if they use their fingers to push up a little from the bottom to get the fold started. They need to ignore this push when interpreting the model and describing the stresses. Figure 8 shows construction of a sample model.

FIGURE 8. Making an anticline. Upper left: Large piece of clay cut into 3 pieces by floss. Upper right: Five pieces flattened into rectangular shapes. Lower left: Stacked layers. Lower right: Anticline fold.

B. Syncline

Synclines are like basins – they are U-shaped folds in which strata dip towards the fold axis and the strata become younger as one moves towards the fold axis.

To make a syncline, students use the same procedure for making an anticline, except that they push the center of the clay downward to make a U-shaped fold.

C. Monocline

A monocline is an open, step-like structure in which the layers are all inclined in the same direction on either side of the fold axis. On the Colorado Plateau, there are broad areas of nearly flat lying strata (plateaus) separated by bends along monoclinal folds. Imagine a normal fault in the basement rocks with sedimentary rocks draped over the top. This is one of many ways that monoclines form, and probably the simplest way for students to model. In this case, the vertical edge of the book (see Figure 9 below) would equate to the fault plane of a normal fault, the book as the upthrown block of the normal fault, and the table as the down-dropped side of the normal fault.

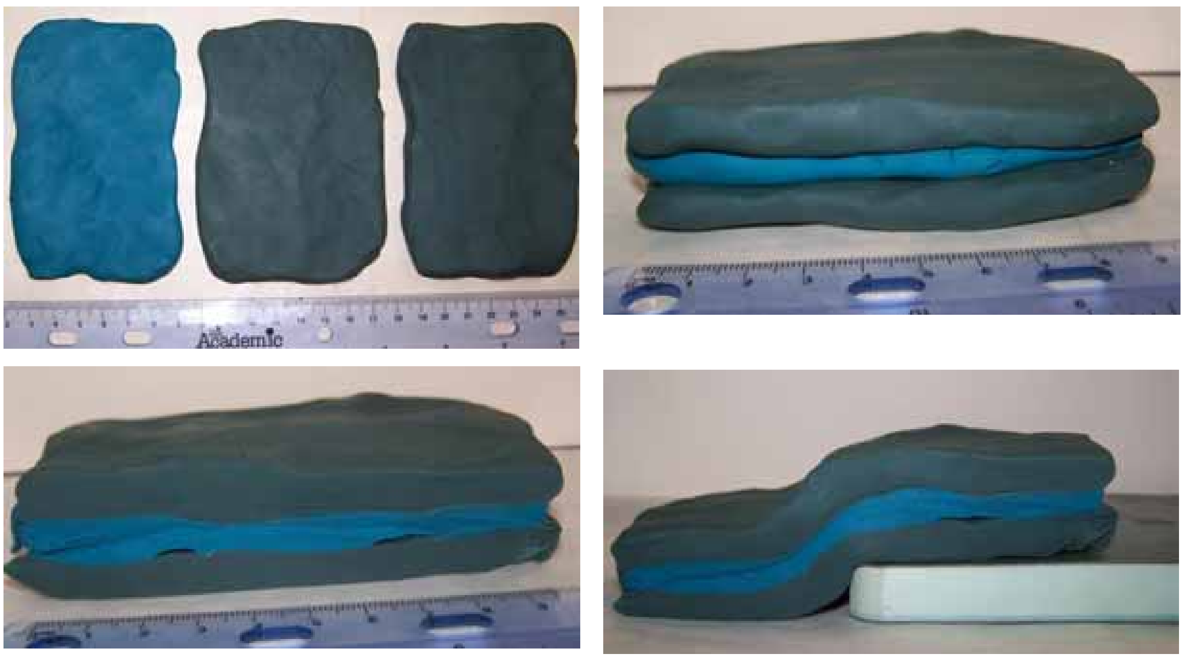


FIGURE 9. Upper left: Three flat pieces of clay needed for structure. Upper right: Layers stacked with alternating colors. Lower left: Thin slice taken off side of long face to reveal layers more clearly. Lower right. Finished monocline fold.

D. Normal Fault

Normal faults most often form due to tensional stress. Uplifting a broad region like the Colorado Plateau stretched the brittle crust, creating tension which fractured the strata. A number of north-south trending normal faults dissect the Colorado Plateau. At Parashant, the huge, nearly vertical fault scarps that make up the Hurricane Cliffs and Grand Wash Cliffs are dramatic examples of this structural feature.

Figure 10 shows a side view through a normal fault created in a clay model (with stress directions shown in arrows, and motions of the fault blocks shown for your information). A drop or two of liquid soap will lubricate the surface so that the sides can slide along the fault. The relatively high angle of the normal fault may lead students to have difficulty comprehending how normal faults are due to tensional stress. If this happens, ask them to put their left hand over their right hand in front of themselves, palms down, with elbows out and fingers parallel to their bodies (fingers point towards opposite elbow). The surface between their hands would be the fault plane. Then ask them to move their elbows apart to slide their left hand (the hanging wall of the fault because it hangs over the fault plane) down over their right hand (the footwall or layers below the fault plane). Challenge them to obtain this relative motion by pushing their hands together rather than pulling. It isn't possible to create this relative motion through compression.

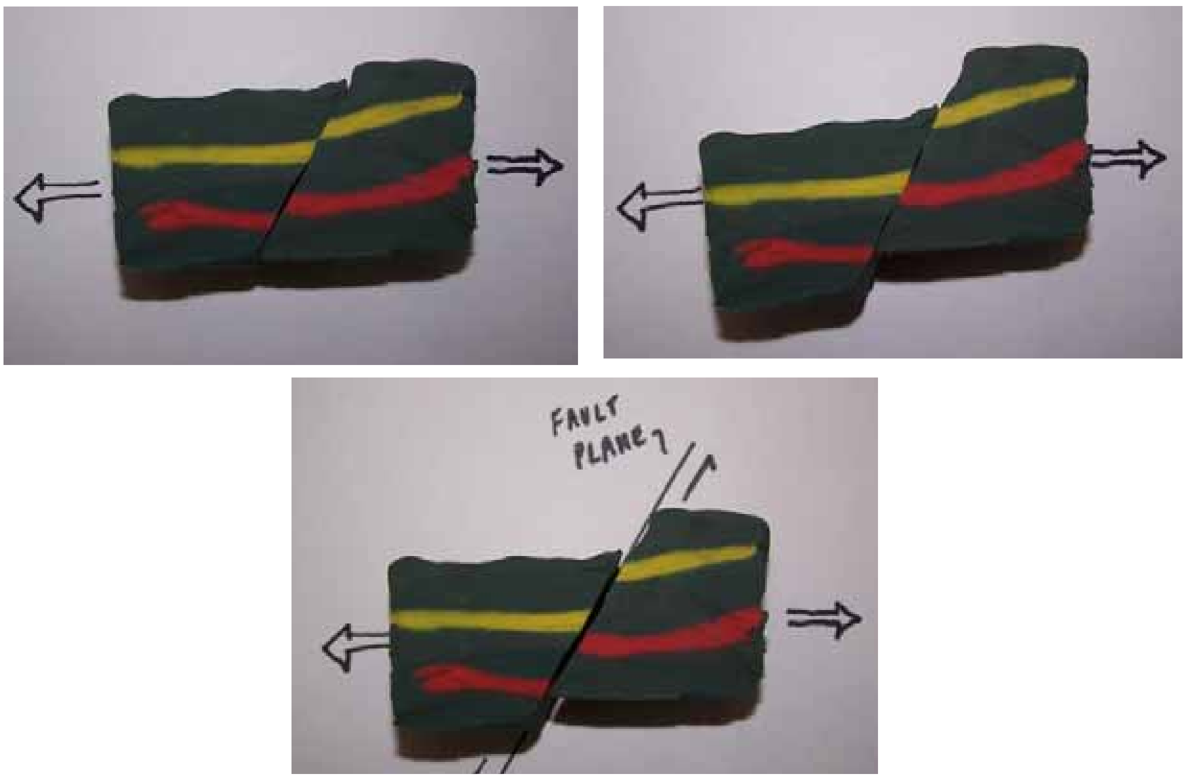


FIGURE 10. Upper left: Side view of the start of normal fault movement. Upper right: Side view of the completion of normal fault movement. Lower: Normal fault showing fault plane, stresses, and direction of movement along the fault. On all photos, footwall is to the right, and hanging wall to the left of fault.

E. Reverse Fault

Reverse faults form most often due to compression – forces that push rock together, breaking the rock and creating a fault. Low-angle (< 30 degree) reverse faults are called thrust faults. If you wish to form eight groups, you can add this model to the list as model G.

Figure 11 shows the reverse fault model. In nature, rock layers do not hang over the top of one another like this. They are smoothed by erosion. The angle of inclination of the fault and the age of the rock layers on either side provide some of the evidence used to identify them. Note for example that if the hanging wall on the model below was eroded, the “older” yellow layer on the left (hanging wall) side of the fault would be at the same position as the top green “younger” layer on the footwall side.

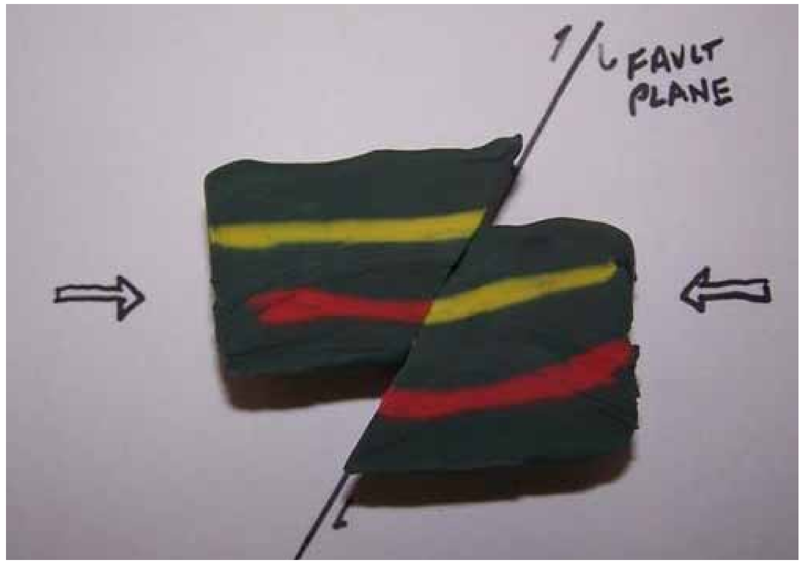


FIGURE 11. Side view of reverse fault with arrows showing direction of movement of rock units along the fault plane, and larger arrows showing the direction of compressional stress.

Lubricating the surfaces of the fault with a drop of liquid soap on each side is necessary to get the sides to slide past one another.

F. Strike-slip Fault

Strike-slip faults arise due to shear stress – forces moving past one another. Strike-slip faults are typically nearly vertical and move rock horizontally past each other on either side of the fault. The San Andreas Fault in California is a famous example. When the side across the fault moves to the right, it is called a right-lateral strike-slip fault. If the side across the fault moves to the left, it is a left-lateral strike-slip fault. The fault shown in Figure 12 is right lateral. The line traced on the model helps to illustrate the relative motion, and would represent the motion of rock, a fence-line, or stream course in nature. Horizontal motion dominates over vertical motion on strike-slip faults.

FIGURE 12.. Strike-slip faulting. Upper left: Top view prior to faulting. Upper right: Side view prior to faulting. Lower left: Top view after faulting showing motion along fault plane. Lower right: Side view after faulting.

EXPLAIN

Assign for reading during class or as homework (even if the entire activity has not yet been completed). You can supplement the explanation phase of the lesson with a discussion or lecture. Photographs of local or regional structural features would illustrate products of tectonic stress and provide relevant examples to students.

ELABORATE

40 Minutes

In this activity, students interpret a cross-section of the western side of Parashant. The western edge marks the transition zone between the Colorado Plateau to the east and the Basin and Range to the west. Thus, the cross section illustrates one of the more prominent faults and cliffs of the monument (Grand Wash Cliff) and there are more faults here for students to interpret. The intended focus is geologic structure, not other geological principles (uncomformities, geologic time, geologic history, etc.), which students do not need to know in order to interpret the cross-section.

Students will need a clean copy of the cross section and legend, and a ruler (preferably transparent).

Have students work in groups to promote discussion. Things you might wish to point out to students to introduce them to the activity include:

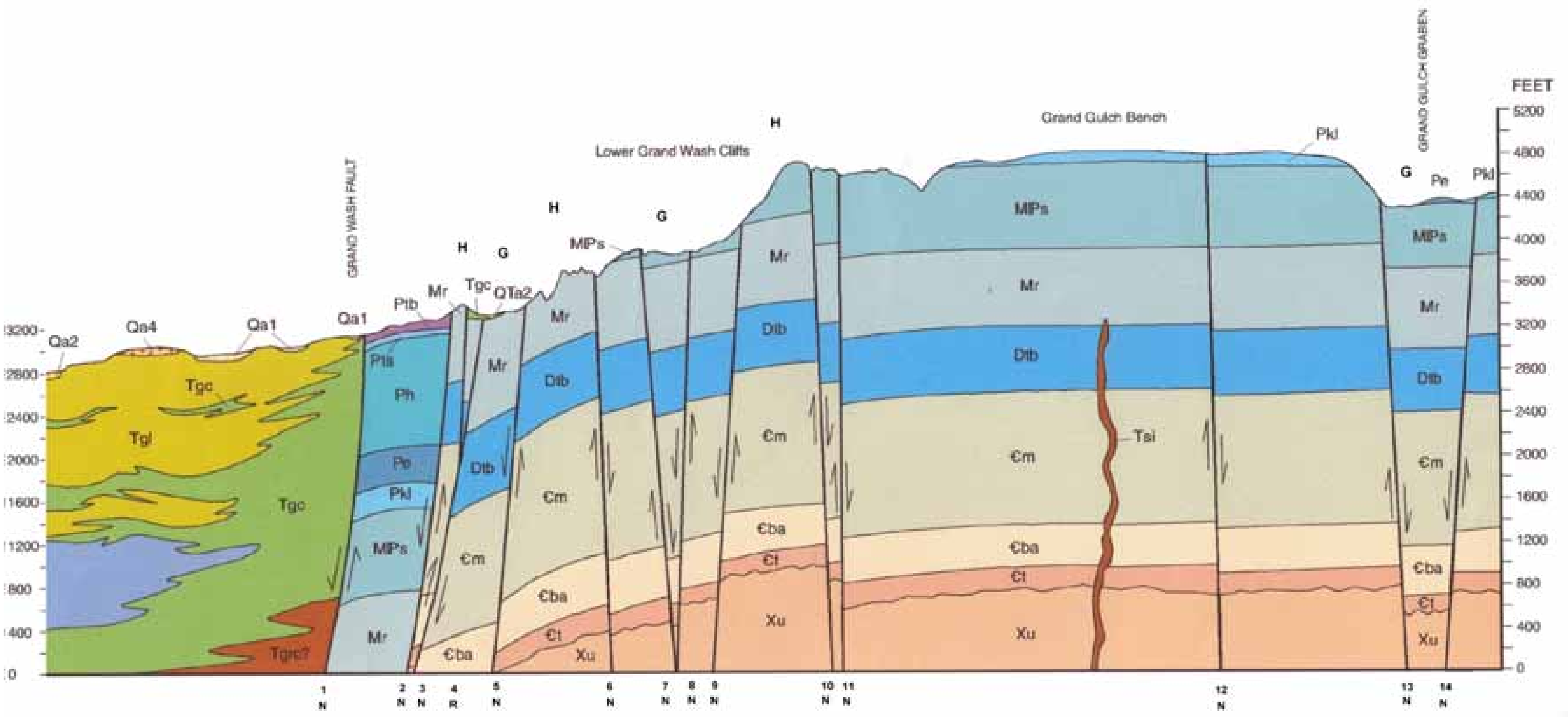
- ⇒ The top level of the section is the ground surface. It's a topographic profile.
- ⇒ Rock units is a general term – some units are sediments (young and not cemented) and others are many millions of years old.
- ⇒ Vertical exaggeration 2X means that 5200 vertical feet is 2600 horizontal feet. The section is about 5800 feet wide (about one mile).
- ⇒ Zero on the vertical scale is sea level.
- ⇒ The relative positions of units are more important than the Era, Period, Epoch, or ages in millions of years. That is just extra information about the rocks and sediments.
- ⇒ The cross-section itself is an interpretation. Geologists had to interpret the evidence of faulting at the surface and infer what happened beneath the surface.
- ⇒ The edges of the units to the west of the Grand Wash Fault are not folds, but facies, which show changes in sediment horizontally.
- ⇒ Unit Xu is the ancient crystalline basement rock (metamorphic and igneous).

Answers to questions are provided below. An annotated version of the cross section follows.

1. Fourteen faults are visible.
2. Numbered from left to right, the only reverse fault on the section is number 4 (found just below the letters “Tgc”.
3. There are three grabens.
4. There are three horsts.
5. Fault 1 (Grand Wash Fault) has the greatest vertical displacement. Unit Ptb on the right side of the fault is not visible on the left side of the fault, so it must be dropped down below sea level.
6. The minimum amount of vertical displacement on the Grand Wash Fault is 3100 feet.
7. The elevation of the top of rock unit MPs on the eastern side of the section is 3950 feet.
8. The elevation of the top of unit MPs on the western side of the section, adjacent to the Grand Wash Fault, is about 1500 feet.
9. The change in elevation of unit MPs from west to east is 3950 feet – 1500 feet = 2450 feet.

Challenge Question:

There is a greater thickness (1700 feet) of strata above MPS just east of the Grand Wash Fault and little to no thickness of those rocks to the east because uplift exposed them to erosion on the east.



Answer key showing fault numbers, types, and locations of grabens and horsts.

Cross section from: Billingsley, G.H., Beard, L.S., Priest, S.S., Wellmeyer, J.L., and Block, D.L., 2004, Geologic map of the Lower Grand Wash Cliffs and vicinity, Mohave County, northwestern Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-2427, scale 1:31,680, 17 p. [http://pubs.usgs.gov/mf/2004/mf2427/]

EVALUATE

1. Tensional stress (normal faults), compressional stress (reverse faults), and shear stress (strike-slip faults)
2. Answers should include bending an object like a pencil, piece of uncooked spaghetti, twig, etc.) as ductile stress and when it breaks, the object behaves like a brittle solid.
3. Where two plates collide, compressional stresses occur, and compression is more likely to fold rocks than tensional stress.
4. Faults played a bigger role in creating the landscape at Parashant because they help to elevate the land. Folds are small and limited to local sinkholes.
5. The person shown in Figure 6.11 is pointing to a fault. The angle of the fault is from upper right to lower left. Is this a reverse fault or a normal fault? Explain your decision.
6. Rocks break during brittle deformation. The blocks of rock look like they were fractured, forming joints.

LESSON 6: GEOLOGIC STRUCTURE AND THE PARASHANT LANDSCAPE

ENGAGE

Look at Figure 6.1. Sedimentary rocks at Parashant came from sediments deposited in nearly flat continuous layers.

1. Are the layers in Figure 6.1 lying flat?

2. Are the layers continuous (can you trace a single layer all the way across the photo)?

3. What do you think happened to these rocks since they first formed?

FIGURE 6.1. What do you notice about these layers of sedimentary rock near Mt. Logan at Grand Canyon-Parashant? Width shown is about 100 meters.

Write down your ideas. Discuss your ideas with a partner and the rest of the class.

EXPLORE

How do solids respond to forces that put them under stress? In the following activities, you will model forces that deform and break rock layers. These forces have played a key role in shaping the landscape at Parashant.

Part A: Modeling Stress and Strain

How many basic kinds of stress are there? Do rocks respond differently when different stresses are applied?

1. From your teacher, obtain a 12-ounce block of modeling clay (from Lesson 5), a plastic bottle cap, a sheet of waxed paper, and a metric ruler.

2. Form a rectangular solid out of the modeling clay roughly 9 cm by 4 cm by 4 cm. Start by rolling the clay into a cylinder about 9 cm long. With the clay in your hands, form four roughly flat faces. Flatten the surfaces by pressing each one down onto the table. Flatten the ends by pressing them into the table as well.

3. Lightly press the open end of a bottle cap into the center of one of the long flat surfaces, to make a circle. With a pencil tip, carve two perpendicular lines inside the circle, as shown in Figure 6.2.

4. The circle you have made will allow you to see how the clay model responds when forces are applied to it. **Stress** is a force applied to rocks. **Strain** is how the rock responds to stress, usually a change in shape or volume.

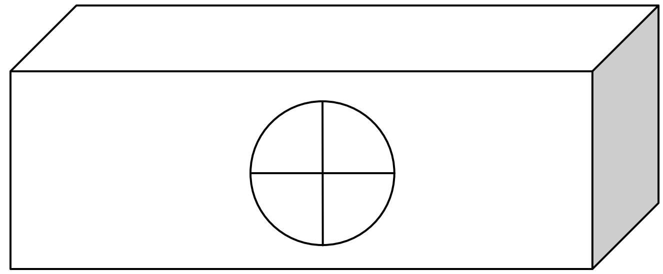


FIGURE 6.2. Diagram of clay model with reference circle and cross-lines.

Measure the diameter of the circle with a metric ruler. Draw your circle on a sheet of graph paper, to scale. Label this drawing "Side view: Original shape". You do not need to draw the entire model – just the circle and cross-lines. You can use the bottle cap to trace the circle.

5. Subject the rock to **compressional stress** by pushing the long ends of the model towards each other with your palms. Compress the model until it is half of its original length.

6. Record the strain on the model by measuring the lengths of the two cross lines and drawing a diagram of the new shape of the circle. Be sure to show any change in the angles between the two cross lines (they began as nearly right angles to each other). Draw large arrows pointing inward from the sides to show the compressional stress. Label this diagram "Side view: Shape after compressional stress".

7. Reshape the clay into a rectangular solid again. Try to make the clay about the same length and width as the original (9cm by 4cm by 4cm). Use the bottle cap and pencil tip to make the circle and two perpendicular cross lines on the side.

8. Subject the model to **tensional stress** by pulling on the clay lengthwise. Hold the clay in your hands like you would a sandwich and pull slowly, holding it firmly as you pull. Stretch the clay to about twice its original length without tearing it in two.

9. Record the strain on the model by measuring the lengths of the two cross lines and drawing a diagram, as before. Draw large arrows pointing outward (away from) and parallel to the circle. Label the arrows "tensional stress" and label the diagram "Side view: Shape after tensional stress".

10. Reshape the clay into a rectangular solid one more time, with the same dimensions as before. Carve the reference circle and two cross lines.

11. Draw a new diagram of the original shape because this time, you are going to focus on what happens to the top of the model. Label this drawing "Top view: Original shape".

12. Model how the clay responds to **shear stress**. To do this, lay the model on its side so that the circle is facing up. With your hands on each end of the model (like holding a sandwich), move your left hand towards you and your right hand away from you. Do this until the top of the left-hand side lines up with the bottom of the right-hand side. Stop before the clay breaks or tears.

13. Record the strain on the model, measuring and drawing, as before. Label the diagram “Top View: Shape after shear stress”. Draw large arrows to show the direction of the stress – the directions in which you moved each hand.

14. In your own words, summarize the strain of the model in response to each kind of stress: compressional, tensional, and shear.

15. Put materials away and wash your hands.

Part B: Modeling Folds and Faults

How do rocks respond to stress? Stresses within the Earth strain or deform rocks. When deformation is ductile, rocks bend without breaking, forming folds. When deformation is brittle, rocks break, forming joints or faults. In this activity, your group will model and study a type of ductile or brittle deformation, then present your model to the rest of the class.

Table 1. Results of Modeling Stress and Deformation of Rocks

Structure	Stress: Compressional, tensional, or shearing	Deformation: Brittle or Ductile	Diagram: (Label Top or Side View; Use arrows to show directions of stress)	Explanation
A. Anticline				
B. Syncline				
C. Monocline				
D. Normal Fault				
E. Reverse Fault				
F. Strike-Slip Fault				

A. Anticline

1. Obtain a large piece of modeling clay (from Part A) and two smaller pieces of clay of different colors (use scraps from earlier lessons).
2. Divide the large piece of clay into three equal pieces. Flatten them into rectangular shapes about 9 cm long. Flatten the two smaller pieces into rectangles as well. It is okay if they wind up thinner than the larger pieces.
3. Stack the five layers, alternating colors.
4. Use a piece of dental floss to slice a clean face off of the long side. The end result should be a clean, flat surface 9-cm long when viewed from the side.
5. Holding the ends of the clay, press your hands together while pushing up a little with your thumbs to make a fold that points upward (an upside-down U).
6. Fill in the information in the correct row of Table 1, including a diagram of the side view of the model.

B. Syncline

1. Follow the same procedure for an anticline, but press down a little with your fingers to make a fold which points downward, like a "U".
2. Fill in the information in the correct row of Table 1, including a diagram of the side view of the model.

C. Monocline

1. Obtain a large piece of modeling clay (from Part A), a smaller piece of clay of a different color (use scraps from earlier lessons), a thin textbook (or wood block), and a piece of dental floss.
2. Divide the large piece of clay in two equal parts. Shape the three pieces of clay into rectangular shapes 6cm wide by 9cm long.
3. Stack the three layers, alternating the colors.
4. Use a piece of dental floss to slice a clean face off of the long side. The end result should be a clean, flat surface 9-cm long when viewed from the side.
5. Lay a thin flat book (or wood block) on the table. Drape the model

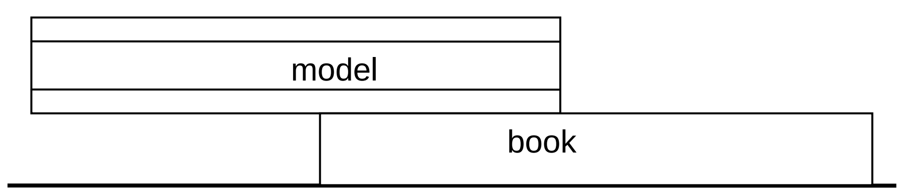


FIGURE 6.3. Set-up of the monocline fold model.

across the book lengthwise so that half of the model is hanging off (see Figure 6.3).

6. Put the palm of your hand on the book-side of the model. With your other palm, press straight down on the overhanging side until it is flat against the table. This will create a fold across the edge of the book, like a stair step.

7. Fill in the information in the correct row of Table 1, including a diagram of the side view of the model. Note: Although you pressed one side of the model down to form the fold, the book also pushed upward on the other side of the model. Use arrows to show both directions of stress on your diagram.

D. Normal Fault

1. Obtain a large piece of modeling clay (from Part A), two smaller piece of clay of a different color (use scraps from earlier lessons), a dropper bottle of liquid soap, and a piece of dental floss.

2. Divide the large piece of clay in two equal parts. Shape the three pieces of clay into flat rectangular shapes 4cm by 4cm by 9cm.

3. Stack the five layers, alternating the colors.

4. Turn the model on its side so that you look down on the layers. With a piece of dental floss, slice the model at a 45 degree angle from upper right to lower left (see Figure 6.4). This slice is called the **fault plane**.

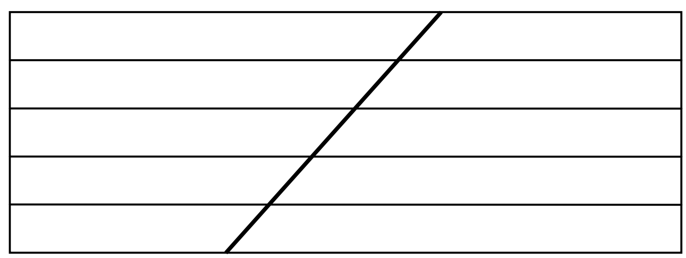


FIGURE 6.4. Side view of model showing fault plane (heavy line).

5. Separate the two sides of the fault and put a drop of liquid soap on the fresh surfaces you have just sliced (the fault plane). This will prevent the clay from sticking and make it easier for sides of the model to slide along the fault.

6. Holding the model in your hands, pull the model apart, sliding the left side of the model down the fault plane, and the right side of the model up the fault plane.

7. Fill in the information in the correct row of Table 1. In your diagram of the side view of the model, include large arrows showing the direction of stresses (the directions in which you pulled) and small arrows to show the movement of layers on each side of the fault plane.

E. Reverse Fault

1. Follow the same procedure for setting up a normal fault. Instead of pulling the model apart, push the model together, sliding the left side of the model up the fault plane and the right side of the model down the fault plane.
2. Fill in the information in the correct row of Table 1. In your diagram of the side view of the model, include large arrows showing the direction of stresses (the directions in which you pulled) and small arrows to show the movement of layers on each side of the fault plane.

F. Strike-slip Fault

1. Obtain a large piece of modeling clay (from Part A), two smaller piece of clay of a different color (use scraps from earlier lessons), a dropper bottle of liquid soap, and a piece of dental floss.
2. Divide the large piece of clay in two equal parts. Shape the three pieces of clay into flat rectangular shapes 4cm by 4cm by 9cm.
3. Stack the five layers, alternating the colors.
4. With a pencil tip, carve a light groove down the length of the top layer (see Figure 6.5).
5. With a piece of floss, slice the model from top to bottom vertically (see Figure 6.5).
6. Separate the two sides of the fault and put a drop of liquid soap on the fresh surfaces you have just sliced (the fault plane). This will prevent the clay from sticking and make it easier for sides of the model to slide along the fault.
7. Looking down on the model, push the right side of the model "north" (away from you) and pull the left side of the model "south" (towards you).
8. Fill in the information in the correct row of Table 1. In your diagram of the top view of the model, include large arrows showing the direction of stresses (the directions in which you pulled and pushed) and small arrows to show the movement of the layers on each side of the fault.

FIGURE 6.5 Top view of strike-slip fault model. Light line shows the groove. Heavy line shows the fault line.

EXPLAIN

Comparing Clay Models to Real Structures

FIGURE 6.6 Rocks exposed here at Parashant are the uplifted block of a normal fault. The downthrown side on the valley floor has been buried by sediments (alluvium).

Clay models gave you a chance to think about how the rock layers shown in Figure 6.1 came to be deformed. But processes in nature are often more complex than our simple physical models. Let's look at ways that rocks and stresses are similar to and different from the clay models.

The force you applied to move the clay simulated stress on rocks. In nature, these forces arise when huge plates of Earth's crust and upper mantle meet (often very far away). Plates meet three different ways. In general, plate collision produces compression, separation causes tension, and plates that slide past one another horizontally cause shear. Geologists group all three as **tectonic stresses**. One kind of stress can produce another kind. For example, plate collision in the western US peaked between 65 and 50 million years ago. When the Pacific (oceanic) plate dove at a low angle beneath the continental North American Plate, it caused shear stress in the lower crust. Shearing then caused compression in the upper crust, sending rocks upward to form the Rocky Mountains.

Time, heat, pressure, and the thickness of rock layers also control rock deformation. Unlike the clay model that you held in your hands, rock is buried in the Earth (until it is brought to the surface by tectonic forces or erosion, which strips away overlying material). Burial makes rock hot and puts it under great pressure due to the weight of the rocks above it. Heat and pressure applied over a long time make the rock more likely to deform by flowing and folding. A sitting bench made out of a piece of Kaibab Limestone would shatter when hit with a heavy hammer, but would sag under its own weight over time. Rock that is cooler, under less pressure (closer to the surface), and stressed rapidly tends to deform by breaking (fracture). Obviously, you ran your models and stress tests with different materials under very different conditions than what is found within the Earth, but the general concepts apply.

A final comparison is that your models focused on folding and faulting separately. In nature, the forces that create faults can also create folds. Rock may also begin to flow and fold and then suddenly break to form a fault. In your models, you sliced the clay to make a fault. This was done so that you could focus on the specific type of feature that forms. If you were to try to create the fault without slicing the clay, you would see the clay begin to flow and fold prior to faulting. In sum, even though the processes that deform rocks are more complicated and can take millions of years, your models showed the basic kinds of structures that forces in the Earth create.

Brittle Deformation – Joints, Faults, and Earthquakes

When rock behaves like a brittle solid, it fractures. Fractures include joints and faults. Anytime a solid breaks or cracks, it becomes weaker. This allows water to seep in more quickly and can be a passageway through which magma reaches the surface.

FIGURE 6.7 Nearly vertical joint in an ancient sand dune (sandstone) at Parashant .

Joints are fractures in rock along which very little movement has occurred (see Figure 6.7). Have you ever seen mud cracks that form after muddy water has evaporated? The cracks in the mud are like joints in rock. Some joints are made by tectonic stress. Cooling of magma or lava also causes stress that can create joints. As the magma or lava cools, it shrinks or contracts. The basalt columns shown in Figure 6.8 formed when cooling caused joints to form polygons Joints can extend for miles in rock. Weathering makes them wider over time, creating spectacular landscape features. Canyons, arches, natural bridges, pinnacles, and columns are examples of features largely controlled by joints.

FIGURE 6.8 Joints in this columnar basalt formed due to stress as lava cooled and contracted.

Faults are fractures in rock along which vertical or horizontal movement (or both) has occurred. The surface formed by the break is a zone of weakness called a **fault plane**. Once a fault forms, rocks along it will continue to deform as long as stress is applied. The rocks continuously store the energy built up by stress. If the releases its stored energy suddenly, we feel the vibrations as an **earthquake**. Faults can remain inactive for millions of years, only to be renewed by renewed stress.

As you learned in Part B of the activity, the type of stress applied influences the type of fault that forms. At a basic level,

FIGURE 6.9 Fault at Parashant (fault outlined in black). Is this a normal or reverse fault?

compression creates reverse faults and thrust faults (low angle reverse faults with lots of horizontal motion), extension causes normal faults, and shear causes strike-slip faults. Of course, forces and stresses in nature are more complicated. Faulting can go hand-in-hand with folding. Faults vary in age, length, amount and frequency of movement, and depth, with some faults extending for hundreds of miles along the surface. An example of this complexity will be discussed below in the section on geologic structure at Parashant.

Ductile Deformation - Folds

Folds form when rocks respond to stress by ductile deformation. It may be difficult to think about solid rocks flowing like a stick of warm taffy held in your fingertips. But remember, rocks are warmer inside the Earth, and stress is applied very slowly, over millions of years. This enables rocks to bend before other forces bring the folded layers to the surface for us to see. Folds range in size from microscopic to kilometers (see Figure 6.10). They often result from compressional stress. Large-scale folding is often evidence of plate collision. The intricate ribbon-like pattern of anticlines and synclines that make up part of the Appalachian Mountains formed when the North American Plate slammed into the Eurasian Plate more than 200 million years ago.

FIGURE 6.10 A small monocline in sedimentary rocks just north of Parashant.

Some folds are due to uplift. If sediment buries a thick layer of salt, the salt may become ductile enough to flow upward dome the layers above. Large bodies of magma that rise upward also form domes. Monoclines are one-sided folds that can form when sedimentary rocks are draped over deeper faults in basement rock, like a rug draped over a step (or your clay model draped over a book!).

Major Geological Structures at Parashant

What do Mt. Everest and Parashant have in common? More than you might think! For one, limestone that formed from marine sediments now caps both Everest and Parashant's Kaibab Plateau. Colliding plates played a big role in shaping the geological structures of both places. To understand how the landscape of Parashant formed, it helps to start by thinking about its elevation and the types of rocks that make up the land.

The monument sits on the Colorado Plateau, a large raised area of mostly desert land with an average elevation of 5000 feet above sea level. Elevations at

Parashant range from 1200 to 8200 feet. Smaller, flat or gently sloping plateaus made up of thousands of feet of sedimentary rock (and capped by lava flows in places) dominate its landscape. Rocks are tilted gently to the northeast. Stream erosion carved canyons into the plateaus, and volcanoes erupted lava many times. Beneath the sedimentary and volcanic rocks lie rocks that make up what geologists call the **basement**. At Parashant, basement rocks are metamorphic (gneiss and schist) and rocks that formed from cooling magma (igneous). Most of the strata on the monument, including the marine limestone called the Kaibab Formation that caps the eastern plateaus, came from sediments deposited under water. Further deposition buried these beds under thousands of feet of overlying deposits, turning them into rock. So why do we see them today atop plateaus? How can the landscape be so elevated and yet gently sloping? What happened?

It turns out that the geologic structures (mainly faults) within basement rocks have played a crucial role. Some 300 million years ago, the collision of plates that formed the ancient Rocky Mountains caused compression in the Colorado Plateau. The compression deformed and faulted Parashant's basement rocks. As mentioned earlier, once faults form, they remain as zones of weakness that later stresses can renew. And the Colorado Plateau has undergone several periods of major geologic stress in the past 300 million years. Scientists are still trying to figure out the history and causes of uplift of rocks in the Colorado Plateau. One thing that agree about is that the Plateau has acted like a rigid stable block (rather than being tilting severely or forming complex folds). In contrast, the land that surrounds the Plateau reacted differently to these forces and was pulled apart. The tensional stress led to normal faulting of the Basin and Range region west of Parashant. This activity continues today. The Plateau continues to rise, while faults remain active around the edges.

The interaction between plate collision and older basement faults left Parashant with a number of major north-south trending faults. These include the Grand Wash, Dellenbaugh, Shivwits, Main Street, Hurricane, and Toroweap Faults. The Grand Wash Fault makes the boundary for the west side of the Colorado Plateau. This spectacular normal fault has about 24,000 feet of vertical displacement! The Hurricane Fault extends for some 150 miles across northern Arizona and into Utah. Geologists believe that motion of the faults has shifted over time. That is, basement faults that began as normal faults changed direction during compression, causing reverse faults. Later, tectonic stresses produced normal fault motion. Several remain active today as normal faults. Traces of these faults are visible where they break through basalt flows and layers of sediment at the bases of cliffs, and minor earthquake activity occurs.

Some geological structures at Parashant came not from tectonic stress but arose due to the collapse of underlying layers. For example, many bowl-shaped depressions exist at the surface in the Kaibab Formation. The rock layers dip inward, but they are not tectonic folds. Instead, they are the surface features of column-shaped **breccia pipes** that form when groundwater dissolves older limestone below the Kaibab rock layers. The breccia pipes also become conduits for fluids that concentrate minerals like uranium and copper. The dissolution of gypsum layers in the Kaibab Formation also creates sinkholes and minor folds on several plateaus within the monument.

ELABORATE

In this activity, you will interpret a cross-section (side-view) of the western side of Parashant that shows the Grand Wash Fault. The legend explains the symbols on the section that indicate the ages and names of rock units. All but two units are sedimentary rocks or sediments. To interpret the cross-section, assume that most of the sedimentary rocks were once lying flat in continuous layers. The vertical scale of the section is twice that of the horizontal. This makes faults and slopes look steeper. The faults are not vertical, so you should be able to tell a normal fault from a reverse fault.

1. How many faults do you see?

2. Number each fault from west to east. Place the numbers below the bottom of the faults.

3. Based upon the inclination of the fault and the positions of rock layers on either side of the fault, identify the faults as normal faults or reverse faults. Below each number, write an N for a normal fault and an R for a reverse fault.

4. Grabens are lowered blocks bounded by two normal faults. How many grabens can you see? Label each graben with a G.

5. Horsts are raised blocks bounded by two normal faults. How many horsts can you see? Label each horst with an H.

6. Which fault has the greatest vertical displacement? How do you know?

7. Based upon what you can see in the cross-section, what is the minimum amount of vertical displacement on the Grand Wash Fault?

8. What is the elevation of the top of rock unit MPs on the eastern side of the section on the Grand Gulch Bench?

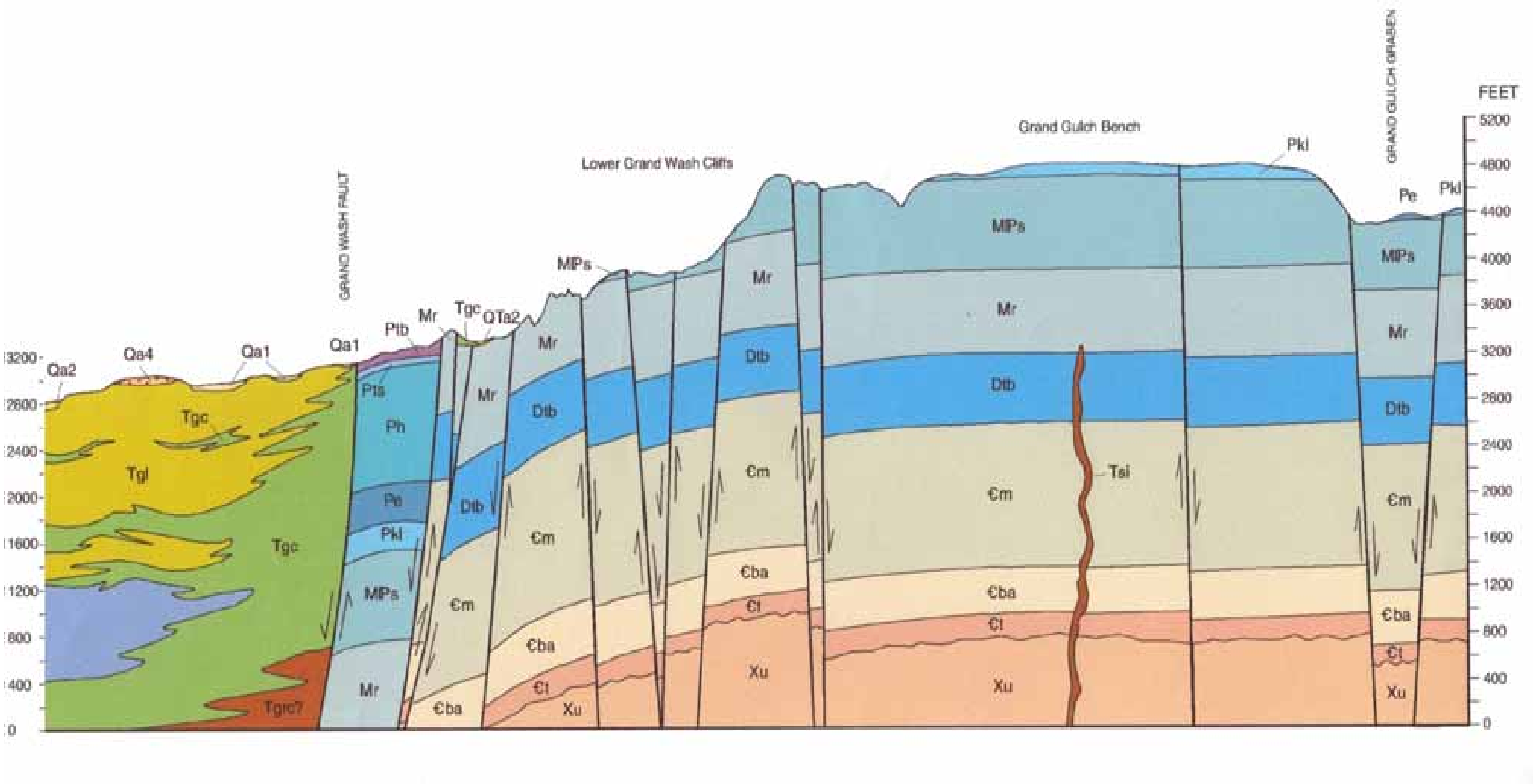
9. What is the elevation of the top of unit MPs on the western side of the section, adjacent to the Grand Wash Fault?

10. What is the change in elevation of unit MPs from west to east between those two locations?

Challenge Question: The higher the elevation of the landscape, the more likely it is to be eroded. What evidence do you see in the cross-section to support this claim? Hint: Use the units that lie above Unit MPs as a guide.

Legend for the Cross Section through Grand Wash Fault

Era Million years ago	Period	Epoch	Symbol	Rock Unit
Cenozoic 65-present	Quaternary	Holocene	Qa1	Youngest alluvial fan deposits
		Pleistocene	Qa2	Young alluvial fan deposits
			Qa4	Old alluvial fan deposits
			QTa2	Intermediate alluvial fan deposits (Pleistocene or Pliocene?)
	Tertiary	Pliocene	Tsi	Dikes and Necks (igneous intrusions)
		Miocene	Tgl	Limestone and siltstone facies
			Tgg	Gypsum and gypsiferous sitstone facies
			Tgc	Red Paleozoic clast conglomerate facies
			Tgrc	Grey Paleozoic clast conglomerate facies
		Oligocene		
		Eocene		
		Paleocene		
Mesozoic 248-65	Cretaceous			
	Jurassic			
	Triassic			
Paleozoic 543-248	Permian		Ptb	Toroweap: Brady Canyon Member
			Pts	Toroweap: Seligman Member
			Ph	Hermit Formation
			Pe	Esplanade Sandstone
			Pkl	Pakoon Limestone
	Penn-Miss.		MPs	Lower Supai Group
	Mississippian		Mr	Redwall Limestone
	Devonian		Dtb	Temple Butte
	Silurian			
	Ordovician			
	Cambrian		Cm	Muav Limestone
			Cba	Bright Angel Shale
			Ct	Tapeats Sandstone
Proterozoic 2500-543			Xu	Crystalline Rocks (basement)
Archean 3800-2500				
Hadean 4500-3800				



Vertical Exaggeration ~2X

Cross section from: Billingsley, G.H., Beard, L.S., Priest, S.S., Wellmeyer, J.L., and Block, D.L., 2004, Geologic map of the Lower Grand Wash Cliffs and vicinity, Mohave County, northwestern Arizona: U.S. Geological Survey Miscellaneous Field Studies Map MF-2427, scale 1:31,680, 17 p. [http://pubs.usgs.gov/mf/2004/mf2427/]

EVALUATE

1. Describe the three kinds of stress on rocks and name the types of fault that each commonly produces.
2. Use a common everyday object to illustrate stress produces brittle versus ductile deformation.
3. Why is folding more common where two plates collide than where two plates separate?
4. What type of deformation is more important in producing the Parashant landscape – folding or faulting? Explain.
5. The person shown in Figure 6.11 is pointing to a fault. The angle of the fault is from upper right to lower left. Is this a reverse fault or a normal fault? Explain your decision.
6. Look at the blocks of conglomerate shown in Figure 6.12. The largest blocks are 2 meters across. Are the blocks the result of brittle or ductile deformation? Explain.

FIGURE 6.11 Fault in Mesozoic strata north of St. George, Utah.

FIGURE 6.12 Blocks of the Shinarump Conglomerate near Snow Canyon State Park, Utah.

LESSON 7: EROSION AND DEPOSITION – FROM WASHES TO CANYONS AT PARASHANT

GEOLOGICAL ADVENTURES AT PARASHANT

EXPLORING THE GEOLOGY OF

GRAND CANYON-PARASHANT NATIONAL MONUMENT

NATIONAL PARK SERVICE

THE GEOLOGICAL SOCIETY OF AMERICA®

SCIENCE • STEWARDSHIP • SERVICE

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF LAND MANAGEMENT

LESSON 7 GUIDE: EROSION AND DEPOSITION - FROM WASHES TO CANYONS AT PARASHANT

OVERVIEW

Students interpret a photograph of gravels and cobbles exposed in Whitmore Wash at the monument. They clip an overhead transparency to a photograph of the sidewall of a wash and draw lines through the longest axes of flattened cobbles, and use the overall pattern of lines to infer the direction of stream flow. Students read about the processes of erosion and deposition that are most prevalent on the monument. In an elaboration activity, students return to the photograph of Whitmore Wash to interpret the percentages of various rock types found in the deposit. After building a class data set using representative square-meter areas of the deposit, they draw inferences about the geology of the mountain range that produced the deposit.

Objectives After interpreting a photo of clast orientations in a wash deposit, reading about processes of erosion and deposition at Parashant, and interpreting the types of rocks exposed in a wash and making inferences about the geology of the mountains from which the deposit came, students will understand:

- Running water orients clasts in streams in ways that enable us to reconstruct the directions of ancient stream flow;
- Erosion is the transport of sediment by wind, water, gravity, and ice, and wears down the land;
- Deposition is the settling of eroded sediment at a lower elevation and builds up the land;
- Running water is the most important agent of erosion in the desert;
- Rocks are broken into smaller pieces over time through chemical and mechanical weathering;
- The composition of rocks in ancient stream deposits provides clues about the existence and nature of ancient mountains.

Concepts Wash, ephemeral stream, clast imbrication, erosion, deposition, mechanical and chemical weathering, mass movement, canyon formation.

Duration Two 45-minute class periods

Audience Students in grades 6 to 9

Materials **Explore Activity** (per group of students)

- a color copy of Worksheet 7.1 (Whitmore Wash Photo)
- overhead transparency
- nonpermanent transparency marker
- clear tape
- ruler

Elaborate Activity (per pair of students)

- a color copy of Worksheet 7.2 (Whitmore Wash Photo)

- a color copy of Worksheet 7.3, 7.4, 7.5, or 7.6 (one per student pair)
- an overhead transparency,
- a nonpermanent transparency marker
- clear tape
- calculator

Extensions **For All Students**

- Arrange for a field trip to a local stream where students can examine clast imbrication, clast shape, and collect rock samples to make inferences about the composition of possible source rocks upstream.
- Take students outdoors to simulate wind erosion, deflation, and the formation of a desert pavement by spreading a bucket of dry sand and gravel out on a plastic tarp and running a strong fan over the sand.

For honors, gifted, and higher grade-level students

- Have students handle data from the activity in the Elaborate portion of the lesson in MS Excel, producing bar graphs or pie charts of clast lithology for the four sectors and the class total.

Resources

- A lucid description of weathering and erosion in desert environments prepared by the USGS is available at http://pubs.usgs.gov/of/2004/1007/erosion.html

ENGAGE

This section describes an experiment conducted by a student in order to engage students in thinking about how the forces associated with running water affect different-shaped particles in streams or washes. Ask volunteers to share ideas. Accept all reasonable ideas and write them on the board. Avoid providing the “right” answer – students will investigate the relationship between stream flow direction and clast orientation (imbrication) in the Explore phase of the lesson. Sample responses to questions are provided for your information below.

1. Students will likely respond that the round rock (A) will roll whereas rushing water will push over or tumble the rock shaped like a discus (B).

2. Accept all reasonable responses. While it is possible for rock B to get lodged in sediment with the arrow pointing upstream, it is far more likely that the arrow will point downstream, allowing water to flow easily over the sloping flat backside of the rock.

EXPLORE

Determining Stream flow Direction

1. Distribute materials to students. Make high quality color copies of Worksheet 7.1 (Whitmore Wash Photo) and laminate to protect them.

Each group will need one copy. Students will need an overhead transparency and a washable transparency marker to do their interpretations. Students will also need clear tape to secure the transparency to the photo, and a ruler to use to draw straight lines through clasts.

2. Help students to understand that the photograph in Worksheet 7.1 is a side view of an older deposit that was exposed by erosion in a wash (dry streambed). Figure 7.2 provides the context view. The light gray gravel at the bottom of the photo is the bottom of Whitmore Wash. As a side note, see how the sediments fine upwards, from coarse boulders at the base of Figure 7.2 to finer brown sand, silt, and clay above the black square. Fining upward sequences are common – as streams lose energy, the coarsest material settles first and becomes progressively finer. The photo was taken in the upper end of Whitmore Wash, where the wash is less than five meters wide. Whitmore Wash widens and deepens with distance, becoming Whitmore Canyon, and eventually joining the Grand Canyon to the south.

FIGURE 7.2 Rocks exposed in Whitmore Wash at Parashant. The box outlines the area shown in Worksheet 7.1.

3. Remind students how their study relates to the diagram (7.1) and questions in the Engage activity.

4. If you laminate the photographs and use non-permanent markers, the overhead transparencies will not be necessary.

5. This step explains why students are to focus on the elongate rocks in their interpretations. Elongate rocks allow them to explore whether or not flowing water orients rocks in a preferred direction in a stream. Figure 7.1 provides a reference for what is meant by an elongate clast. If you think that students will have difficulty understanding what to do, make an overhead transparency of Worksheet 7.1 and ask students to pick out an elongate rock, and then draw the line down the axis to show them.

FIGURE 1 Sample interpretation of clast orientation for 20 clasts in a wash deposit exposed at Whitmore Wash. All 20 clasts are oriented with the high end pointing to the left.

6. Results will vary depending on the rocks students select, but expect between 90 to 100% of the rocks having a preferred orientation of up and to the left (see Figure 1 above).

7. You could demonstrate the preferred orientation of rocks in a stream by standing four books on end on your demonstration table and gently pushing them over. Ask students what the force of your hand represents (the force of flowing water in a stream). The books will stack on top of each other, and water will flow up the flat back of the books due to their streamlined shapes. Demonstrate how much work is involved to try to flip the books over once they are in this position.

8. Water flow in the older deposit at Whitmore Wash was from right to left.

9. A geologist can use an ancient conglomerate to make inferences about the location of an ancient mountain range that no longer exists by looking at the orientation of the rocks in the conglomerate (to see which direction would have been upstream at the time, assuming that the rocks have not been disturbed).

10. Hold a brief class discussion. If you can project a copy of Worksheet 7.1, students can come to the front of the room to point out particular rocks they want to discuss.

EXPLAIN

Assign for reading during class or as homework (even if the entire activity has not yet been completed). You can supplement the explanation phase of the lesson with a discussion or lecture. Photographs of outcrops of sedimentary rocks, sample of rocks, diagrams of environments of deposition, and photographs of how we use sedimentary rocks as natural resources would be most relevant to the lesson. Photographs of local or regional outcrops would increase the relevance to students.

ELABORATE

1. You will need to make one overhead transparency of Worksheet 7.2 to project to the class (or project the image on a computer) so that they understand how the square they are studying relates to the wash deposit.

Students will need a color copy of Worksheet 7.1 (Whitmore Wash Deposit) as a context photo and a color copy of one of the following: Worksheet 7.3, 7.4, 7.5, or 7.6. Each of the four worksheets is a close-up view of one of the four squares shown in Worksheet 7.2. They will also need a nonpermanent marker, an overhead transparency, and a magnifying glass (to look more closely at rocks in the photo). Students will also need a calculator to calculate percentages of rock compositions.

2. You can project your copy of Worksheet 7.1 (from the Explore activity). Students may note as many as ten different kinds of rocks due to the range of colors. However, there are a variety of colors of limestone and basalt in the photo, and one kind of sandstone, so there are three kinds of rocks in the photo. Light brown soil from the wash deposit coats some rocks, obscuring their identification.

3. Project a copy of Worksheet 7.2 labeled with the types of rocks and help students to see the differences between the colors of basalt, the colors of limestone, the sandstone, and examples of rocks that might be labeled uncertain because they are in shadow or covered with soil.

a. White, light-grey, and light blue-gray rocks labeled A are **limestone**.

b. Medium-grey, dark-grey, black, and reddish-purple rocks labeled B are **basalt**. Some of the basalt rocks have holes (or dimples) made by gas trapped in the lava when it cooled. Basalt is a dark grey rock, but it often weathers into various colors.

c. Orange-red rocks labeled C are **sandstone**. The red color indicates iron between the grains of sand.

4. Point out that worksheet 7.2 shows four squares that correspond to the photos on Worksheets 7.3 to 7.6. The squares allow students to take representative samples of the wash deposit, roughly one square meter each. Assign a quadrant of Worksheet 7.2 to each pair of students. The data from studies of all four squares (as well as duplicate quadrants) can be averaged together. Ask students about the advantages of taking representative samples and averaging, rather than counting every rock in the photo.

5. Have students copy Table 1 into their notebooks. They should add the name of the quadrant you have assigned them to the location section at the top of the table (Upper Left, Upper Right, etc.).

Table 1. Rock Types in Whitmore Wash Deposit

	Location: _______________		**Grand Total**	
Rock Type	Number of Clasts	Percent of Total	Number of Clasts	Percent of Total
Limestone				
Basalt				
Sandstone				
Uncertain				
Total				

6. Students count the number of each kind of rock in the square meter sample area assigned to them. Circulate and address student's questions. When they have labeled all the rocks they can see that are longer than 1cm on the photo, they should count each rock type and put the data in Table 1. A sample interpretation is provided in Figure 2 on the next page.

7. Students may need assistance calculating percentages. You can do an example on the board for them.

8. Hold a class discussion in which you record for the class the results for each quadrant. Keep in mind that results are likely to vary between quadrants, and even between duplicate pairs of students assigned to each quadrant. Ask students how they think they should handle differences. The time available for discussion will dictate this to some extent, but the conversation presents a great opportunity to help students to understand the process of science and how to resolve disagreements.

FIGURE 2 Sample interpretation of Worksheet 7.3 - Wash Rocks Upper Left.

As a class, add the data for the four different squares together to find the grand total number of each type of clast. Then calculate the percentage of each rock type represented in the wash deposit.

9. Students will find a slight difference between the amount of limestone and basalt, and a large difference between those two rock types and the amount of sandstone.

10. The purpose of this question is for students to think about the role of chemical and mechanical weathering in changing the composition of rocks as they are transported. The rate at which rocks weather will influence the percentages of rock found in a stream deposit. Basalt is made of hard, silicate minerals, whereas limestone is made of softer calcite, which dissolves more easily in water.

a. The rocks probably did not travel a great distance because there is a high percentage of limestone in them.

b. Answers will vary, but the ratio of limestone to sandstone is at least 10:1.

c. The ratio of limestone (calcite) to quartz should decrease with distance from the mountain because quartz is more resistant to weathering than calcite, which will be broken down and dissolved.

EVALUATE

Address these questions in a class discussion, assign them for group work, or include them as part of a homework assignment.

1. Chemical and mechanical weathering both break down rock into smaller pieces. Mechanical weathering breaks rock without changing the chemical composition, whereas chemical weathering creates new substances.

2. The orientation of clasts in a stream reveals the direction of stream flow. The clasts will lean over and the high ends will point downstream.

3. Answers will vary. Erosion removes sediment from mountains and transports it down slopes, washes, and canyons. Deposition builds up the land where the sediment settles.

4. Running water is such a major agent of erosion in an arid region like Parashant because there is little vegetation holding the soil in place, so the sediment can be dislodged easily by rainfall. In addition, rainfall comes in intense thunderstorms and when sediment-rich water collects in channels, it has great erosive power.

5. As rocks tumble in a stream, they smash against each other. This is mechanical weathering. The water helps to dissolve the rocks, which is chemical weathering.

6. Quartz is such a major component of the sand found on many beaches because it is one of the most resistant minerals to chemical and mechanical weathering. Other minerals are broken down and dissolved, leaving the quartz sand behind.

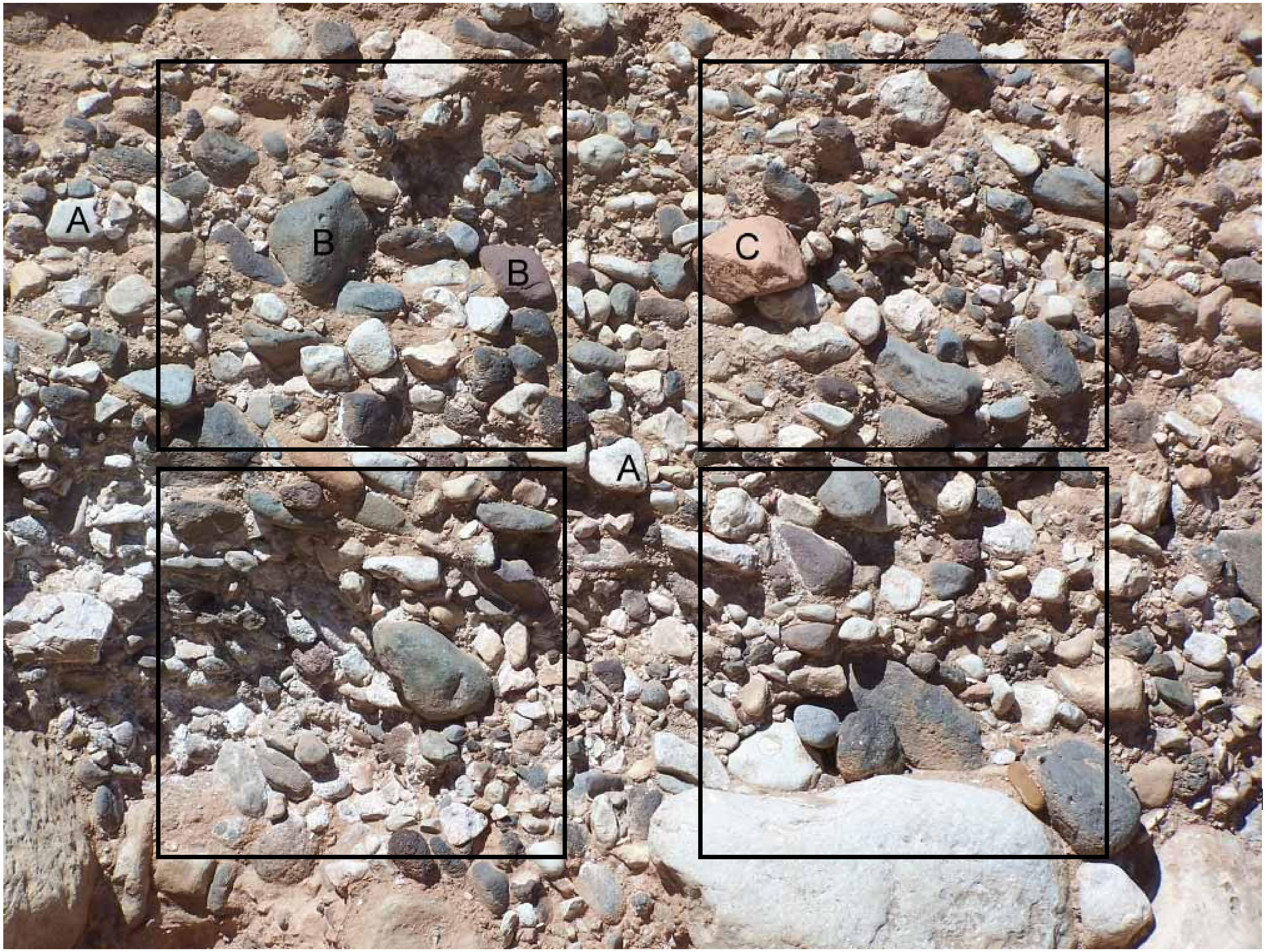
7. The farther water travels in a wash at Parashant, the deeper the wash become and the more water the wash can hold, which increases the erosive power of water.

Challenge Question

Expect various interpretations. It appears as though there are a variety of rocks and particle sizes in the conglomerate and that they are less rounded than what students saw in the rocks in Whitmore Wash. This would mean that the deposit is close to the mountain range from which the rocks came. However, the penny shows that even though a range of sizes is present, the rocks are rather small, especially compared to those exposed at Whitmore Wash, which lends support to the idea that the rocks traveled some distance. A counter argument to this claim about particle size is that the rocks in the conglomerate were transported by a smaller stream, which lacked the energy needed to carry large rocks. If the pebbles were deposited far away, there would be less variety, even greater rounding, and more uniform sizes of sediment particles.

WORKSHEET 7.1 – OLDER WASH DEPOSITS EXPOSED AT WHITMORE WASH

WORKSHEET 7.2 – OLDER WASH DEPOSITS EXPOSED AT WHITMORE WASH



WORKSHEET 7.3 – WASH ROCKS UPPER LEFT

WORKSHEET 7.4 – WASH ROCKS UPPER RIGHT

WORKSHEET 7.5 – WASH ROCKS LOWER LEFT

WORKSHEET 7.6 – WASH ROCKS LOWER RIGHT

Lesson 7: Erosion and Deposition - From Washes to Canyons

ENGAGE

Study Figure 7.1 and its caption. It shows two rocks A and B that a student stuck into the sand in the bottom of a wash (dry streambed) as part of a study on water erosion. Earlier, she had painted an arrow on each rock to show the top of each rock at the start of the study. After she leaves, a thunderstorm occurs that makes water flow down the wash (dotted line) fast enough to move the two clasts.

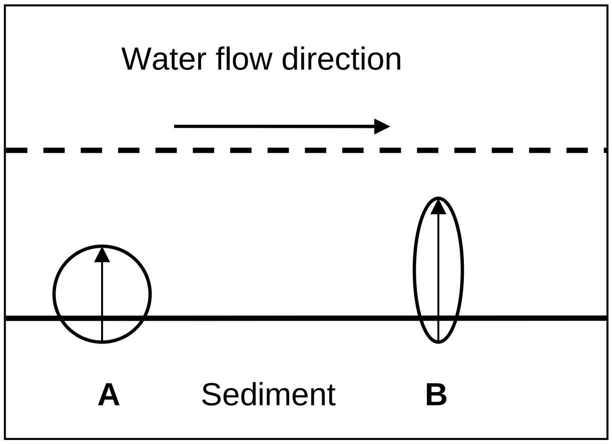


FIGURE 7.1 Diagram of two rocks on the bottom of a wash. The dashed line is level of water during a thunderstorm.

1. Describe what you think the rushing water will do to each rock.

Two weeks after the thunderstorm, the student returns and finds the two rocks in the wash, which is now completely dry. The rocks have moved downstream and the arrow on rock B shows that it was tilted.

2. Do you think she found the arrow at the top of rock B pointing downstream or upstream? Explain.

EXPLORE

Imagine a mountain range that formed so long ago that it weathered and eroded away into a flat plain. No evidence of the mountain exists. Or does it? If we dig into the plain that surrounded the ancient mountain, we might find rocks carried by the streams that eroded the mountain away. Can we use the orientation of the stream rocks to figure out the flow direction of water, and thus, where the mountain used to be upstream? In this activity, you will study rocks exposed in the side of a wash to make inferences about erosion by running water.

Determining Stream flow Direction

1. From your teacher, obtain a color copy of Worksheet 7.1 (Whitmore Wash Photo), an overhead transparency, a nonpermanent transparency marker, clear tape, and a ruler.

2. Worksheet 7.1 shows a side view of rocks exposed in Whitmore Wash at Parashant. The rock and sediment in the photo make up an older wash deposit exposed by erosion of the current wash. Figure 7.2 shows the location of the photo in Worksheet 7.1.

3. When the current wash floods, water flows from right to left across Figure 7.2. Your goal is to find out the direction in which the older wash flowed. To do this, you need to study the orientation of the rocks in that deposit.

4. Place an overhead transparency on top of Worksheet 7.1 and tape it on four sides to keep it from moving.

FIGURE 7.2 Rocks exposed in Whitmore Wash at Parashant. The box outlines the area shown in Worksheet 7.1.

5. Assume that running water will orient the elongate rocks in a preferred direction as it flows downstream. Running water might also orient the rocks that are more like spheres, but it will be more difficult to see any orientation.

With a nonpermanent marker, draw a line down the middle of the long axis of 20 elongate rocks. Put an arrow on the highest the end of each line (use rock B in Figure 7.1 as a reference). The rocks you pick can be any size, but must be longer than they are wide or tall.

6. Calculate the percentage of rocks pointing up and to the left versus pointing up and to the right (hint: If you have 20 rocks, each rock is 5% of your sample).

7. As you might have predicted from the Engage activity, as water flows over an elongate rock in a wash, the force of the water pushes the rock over. Once the high end of the rock is pointing downstream, it becomes more stable and remains in that position as the water level falls.

8. On the basis of this information and your interpretation, in which direction did water flow in the older deposit at Whitmore Wash – from right to left or left to right?

9. If buried deeply enough for a long time, deposits like the mixture of rocks and sediment exposed at Whitmore Wash form a sedimentary rock called conglomerate. How can a geologist use an ancient conglomerate to make inferences about the location of an ancient mountain range that no longer exists?

10. Share your results in a class discussion.

EXPLAIN

Erosion and Deposition

In the activities, you investigated two processes that change the surface of the Earth – erosion and deposition by running water. **Erosion** is the movement or transportation of sediment due to the action of gravity, wind, water, or ice. Whatever carries the sediment, it eventually settles in a new location at a lower elevation. The settling out of sediment is called **deposition**. Erosion wears down the land and deposition builds up the land in a new place. At Whitmore Wash, floodwaters eroded and carried sediment and exposed older deposits in the walls of the wash.

FIGURE 7.3 This large block of limestone has paused temporarily on its trip downhill under the force of gravity.

Erosion occurs in a number of ways. **Mass movement** is a common form of erosion. Mass movement is driven by gravity, the force that pulls objects towards Earth's center. The higher a rock or sediment is on a slope and the steeper the slope, the more likely it is to move downhill under the force of gravity (see Figure 7.3). Movement can take place quickly, as with landslides, rock falls, slumps, or mudflows, or slowly, as happens with creep. At Parashant, steep slopes are common, making rock falls and landslides the main types of mass movement that erode slopes. In addition, soil forms very slowly in the monument's desert climate, leaving much of the rock and sediment on slopes exposed to erosion.

Wind erosion is the weakest agent of erosion, yet where fine sediments lie at the surface and vegetation is sparse, as in desert regions like Parashant, wind plays a small role. In a process known as **deflation**, wind erosion removes loose finer particles (clay, silt, and sand) and may create dunes where sediment accumulates and leave behind a coarse-grained ground surface called desert pavement (Figure 7.4). In addition, windblown silt and sand collide with and abrade rocks along the ground, which can create spectacular rock sculptures.

FIGURE 7.4 Wind erosion removes finer particles of sediment, leaving a coarse-grained desert pavement behind.

It may surprise you, but running water plays the most important role in eroding the Parashant landscape. After all, Parashant has no permanent streams, only **ephemeral streams** – streams that flow during or immediately after a rain. Its dry, flat-bottomed streambeds are called **washes** (or arroyos and coulees in other regions). An arid region that receives little precipitation during much of the year, Parashant's summer monsoon rains fall as intense thunderstorms. Rains saturate the sediment on slopes, adding weight that makes it more likely to move down the slope under the force of gravity.

Erosion by running water begins with millions of raindrops striking the ground. With little vegetation to hold soil and sediment in place, the force of raindrops dislodges sediment and starts it moving downhill. The mixture of fine-grained sediment and water collects in small channels called rills and gullies higher on the slope. The channels grow larger down slope due to the greater erosive power of sediment-laden water (Figure 7.5). The larger the channel, the more water it can carry and the greater its ability to erode. This creates a self-perpetuating system, widening and deepening washes that lead into canyons farther downstream.

FIGURE 7.5 Canyon forming north of Parashant. Down slope is to the lower right. Note how the canyon becomes wider and deeper over its course, and how smaller channels feed into the larger main channel.

Another important kind of deposit at Parashant and in many mountainous regions is **alluvium**. Alluvium is recent sediment – freshly eroded rock particles in a range of sizes that accumulate on slopes (see Figure 7.7). Alluvium is transported by water and mass movement. Rainfall that soaks into alluvium makes it more likely to flow in a landslide, slump, or debris flow.

FIGURE 7.7 Alluvium covers the slopes along the Grand Wash Cliffs at Parashant to the point where little of the sedimentary rock layers are visible.

Weathering

During their journey from higher to lower elevations, rock and sediment change in size and chemical composition. The reduction in the size of rock is known as **weathering** (Figure 7.8). High on the slopes, rocks are more likely to be angular and have sharp, jagged edges, like the block of limestone shown in Figure 7.3. As rocks tumble on slopes, enter washes, and bounce along the bottom during floods, rocks become smoother and smaller. This physical breakdown of rock into smaller pieces is **mechanical weathering**. The smaller the particle, the more susceptible it becomes to **chemical weathering**, or processes that change the minerals that make up a rock into different substances. For example, the calcite minerals that make up limestone that is so common at Parashant begin to dissolve in water. Minerals dissolved in water help make the ocean salty. The feldspar minerals in basalt weather into fine clay minerals, and the iron silicate minerals in basalt combine with oxygen in the presence of water to form new minerals called oxides. The range of colors in the basalt rocks exposed in Whitmore Wash reflects the variety of iron and manganese oxides formed by chemical weathering.

FIGURE 7.8 Chemical weathering gives the Navajo Sandstone at Parashant its red color. Mechanical weathering disintegrates it into sand, seen at the base of the outcrop.

One of the minerals most resistant to chemical weathering is quartz, which makes up the majority of sandstones and siltstones. By the time sediment completes its journey to the ocean, mechanical and chemical weathering reduces the massive blocks of rock on mountain slopes into clay, silt, and sand-sized particles. As you observed in the photos, the rocks of Whitmore Wash vary greatly in size. They range from meter-sized boulders to fine clay (the brown “dirt” between the rocks). The rocks are slightly rounded, and several kinds of rocks are present. During the journey, the farther sediment travels in a stream, the smaller and rounder it gets, the more uniform in size it becomes, and the higher the overall percentage of quartz. How do you think the rocks at Whitmore Wash will change as they continue their trip to the Colorado River?

ELABORATE

Interpreting Clast Lithology

Think again about the deposit of rocks exposed in the walls of Whitmore Wash. How do the rocks in the wash relate to the types of rocks that made up the eroding mountain? In this activity, your goals are to interpret the kinds of rocks found in the wash deposit and use this information to make inferences about the rocks found in local mountains.

1. From your teacher, obtain a color copy of Worksheet 7.1 (Whitmore Wash Deposit), a color copy of Worksheet 7.3, 7.4, 7.5, or 7.6, a nonpermanent marker, an overhead transparency with four squares marked as grids, a metric ruler, and a sheet of graph paper.

2. Look closely at Worksheet 7.1. How many different colors of rocks can you see? Record your ideas. Share your ideas in a class discussion.

3. Your teacher will project a copy of Worksheet 7.2 labeled with the main types of rocks.

d. White and light-grey rocks labeled A are limestone.

e. Medium-grey, dark-grey, black, and reddish-purple rocks labeled B are basalt. Some of the basalt rocks have holes made by gas trapped in the lava when it cooled. Basalt is a dark grey rock, but it often weathers into various colors.

f. Orange-red rocks labeled C are sandstone. The red color indicates iron between the grains of sand (the sand grains are quartz, which is clear to white).

4. Worksheet 7.2 also shows four squares that correspond to the photos on Worksheets 7.3 to 7.6. The squares allow you to take representative samples of the wash deposit, roughly $1m^2$ each. The data from studies of all four squares can be averaged together.

5. Copy Table 1 into your notebook.

Table 1. Rock Types in Whitmore Wash Deposit

	Location: _______________		**Grand Total**	
Rock Type	Number of Clasts	Percent of Total	Number of Clasts	Percent of Total
Limestone				
Basalt				
Sandstone				
Uncertain				
Total				

6. With your partner, count the number of each kind of rock in the square meter sample area assigned to you. As it will be too difficult to identify the smaller rocks, limit your work to rocks that are at least one centimeter in length on the photo. You should end up labeling and counting between 50 and 75 rocks.

One way to do this is to tape an overhead transparency onto your worksheet and use a marker to label the rocks L for limestone, B for basalt, and S for sandstone. If you are uncertain about a rock type, label it with a U (for uncertain). Some rocks have a light brown coating of soil, so do your best to identify the type of rock it is.

When you have labeled all the rocks that are at least 1cm long on the photo, count the number of rocks for each rock type and put the data in Table 1.

7. Calculate the percentage of each rock type in your square meter of the deposit. To do this, sum the clasts and write the total at the bottom of Table 1. Divide the number of clasts of each rock type by the total number of clasts, and then multiply the result by 100. Add this data to your data table.

Share your results in a class discussion

8. As a class, add the data for the four different squares together to find the grand total number of each type of clast. Add this to your data table, and then calculate the percentage of each rock type represented in the wash deposit.

9. If the percentages of rock types in the wash are the same as those that made up the mountain before it was eroded, was the mountain made mostly of limestone, basalt, or sandstone? Explain.

10. You observed at least three types of rocks in the Whitmore Wash deposit. Given the percentage of limestone (which dissolves in water and is made of a softer mineral than those in basalt), answer the following questions:

a. Did the rocks in the deposit travel a great distance? Explain.

b. Calculate the ratio of limestone clasts to sandstone clasts (for the four quadrants combined) by dividing the value for limestone by the value for sandstone.

c. Predict how the ratio of percentage quartz to percentage limestone will change as the rocks fall into Whitmore Wash and travel downstream. Explain your prediction.

EVALUATE

1. Compare and contrast chemical weathering and mechanical weathering. How are they similar? How are they different?

2. What does the orientation of clasts in a stream reveal about the direction in which water flows?

3. Give an example of how erosion wears down the land and how deposition builds up the land.

4. Why is running water such a major agent of erosion in an arid region like Parashant?

5. Refer to Figure 7.9. Describe one way that flash floods cause chemical weathering of rock and one way that they cause mechanical weathering of rock.

6. Why is quartz such a major component of the sand found on many beaches? Refer to weathering in your response.

FIGURE 7.9 The person who photographed this flash flood in the Grand Wash at Parashant noted hearing sounds made by boulders tumbling in the water.

7. How does the erosive power of water change with distance at Parashant?

Challenge Question

Refer to Figure 7.10, a photo of an ancient conglomerate. Based on the variety of rocks, the degree of rounding, and the sizes of the particles present, were the sediments deposited close to or far away from the mountain range from which the pebbles were eroded? Explain.

FIGURE 7.10 Clasts in an ancient conglomerate. Penny for scale.

Lesson 8: Copper Calling at Grand Gulch Mine

Geological Adventures at Parashant

Exploring the Geology of

Grand Canyon-Parashant National Monument

National Park Service
The Geological Society of America®
Science • Stewardship • Service
U.S. Department of the Interior
Bureau of Land Management

LESSON 9: UNDERSTANDING TIME AT PARASHANT

GEOLOGICAL ADVENTURES AT PARASHANT

EXPLORING THE GEOLOGY OF
GRAND CANYON-PARASHANT NATIONAL MONUMENT