LESSON 4: METAMORPHIC ROCKS – BASEMENT OF PARASHANT

GEOLOGICAL ADVENTURES AT PARASHANT

EXPLORING THE GEOLOGY OF

GRAND CANYON-PARASHANT NATIONAL MONUMENT

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
- Optional: 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.

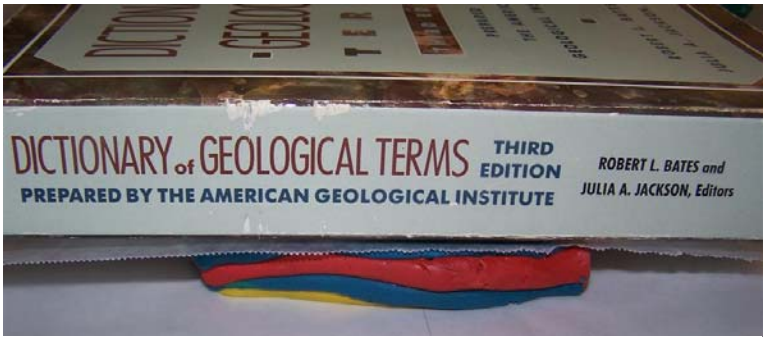

Figure 4 Model after being compressed by a book.

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.

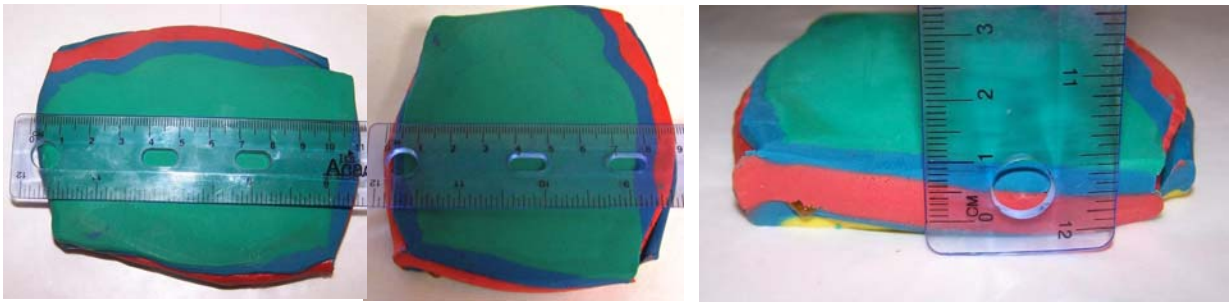

Figure 5 Clay model after being compressed, showing length, width, and height.

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.

Figure 6 Side view of model after folding.

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).

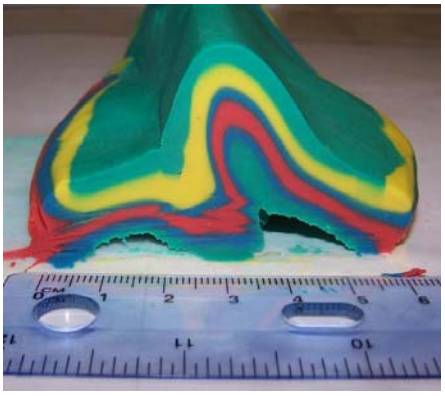

Figure 7 Side view of sliced model after folding.

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°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

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

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?

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 heat changes rocks: when magma or lava touches rock, and when rock gets buried deeply. You will now work with your model to explore how pressure 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.

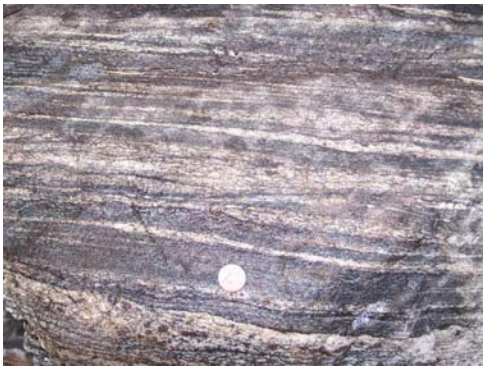

FIGURE 4.7 Gneiss at Parashant. Penny for scale.

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).