# Geology of the Grand Canyon

Remember that learning about the geology of someplace new begins with finding out its tectonic setting and looking at a geologic map of the region. The Grand Canyon is at the southern edge of the Colorado Plateau. This is a region of relatively undeformed sedimentary rocks, underlain by igneous and metamorphic rocks, all uplifted in “recent” geologic time (approximately the past 6 million years). You know a bit about how each of those rocks formed; now let’s take a closer look at them and their distribution within the park. This will require an understanding of the canyon’s topography, too, so we will compare the geologic and topographic maps.

***First, get yourself oriented.*** *Compare the topographic and geologic maps of this area to answer the following questions. Notice that the geologic map uses the topographic map for a base.*

In what state is the Grand Canyon located?

Do these maps show the exact same region? Are they made at the same scale?

*Approximately* how large an area (in square miles) is shown? (This is **NOT** the entire Grand Canyon!!!! It is not even close. Don’t think that it is. A larger portion (still not the whole canyon!!) is shown on the geologic map on the wall of our classroom.)

Do these two maps use the same contour interval? What units do they use for elevations?

If you were standing at the Visitors’ Center on the south side of the canyon, how far above the river would you be?

Does the Colorado River flow east to west, or west to east? [Hint: water flows downhill…]

If you were standing at the Visitors’ Center on the south side of the canyon, how far away would the north side of the canyon be?

Is the north rim of the canyon at the same elevation as the south rim?

***Now, about the rocks….***

If you hiked down from the Visitors’ Center, what rock units would you see on the way? List the formation names in the order that you would see them.

How old are the rocks at the top of the canyon, by the Visitors’ Center? [To what geologic time period do they belong, and when was that period, in years? See the geologic time scale in your text.]

*Find the description of all of the Paleozoic rock formations you would see on your hike, a few pages ahead in this handout. [Remember, all of the Paleozoic rocks are sedimentary, although the Precambrian rocks of the canyon are not.] Also, take a look at the representative rock and fossil samples at the back of the classroom.*

*For EACH of the* ***Paleozoic*** *rock units, answer the following questions:*

How old is this unit?

What specific types of sedimentary rocks are present?

Are there any sedimentary structures present? If so, which one(s)?

How does each of those sedimentary structures form? [Consult your textbook if you don’t remember.]

What does each of those sedimentary structures tell you about the sediments in these rock formations?

Are there any fossils present?

Considering rock type, sedimentary structures, and fossils: in what depositional environment was this rock unit MOST LIKELY deposited?

If you were hiking down from the Visitors’ Center, would the rock units you saw get progressively older or younger as you hiked?

Look at those sedimentary, **Paleozoic** rock units on the cross-section. What is their approximate spatial orientation? That is, are these rocks horizontal, tilted gently, tilted steeply, vertical, or what?

What is the relationship between elevation and age, for the Paleozoic rocks? [For example, “older Paleozoic rocks are found at (higher, middle, lower) elevations.”]

What principle does that relationship illustrate? (See p. 216-217 [272-274] of your text.)

***Now for the non-sedimentary rocks of the canyon….***

What rock units are at the bottom of the canyon?

How old are they? [In terms of geologic period, and in years? See the geologic time scale in your text, again.]

The Precambrian rocks at the bottom of the canyon are NOT sedimentary rocks. Look up their names in your textbook (try the glossary, then the index). Are they igneous, metamorphic, or both?

How far down into the canyon would you have to hike to see igneous or metamorphic rocks? That is, what vertical elevation change would you experience?

Now, suppose you were with John Wesley Powell’s expedition, rafting down the Colorado River, in the first group of non-native people exploring the Grand Canyon. How far ***up*** the canyon would you have to hike, to see sedimentary rocks?

Although the rocks of this region are extremely old, the canyon is a very recent feature, geologically speaking: it only began forming about six million years ago. (This is not unlike the deposition of rocks in central Kentucky several hundred million years before they were dissolved to form Mammoth Caves.) The rocks were there first, then the canyon developed.

Why is this canyon here? That is, how did it (the canyon, ***not*** the rocks of the canyon walls) form?

How much time is “missing” between when the youngest rocks in the canyon walls were deposited and the time when the canyon began to form? [Note: the landslide deposits don’t count as rocks in the canyon walls.]

*Make a clay model of layers of rock representing the Paleozoic rock units, and then cut through it to make a canyon. A few, thin, big layers work better than lots of smaller layers. Make sure that your canyon walls* ***slant*** *downward, just like the real canyon walls. In fact, the more your walls slant, the easier it will be to understand the next question. It is worth making your model carefully just for that.*

Now look at the **Paleozoic** rock units on the geologic map. We call the pattern they make a “dendritic” pattern. **Why** do they make such a crazy map pattern? [By the way: any time you see a *dendritic* map pattern like this, you can interpret it as having formed in much the same way *this* dendritic pattern formed.]

***Fill in the timelines provided for the Grand Canyon. On your line, show during what time periods each rock unit was forming, as well as when the canyon itself formed. Include the environment of deposition for each of the Paleozoic rocks. We will add details to this geologic history in future classes, but you should have most of them filled in today. These timelines provide you with a visual framework of the canyon’s history – a list of what happened when.***

After you have filled in your timelines:

One reason the Grand Canyon is so famous is that it exposes so much of geologic time to our view…. How much time ***is*** represented by the rocks exposed in the canyon walls?

There are several “gaps” on your timelines, during which none of these rocks were formed, and the canyon was not forming. When are those gaps? List them.

Approximately what fraction of the Earth’s history is displayed in the Grand Canyon?

**Descriptions of the Paleozoic rocks of the Grand Canyon**

summarized from “Geologic History of the Bright Angel Quadrangle,” by John. H. Maxson, 1968.

**Kaibab Formation:** Massive marine limestones form the uppermost cliff along the rim of the canyon. Some layers contain white chert. Abundant marine fossils.

**Toroweap Formation:** Red and yellowish sandstones sandwiched between gray limestones.

**Coconino Sandstone:** Massive, white to buff, crossbedded sandstone. Rather pure, uniformly fine-grained quartz sandstone. Grains are rounded and commonly frosted. Trails of small reptiles or amphibians found on some crossbeds.

**Hermit Shale:** Deep red shales and siltstones with a few lenses of sandstone. Some shales have mud cracks and ripple marks. Contains thirty-five species of fossil plants, mostly ferns. Some quadrupedal footprints.

**Supai Formation:** Alternating red crossbedded sandstones and shales. Lowest portion includes calcareous sandstones and limestones. Amphibian or reptile footprints.

**Redwall Limestone:** Thick to massively bedded bluish-gray limestone, with localized white chert nodules. Weathers to a deep red, from iron oxide washed down from the overlying Supai Formation. Various marine invertebrate fossils.

**Muav Formation:** Primarily gray and buff limestones. Marine fossils, including trilobites.

**Bright Angel Formation:** Thin-bedded sandstones and greenish to buff micaceous shales. Several dolomite beds in the upper layers. Trilobites characteristic.

**Tapeats Sandstone:** This basal conglomerates, arkoses, and quartzite breccias beneath thick brown crossbedded sandstone.

**Glossary:**

Crossbedding, mud cracks, and ripple marks are described on p. 180-182 [235-238].

Basal: at the base, or bottom

Bedding: layering in a sedimentary rock

Buff: approximately the color of my skin

Calcareous: composed of calcium carbonate

Frosted: having a white surface coating; commonly interpreted to form by windblown impacts

Massive: homogeneous in texture, and lacking obvious bedding on the scale of inches or feet

Micaceous: containing mica, a flaky, shiny mineral

Nodules: blobs. You may have seen chert nodules at Ohio Caverns.

Quadrupedal: having four feet

Quartzite: a metamorphic rock made of quartz. The breccia you have seen is a quartzite breccia.

Thick-bedded: rock layers that are about 2-4 feet thick

Precambrian rocks of the Grand Canyon

Today we continue our study of the rocks of the Grand Canyon, moving down to the oldest, Precambrian, units. As always, rocks have stories to tell about their origins; our goal is to decipher those stories. We will tackle that by filling in the charts below.

**1.8-1.6 billion years ago:**

|  |  |  |  |
| --- | --- | --- | --- |
| **Rock unit:** | **Rock type:** | **Protolith:** | **In what kind of environment did that protolith form?** |
| Vishnu Schist | Quartz-mica schist, with index minerals such as garnet, staurolite and sillimanite | Sedimentary rocks, probably a mix of shales and sandstones, but mostly shales |  |
| Brahma Schist | Hornblende schist | Volcanic rocks, mostly basalts |  |

|  |  |  |
| --- | --- | --- |
| **Time period:** | **What happened?** | **How did that happen?** |
| About 1.6 billion years ago | The Mazatzal Orogeny occurred.  | This was a series of collisions between the southern edge of the “North American” continent and volcanic island arcs.  |
| About 1.6 billion years ago | The Zoroaster Granite intruded the Vishnu and Brahma Schists, at depths of 10-20 kilometers, further metamorphosing them. | The magma was generated by the heat from the collisions. It probably came from molten lower continental crust. |
| 1.6-1.2 billion years ago | A nonconformity was formed. |  |

**1.2 billion – 800 million years ago:**

|  |  |  |
| --- | --- | --- |
| **Rock unit:** | **Description:** | **For the sedimentary units: In what kind of environment did those rocks form?** |
| Bass Limestone | Gray dolomite. Upper levels include interbedded shales and sandstones with ripplemarks. Fossilized algal mats (stromatolites). |  |
| Hakatai Shale | Reddish shales with some sandstones. Ripplemarks, mud cracks, and raindrop imprints are common. |  |
| Shinumo Sandstone | Thick bedded sandstone, many with crossbeds and ripplemarks. |  |
| Dox Formation | Mostly reddish-brown sandstones with interbedded shales. Ripplemarks and crossbedding. |  |
| Rama Formation | Diabases and basalts | Igneous intrusions as dikes and sills |

|  |  |  |
| --- | --- | --- |
| **Time period:** | What happened? | **How did that happen?** |
| 800-540 million years ago | An angular unconformity was formed. |  |

Metamorphic rocks

Metamorphism:

Metamorphic rocks are rocks that have been changed as a result of heat, pressure, and/or circulating fluids. These changes can be textural, involving the way in which the mineral grains in the rock are assembled. The changes can also be mineralogical, involving the formation and growth of new minerals at the expense of old ones. Typically, both types of change occur together. The types of changes and the resulting rock depend both on the protolith, or parent rock, and on the temperature, pressure, and fluid conditions during metamorphism.

Any rock can be metamorphosed, by being subjected to higher temperatures &/or pressures, or through interaction with fluids. One of the most basic questions we like to answer about metamorphic rocks is “what was this rock prior to metamorphism?” We call the rock before it was metamorphosed the “protolith.” Here are a few examples of metamorphic rocks and their protoliths. Notice that some metamorphic rocks have multiple possible protoliths, and some protoliths may form a variety of metamorphic rocks, depending on the conditions under which they are metamorphosed. As you identify each sample in this lab, be thinking about what the protolith was.

|  |  |
| --- | --- |
| **Protolith** | Metamorphic rock |
| limestone | marble |
| dolostone | dolomitic marble |
| sandstone | quartzite |
| lignite or bituminous coal | anthracite coal |
| shale | slate 🡪 phyllite 🡪 schist 🡪 gneiss |
| slate | phyllite 🡪 schist 🡪 gneiss |
| phyllite | schist 🡪 gneiss |
| schist | gneiss |
| granite or diorite | gneiss |
| basalt | hornfels |
| basalt | greenstone 🡪 greenschist 🡪 amphibolite 🡪 granulite |
| greenstone | greenschist 🡪 amphibolite 🡪 granulite |
| greenschist | amphibolite 🡪 granulite |
| amphibolite | granulite |
| basalt | blueschist |

The other thing geologists like to figure out from metamorphic rocks is, under what conditions was this rock metamorphosed? That is, to what temperatures and pressures was it subjected? Fortunately, that question can often be answered, at least approximately, on the basis of the minerals in the rock. For example, garnet forms under higher temperatures and pressures than muscovite and biotite do. [See pp. 205-207 in your text for more information about this.] In this lab, you will see some of those metamorphic minerals. ***With schists, gneisses, and some other metamorphic rocks, it is conventional to include the most common minerals in the rock name. That is, if you see a schist with garnets in it, you would call it “garnet schist.”***