

PHYSICAL GEOLOGY



Anne Huth
Achieving the Dream

Book: Physical Geology (Huth)

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CHAPTER OVERVIEW

1: Earth's Origin, and an Introduction to Topographic Maps

[1.1: Introduction](#)

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1.1: Introduction

Module 1

Earth's Origin, and an Introduction to Topographic Maps



Figure 1. The ESO 3.6-metre telescope at La Silla, during observations. Across the plan of the picture, is the Milky Way, our own galaxy, a disc-shaped structure seen perfectly edge-on. Above the telescope's dome, here lighted by the Moon, and partially hidden behind dark dust clouds, is the yellowish and prominent central bulge of the Milky Way. The whole plan of the galaxy is populated by hundred thousand million of stars, as well as a conspicuous amount of interstellar gas and dusts. The dust absorbs the visible light and reemits it at longer wavelength, appearing totally opaque at our eyes. Located 600 km north of Santiago, at 2400 m altitude in the outskirts of the Chilean Atacama Desert, La Silla was first ESO site in Chile and the largest observatory of its time.

Introduction

In the first module of the course, we will briefly introduce you to the field of geology (Chapter 1). It will also give you a sense of the diversity of topics we will be discussing in detail during the semester. Then, we will move on to the origin of Earth and the Solar System (Chapter 22). This information is important for understanding the key processes and forces at work on both our planet and throughout the universe.

In addition to learning about the formation of our planet, you will also be introduced to topographic maps and their use in visualizing Earth's surface. A topographic map is an extremely useful type of map that adds a third dimension (vertical) to an otherwise two-dimensional map defined by the north, south, east, and west compass directions. This third dimension on a topographic map is represented by contour lines, which are imaginary lines drawn on a map that represent an elevation above sea level. A map with such elevation lines will provide the map reader with detailed information regarding the shape of the Earth's surface.

Knowledge of how to interpret a topographic map will allow a person to locate and identify features on the Earth's surface such as hills, valleys, depressions, steep cliffs and gentle slopes. In addition, the map reader will be able to identify areas that may be prone to geologic hazards such as landslides and flooding. Any person interested in purchasing property, landscaping, planning a hike or camping trip, or who needs to survey an area for construction of a road, dam, or building will want to first consult a topographic map.

Select images throughout this course to see them larger.

Select an image to view larger



Figure 2. Sitting atop Cerro Paranal high above the Atacama Desert in Chile, two of the Very Large Telescope's Unit Telescopes quietly bask in the starlight, observing the Milky Way as it arches over ESO's Paranal Observatory. Several interesting objects can be seen in this picture. Some of the most prominent are the two Magellanic Clouds — one Small (SMC), one Large (LMC) — which appear brightly in between the two telescopes. By contrast, the dark Coalsack Nebula can be seen as an obscuring smudge across the Milky Way, resembling a giant cosmic thumbprint above the telescope on the left. The Magellanic Clouds are both located within the Local Group of galaxies that includes our galaxy, the Milky Way.



Figure 3. VST image of the star-forming region Messier 17



Figure 4. Topographical map of Tucson showing Saguaro National Park (West)

Module Objectives

At the completion of this module you will be able to:

1. Explain what the field of geology is, why it is important, and the type of work geologists do.
2. Describe what happened during the Big Bang, when it happened, and the evidence for it.
3. Explain how clouds of gas and dust can form stars, planets, and solar systems.
4. Describe the early stages of Earth's formation, how the moon formed, and the age of each.

Activities Overview

See the Schedule of Work for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

Physical Geology by Steven Earle

- Chapter 1 (Introduction to Geology)
- Chapter 22 (The Origin of the Earth and the Solar System)

Discussion

30 points, class participation

For this week's discussion topic, "Introductions" you should earn at least 30 points toward your required 150 points of class participation.

Pay close attention to the Course Schedule for when each of your posts are due. Some are due earlier than others. Failure to post on time will result in lost points.

Discussion 1 Instructions

Module 1 Assignment: Topographic Maps

10 points

After you complete the reading, you can start working on [Module 1 Assignment – Topographic Maps](#).

Module 1 Quiz

10 points

Module 1 Quiz has 10 multiple-choice questions and is based on the content of the Module 1 readings and Assignment 1.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

Your Questions and Concerns...

Please contact me if you have any questions or concerns.

General course questions: If your question is of a general nature such that other students would benefit from the answer, then go to the discussions area and post it as a question thread in the “General course questions” discussion area.

Personal questions: If your question is personal, (e.g. regarding my comments to you specifically), then send me an email from within this course.

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1.2: Assignment- Topographic Maps

Module 1 Assignment

Topographic Maps

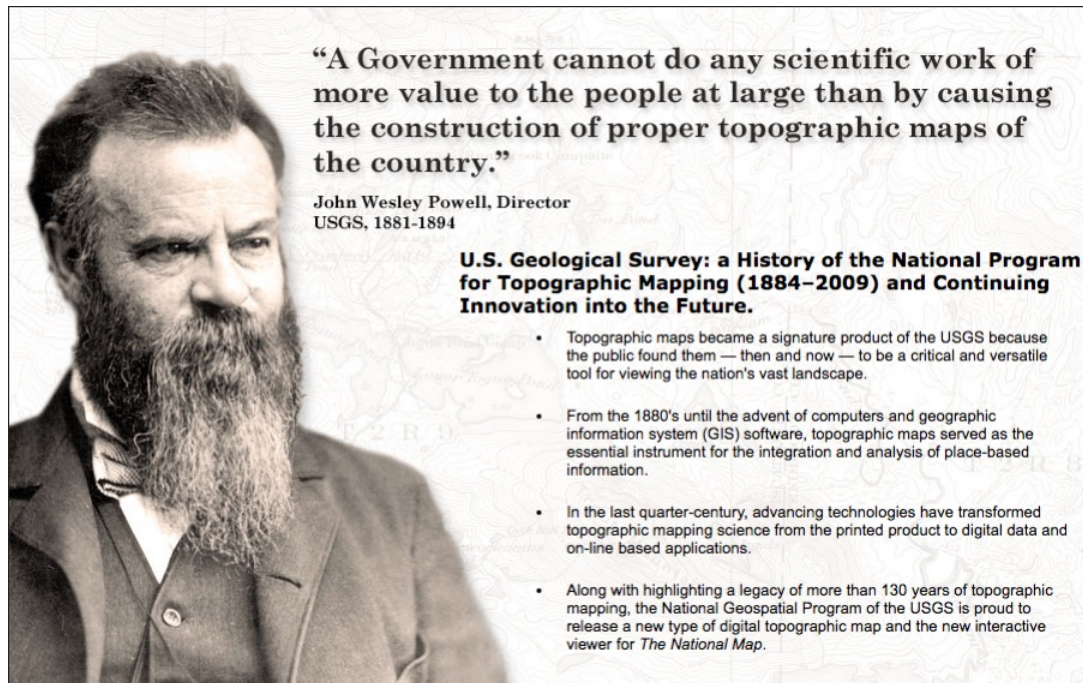


Figure 1.

Instructions

NOTE: For all of the following figures, assume North is up.

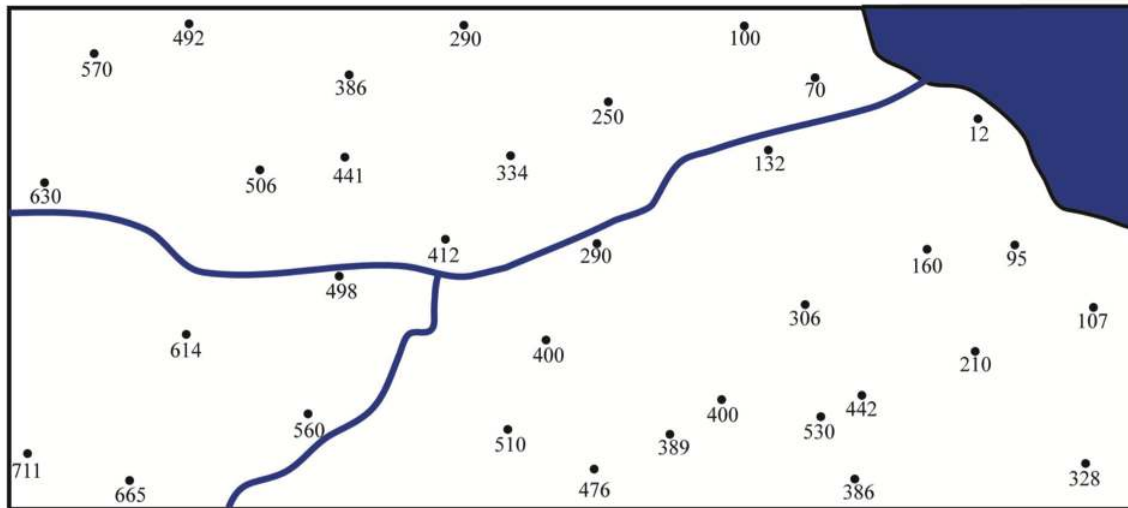
1. (2 pts) The following topographic map is from a coastal area and features an interesting geological hazard in addition to the ocean. Using a contour interval of 40 meters, label the elevation of every contour line on Map 1 below. (Note: elevation is meters above sea level, which makes sea level = ___m)



Map 1.

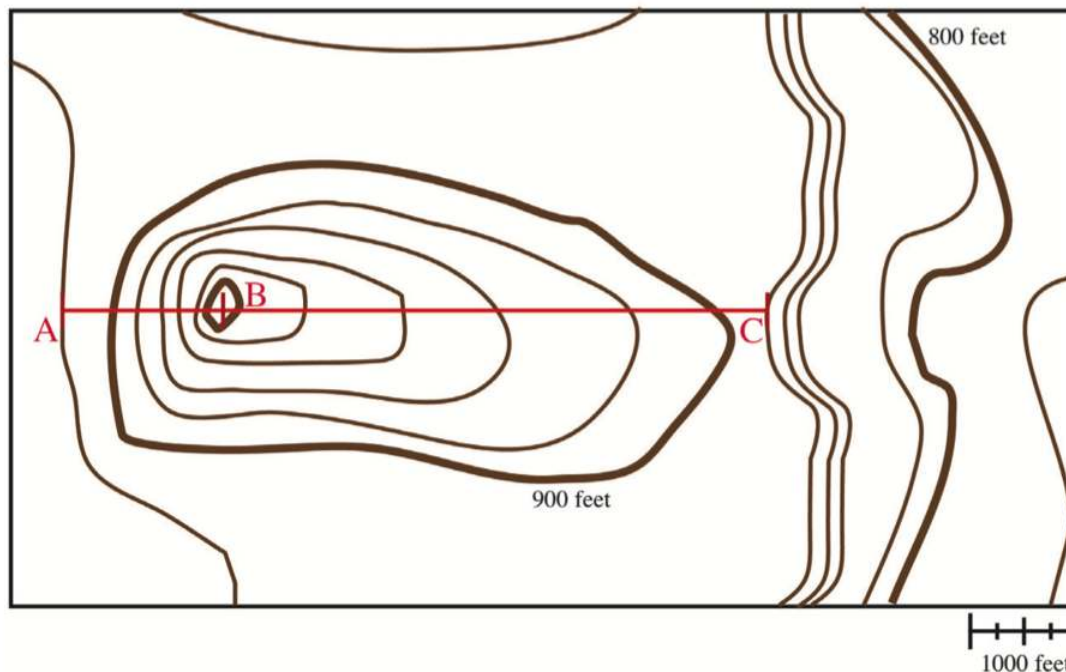
2. (4 pts) Imagine you are a geologist for the United States Geological Survey. You are tasked with creating your own coastal topographic map, so you hike around the area with a GPS receiver (Global Positioning System) and every so often you record your position along with the elevation in meters at that point, which results in Map 2 below. Complete this map by adding in the contour lines using a contour interval of 100 meters. Draw the contour lines so that they are continuous (do not die off), and either continue off the map or form an enclosed circle (look at the topographic map in Question 1 for an example). More often

than not, your contour lines will fall between the GPS points on your map, so do your best to determine the contour line positions.



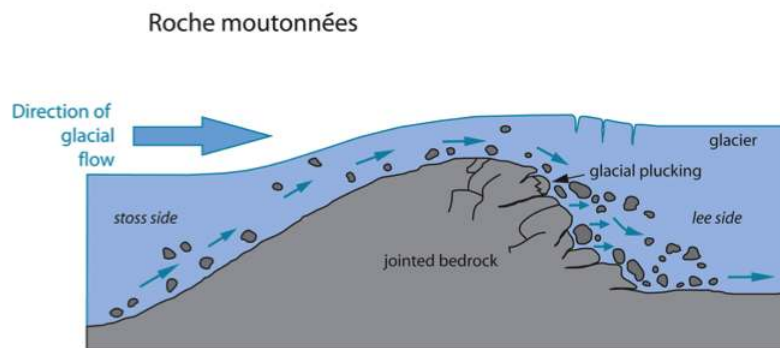
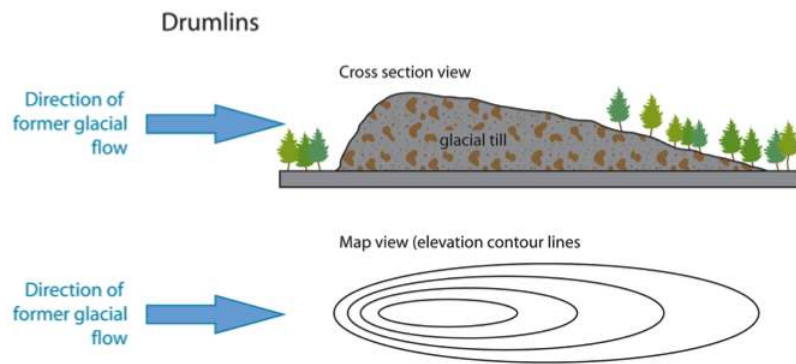
Map 2.

3. (1 pt) What is the contour interval on Map 3 above?



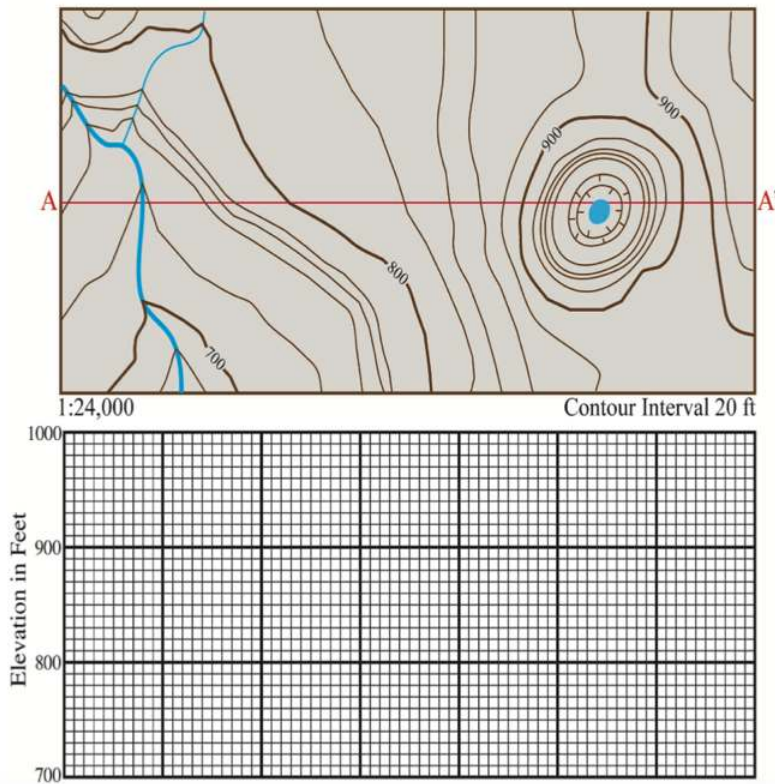
Map 3.

4. (1 pt) What is the regional relief on Map 3 above?
5. (1 pt) Using the contour lines on Map 3, which area along the red line is steeper— A to B or B to C? Explain how you came to this conclusion.
6. (2 pts) What is the gradient from A to B and B to C on Map 3? Show your work.
7. (2 pts) Drumlins can be used to determine the original direction of flow in a glacier, with the glacier originally moving toward the shallower side of the structure and then retreating in the opposite direction (see illustration below). Using your previous answers from Questions 5 and 6 above and the illustration below, what direction was the glacier traveling originally traveling, before it retreated? Explain your answer. (Remember that North is up on the map.)



Map 4.

8. (4 pts) Construct a topographic profile from A to A' on the graph paper below.



Map 5

9. (3 pts) Based on the scale you choose for the topography (vertical axis) in question 8, calculate the amount of vertical exaggeration on the topographic profile you constructed above. Show your work.

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1.3: Discussion 1- Introduce Yourself

Module 1 Discussion

Introductions



Figure 1. Horseshoe Bend, a meander of the Colorado River, near Page, Arizona

Introduction

Welcome to the class! It is important to feel engaged in this class – you shouldn’t feel isolated and alone at your computer. That is the purpose of these class discussions.

If you read the directions carefully, follow the listed suggestions, use proper grammar and spelling, make lots of meaningful replies, and post on time, you will have no trouble earning all of the required participation points in this class, and will likely earn lots of extra credit points, too!

For this discussion, you will write an initial post and reply to at least TWO of your classmates’ posts. Follow the guidelines for each posting below:

Basic Guidelines for Initial Post

(20 points, required)

Under the Discussion 1 topic, create a new thread. You need to include all of the following in your post:

1. Put your full name somewhere in the subject line. For example, you could write “Hello from so and so...”.
2. In the message box, start by telling us your preferred name, if you have one other than what the school assigned you, and let us know where you are currently located. It is fun to see who is located outside of Pima County, and it could help me to plan ahead for field trips.

3. Share with your instructor and fellow students why you are taking this class. Is it to fulfill your transfer or AGEC requirements, or the requirements of a particular program at this or another college? Explain. This information is particularly helpful to me in terms of future planning for this online course. If you are willing to share, I would also like to know why you chose this particular course and format (online), rather than enroll in a different one.
4. Tell us whatever else you want to share about yourself. You might consider including information about your major, current job, current classes, educational goals, family, recent accomplishments, etc. It is up to you what you want to include.
5. Talk about your experience with taking online classes. Is this your first online class, or have you taken many of them? If you are new to online, share your fears or reservations about this class format. If you have taken other online courses, please share your tips for success. What do you think are your personal challenges to success in this class?
6. Upload a picture of yourself. Be sure that it is large enough so that we can clearly see you, and tell us which person in the picture is you if there are multiple people shown. Being able to see what each other looks like will make us feel more like a community, and this class feel as much like a regular, face-to-face classroom as possible. Seeing each other helps a lot!

Basic Guidelines for Replies to Students

(10 points, required)

1. You are free to make replies to students with regard to either
 - a. your own introductory post, or
 - b. another student's introduction (including mine).
2. Each reply must contain 6 or 7 meaningful sentences responding to a student's post. Any encouraging phrases and support are welcome!
3. You must reply to at least 2 other students. (3, or more, for extra credit.)
4. If your replies are too short, you will need to make more than 2 replies to reach your full sentence count for the discussion (2 replies x 6 or 7 sentences each = 12-14 sentences required in each discussion).
5. Do not wait until the last day of the discussion to make your replies. You only receive credit for one reply (up to 10 points max) on the last day.
6. Reply early and often, and earning your full discussion points will be easy!

Extra Credit

(5 points, optional)

Make a third reply (or more!) to a student following the guidelines above.

Learning Outcomes

As a result of your participation in the discussion, you will be introduced to the other students in the course and your instructor. It will also give you a chance to evaluate yourself as an online learner, as well as an opportunity to share successful study tips with your fellow classmates.

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CHAPTER OVERVIEW

2: Earth's Interior

Learning Objectives

Module Objectives

- At the completion of this module you will be able to:
- Explain the variations in the composition and characteristics of Earth's different layers
- Compare the characteristics, behavior, and velocities of the two types of seismic body waves, and how they can be used to interpret Earth's interior.
- Describe temperature variations within the interior and how this relates to mantle convection.
- Explain the origins of Earth's magnetic field.
- Describe the isostatic relationship between the crust and the mantle, and the implications of that relationship for geological processes on Earth.

[2.1: Introduction](#)

[2.2: Assignment- Exploring Earth's layers and seismic-wave travel times](#)

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2.1: Introduction



Figure 1. Lava Flow, Hawaii Volcano Observatory

Introduction

Earth is a dynamic planet, but not everything happens on the surface! A lot of the exciting activity is also happening in Earth's interior. Before we move into a discussion of Plate Tectonics (Module 3), we first need to learn something about the inside of the Earth. Unfortunately, geologists don't have any way to see what's going on in the interior, so they have to use other tools that can help visualize its inner workings.

Studying the Earth's interior poses a significant challenge due to the lack of direct access. Many processes observed at the Earth's surface are driven by the heat generated within the Earth, however, making an understanding of the interior essential. Volcanism, earthquakes, and many of the Earth's surface features are a result of processes happening within the Earth.

Much of what we know regarding the Earth's interior is through indirect means, such as using seismic data to determine Earth's internal structure. Scientists discovered in the early 1900s that seismic waves generated by earthquakes could be used to help distinguish the properties of the Earth's internal layers. The velocity of these waves (called primary and secondary waves, or P and S waves) changes based on the density of the materials they travel through. As a result, seismic waves do not travel through the Earth in straight lines, but rather get reflected and refracted, which indicates that the Earth is not homogeneous.

The Earth's interior consists of an inner and outer core, the mantle, and the crust. Located in the center of the Earth is the inner core, which is very dense and under incredible pressure, and is thought to be composed of an iron and nickel alloy. It is solid, and surrounded by a region of liquid iron and nickel called the outer core. The outer core is thought to be responsible for the generation of the Earth's magnetic field. A very large portion of the Earth's volume is in the mantle, which surrounds the core. This layer is less dense than the core, and consists of a solid that can behave in a plastic (deformable) manner. The thin outer layer of the Earth is the crust. The two types, continental and oceanic crust, vary from each other in thickness, composition, and density.

Activities Overview

See the Schedule of Work for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

[Physical Geology by Steven Earle](#)

- Chapter 9 (Earth's Interior)

[Module 2 Assignment: Exploring Earth's Layers and Seismic-wave Travel Times](#)

10 points

After you complete the reading, you can start working on [Module 2 Assignment – Exploring the Earth's Layers and Seismic-wave Travel Times](#).

Module 2 Quiz

10 points

Module 2 Quiz has 10 multiple-choice questions and is based on the content of the Module 2 readings and Assignment 2.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

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2.2: Assignment- Exploring Earth's layers and seismic-wave travel times

Module 2 Assignment

Exploring Earth's layers and seismic-wave travel times



Figure 1. Once in a while a piece of the Earth's interior is visible on Earth's surface! This is an ophiolite outcrop located near Firenzuola, Italy. An ophiolite is piece of the interior where mantle meets ocean crust that has been pushed up on the Earth's surface.

Overview

Earth's interior layers can be distinguished in two ways: by their chemical composition or by their physical characteristics and the way they “move” (in a rigid or a “plastic” manner, for instance). Sometimes the different terms we use to describe the interior are confused with one another, or they are treated as interchangeable terms, when really they are quite different. For example, the terms crust, mantle, and core are differentiated by their chemical composition, while the terms lithosphere and asthenosphere are differentiated by their physical (mechanical) properties. However, the terms crust and lithosphere are often (and incorrectly) used interchangeably.

Instructions

Part 1

1. Consider the following terms that are used to describe various layers of Earth's interior:

- Crust
- Continental crust
- Oceanic crust
- Lithosphere
- Asthenosphere
- Mantle

- Mesosphere
- Core
- Outer core (liquid)
- Inner core (solid)

How might you hand-draw a figure for a textbook that includes all of these components of Earth's interior? In other words, how might you reconcile these components of Earth's interior and the two different ways they are characterized (chemical vs. physical/mechanical properties) in a single illustration?

2. Write a paragraph (at least 5 – 6 sentences) that summarizes what tools scientists use to determine the depths at which these layers are situated in Earth's interior.

Part 2

1. The March 11th, 2011 earthquake in Japan was a magnitude 9.1— one of the most powerful earthquakes to ever be recorded on Earth. Let's assume the P-waves traveled outward from the focus of the earthquake at a rate of 5 km/s, and the S-waves traveled outward at a rate of 4 km/s.
 - a. Which waves, P or S, would arrive at seismograph stations first?
 - b. S-waves are more damaging than P-waves, and surface waves are the most damaging seismic waves of all. How much warning did residents of the following cities have before the more serious shaking began, starting with arrival of the S-waves? (*Hint: Calculate the difference in arrival time between the P- and S-waves in each city.*) **Show all your work.**
 1. Sendai (130 km from epicenter)
 2. Tokyo (373 km from epicenter)
 3. Osaka (770 km from epicenter)

Grading

10 points: Accurately responded to each question, including a clearly drawn figure of Earth's interior, a well-written brief summary, and showing the math for each of the 3 calculations. Any sources used were cited.

8 points: Responded to each question, but may have addressed one or two incorrectly.

5 points: More than two questions missed or answered incorrectly; sources were not cited.

2 points: Only very partial information provided.

0 points: Did not complete the assignment.

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CHAPTER OVERVIEW

3: Plate Tectonics

[3.1: Introduction](#)

[3.2: Assignment- Using Google Earth to Visualize Plate Boundaries](#)

[3.3: Discussion 2- Plate Tectonics](#)

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3.1: Introduction

Module 3

Plate Tectonics



Figure 1. Mt. Denali, Alaska. Because of active plate tectonics, earthquakes are frequent in the Denali area. It is estimated that there are some 600 seismic events per year. This seismic activity at the root of Denali suggests that uplift of the mountain continues to this day. Numerous faults, including the Denali fault (a major fault system), demonstrate a long history of active plate tectonics and associated earthquake activity. (National Park Service)

Introduction

In this module, you will be introduced to a fundamental theory in geology: Plate Tectonics. You will learn about the important hypotheses that eventually led to the development and acceptance of the plate tectonics theory over the last century, including Alfred Wegener's hypothesis of continental drift and Harry Hess' hypothesis of sea floor spreading. You will also learn about the key drivers of plate movement and the tectonic processes at work at plate margins. We will revisit this topic many times during the semester.

A theory is a well-supported explanation for a natural phenomenon that still cannot be completely proven. A Grand Unifying Theory is a set of ideas that is central and essential to a field of study such as the theory of gravity in physics or the theory of evolution in biology. The Grand Unifying Theory of geology is the theory of Plate Tectonics, which defines the outer portion of the earth as a brittle outer layer that is broken into moving pieces called tectonic plates. This theory is supported by many lines of evidence, including the shape of the continents, the distribution of fossils and rocks, the distribution of environmental indicators, as well as the location of mountains, volcanoes, trenches, and earthquakes. The movement of plates can be observed on human timescales and easily measured using GPS satellites.

Plate tectonics is integral to the study of geology because it aids in reconstructing earth's history. This theory helps to explain how the first continents were built, how oceans formed, and it even helps inform hypotheses for the origin of life. The theory also helps explain the geographic distribution of geologic features such as mountains, volcanoes, rift valleys, and trenches. Finally, it helps us

assess the potential risks of geologic catastrophes such as earthquakes and volcanoes across the earth. The power of this theory lies in its ability to create testable hypotheses regarding Earth's history, as well as predictions regarding its future.

Select an image to view larger



Figure 2. Satellite view of the Himalayas, on the border between southeastern China and northern India. This majestic mountain range formed at a continent-continent convergent boundary between two tectonic plates.



Figure 3. A GPS station in Denali, near Tokosha. The Plate Boundary Observatory (PBO) has installed more than 1,100 Global Positioning System stations in North America, including two in Denali—near Tokosha (above) and on Wickersham Dome.



Figure 4. Capital Reef, Utah. Long after the sedimentary rocks were deposited, the entire region was uplifted thousands of vertical feet, due to large-scale plate tectonic forces. Most of the Colorado Plateau was uplifted relatively evenly, keeping the layers roughly horizontal, creating the 'layer cake' appearance common throughout the region (such as at the Grand Canyon). Capitol Reef is a giant exception to this pattern—due to the Waterpocket Fold. The Waterpocket Fold defines Capitol Reef National Park. A nearly 100-mile long warp in the Earth's crust, the Waterpocket Fold is a classic monocline, a 'step-up' in the rock layers. It formed between 50 and 70 million years ago when a major mountain building event in western North America, the Laramide Orogeny, reactivated an ancient buried fault in this region. Movement along the fault caused the west side to shift upwards relative to the east side. The overlying sedimentary layers were draped above the fault and formed a monocline. The rock layers on the west side of the fold have been lifted more than 7,000 feet (2,134 m) higher than the layers on the east.



Figure 5. Dante's View in Death Valley National Park, California. Time passed and the sea began to slowly recede to the west as land was pushed up. This uplift was due to movement occurring far beneath the Earth's surface. Scientists have discovered that the Earth's crust is composed of inter-connected sections, or plates. Death Valley lies near the boundary between two of these plates. As the plates slowly move in relation to each other, compressional forces gradually fold, warp and fracture the brittle crust. This widespread rock deformation and faulting occurred through most of the Mesozoic Era (251 – 65.5 million years ago.) While the Rocky Mountains and the Sierra Nevada formed, active mountain building alternated with times when erosion prevailed, working to breaking down the mountains that had formed. (National Park Service)

Module Objectives

At the completion of this module you will be able to:

1. Describe the development of the theory of plate tectonics, including the concepts of seafloor spreading and continental drift.
2. Name the three types of plate boundaries, describe the type of motion, and describe the features associated with each.
3. Explain the distribution and origin of most volcanoes, earthquakes, young mountain belts and major seafloor features.

Activities Overview

See the Schedule of Work for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

Physical Geology by Steven Earle

- Chapter 10 (Plate Tectonics)

Discussion 2 – Plate Tectonics

30 points

This week we will be having a conversation about plate tectonics and the ways in which the hazards associated with movement of the plates might personally affect you or your family. Now that you have completed Module 3 (Plate Tectonics), you should have some basic knowledge about the subject and can make educated post(s).

Discussion 2 Instructions

Pay close attention to the Course Schedule for when each of your posts are due. Some are due earlier than others. Failure to post on time will result in lost points.

Module 3 Assignment: Using Google Earth to Visualize Plate Boundaries

10 points

After you complete the reading, you can start working on [Module 3 Assignment: Using Google Earth to Visualize Plate Boundaries](#)

Module 3 Quiz

10 points

Module 3 Quiz has 10 multiple-choice questions and is based on the content of the Module 3 readings and Assignment 3.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

Your Questions and Concerns...

Please contact me if you have any questions or concerns.

General course questions: If your question is of a general nature such that other students would benefit from the answer, then go to the discussions area and post it as a question thread in the “General course questions” discussion area.

Personal questions: If your question is personal, (e.g. regarding my comments to you specifically), then send me an email from within this course.

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3.2: Assignment- Using Google Earth to Visualize Plate Boundaries

Module 3 Assignment

Using Google Earth to Visualize Plate Boundaries



Figure 1. Snorkeling in the Silfra canyon, a rift between the tectonic plates (North American and Eurasian), Þingvellir National Park, Southern Region, Iceland.

Overview

This week you will complete an exercise on plate boundaries using Google Earth tools and any other Internet or textbook resources at your disposal. Please make sure you have completed the module reading before you complete the assignment. Please write your answers in a separate document and submit it to Assignment 1 in the Assignments Tool.

Installation

You should have the Google Earth application downloaded on your computer.

If you haven't done that yet, please visit <https://www.google.com/earth/> to download it and install it on your machine.

It is not recommended to use an iPad or a Chrome book to do this assignment. The .kmz file may not load properly and you will be unable to do the assignment.

Downloading and opening the KMZ file:

1. Download this KMZ file: [Plate Boundaries](#)
2. Launch the Google Earth application. Choose File → Open... and navigate to the Downloads folder on your computer.
3. Choose the "plate-boundaries.kmz" file to open it in Google Earth.



Figure 2. Screenshot of the Google Earth Application

Instructions

When opening the “plate-boundaries.kmz” file in Google Earth, it should automatically zoom in on the San Andreas Fault Zone in California. Take some time to acquaint yourself with the Google Earth zoom and rotation tools on the right-hand side of the window and with legend on the left side of the Google Earth window. Explore the plate boundaries in this region and across the globe. To return to the original view, simply double-click on the name of the KMZ file (“Earth’s Tectonic Plates” in the Places legend on the left-hand side of the Google Earth window). The yellow arrows indicate relative relative movement between the plates. Your current view should look like this:



Figure 3. This is what your Google Earth window should look like when the KMZ file is first launched.

West Coast Tectonics

As you have learned, the San Andreas Fault is actually a transform boundary between the Pacific and North American plates.

1. Name the two plates that form the San Andreas transform fault boundary. What direction is each plate moving relative to the other? *Next, zoom in on the San Andreas Fault Zone until the cities of Los Angeles and San Francisco appear on your map. (Hint: They will appear as red labeled dots. Los Angeles may appear on the map first, then zoom in a bit more and San Francisco should appear, as well).*
2. On which tectonic plate are the following cities located (please include one screenshot of the general area that includes at least two of these cities):
 - a. Los Angeles, CA

- b. Bakersfield, CA
- c. San Francisco, CA
3. Based on the relative motion between these two plates, is the distance between San Francisco and Los Angeles becoming greater or shorter over time? Briefly explain. *Next, return to the original map view by double-clicking the name of the KMZ file "Earth's Tectonic Plates" under the Places Legend on the left side of the Google Earth window.*
4. Describe the names and types of plate boundaries, as well as their relative movement, along the West coast of North America, from the Gulf of California (Sea of Cortez) northward to British Columbia, Canada. *Next, zoom in on the Juan de Fuca plate, just off the coast of Washington and Oregon.*
5. Based on the types of plate boundaries that form the perimeter of the Juan de Fuca plate, in addition to what you have learned in the textbook about their relative rate of movement, what is the ultimate fate of the Juan de Fuca plate?
6. Describe the tectonic processes that formed the Cascade Range (which includes Mt. St. Helens) in the U.S. Pacific Northwest.

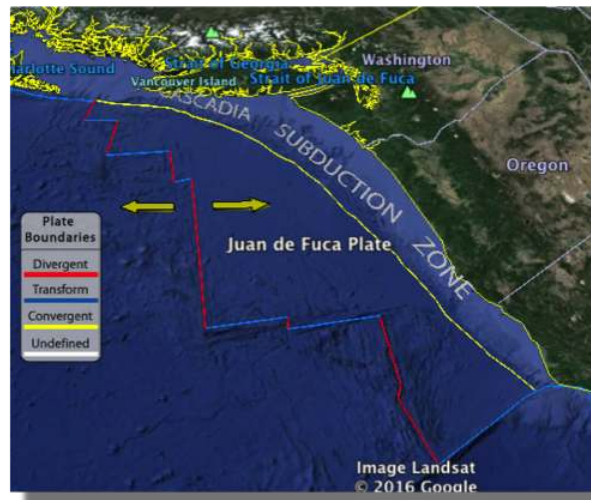


Figure 4. Screenshot of the Juan de Fuca plate.

Divergent Plate Boundaries

Next, zoom out and take a few minutes to explore the other plate boundaries around the globe.

7. Where are most of the divergent plate boundaries located around the globe— on landmasses or in ocean basins?
8. Identify at least one location where a divergent boundary is situated in a shallow, narrow sea between landmasses. Include a screenshot. *You might notice that divergent and transform boundaries often occur together in an alternating pattern. Zoom in on a region on Earth where this occurs.*
9. Why are mid-ocean ridges (divergent boundaries) usually offset by numerous transform faults along their length? Feel free to refer to your textbook or do some internet research (citing your sources) to determine this. Include a screenshot of the location you chose to zoom in on.

Spreading Rates

Please visit the National Oceanic and Atmospheric Administration (NOAA) website: [2008 Age of Oceans Plates](https://www.noaa.gov/education/outreach/2008-age-of-oceans-plates)

Take a moment to study and zoom in on the map and its legend (see the screenshot of this image on the next page).

10. Describe what this image is illustrating.
11. Using data from the image, where is the oldest seafloor in the world and what is its age? How does this age compare to the oldest continental rocks?
12. What is the reason for the discrepancy between these two ages?

Age of Oceanic Lithosphere (m.y.)

Data source:

Muller, R.D., M. Sdrolias, C. Gaina, and W.R. Roest 2008. Age, spreading rates and spreading symmetry of the world's ocean crust, *Geochem. Geophys. Geosyst.*, 9, Q04006, doi:10.1029/2007GC001743.

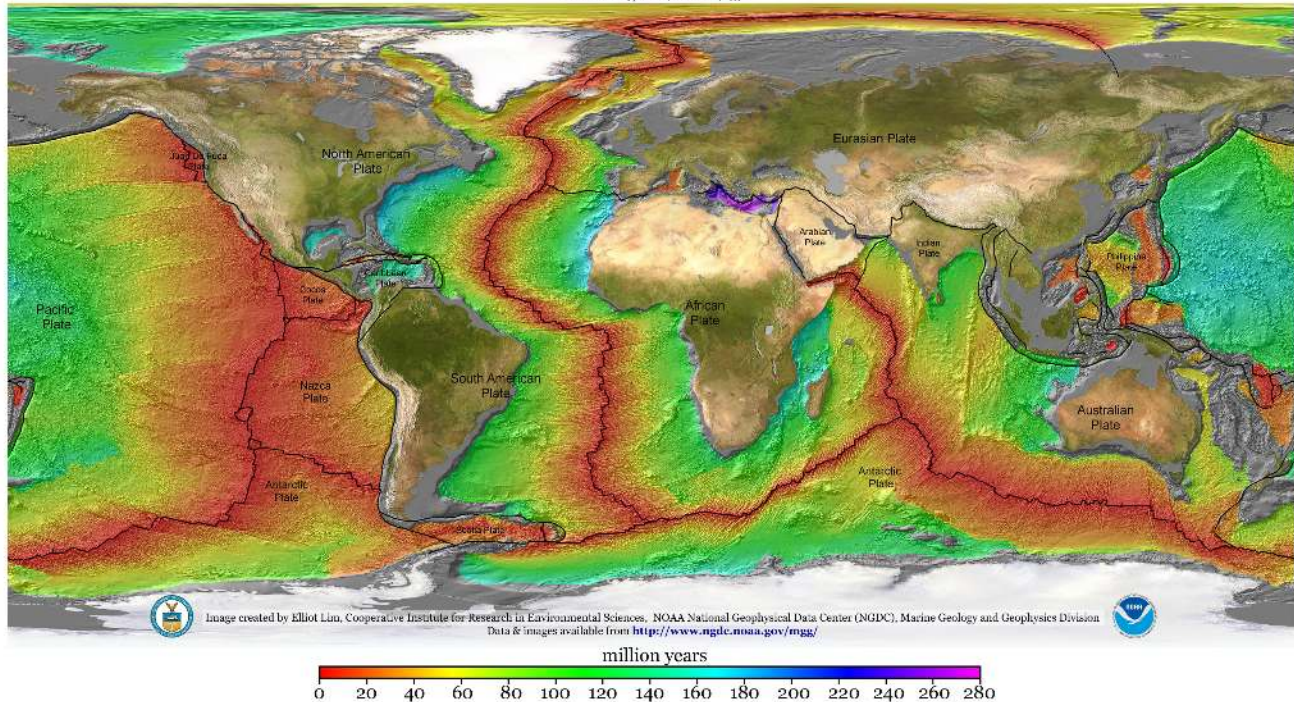


Figure 5. 2008 Age of Oceans image from NOAA [website](#). Next, use both Google Earth and the image above to explore the types of plate boundaries and the seafloor ages in the mid-Atlantic Ocean and Pacific Ocean basins.

13. Compare the seafloor ages between the mid-Atlantic Ocean and the Pacific Ocean, off the coast of South America. Which spreading ridge is spreading faster? How does seafloor age help you determine this?

Grading Rubric

- 10 points:** All questions were answered thoroughly and accurately. Screenshots were included where requested.
- 8 points:** All questions were answered and were mostly accurate. Screenshots were included where requested.
- 5 points:** Answers were too brief and a 1-2 questions were unanswered. Screenshots were not included.
- 2 points:** Only very partial information was given. Screenshots were not included.
- 0 points:** Did not complete the assignment.

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3.3: Discussion 2- Plate Tectonics

Discussion 2

Plate Tectonics



Figure 1. Vasequez Rocks. Just north of Los Angeles, the uplifted rocks are a result of collisions along the Elkhorn Fault, an offshoot of the San Andreas Fault.

Introduction

This week we will be having a conversation about plate tectonics and the ways in which the hazards associated with movement of the plates might personally affect you or your family. Now that you have completed Module 3 (Plate Tectonics), you should have some basic knowledge about the subject and can make educated post(s).

For this discussion, you will write an initial post and reply to at least TWO of your classmates' posts. Follow the guidelines for each posting below:

Basic Guidelines for Initial Post

(20 points, required)

Under the Discussion 2 topic, create a new thread. Answer the following questions thoroughly. Each question should be addressed in complete sentences and 4 – 5 sentences each.

1. Where did you grow up, or where do you call home? Where are the closest plate boundaries to your home (name the specific plates involved)? Is the boundary you identified a divergent, transform, or convergent boundary, or some combination of these? Describe this boundary in more detail if possible.

2. If a family member asked you to describe the potential danger of living near the plate boundary located closest to your home, what would you tell them?
3. Knowing what you do now about plate tectonics and the hazards associated with plate boundaries, how would this new knowledge play a role in where you choose to live in the future? How much risk might you be willing to live with?
4. Find two web pages or articles from two different sources that you feel provide a good overview of plate tectonics. How might you determine if it is a credible source for information? Describe what you liked (or didn't like) about the way the information was presented.

Basic Guidelines for Replies to Students

(10 points, required)

1. Make **two** replies to **two** different students, thoughtfully addressing
 - a. their concerns and/or assessments about the hazards associated with plate tectonics as they relate to them, and
 - b. at least one of the websites they chose as a good source for information on plate tectonics.
2. Each reply must contain 6 or 7 meaningful sentences directly related to article content. Phrases like “that is a great article!” and “I really liked your summary” do not count as meaningful content. However, these are still encouraging phrases in support of your peers so please feel free to include them in your post.
3. You must reply to at least 2 other students. (3, or more, for extra credit.)
4. Do not wait until the last day of the discussion to make your replies. You only receive credit for one reply (up to 10 points max) on the last day.
5. Reply early and often, and earning your full discussion points will be easy!

Extra Credit

(5 points, optional)

Make a third reply (or more!) to a student following the guidelines above.

Learning Outcomes

As a result of your participation in the discussion, you will become more aware of current events and news articles relating to topics in geology (i.e. become a more informed citizen). You will have some freedom in customizing this course to pursue your own interests in geology, including things not covered in the content of this course, by finding news articles on topics that relate to you.

Grading Rubric

Initial Post

20 points: Initial post met length and content requirements

15 points: Initial post needs minor improvements in length and content

10 points: Initial post needs major improvements in length or content

5 points: Initial post was made but with very little effort

0 points: Initial post was not made

Reply posts (each)

5 points: Reply was thoughtful, relevant, and met length requirements.

4 points: Reply needs minor improvements in relevancy and/or length.

2.5 points: Reply needs major improvements in relevancy and/or length.

1 points: Reply was made but with very little effort.

0 points: Reply was not made.

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CHAPTER OVERVIEW

4: Minerals

[4.1: Introduction](#)

[4.2: PCC Rock and Mineral Guide \(optional\)](#)

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4.1: Introduction

Module 4

Minerals



Figure 1. Malachite construction on allophane from Valcroze mine in the South of the France.

Introduction

In this module you will be learning about the building blocks of all of the materials that exist on the Earth. Atoms, comprised of protons, electrons and neutrons, form the elements of the Periodic Table. In turn, different elements combine to form different types of minerals. The properties of different materials are directly dependent on the elements that they contain. During this module, you will be learning about different minerals and carrying out a lab experiment to see first hand how properties vary from mineral to mineral.

Have you used a mineral yet today? While many people may initially say no, answer these questions: Have you brushed your teeth? Have you eaten anything that might contain salt? Did you put on makeup this morning, or do you have painted fingernails or toenails? Have you used a cellphone? What about a car, bike, or public transportation? If you have done any of those things, you have used at least one mineral, and in many cases you have used a great number of minerals. Minerals are very useful and common in everyday products, but most people do not even realize it.

A mineral is defined as a naturally occurring, inorganic solid with a definite chemical composition and a characteristic crystalline structure. Let's break that definition down. By naturally occurring, it means that anything humans have created, like the beautiful synthetic bismuth in the figure below, does not count as a mineral.



Figure 2. Bismuth is a chemical element that has the symbol Bi and atomic number 83. This is a bismuth crystal, that may be synthetic (see Hopper crystal).

To be an inorganic solid, the mineral must not be composed of the complex carbon molecules that are characteristic of life and must be in the solid state, rather than vapor or liquid. This means that water, a liquid, is not a mineral, while ice, a solid, would be (as long as it is not man-made). A definite chemical composition refers to the chemical formula of a mineral. For most minerals, this does not vary (for example, halite is NaCl), though some minerals have a range of compositions, since one element can substitute for another of similar size and charge (for example, the chemical formula for olivine is $(\text{Mg,Fe})_2\text{SiO}_4$, indicating its magnesium and iron content can vary). The atoms within minerals are lined up in an orderly fashion, so that the characteristic crystalline structure is just an outward manifestation of the internal atomic arrangement. Minerals are not only important for their many uses, but also as the building blocks of rocks.

Select an image to view larger



Figure 3. Quartz is one of the most common minerals in the Earth's crust, and also one of the most recognizable.

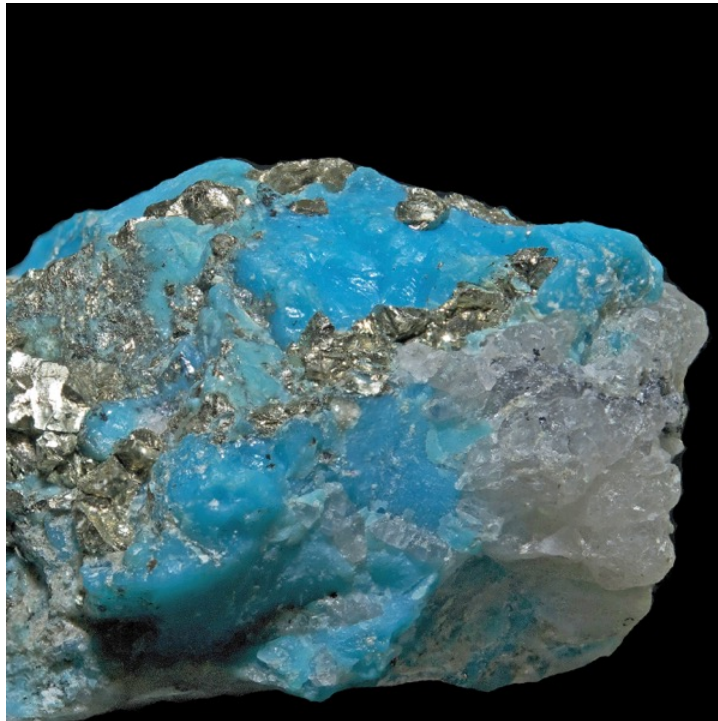


Figure 4. Crystals of turquoise, crystals of pyrite, crystals of quartz. Copper Cities Mines, Gila, Arizona



Figure 5. Wulfenite from the Defiance Mine, Arizona

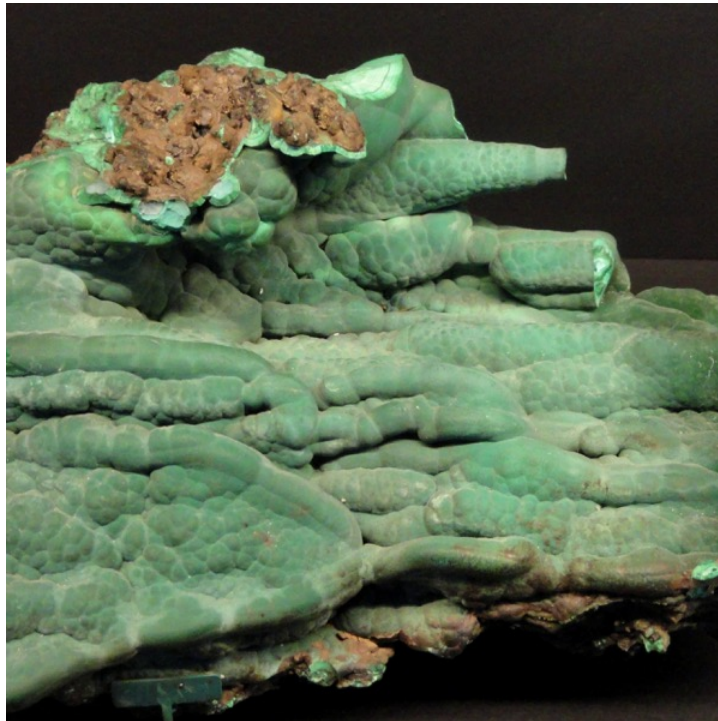


Figure 6. Malachite, Bisbee, Arizona – Natural History Museum of Utah



Figure 7. Zincite from Arizona



Figure 8. Malachite, Quartz, Chrysocolla, Globe Arizona. A gorgeous specimen with an antique Ward's Science Establishment label dating it to pre-WWI in the early 1900s. Ward's was an active buyer at the time, but an even older (unidentified, calligraphy) label glued to the back indicates this may date to the earliest days of copper camp mining in Arizona.

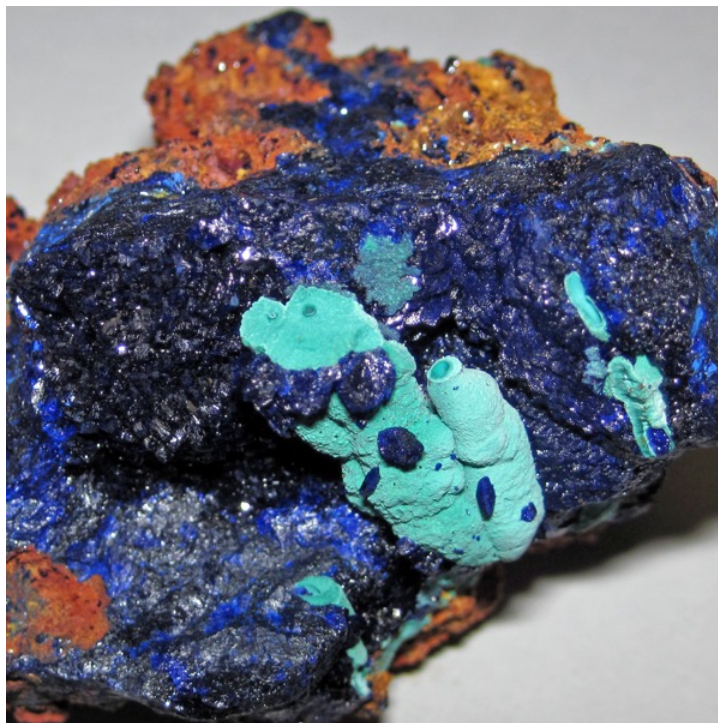


Figure 9. Azurite and malachite on iron oxide gossan from Arizona, USA. Blue = azurite, Green = malachite, Reddish-brown = gossan matrix

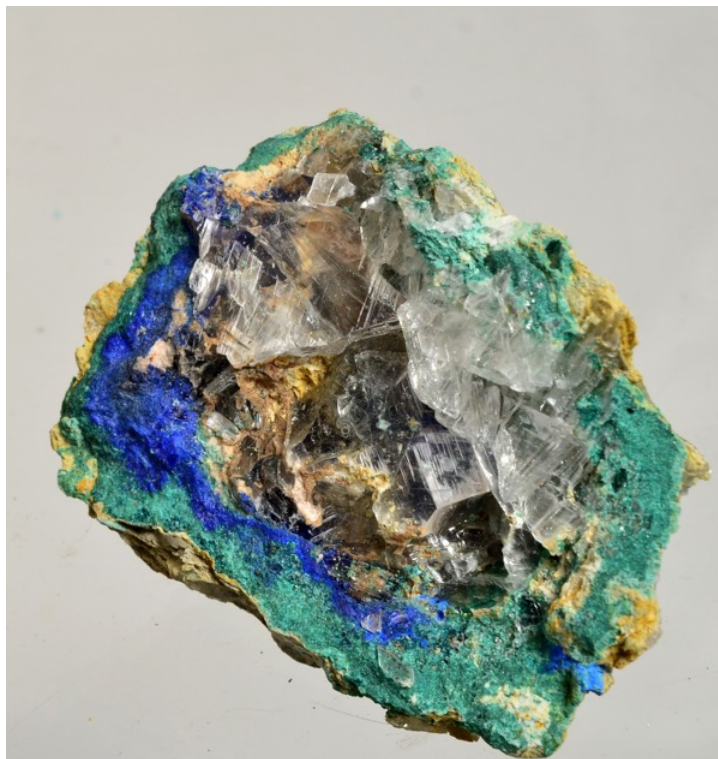


Figure 10. Gypsum & Smithsonite & Azurite & Malachite from the Grand Canyon, Arizona.

Module Objectives

At the completion of this module you will be able to:

1. Describe what an atom is and identify the elements that are important in geology.
2. Name common minerals and describe their structure.
3. Explain how to identify a mineral from its physical properties, and give examples for common minerals.

Activities Overview

See the *Schedule of Work* for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

Physical Geology by Steven Earle

- Chapter 2 (Minerals)

Optional Resources

- [PCC Rock and Mineral Guide](#)
- [Geology.com Mineral Guide](#)
- [Geology.com Rock Guide](#)
- [Minerals A-Z](#), Minerals.net

Module 4 Quiz

10 points

Module 4 Quiz has 10 multiple-choice questions and is based on the content of the Module 4 readings.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

Prepare for Exam 1

75 points

For Exam 1, you will be asked to put your knowledge to work in the Great Outdoors or at your local rock shop! You will be assembling a mineral kit with 5 minerals of your choice, composed of samples you have collected yourself or purchased individually. As a result, your kit will be customized according to your own interests.

You can read more about this in the [Exam 1 Instructions](#).

This is a “take-home” project. You will submit the results from your project in the Assignments tool during the week of **Module 5**.

Keep in mind that even though this exam is available for viewing a week earlier than the other exams you will take in this course, you will not be introduced to some of the content you need to complete this project until Module 5, so you are advised to keep this in mind as you start thinking about your project.

Your Questions and Concerns...

Please contact me if you have any questions or concerns.

General course questions: If your question is of a general nature such that other students would benefit from the answer, then go to the discussions area and post it as a question thread in the “General course questions” discussion area.

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4.2: PCC Rock and Mineral Guide (optional)

[PCC Rock and Mineral Guide \(optional\)](#)

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CHAPTER OVERVIEW

5: Igneous Rocks

Learning Objectives

At the completion of this module you will be able to:

- Explain the rock cycle and the processes involved.
- Name and describe the different types of intrusive and extrusive igneous deposits.
- Describe the composition of different types of igneous rocks and explain the processes involved in their formation.
- Explain which tectonic environment is associated with which kinds of igneous rock.

[5.1: Introduction](#)

[5.2: Igneous Rock Identification](#)

[5.3: Assignment- Igneous Rock Lab](#)

[5.4: PCC Rock and Mineral Guide \(optional\)](#)

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5.1: Introduction



Figure 1. Devil's Tower in Wyoming is one of the most famous outcrops of igneous rock in the world. It is composed of an igneous rock type called phonolite porphyry.

Introduction

All rocks found on the Earth are classified into one of three groups: igneous, sedimentary, or metamorphic. This rock classification is based on the origin of each of these rock type or the rock-forming process that formed the rock. The focus of this chapter will be on igneous rocks, which are the only rocks that form from what was once a molten or liquid state. Therefore, based on their mode of origin, igneous rocks are defined as those rock types that form by the cooling of magma or lava. You would be right in thinking that there is more to the classification of igneous rocks than stated in the previous sentence, as there are dozens of different igneous rocks that are considered commonplace, dozens of more types that are less common, and also quite a few igneous rock types that are quite scarce. Yet each igneous rock has a name that distinguishes it from all the rest. So, if they all start out as molten material (magma or lava), which must harden to form a rock, then it is logical to assume that these igneous rocks differ from one another primarily due to:

1. the original composition of the molten material from which the rock is derived, and
2. the cooling process of the molten material that ended up forming the rock. These two parameters— composition and texture— define the classification of igneous rocks. Igneous rock composition refers to what is in the rock (the chemical composition or the minerals that are present), and a rocks' texture refers to the features that we see in the rock, such as the mineral sizes or the presence of glass, fragmented material, or vesicles (holes) in the igneous rock.

In this module you will be learning about intrusive and extrusive igneous rocks. Igneous rocks are very commonly encountered in nature. Well-known examples are the basalt rocks of Hawaii that formed during volcanic eruptions on the islands. However, igneous rocks have formed throughout Earth's history and, through the process of plate tectonics, are often located at great distances from active volcanoes. For example, in the Catalina Mountains to the north of Tucson, there are many examples of igneous rocks, including three sills of granite that formed about 50 million years ago through an intrusion into an older granite unit. In this module, you will learn about the different types of igneous deposits, including sills, and how composition is related to the environment in which the rocks formed.

Select an image to view larger

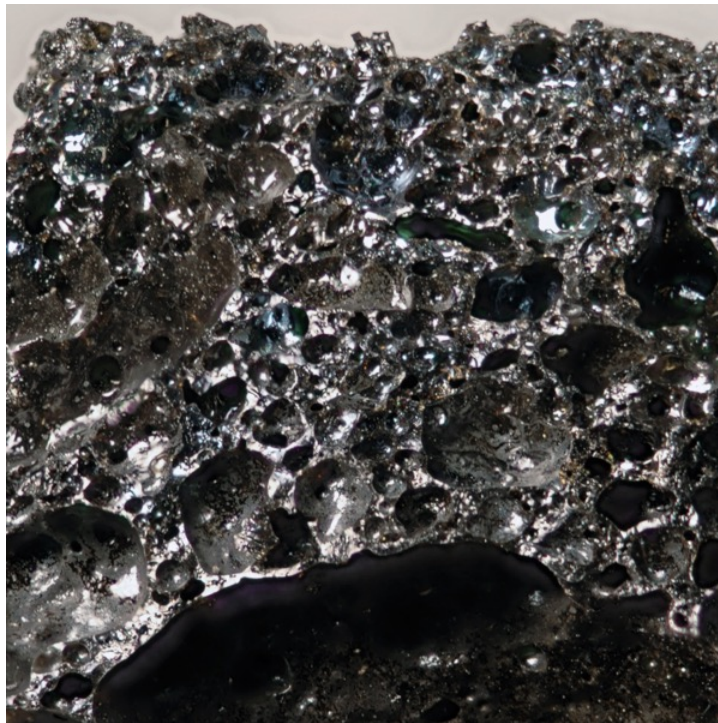


Figure 2. Vesiculated tachylite (basaltic lava flow cross-section, 1969 to 1974 lava tube ceiling, Mauna Ulu Lava Field, East Rift Zone, Kilauea Volcano, Hawaii, USA)



Figure 3. Fosterite-Olivine, Suppat, Northwest Frontier Province, Pakistan



Figure 4. Obsidian (top – shiny black), Pumice (gray below), and Rhyolite (light colored rock on right) at the base of Panum Crater, Mono County, California.



Figure 5. Pumice stone in a wall in Teguise, Lanzarote, Canary Islands, Spain. Pumice is a light-colored, extremely porous igneous rock that forms during explosive volcanic eruptions. It is used as aggregate in lightweight concrete, as landscaping aggregate, and as an abrasive in a variety of industrial and consumer products. (geology.com)



Figure 6. Lava and basalt at Hawaii Volcanoes National Park (2004, Chain of Craters Road)



Figure 7. Lava and basalt at Hawaii Volcanoes National Park (2004, Chain of Craters Road)



Figure 8. The Organ Pipes near Khorixas, Namibia. They are a rock formation that comprises a group of columnar basalts which resemble organ pipes.



Figure 9. The Giant's Causeway on the Antrim Coast of Northern Ireland. A UNESCO World Heritage Site with 40,000 basalt columns from an ancient volcanic eruption.



Figure 10. Giant's Causeway, Ireland



Figure 11. Weaver's Needle seen from the Fremont Pass in the Superstition Mountains band east of Phoenix, Arizona . Weaver's Needle was created when volcanic tuff, the effect of the original volcano eruption, began to undergo rapid erosion, leaving a 1388 meter high turn. The summit was named after the famous climber Pauline Weaver.



Figure 12. Ancestral homes made of tuff, Bandolier National Monument, New Mexico. Tuff is very light and soft. Over time, wind and water gradually eroded away softer areas of tuff, creating holes in the exposed canyon faces. The Ancestral Pueblo people used these to their advantage. With hand tools, they enlarged and shaped cliff openings into useful shelters called cavates (CAVE-eights). They used tuff blocks to build apartment-like homes along the cliff faces in front of the cavates. (National Park Service)

Module Objectives

At the completion of this module you will be able to:

1. Explain the rock cycle and the processes involved.
 2. Name and describe the different types of intrusive and extrusive igneous deposits.
 3. Describe the composition of different types of igneous rocks and explain the processes involved in their formation.
 4. Explain which tectonic environment is associated with which kinds of igneous rock.
-

Activities Overview

See the Schedule of Work for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

Physical Geology by Steven Earle

- Chapter 3 (Intrusive Igneous Rocks)

Module 5 Assignment: Igneous Rock Lab

10 points

After you complete the reading, you can start working on [Module 5 Assignment – Igneous Rock Lab](#).

Module 5 Quiz

10 points

Module 5 Quiz has 10 multiple-choice questions and is based on the content of the Module 5 readings and Assignment 5.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

Exam 1

75 points

Exam 1 is due this module. You will be asked to put your knowledge to work in the Great Outdoors or at your local rock shop! You will be assembling a mineral kit with 5 minerals of your choice, composed of samples you have collected yourself or purchased individually. As a result, your kit will be customized according to your own interests.

You can read more about this in the [Exam 1 Instructions](#).

This is a “work-at-home” project. You will submit the results from your project in the Assignments tool.

Check the Course Schedule for due date.

Your Questions and Concerns...

Please contact me if you have any questions or concerns.

General course questions: If your question is of a general nature such that other students would benefit from the answer, then go to the discussions area and post it as a question thread in the “General course questions” discussion area.

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5.2: Igneous Rock Identification

Introduction

Rocks are made of minerals. Rocks can be a mixture of different kinds of minerals, a mixture of many grains of the same kind of mineral, or a mixture of different grains of rocks. When you split a rock into very small pieces, the pieces are different from each other. For example, when you break granite apart, you get small pieces of quartz (clear), feldspar (pink or white), and mica (black). When you split a mineral into pieces, you still have pieces of the same mineral. If you break a big chunk of quartz into smaller pieces, you still have pieces of quartz.

There are three basic rock types: Igneous, sedimentary, and metamorphic.

Igneous Rocks

Igneous rocks (fiery rocks) are made when molten material inside or outside the earth cools and becomes solid. This melted rock is called *magma* when it is inside the earth. When magma finds its way to the surface through cracks or volcanoes, it is called *lava*. When lava cools on top of the earth's surface, it forms extrusive, or volcanic, igneous rock because it was extruded, or pushed, out onto the surface. Because it cools quickly, it only has time to make very tiny crystals. Extrusive, or volcanic, igneous rocks look dull and do not sparkle much because they are fine grained.

If the magma stays inside the earth and takes thousands of years to cool, it has time to make big crystals. These crystals make a coarse-grained igneous rock called plutonic, or intrusive, igneous rock because the magma was intruded into cracks deep under the earth's surface. These coarse-grained crystals make the rock look sugary as the flat crystal faces reflect the light in hundreds of little sparkles. The name of the igneous rock depends on what minerals are present. If there are lots of light-colored minerals and the rock is coarse grained, it is granite. If there are mostly dark-colored minerals and the rock is fine grained, it is basalt.

Igneous Rock Charts

Igneous – Phaneritic (coarse-grained) or aphanitic (fine-grained [smaller than pencil point])

Igneous Rock Chart

Texture V	Color>	Light colored: Pink, white, Gray, Green, Lavender	Medium to Dark Colored: Purple, Greenish	Dark Gray to Black	Dark Green to Black
—	" style="border: 1px solid rgba(0, 0, 0, 0.15); vertical-align: middle; font-size: 1em; padding: 5px 5px 10px; ">"> Minerals >	10 – 30% orthoclase (potassium-feldspar) 10 – 40% quartz 0-33% Na plagioclase 8-15% amphibole and biotite	55-70% plagioclase feldspar 15-40% biotite & amphibole	25-70% Ca plagioclase 25-75% dark mafic minerals (pyroxene, amphibole, olivine)	0-5% Ca plagioclase 65-100% olivine 0-25% pyroxene 0-10% ore minerals (magnetite, ilmenite, chromite)
Composition	" style="border: 1px solid rgba(0, 0, 0, 0.15); vertical-align: middle; font-size: 1em; padding: 5px 5px 10px; ">">—	Felsic (sialic)	Intermediate	Mafic	Ultramafic

Texture V	Color>	Light colored: Pink, white, Gray, Green, Lavender	Medium to Dark Colored: Purple, Greenish	Dark Gray to Black	Dark Green to Black
Fine = aphanitic	" style="border: 1px solid rgba(0, 0, 0, 0.15); vertical-align: middle; font-size: 1em; padding: 5px 5px 10px;">Extrusive volcanic	Rhyolite	Andesite	Basalt	Komatite
Coarse = phaneritic	" style="border: 1px solid rgba(0, 0, 0, 0.15); vertical-align: middle; font-size: 1em; padding: 5px 5px 10px;">Intrusive plutonic	Granite	Diorite	Gabbro	Peridotite
Environment	" style="border: 1px solid rgba(0, 0, 0, 0.15); vertical-align: middle; font-size: 1em; padding: 5px 5px 10px;">—	Subduction zones	Subduction zones	Mid-ocean ridges, hot spots	Mid-ocean ridges, mantle

Examples of Igneous Rocks

Grain	Color	Rock Name
course	light colored	Granite
course	medium colored	Diorite
course	black (dark) colored	Gabbro
fine	light colored (pastel)	Rhyolite
fine	medium colored	Andesite
fine	black (dark) colored	Basalt
ash particles	fine-grained ash	Tuff
glass	light colored, frothy	Pumice
glass	dark colored, glass	Obsidian

Intrusive Igneous Rocks

How Intrusive Igneous Rocks are Formed:

1. While molten, they intrude (push into) other rocks.
2. They cool below the earth's surface, generally deep.
3. They cool gradually and slowly.
4. Individual crystals have time and space to grow large.

5. Feldspar (pink to white blocky mineral) crystallizes at high temperatures early in the cooling process and, thus, has straight crystal sides.
6. Quartz (clear, glassy mineral) crystallizes later and fills spaces.

Characteristics:

1. Coarse-grained – The grains, or crystals, are big enough to tell what mineral each one is. The crystals are usually larger than 1 millimeter (larger than the point of a pen or pencil). They are commonly 1/8 to 1 inch long.
2. The edges of the crystals interlock. The crystals are shiny, flat surfaces which fit together like jigsaw puzzle pieces, with straight edges on some crystals.
3. The minerals are very hard and will scratch glass. If the rock has been weathered by the elements, it may be crumbly.
4. The texture is generally uniform (the same in all directions).

Extrusive Igneous Rocks

How Extrusive Igneous Rocks are Formed:

1. While molten, they flow out onto the surface or flow into cracks near the Earth's surface.
2. They cool quickly with no time for large crystals to grow.
3. They are, thus, very fine grained.
4. Mineral composition can only be identified with a microscope unless phenocrysts are present (see below).
5. Field identification of hand specimens is based on light or dark color, unless phenocrysts are present.

Characteristics:

1. Fine-grained – The grains are too fine to identify the minerals without a microscope.
2. Some fine-grained igneous rocks have rectangular crystals in them.
3. Very hard! Specimens will scratch glass, although it will be crumbly if it has been out in the weather for a long time.
4. Some volcanic rocks have vesicles, which are holes caused by gas bubbles when the lava was molten.

Porphyritic igneous rocks have coarse crystals in a fine background. Crystals are two to three times size of the matrix, and less than 10% of rock is crystals.

- Porphyritic phaneritic: Smaller crystals surround larger crystals (phenocrysts).
- Porphyritic aphanitic: Massive, structureless ground mass surrounds crystals (phenocrysts).

Matrix, or ground mass, is the fine-grained background.

Phenocrysts are the crystals surrounded by the matrix; these are usually large, straight-sided, and glassy minerals unless they have been weathered.

Porphyritic is used as an adjective to modify the name of any fine-grained igneous rock that has less than 50% phenocrysts in it. Example: Porphyritic basalt, porphyritic andesite. Porphyry is used as a noun after the rock name if more than 50% of the rock is made of phenocrysts. Example: Basalt porphyry.

Vesicular volcanic rocks: Vesicular is the adjective used to modify the name of any fine-grained igneous (volcanic) rock which has vesicles (holes from gas bubbles), making a cinder-like or clinker-like appearance. Example: Vesicular basalt.

Scoria: Basalt with over 50% vesicles. It looks like cinders. It is irregularly porous with rough surfaces and sharp edges and is often red brown.

Volcanic Glass

How Volcanic Glass Rocks are Formed:

Formed by sudden cooling with no time to form even tiny crystals. This rapid crystallization produces glass with a random arrangement of atoms, therefore, these rocks are slightly less dense. The volcanic glasses are usually from a more viscous (harder to flow) lava of rhyolite chemical composition.

Vitrophyre is a glassy rock containing crystals (phenocrysts).

Obsidian is a black glass with conchoidal (circular) fracture.

Pumice is a light gray, glass froth with many, many holes from gas bubbles. If there are enough holes that are not connected, pumice will float. It is very light because of all the holes.

Igneous – Glassy Chart

Texture	Composition	Characteristics	Rock Name
Glassy	? not applicable	Massive, black glass	Obsidian
Glassy	? not applicable	Frothy, gray glass of sub parallel glass fibers with many squashed air bubbles – may float	Pumice
Glassy	? not applicable	Gray glass, rounded spherical structures	Perlite

Volcanic Fragmental Rocks

How Volcanic Fragmental Rocks are Formed:

Formed by explosive eruptions of solid fragments and ash.

Tuff: A light colored volcanic ash, sometimes with glass and pumice fragments in it. Some tuffs are light in weight if they were not compacted. Some are welded tuffs and look like rhyolite.

Agglomerate: Contains volcanic fragments larger than 2 centimeters (about 1 inch in diameter) that were blown out of a volcanic vent. They are larger than ash particles, but have the same origin.

Igneous – Pyroclastic (Fragmental) Chart

Texture	Composition	Characteristics	Rock Name
Pyroclastic	Volcanic ash, pumice fragments, some rock fragments or glass	Light-colored volcanic ash, sometimes with glass and pumice fragments	Tuff
Pyroclastic	Volcanic ash, pumice fragments, some rock fragments or glass	Fine-grained or gritty, light in weight if not compacted; light color	Ash fall tuff
Pyroclastic	Volcanic ash, pumice fragments, some rock fragments or glass	Particles or grains are fused or welded, with flow lines	Ash fall tuff
Pyroclastic	Round pebbles and bombs that were blown out of a volcanic vent, with ash	Volcanic fragments larger than 2 millimeters (about size of pencil point)	Agglomerate
Pyroclastic	Volcanic bombs, pebbles, ash, pumice fragments, some rock fragments, or glass	Sharp, angular volcanic fragments larger than 2 centimeters (1 inch diameter) mixed with others	Volcanic breccia

Characteristics of Important Minerals in Igneous Rocks

- **Quartz:** Occurs as irregular, glassy grains, commonly clear to smoky with no cleavage.
- **Muscovite:** Brass or clear gray-colored flakes associated with quartz or K-feldspar. Perfect cleavage in 1 direction (layers)
- **Orthoclase (K-feldspar):** Porcelain luster; commonly colored pink, white, or gray. Cleavage in 2 directions at right angles may be detected by a reflection of light when specimen is rotated.
- **Plagioclase:** Usually gray or white in granite, dark-bluish color in gabbro. Striations common. 2 cleavage directions at right angle may be detected.

- **Biotite:** Small black flakes with perfect cleavage in 1 direction (layers), reflects light.
- **Amphibole (Hornblende):** Long, black crystals in a light-colored matrix. Cleavage at 60 and 120 degrees.
- **Pyroxene (Augite):** Short, dull, greenish-black minerals in darker rocks. Cleavage in two directions at 90 degrees.
- **Olivine:** Glassy, light-green to dark green grains.

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5.3: Assignment- Igneous Rock Lab

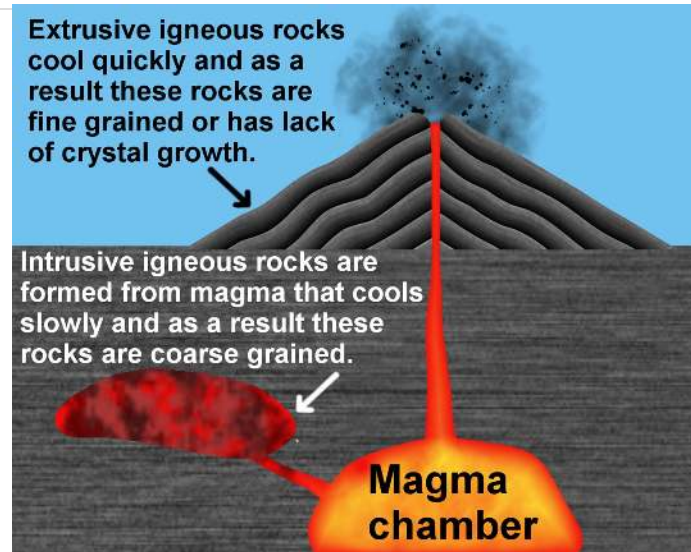


Figure 1.

Overview

You can start the activity after you have completed the reading assignment.

In this lab you will be applying the principles that you have been studying and determining properties for a selection of the igneous rock you will study from photos on the Internet.

In addition to texture and the intrusive/extrusive determination for each sample, you will also be asked to determine the mineral content of the sample to the best of your ability. For example, you can expect to find abundant olivine, and maybe a little pyroxene and Ca-rich plagioclase in an ultramafic rock called peridotite or komatiite. Pyroxene, plagioclase, and possibly some olivine or amphibole may be present in a mafic rock such as gabbro or basalt. You can also expect to see quartz, muscovite, potassium feldspar, and maybe a little biotite and Na-rich plagioclase in a felsic (or silicic) rock such as granite or rhyolite.

The classification of an igneous rock depends partly on the minerals that may be present in the rock, and since the minerals have certain colors due to their chemical makeup, then the rocks must have certain colors. For example, a rock composed of mostly olivine will be green in color due to olivine's green color; such a rock would be called ultramafic. A rock that has a large amount of ferromagnesian minerals in it will be a dark-colored rock because the ferromagnesian minerals (other than olivine) tend to be dark colored; an igneous rock that is dark in color is called a mafic rock ("ma-" comes from magnesium, and "c" from ferric iron). An igneous rock with a large amount of nonferromagnesian minerals will be light in color, such as the silicic or felsic rocks ("fel" from feldspar, and "sic" from silica-rich quartz). So, based on color alone, we've been able to start classifying the igneous rocks.

Instructions

A. Before you begin this activity, you may also wish to review the [Igneous Rock Identification](#) page. Some optional resources you can use are:

- [PCC Rock and Mineral Guide](#)
- [Geology.com Mineral Guide](#)
- [Geology.com Rock Guide](#)
- [Minerals A-Z](#), Minerals.net

B. Select each photo below to view the igneous rock samples larger. You can also view the images in Flickr by clicking the link, and zoom in on each of these samples in the picture to get a better view of their texture:

Select an image to view larger

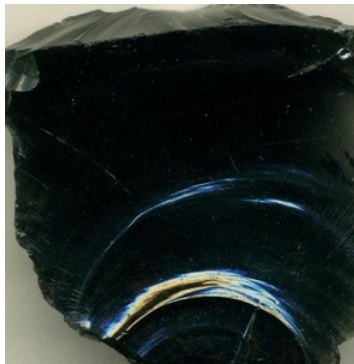


Figure 2. Obsidian is an easily recognizable igneous rock. It is a glassy-textured, extrusive igneous rock. Obsidian is a natural glass – it lacks crystals, and therefore lacks minerals. Obsidian is typically black in color, but most obsidians have a felsic chemistry. Felsic igneous rocks are light-colored, so a felsic obsidian seems a paradox. Mafic obsidians are scarce, but they have the same appearance. Obsidian is an uncommon rock, but can be examined at several famous localities in America, such as Obsidian Cliff in the Yellowstone Caldera (northwestern Wyoming, USA) and Big Obsidian Flow in the Newberry Volcano Caldera (central Oregon, USA). Obsidian is moderately hard, has conchoidal fracture (smooth & curved fracture surface), and has exceedingly sharp edges. Freshly-broken obsidian has the sharpest edges of any material known, natural or man-made (as seen under scanning electron microscope). Obsidian forms two ways: 1) very rapid cooling of lava, which prevents the formation of crystals; 2) cooling of high-viscosity lava, which prevents easy movement of atoms to form crystals. An example of obsidian that formed the first way is along the margins of basaltic lava flows at Kilauea Volcano (Hawaii Hotspot, central Pacific Ocean). This is an example of obsidian that formed the second way . – James St. John



Figure 3. Granite from the Precambrian of Wyoming, USA. (8.9 cm across at its widest) This is a sample of Precambrian basement rock from the Rattlesnake Mountain Uplift (a.k.a. Rattlesnake Mountain Anticline) in northwestern Wyoming. The uplift is part of an extensive set of mountain ranges from New Mexico to western Canada that were formed during the Laramide Orogeny (late Mesozoic to mid-Cenozoic). Locality: float from roadcut on the northern side of Rt. 16 / 20, just west of third tunnel west of Cody, next to Buffalo Bill Reservoir, central Park County, northwestern Wyoming, USA – James St. John

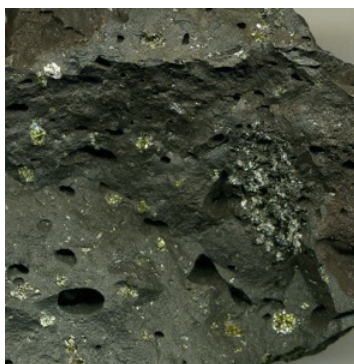


Figure 4. Basalt from the upper Holocene of Hawaii (~6.5 cm across at its widest). This attractive piece of lava is from the 13 January to 19 February 1960 Kapoho Eruption at the easternmost point of Hawaii. The former town of Kapoho was located in the Kapoho Graben (Puna Rift Zone) segment of Mt. Kilauea's East Rift Zone. Kapoho was famously burned, buried, and destroyed by aa lava flows erupting continuously for a little over a month in early 1960, despite the hasty construction of barriers. The lava flows overtopped the barriers and even "burrowed under" the barriers. The rock is a vesicular porphyritic olivine basalt (more technically, it can be called vesicular tholeiitic picrite basalt). It has abundant subrounded to stretched vesicles and common large greenish forsterite olivine phenocrysts. The basalt matrix is lustrous and cryptocrystalline, with very small crystals of plagioclase feldspar and pyroxene. The sample has an obvious black-and-white speckled xenolith of gabbro from the lower oceanic crust. – James St. John



Figure 5. Pumice is a distinctively frothy-textured, felsic, extrusive igneous rock. Frothy textured igneous rocks have large numbers of tiny holes formed by the presence of many gas bubbles in the original volcanic lava. If cooling & solidification was completed before all the gas bubbles escaped to the lava surface, the result is a rock with lots of empty space (porosity). Pumice is actually a volcanic glass having a frothy texture. The solid portions of pumice are not crystalline. So, pumice has no minerals – it has the elemental chemistry of granite & rhyolite, but it doesn't have any minerals. Pumice is typically whitish, light grayish, or very light brown in color. Most pumice samples are so lightweight that they float on water. After the August 1883 eruption of Krakatoa in Indonesia, sailors observed pumice floating in the Indian Ocean for many months. Pumice is typically encountered in the form of small chunks littering the land surface around eruptive centers. They typically fall to Earth and form air fall pumice deposits. James St. John

Figure 6. Rhyolite is a felsic, extrusive igneous rock. It has the same chemistry & mineralogy as granite, but is very finely crystalline (aphanitic texture; crystals <1 mm in size) due to cooling of high-viscosity lava. Rhyolites are often light gray to pinkish to somewhat reddish in color. Rhyolite lavas are highly viscous (thick & slow-moving) when erupted and often appear as if they have flowed like oozing toothpaste. Sometimes the term felsite is applied to rhyolites. There does not seem to be a consistent definition of felsite, cf. rhyolite. However, felsite appears to be the broader term, applicable to all light-colored volcanic rocks. – James St. John

- [Obsidian](#)
- [Granite](#)
- [Basalt](#)
- [Pumice](#)
- [Rhyolite](#)

C. Determine the following characteristics to the best of your ability from the photos of the samples above:

1. Color
2. Texture (aphanitic, phaneritic, glassy, vesicular, frothy, porphyritic, pyroclastic?)
3. Mineral content
4. Is the rock mafic, felsic, intermediate, or ultramafic (based on mineral content you identified above)?
5. Is the rock extrusive or intrusive (based on its texture you identified)?
6. For each sample, compare your observations to the sample(s) listed in the Rock and Mineral Guide. Are your findings consistent with the guide?
7. For one of the rock samples of your choice, write a half-page summary describing the physical characteristics you can determine from the photo or from any personal sample you have collected. If using a personal sample, please include a photograph. For all the other samples above, include a table summarizing the characteristics you observed (1 – 6). You will be graded on this activity as described in the rubric below.

Grading Rubric

10 points: Report accurately summarized the igneous rock characteristics, spelling and grammar are correct and complete sentences are used, including a photograph. Characteristics of the other samples are included in a table and are accurate.

8 points: Report mostly captured the igneous rock characteristics, spelling and grammar are mostly correct and complete sentences are used, including a photograph. Characteristics of the other samples are included, but one or two details were missing.

5 points: Report missed two or more characteristics, included spelling and grammar errors, and/or did not include a photograph. Characteristics of the other samples are included, but over half of the minerals and/or characteristics are missing.

2 points: Report was inaccurate, included significant spelling and grammar errors, and/ or did not include a photograph. Characteristics of the other samples are not included. **0 points:** Did not complete the assignment.

0 points: Did not complete the assignment.

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5.4: PCC Rock and Mineral Guide (optional)

[PCC Rock and Mineral Guide](#)

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CHAPTER OVERVIEW

6: Volcanism

[6.1: Introduction](#)

[6.2: Assignment- Exploring Volcanic Features of the United States](#)

[6.3: Discussion 3- Current Events in Geology](#)

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6.1: Introduction

Module 6

Volcanism



Figure 1. The Mount Bromo volcano on the island Java of Indonesia. Depending on the degree of volcanic activity, the Indonesian Centre for Volcanology and Disaster Hazard Mitigation sometimes issues warnings against visiting Mount Bromo.

Introduction

In the previous module, we studied different types of igneous rocks and intrusive igneous processes. Now, we are moving on to consider volcanism and extrusive activity. Without doubt, volcanic eruptions are among the most spectacular of Earth's processes. Activity ranges from gentle eruptions that do not represent significant hazards to humans, as is the case in Hawaii, up to highly explosive and large events that have the potential to impact global climate. In this module, you will learn about the different types of volcanism and the hazards that they represent. In addition, you will read about several specific volcanoes to better understand the processes associated with different eruptions.

How would you like to live on an active volcano? Surprisingly, a lot of people are living on or near active volcanoes, and many more live near volcanoes that are currently considered to be “dormant,” exhibiting a volcanically-quiet period of time over the past 10,000 years, but with the potential to erupt in the future. Are they crazy? Maybe some are, but not all volcanoes erupt explosively; for example, the type of volcano that forms the Hawaiian Islands is a type that erupts effusively, with lava running down the sides (flans) of the volcano. Hawaiian citizens are familiar with this style of eruption, and they are also aware that their particular volcano will not erupt explosively.

Explosive eruptions are more likely for the volcanoes that make up the Islands of Sumatra and Java (Indonesia); these volcanoes are very dangerous, and yet Indonesia is one of the most densely populated countries in the world. So, it would seem very important to know why some volcanoes are dangerous, and why others are not. Of the “dangerous” types that are currently dormant, will we have enough of a warning before they erupt? Is it only the eruption that we should worry about, or are there other

hazards that we must be aware of? These questions will be addressed in this module, along with a few other questions that you might have, such as why volcanoes form in certain locations, especially in relation to plate tectonics, and the association of magma type with volcano type and eruptive style.

Select an image to view larger



Figure 2. This photo from the U.S. Geological Survey offer a glimpse into the destructive volcanic eruption now occurring on the East Rift Zone of Hawaii Island. At 07:45 a.m. HST, May 7, 2018, lava from fissure 7 slowly advanced to the northeast on Hookapu Street in Leilani Estates subdivision on Kilauea Volcano's lower East Rift Zone.



Figure 3. Strombolian eruption of Pacaya in Guatemala, 1992.



Figure 4. 'This is the view, as close as I was willing to go, of inside mount Merapi in Indonesia' – Jimmy McIntyre, Editor of HDR One Magazine

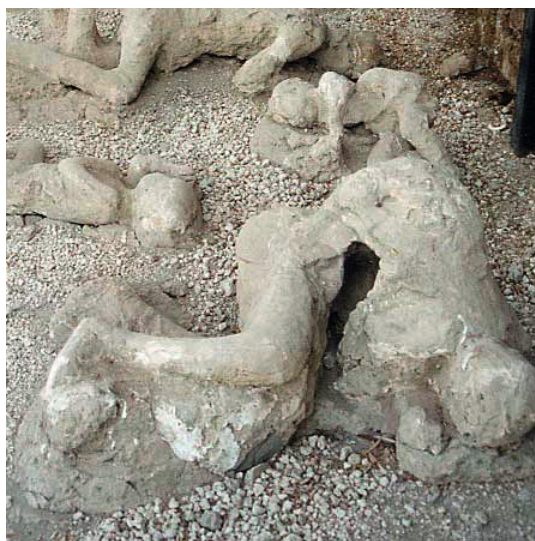


Figure 5. Casts of some of the Pompeian victims of Mt. Vesuvius' eruption in AD 79. The people and buildings of Pompeii were covered in up to 12 different layers of tephra, in total 25 metres (82.0 ft) deep, which rained down for about six hours.

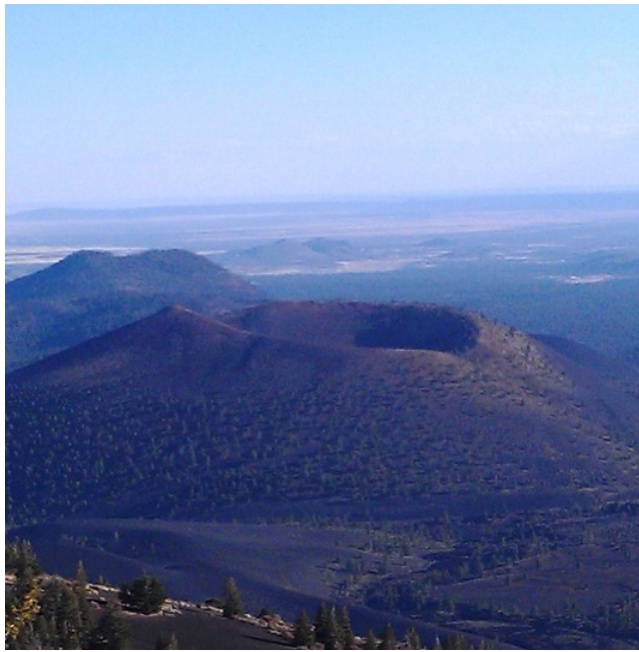


Figure 6. Sunset Crater Volcano National Monument, just north of Flagstaff, Arizona. Around 1085 the ground began to shake, and lava spewed high into the air. When the eruption finished, it had changed both the landscape and the people who lived here.



Figure 7. A lake has filled the caldera at Mt. Pinatubo, Philippines. It is an active stratovolcano that lasterupted in 1993, but its massive eruption in 1991 was arguably one of the largest eruptions inmore than 100 years. It caused a volcanic winter by dropping global temperatures by 1 °C inthe Northern Hemisphere.

Module Objectives

At the completion of this module you will be able to:

1. Describe the different types of volcanoes.
2. Explain why there are different types of lava.
3. Explain how volcanism, igneous rocks and plate tectonics relate.
4. Describe the hazards associated with volcanism.
5. Explain how volcanism can impact life on Earth.

Activities Overview

See the *Schedule of Work* for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

Physical Geology by Steven Earle

- Chapter 4 (Volcanism)

Discussion 3

30 points, class participation

For this week's "Current Events in Geology" discussion. It is important that you feel engaged in this class. Discussion topics are very flexible, and can cover anything in geology or a related field, including hydrology or water resources, environmental or climate science, paleontology, planetary geology, etc. This is a great opportunity for you to learn about topics in geology that interest YOU, and to see that many interesting things relating to geology are currently making headlines in the news. You are also helping your instructor to become aware of what is going on and to learn new things, so I appreciate your efforts and look forward to reading what you find!

Discussion 3 Instructions

Pay close attention to the Course Schedule for when each of your posts are due. Some are due earlier than others. Failure to post on time will result in lost points.

Module 6 Assignment: Exploring Volcanic Features of the United States

15 points

After you complete the reading, you can start working on [Module 6 Assignment – Volcanic Features of the United States](#)

Module 6 Quiz

10 points

Module 6 Quiz has 10 multiple-choice questions and is based on the content of the Module 6 readings and Assignment 6.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

Your Questions and Concerns...

Please contact me if you have any questions or concerns.

General course questions: If your question is of a general nature such that other students would benefit from the answer, then go to the discussions area and post it as a question thread in the "General course questions" discussion area.

Personal questions: If your question is personal, (e.g. regarding my comments to you specifically), then send me an email from within this course.

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6.2: Assignment- Exploring Volcanic Features of the United States

Module 6 Assignment

Exploring Volcanic features of the U.S.



Figure 1. For more than nine hours a vigorous plume of ash erupted, eventually reaching 12 to 15 miles (20-25 kilometers) above sea level. The plume moved eastward at an average speed of 60 miles per hour (95 kilometers/hour), with ash reaching Idaho by noon. By early May 19, the devastating eruption was over. Shown here is a close-up view of the May 18 ash plume.

Overview

You can start the activity after you have completed the reading assignment.

Mount St. Helens Reawakens

The first earthquakes struck on March 20, 1980. Seismologists quickly determined that the quakes were centered beneath a snowy mountain, known to them, but not to the general public, as a potentially dangerous volcano, which had been dormant for more than a century. During the next week, the number of earthquakes increased, and these quakes triggered snow avalanches, which in turn forced closure of winter recreation areas around the mountain. Geologists and geophysicists converged on the scene to monitor the activity and met with local authorities to alert them to the possibility of an eruption. On March 27, steam and ash exploded from the summit of the volcano and marked the beginning of several small eruptions during the next two months.



Figure 2. Mount St. Helens before the May 18, 1980 eruption. View from the northeast of Spirit Lake.

Public authorities prudently closed the area surrounding the mountain after being informed of the volcano's past violent behavior by those who had conducted careful geological studies during the preceding 20 years. Although closure was a necessary precautionary measure, it created discontent and even anger on the part of some citizens who wanted access to their property and recreation sites. Continued monitoring of the volcano indicated that its north flank, which towered above the most popular recreation area, was becoming increasingly unstable. Warnings were issued for landslides and large-scale snow avalanches. These warnings supported the need for continued closure of the area, although public pressure eventually led to brief, authorized forays into the area by cabin owners to retrieve belongings. One such trip was scheduled for the morning of May 18, but it never took place.



Figure 3. Car after Mount St. Helens 1980 Eruption (May 31). Reid Blackburn's (photographer, National Geographic, Vancouver Columbian) car, about 10 miles from Mount St. Helens.

For more than nine hours a vigorous plume of ash erupted, eventually reaching 12 to 15 miles (20-25 kilometers) above sea level. The plume moved eastward at an average speed of 60 miles per hour (95 kilometers/hour), with ash reaching Idaho by noon. By early May 19, the devastating eruption was over.

At 8:32 a.m. on May 18, an earthquake triggered a gigantic landslide on the unstable north flank, which in turn unleashed a scorching, explosive blast of hot gas laden with rock fragments; massive floods of mud and rock down most river valleys; flows of hot, gas-rich volcanic rock; and an enormous plume of ash. The water-soaked landslide debris produced a series of dense slurries that raced downstream and nearly severed Interstate Highway 5 and the AMTRAK rail line connecting Portland, Oregon, and Seattle, Washington. These debris flows brought shipping on the Columbia River to a halt and came close to blocking cooling-water intakes at an operating nuclear power plant. These events transformed a lush landscape of dense, green forest into a dusty volcanic wasteland and killed 57 people who were too close to the mountain. The eastern half of the State, where people were virtually unaware of any volcanic hazard, was blanketed with ash. The death toll, though large, could have been much, much higher without the previous warnings and resultant land closure. Luck also played a role in keeping the number of fatalities down.



Figure 4. Mount St. Helens in 1982> After the 1980 eruption, there was a massive debris avalanche that reduced the elevation of the mountain's summit from 9,677 ft (2,950 m) to 8,363 ft (2,549 m), leaving a 1 mile (1.6 km) wide horseshoe-shaped crater.

Had the eruption occurred on Monday rather than Sunday, several hundred loggers, working in an area near the volcano but outside the closed area, would have died. During the next decade, continued enforcement of restricted zones and careful observation and prediction of activity warned the public of impending eruptions, and no additional lives were lost. Research into what had caused the catastrophic eruption led to increased appreciation of the inherent instability of high, snow-covered volcanoes and the hazards they pose. (Excerpts from *Living With Volcanoes*, by T.L. Wright and T.C. Pierson, The U.S. Geological Survey's Volcano Hazards Program: U.S. Geological Survey Circular 1073, 57p. 1992.)

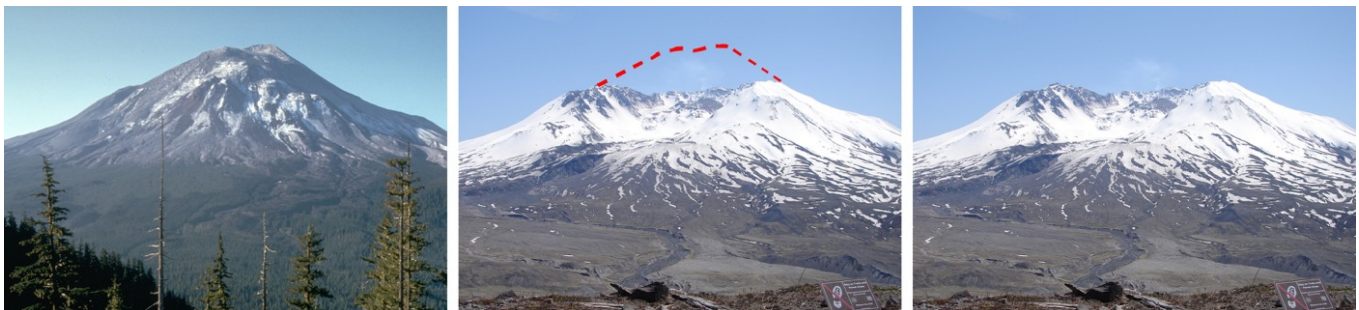


Figure 5. Mount St. Helens before and after the 1980 eruption showing the reduction in height and the resulting crater.

How Rocks Melt

Most magma is generated at the base of the earth's crust; the figure below is a pressure-temperature diagram. On the left side of the solid black line (called the solidus) is a region where the temperature is too low for a rock to melt. On the right side of the solidus line is the region where rock will melt. Notice that the solidus line is not a vertical line going straight down, but is sloped at an angle less than vertical, demonstrating that with increasing pressure the temperature must also increase in order for a rock to melt.

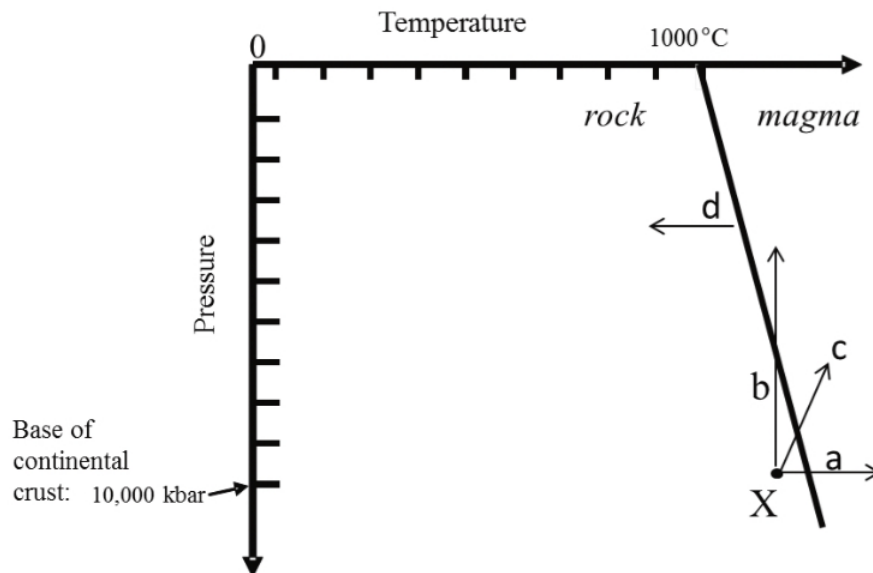


Figure 6. Pressure and Temperature graph of crustal rocks. The line that separates the region of solid versus liquid rock is called the solidus. Note that a rock at point X cannot melt unless one of the following conditions occur: either a temperature increase (arrow “a”), or a pressure decrease (arrow “b”), or any combination of these two changes (arrow “c”), or by adding water to change the melting conditions which shifts the solidus line to the left (arrow “d”).

Now take a look at the conditions at the base of the crust, at point “X”. This rock at “X” is not hot enough to melt; or it can be said that the rock at point X is under too much pressure to melt. To make this rock melt, either the temperature must increase (arrow “a”), or the pressure must decrease (arrow “b”), or we can have both hotter temperature and lower pressure occur simultaneously (arrow “c”). Regardless of the path taken, we can make this rock X cross the solid line and become magma. The only other way we can make rock X cross the solid line and become magma is to move this line (arrow “d” in the figure); in other words, change the melting temperature of the rock. This can be done by adding water, which lowers the melting temperature of rock, and now we can make rock X melt without actually having to change the temperature and pressure conditions.

Now let us think of plate tectonics and the types of boundaries that have magma associated with them (see figure below). Tectonic plates that are diverging (or pulling apart), causes the underlying region of the mantle to experience reduced pressure conditions. If the mantle is already fairly warm, the decreased pressure may just be enough for magma to be produced (arrow “b” in the figure below). Where tectonic plates are converging (coming together), one of the plates may subduct below the other plate; recall that subduction will only occur if the tectonic plate has an oceanic crust type. This subducting oceanic crust-topped plate will contain minerals that are hydrated (water in their crystal structure), and as the plate subducts, the hydrated minerals will become unstable and water will be released.

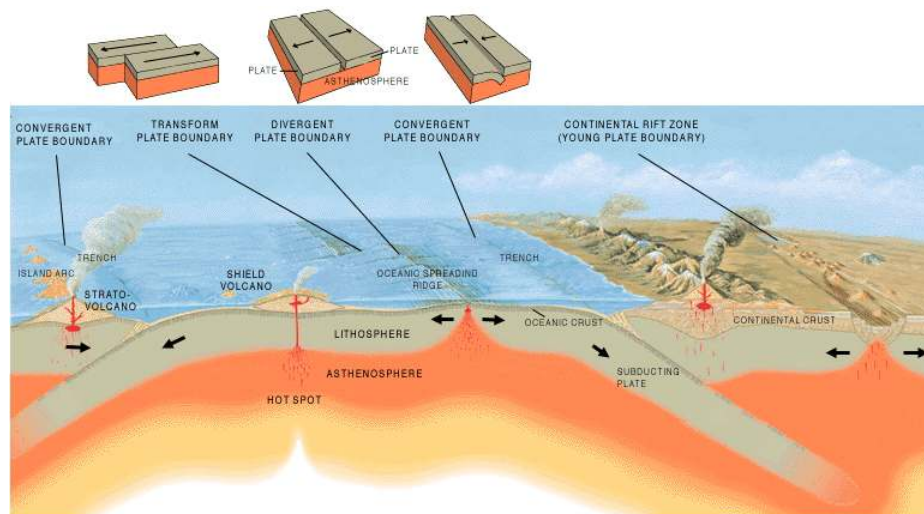


Figure 7. Areas of magma generation at certain plate boundaries (b and d), or within a plate due to a hot spot (a). Arrows a, b, and d correspond to the same arrows as shown in Figure 6.

This water will lower the melting temperature of the mantle region directly above the subducting plate, and as a result magma is produced (arrow “d” in the figure). The last way to melt rock is to just increase the temperature of the rock; this particular melting mechanism does not have to be associated with any particular plate boundary. Instead there must be a region known as a hot spot, caused by mantle plumes (arrow “a” in the figure above). Mantle plumes are thought to be generated at the core-mantle boundary, and are regions of increased temperature that can cause melting of the lithospheric region. With the lithosphere broken into several tectonic plates that have been migrating over these plumes throughout geologic time, the resulting hotspot-generated volcanoes can be found anywhere in the world.

Instructions

Before you begin this activity, please revisit section 3.2 of Chapter 3 in Physical Geology on how magma is formed. You can also review the following [excerpt on how rocks melt](#). This website briefly reviews the 3 main ways that rocks melt (decompression melting, flux melting [volatiles], and addition of heat [conduction]).

1. Visit the [USGS Geology of the National Parks](#). Select the link for each of the following parks and take the “standard” photo tour to explore the region:
 - Hawaii Volcanoes National Park
 - Devils Tower National Monument
 - Yellowstone National Park
 - Crater Lake National Park
 - Pinnacles National Park
 - Mount St. Helens National Volcanic Monument
 - Lava Beds National Monument
2. Pick four sites from the list above that intrigue you the most. For each of the four sites, address the following questions. Feel free to use other credible websites (such as NPS.gov) to help you explore the answers (be sure to cite your other sources):
 - Where is the park located (e.g. near which city, state, or specific region of the country?).
 - In 2 – 3 sentences, describe the central volcanic feature in the park. Is it an active, dormant, or extinct volcanic site, or is it another type of feature? If it is a volcano, what type of volcano is it (shield, stratovolcano, cinder cone, caldera, etc.)? If it is an active volcanic site, what specific type of volcanic activity does the USGS photo tour depict to help you determine this? (Include a screenshot of this activity from the photo tour where applicable.)
 - In 2 – 3 sentences, please describe the tectonic processes that resulted in the volcanic feature(s) in the park. For example, was the volcanic feature a result of activity at a plate boundary, a hot spot, or some other activity?
 - In 2 – 3 sentences, please give your own assessment of what type of melt process is occurring at each location. Is there more than one type of melt? Use the information you have learned in the text and from the excerpt above on How Rocks Melt.
 - What specific questions arose while you researched each feature, and were you able to find satisfactory answers to address your curiosity? Submit a short report (maximum 2 pages, 1.5 spacing) discussing your answers to these questions. You will be

graded on this activity as described in the following rubric.

Note that points may be deducted for spelling or grammar errors, or for not following the line spacing and length rules.

Grading Rubric

15 points: Accurately responded to the questions for each of the four volcanic sites. Any additional references used were cited.

12 points: Accurately responded to the questions for each of the sites, missing or answering incorrectly only one or two questions. Any additional references used were cited.

8 points: More than two questions missed or answered incorrectly. References (if applicable) were not included.

5 points: Only very partial information provided.

0 points: Did not complete the assignment.

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6.3: Discussion 3- Current Events in Geology

Discussion 3

Current Events in Geology



Figure 1. Pinnacles, or Hoodoos, of Massai Point, Chiricahua National Monument. The monument is located approximately 36 miles (58 km) southeast of Willcox, Arizona. Geologists believe that it preserves the remains of an immense volcanic eruption that shook the region some 27 million years ago. The thick white-hot ash spewed forth from the nearby Turkey Creek Caldera, cooled and hardened into rhyolite tuff, laying down almost two thousand feet of dark volcanic ash and pumice, highly siliceous in nature, which eventually eroded into the natural features visible that we see at the monument today.

Introduction

For this discussion, topics are very flexible, and can cover anything in geology or a related field, including hydrology or water resources, environmental or climate science, paleontology, planetary geology, etc. This is a great opportunity for you to learn about topics in geology that interest YOU, and to see that many interesting things relating to geology are currently making headlines in the news. You are also helping your instructor to become aware of what is going on and to learn new things, your efforts are appreciated. Looking forward to reading what you find!

For this discussion, you will write an initial post and reply to at least TWO of your classmates' posts. Follow the guidelines for each posting below:

Basic Guidelines for Initial Post

(20 points, required)

Click on "Start a New Thread". You need to include all of the following in your own thread:

1. Find a geology or geology-related article that is dated no earlier than 3 days before the discussion first opened (for example, if the discussion opens on March 10, then you would need to find an article dated March 7 or after).
2. Initial post must be made before 3 days (72 hours) before the discussion closes.
3. Start a New Thread in the discussion, and put the full title of your article in the “enter a subject” line. Do not just leave it blank. It is very important that other students can see the title without entering your thread, so that it is easy for them to search for what they find most interesting.
4. In your post, please include the following information:
 - What is the title of your article? On what date (day/month/year) was it published online?
 - What is the full URL of your web-based source? (copy the whole web address; we must be able to visit the site and read the full article)
 - Why did you find this particular article interesting? In other words, what caught your attention, thus leading you to choose to share it?
 - In your own words, write a brief summary of what happened or was learned. In other words, what significant finding is being reported? (your answer must be at least five complete and meaningful sentences long, and **MUST** be in your own words; you will not get credit for sentences that you just copy/paste from the article!)

Basic Guidelines for Replies to Students

(10 points, required)

1. You are free to make replies to students with regard to either
 - a. your own article you may have posted for extra credit, or
 - b. another student’s article.
2. Each reply must contain 6 or 7 meaningful sentences directly related to article content. Phrases like “that is a great article!” and “I really liked your summary” do not count as meaningful content. However, these are still encouraging phrases in support of your peers so please feel free to include them in your post.
3. You must reply to at least 2 other students. (3, or more, for extra credit.)
4. If your replies are too short, you will need to make more than 2 replies to reach your full sentence count for the discussion (2 replies x 6 or 7 sentences each = 12-14 sentences required in each discussion).
5. Do not wait until the last day of the discussion to make your replies. You only receive credit for one reply (up to 10 points max) on the last day.
6. Reply early and often, and earning your full discussion points will be easy!

Extra Credit

(5 points, optional)

Make a third reply (or more!) to a student following the guidelines above.

Learning Outcomes

As a result of your participation in the discussion, you will become more aware of current events and news articles relating to topics in geology (i.e. become a more informed citizen). You will have some freedom in customizing this course to pursue your own interests in geology, including things not covered in the content of this course, by finding news articles on topics that relate to you.

Grading Rubric

Initial Post

20 points: Initial post met length and content requirements

15 points: Initial post needs minor improvements in length and content

10 points: Initial post needs major improvements in length or content

5 points: Initial post was made but with very little effort

0 points: Initial post was not made

Reply posts (each)

5 points: Reply was thoughtful, relevant, and met length requirements.

4 points: Reply needs minor improvements in relevancy and/or length.

2.5 points: Reply needs major improvements in relevancy and/or length.

1 points: Reply was made but with very little effort.

0 points: Reply was not made.

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CHAPTER OVERVIEW

7: Weathering, Erosion, and Sedimentary Rocks

[7.1: Introduction](#)

[7.2: Sedimentary Rock Identification](#)

[7.3: Assignment- Sedimentary Rock Lab](#)

[7.4: PCC Rock and Mineral Guide \(optional\)](#)

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7.1: Introduction

Module 7

Weathering, Erosion, and Sedimentary Rocks



Figure 1. View of Monument Valley from Hunts Mesa.

Introduction

This module includes two chapters that are very closely related. Weathering, the subject of Chapter 5, is the process that breaks down existing Earth materials and leads to the creation of soil. Most materials can be broken down by weathering, but some materials are more susceptible than others. For example, igneous rocks are fairly resistant to weathering, but over long periods of time they still erode away. In addition, there are a number of different processes that cause weathering, including mechanical and chemical processes. Different processes affect different materials at different rates, which leads to the formation of different types of sedimentary rocks, as you will discover as you read through Chapter 6.

We are particularly interested in the history and events that occur on the surface of the Earth both because it is easier to directly observe and test, and it has direct relevance to our lives and our own history. Sedimentary rocks are the pages in which Earth's history is written, since they contain powerful environmental indicators, traces of life, and chemical signatures that can inform us about a wealth of subjects from the occurrence of ancient catastrophes to the productivity of life.

The identification of sedimentary rocks is more than applying names, since each name is a loaded term that conveys information regarding its history, where it was formed, potentially when it was formed, and the processes that lead to its formation. Each sedimentary rock is a puzzle and by identifying a set of rocks, how they are layered, the fossils within, and patterns in the rocks a geologist can reconstruct an entire environment and ecosystem. Solving these puzzles is both an academic exercise to better understand the world around us as well as a tool for finding the resources that are important to our lives. In particular, fossil fuels as well as many other natural resources are made of, or are contained within, sedimentary rocks such as coal, natural gas, petroleum, salt, and cement, and more. Therefore, a better understanding of sedimentary rocks and how and where they are formed directly influences your everyday life.

Select an image to view larger

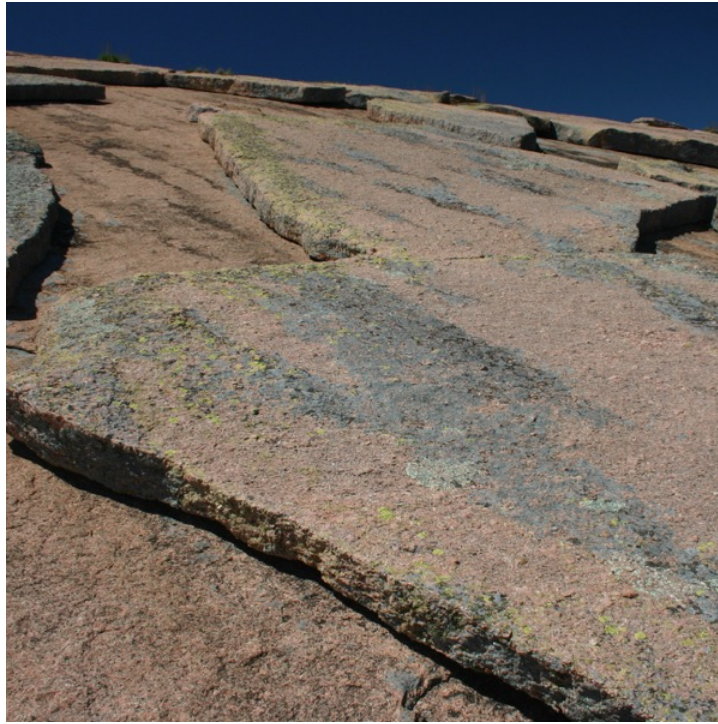


Figure 2. This is an example of sheet foliation, or exfoliation, of a granite dome, which is caused by the release of pressure within the granite as overlying materials were eroded away over time. This photo was taken in Enchanted Rock State Natural Area, Texas.



Figure 3. This photo shows a example of how freezing and thawing have weathered this rock in Iceland.



Figure 4. Sedimentary rock layers at Zion National Park. Most of the rocks in Zion National Park are sedimentary rocks –made of bits and pieces of older rocks that have been weathered, eroded, and deposited in layers. These rock layers hold stories of ancient environments and inhabitants very different from those found in Zion today. In this distant past, Zion and the Colorado Plateau were near sea level, and were even in a different place on the globe—close to the equator. The rock layers found in Zion today were deposited between approximately 110 –270 million years ago –only in recent geologic time have they been uplifted and eroded to form the scenery of Zion National Park. (National Park Service)

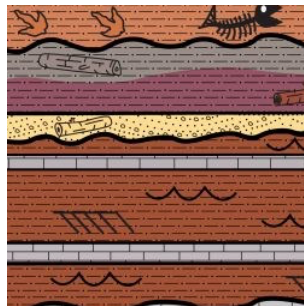


Figure 5. A stratigraphic column showing the history of the layers of rock in Zion National Park, illustrated by Geoscientist-in-the-Park David Tarailo.



Figure 6. Garden of the Gods, Colorado – Ancient sedimentary beds of deep-red, pink and white sandstones, conglomerates and limestone that were deposited horizontally, but have now been tilted vertically and faulted into fins by the immense mountain building forces caused by the uplift of the Rocky Mountains and the Pikes Peak massif.



Figure 7. The red sandstone formations of Cathedral Rock, Sedona, AZ.



Figure 8. 'The Wave' Formation of Vermilion Cliffs, at the border of Utah and Arizona, formed by erosion, water and wind.



Figure 9. Bryce Canyon, Utah. Bryce Canyon is not a 'real' canyon. It is not carved by flowing water. Water is the active ingredient here, but in the form of 'frost-wedging' and chemical weathering. For 200 days a year the temperature goes above and below freezing every day. During the day, melt water seeps into fractures only to freeze at night, expanding by 9%. Now as ice, it exerts a tremendous force (2,000-20,000 pounds per square inch). Over time this 'frost-wedging' shatters and pries rock apart. In addition, rain water, which is naturally acidic, slowly dissolves the limestone, rounding off edges and washing away debris. (National Park Service)

Module Objectives

At the completion of this module you will be able to:

1. Explain why rocks formed at depth in the crust are susceptible to weathering at the surface.
2. Describe the main processes of mechanical weathering and its products.

3. Describe the main processes of chemical weathering and its products.
 4. Explain the type of weathering processes that are likely to have taken place to produce a particular sediment deposit.
 5. Discuss the relationships between weathering and soil formation, the origins of soil horizons, and some of the different types of soil.
 6. Explain the geological carbon cycle, and how variations in rates of weathering can lead to climate change.
 7. Describe the differences between cobbles, pebbles, sand, silt, and clay and explain how clast size relates to the mode of transport.
 8. Describe the various types of clastic and chemical sedimentary rocks, and apply your understanding of their characteristics to infer past depositional environments and climates.
 9. Differentiate between terrestrial and marine depositional environments, and explain how the formation of sedimentary basins can be related to plate tectonic processes.
 10. Explain the importance of and differences between groups, formations, and members
-

Activities Overview

See the Schedule of Work for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

Physical Geology by Steven Earle

- Chapter 5 (Weathering)
- Chapter 6 (Sediments and Sedimentary Rocks)

Module 7 Assignment: Sedimentary Rock Lab

10 points

After you complete the reading, you can start working on [Module 7 Assignment – Sedimentary Rock Lab](#).

Module 7 Quiz

10 points

Module 7 Quiz has 10 multiple-choice questions and is based on the content of the Module 7 readings and Assignment 7.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

Your Questions and Concerns...

Please contact me if you have any questions or concerns.

General course questions: If your question is of a general nature such that other students would benefit from the answer, then go to the discussions area and post it as a question thread in the "General course questions" discussion area.

Personal questions: If your question is personal, (e.g. regarding my comments to you specifically), then send me an email from within this course.

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7.2: Sedimentary Rock Identification

Sedimentary Rock Identification

Introduction

Rocks are made of minerals. Rocks can be a mixture of different kinds of minerals, a mixture of many grains of the same kind of mineral, or a mixture of different grains of rocks. When you split a rock into very small pieces, the pieces are different from each other. For example, when you break granite apart, you get small pieces of quartz (clear), feldspar (pink or white), and mica (black). When you split a mineral into pieces, you still have pieces of the same mineral. If you break a big chunk of quartz into smaller pieces, you still have pieces of quartz.

There are three basic rock types: Igneous, sedimentary, and metamorphic.

Sedimentary Rocks

Sedimentary rocks (layered rocks) are made by the deposition of particles carried in air or water and by the precipitation of chemicals dissolved in water. These particles and chemicals come from the weathering (breaking apart in place) and erosion (carrying away and breaking apart while moving) of rocks on the Earth's surface. Boulders, rocks, gravel, sand, silt, clay, and mud are carried by water currents in streams, rivers, lakes, and oceans. These particles are deposited in stream beds, shores, lake and ocean bottoms, and deltas where rivers empty into lakes and oceans. These particles are cemented together and hardened to form the sedimentary rocks called conglomerate, sandstone, siltstone, shale or claystone, and mudstone.

Chemicals that are leached or dissolved from other rocks are carried invisibly in streams and oceans. When these invisible chemicals reach a lake or ocean, and the water evaporates, the chemicals are left behind in evaporite deposits. Salt around salt lakes and limestone from sea bottoms are examples of these chemical sedimentary rocks. Plants and animals are sometimes buried and preserved in the finer grained sedimentary rocks, such as shale or limestone.

Sedimentary rocks are derived from pre-existing rocks by weathering and erosion. The resulting particles settle out of water or air (clastic rocks such as sandstone and mudstone) or the resulting chemicals precipitate from concentrated solutions (non-clastic rocks such as limestone and salt).

Examples of Sedimentary Rocks

Formation	Characteristic	Rock Name
particles	course-angular	Breccia
particles	course-round	Conglomerate
particles	medium (less than 2 mm)	Sandstone
particles	fine (smooth)	Shale
chemicals	fizzes in dilute HCl acid	Limestone
chemicals	fizzes in acid only if scratched first	Dolomite
chemicals	salty taste	Halite
chemicals	scratched by a fingernail	Gypsum
chemicals	scratches glass, conchoidal fracture, like flint	Chert

Clastic Sedimentary Rocks

How Clastic Sedimentary Rocks are Formed:

1. Pre-existing rock undergoes chemical and mechanical weathering by roots, acid rainwater, gravity, wind, and water.
2. The broken particles are carried through water or air until they settle out in a lower area when the current wasn't fast enough to carry the particles.

3. Quartz is the most stable and has the greatest resistance to the mechanical and chemical abrasion during erosion, so most sand size grains are quartz.
4. Feldspar alters to clay with chemical weathering and erosion, so arkose, which is sandstone with more than 25% feldspar, indicates the sediment was deposited close to the source rock and was not in transport long.
5. Grain size and shape and composition can indicate the composition, distance, and height of the source rock.
6. Textures & structures (ripple marks, cross-bedding, sorting, etc.) and size, shape, and composition can indicate the environment of deposition.

Characteristics:

1. Soft, compared to igneous rocks.
2. Occur in layers or beds from a few millimeters thick to 100 feet thick, most commonly 1-5 ft. thick.
3. Granular and gritty if composed of sand and silt-sized particles; sand is often rounded, sometimes angular.
4. Sedimentary structures (cross-bedding, mud cracks, ripple marks, worm trails and burrows, fossil shells) are not usually visible in hand specimens, but are noticeable in outcrops.
5. Color is not usually significant, because as little as 3% hematite (iron oxide) gives a rich red color. Some pinkish sandstones get their color from feldspar.
6. Fossils are more common in shales than sandstones, because of the higher current activity in sandstones.

Clastic Sedimentary Rock Table

Particles	Size	Minerals	Character	General Size	Rock Name
Gravel	> 2 mm	Rock fragments, quartz, feldspar	>Pebbles	Course	Conglomerate
Sharp Gravel	> 2 mm	Rock fragments, quartz, feldspar	Angular	Course	Breccia
Course Gravel to Fine Clay	> 2 mm	Any rock type	Poorly sorted, non-stratified, angular	Fine to Course	Tillite
Sand	2- 1/16 mm	Quartz, feldspar	Granular	Sandy	Sandstone
Silt	1/16-1/256 mm	Clay, quartz	Gritty	Gritty, fine-grained	Siltstone
Clay	< 1/256 mm	Clay	Platy, massive	Smooth, very fine-grained	Shale, Claystone
Silt and Clay	< 1/16 mm	Clay, quartz	Massive	Smooth, very fine-grained	Mudstone

Non-Clastic Sedimentary Rocks

How Non-Clastic Sedimentary Rocks are Formed:

Formed by chemical precipitation from a concentrated solution in water as salt, gypsum, or limestone.

Characteristics:

1. Soft, because they are composed of soft minerals such as halite, gypsum, calcite. They can easily be scratched with steel or a copper penny.
2. Commonly fine-grained and homogeneous.
3. Fossils are common in limestone.
4. Limestone fizzes in dilute hydrochloric (HCl) acid, because it is composed of the mineral calcite, CaCO_3 .
5. Some limestone contains chert, which is very, very hard silica (like flint). It typically weathers to brown on the surface and occurs in nodules and occasionally replaces fossil shells.

Non-Clastic Sedimentary Rock Table

Mineral	Chemical Form	Characteristics	Rock Name
Calcite	CaCO_3	Fizzes in HCl acid	Limestone

Mineral	Chemical Form	Characteristics	Rock Name
Calcite	CaCO_3	Medium to coarse-grained, fizzes in acid	Crystalline Limestone
Calcite	CaCO_3	Microcrystalline, conchoidal fracture, fizzes in acid	Micrite
Calcite	CaCO_3	Aggregates of small round spheres, fizzes in acid	Oolitic Limestone
Calcite	CaCO_3	Fossils and fossil fragments loosely cemented, fizzes in acid	Coquina
Calcite	CaCO_3	Fossils in calcareous matrix, fizzes in acid	Fossiliferous Limestone
Calcite	CaCO_3	Shells of microscopic organisms and clay, soft, fizzes in acid	Chalk
Calcite	CaCO_3	Banded calcite – cave deposits, fizzes in acid	Travertine
Halite	NaCl	Tastes salty, fine to coarse crystalline	Salt
Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	Fine to coarse crystalline, softer than fingernail, white, grainy	Gypsum
Microscopic quartz chalcedony	SiO_2	Cryptocrystalline, dense, conchoidal fracture, dull, very hard (scratches glass)	Chert
Dolomite	$\text{CaMg}(\text{CO}_3)_2$	Fizzes in acid only if scratched first	Dolomite
Carbon	C	Brownish plant material – soft, porous, fibrous	Peat
Carbon	C	Black, vitreous, crumbly	Coal

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7.3: Assignment- Sedimentary Rock Lab

Module 7 Assignment

Sedimentary Rock Lab



Figure 1. Colorful layers of sedimentary rock in Makhtesh Ramon, Israel

Overview

You can start the activity after you have completed the reading assignment.

In Chapter 6 you learned about the different types of sedimentary rocks, and some of the key characteristics. In this lab, you will study photos of several sedimentary rocks and determine their physical properties.

Instructions

A. Before you begin this activity, you may also wish to review the [Sedimentary Rock Identification](#) page. Some optional resources you can use are:

- [PCC Rock and Mineral Guide](#)
- [Geology.com Mineral Guide](#)
- [Geology.com Rock Guide](#)
- [Minerals A-Z](#), Minerals.net

B. Select each photo below to view the igneous rock samples larger. You can also view the images in Flickr by clicking the link, and zoom in on each of these samples in the picture to get a better view of their texture:

Select an image to view larger



Figure 2. Black shale in Whtstone Creek



Figure 3. Calcareous tufa with plant fragments from the Holocene of Ohio, USA (6.7 cm across at its widest). Calcareous tufa is a scarce, calcitic, crystalline-textured, chemical sedimentary rock. It principally forms around cold springs having water relatively rich in dissolved calcium carbonate. Calcareous tufa is often characterized as a lightweight, porous, friable precursor to travertine (another calcitic, chemical sedimentary rock). Here's a light brown-colored calcareous tufa sample with plant fragments – many of the cylindrical structures visible here are calcite tubes formed around plant stems, axes, or roots. – James St. John



Figure 4. Sandstone from the Paleozoic of Ohio, USA. Sandstone is the second-most common sedimentary rock on Earth. It is composed of sand-sized grains, which are between 2 millimeter and 1/16 of a millimeter in size each. Most sandstones are dominated by quartz grains, but feldspar sand grains and lithic sand grains (= sand-sized rock fragments) are often present as well.—James St. John



Figure 5. A sample of a conglomerate rock.



Figure 6. Grand Canyon_Fossil Brachiopod in Kaibab Limestone

- [Shale](#)
- [Calcareous Tufa](#)
- [Sandstone](#)
- [Conglomerate](#)
- [Limestone](#)

C. Determine the following characteristics to the best of your ability from the photos of the samples above:

1. Color
2. Texture (clastic or crystalline/chemical?)
3. Approximate Grain Size (for clastic rocks only: fine, medium, or coarse grained?)
4. Sorting (for clastic rocks only: well-sorted, poorly-sorted, or somewhere in between?)
5. Depositional Environment (in what general environment was this rock originally formed?)
6. Compare your personal observations with the information in the course Rock and Mineral Guide (above). How is each sample different (or similar) from the Guide?
7. For one of the rock samples of your choice, write a half-page summary describing the physical characteristics you can determine from the photo or from any personal sample you have collected. If using a personal sample, please include a photograph. For all the other samples above, include a table summarizing the characteristics you observed (1 – 6). You will be graded on this activity as described in the rubric below.

Grading Rubric

10 points: Report accurately summarized the sedimentary rock characteristics, spelling and grammar are correct and complete sentences are used, including a photograph. Characteristics of the other samples are included in a table and are accurate.

8 points: Report mostly captured the sedimentary rock characteristics, spelling and grammar are mostly correct and complete sentences are used, including a photograph. Characteristics of the other samples are included, but one or two details were missing.

5 points: Report missed two or more characteristics, included spelling and grammar errors, and/or did not include a photograph. Characteristics of the other samples are included, but over half of the samples and/or characteristics are missing.

2 points: Report was inaccurate, included significant spelling and grammar errors, and/or did not include a photograph. Characteristics of the other samples are not included.

0 points: Did not complete the assignment.

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7.4: PCC Rock and Mineral Guide (optional)

PCC Rock and Mineral Guide

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CHAPTER OVERVIEW

8: Metamorphism and Metamorphic Rock

[8.1: Introduction](#)

[8.2: Metamorphic Rock Identification](#)

[8.3: Assignment- Metamorphic Rock Lab](#)

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8.1: Introduction

Module 8

Metamorphism and Metamorphic Rock



Figure 1. In Black Canyon of the Gunnison National Park, the Gunnison River cuts through Precambrian rock nearly 2 billion years old! Most of these rocks are metamorphic and show evidence of exposure to extreme pressures and temperatures. Some of the rocks are igneous and formed from magma that pushed its way up into cracks in the Earth's crust, where it cooled and crystallized. The metamorphic rock that dominates the walls of the Black Canyon is called gneiss (pronounced 'nice'), and is blended with schist, another rock that normally has flat or elongated crystals. You might spot the intense folding of the alternating light and dark bands in this adjacent photo. These rocks were once buried deep below the Earth's surface where they encountered extreme heat and pressure.

Introduction

In any introductory textbook on physical geology, the reader will find the discussion on metamorphic rocks located after the chapters on igneous and sedimentary rocks, and for very good reason. Metamorphic rocks form by the physical and sometimes chemical alteration of a pre-existing rock, whether it is igneous or sedimentary. In some cases, even metamorphic rocks can be altered into a completely different metamorphic rock. With igneous rocks forming from the melt produced by any rock type and a sedimentary rock forming from the weathered product of any rock type, the alteration of any rock to produce a metamorphic one completes the components of what is known as the rock cycle.

Basically, the rocks we encounter today that we classify as either igneous, metamorphic, or sedimentary, could have belonged to a different rock classification in the past, because rocks are recycled throughout geologic time. This cycle is driven by the motion of the tectonic plates. It is easy to see that increasing the temperature of a rock can produce magma, and that rocks on the surface of the Earth can break up into sediment that can ultimately lithify into a sedimentary rock. But how can we alter a solid rock into a new rock, without melting it or making it become sediment?

All rocks are formed at certain temperatures and pressures either on Earth's surface or, more commonly, beneath the surface. These rocks are the most stable at the conditions under which they form. Therefore, changing the temperature and/or pressure conditions may lead to a different rock, one that changed in order to be stable under new external conditions. This new rock that forms in response to changes in its physical and chemical environment is called a metamorphic rock; the word metamorphism means to change form, and for rocks this means a recrystallization of minerals (crystals) under subsolidus (temperatures too low for melt production) conditions. A metamorphic change can also occur if the rock's composition is altered by hot, chemically reactive fluids, causing a change in the mineral content of the rock. To distinguish between the pre-existing rock and the new metamorphic one, the term protolith, or parent rock, is used to describe the pre-existing rock. Therefore, all metamorphic rocks have at least one protolith that has altered during metamorphism. In this module you will learn that all metamorphic rocks are identified by the mineral content and texture of the rock; for metamorphic rocks, texture refers to the orientation of the minerals in the rock. In addition, crystal size also conveys important information regarding the temperature conditions during metamorphism.

To summarize, metamorphism is the process by which a pre-existing rock (the protolith) is altered by a change in temperature, pressure, or by contact with chemically reactive fluids, or by any combination of these three parameters. The alteration process is a recrystallization event, where the initial rock's minerals (crystals) have changed size, shape, and/or composition in response to these new external conditions. The end result is a new (metamorphic) rock that has an altered appearance, sometimes strikingly different from what it used to look like before metamorphism occurred. The metamorphic rock you end up with is strongly dependent on what rock you started with before the metamorphic event. Of secondary importance is the agent of metamorphic change: was recrystallization a result of increased temperature, pressure, or both? Or were chemically reactive fluids involved?

One must also consider how high the temperatures and pressures were, because metamorphism can occur in a range of temperature and pressure conditions. However, as mentioned in the preceding paragraph, metamorphism occurs under subsolidus conditions, meaning that elevated temperatures that promote the recrystallization of a rock are not high enough to cause melting.

Select an image to view larger



Figure 2. Maps shows the North American distribution of metamorphic rock.



Figure 3. Painted Wall overlook – Painted Wall named for the many light colored granitic dikes that appear to some as an artists brush strokes on a canvas of dark metamorphic rocks. In fact, the granitic dikes are igneous intrusions into the older metamorphic rocks.



Figure 4. Vertically-tilted metamorphic rocks near Carn Eighe in the Northern Highlands of Scotland. These rocks belong to the Glenfinnan Group (part of the Moine Supergroup), and they are of Neoproterozoic age.



Figure 5. Rocks near Pemaquid Lighthouse in Maine. Bands of the metamorphic rock type called gneiss, capped by a light-coloured pegmatite vein, at Pemaquid Point, near Pemaquid Lighthouse in Maine, USA. The gneiss belongs to the Bucksport Formation, formed originally as sedimentary rock during the Silurian period (about 440 to 430 million years ago). Then, during the Devonian period, the sedimentary rock was heated and squashed, which changed the rock into gneiss. Although the pegmatite has not been precisely dated, it may be of Devonian age.



Figure 6. Long's Peak framed by metamorphic rock outcrop From Trail Ridge Road, Rocky Mountain National Park, CO

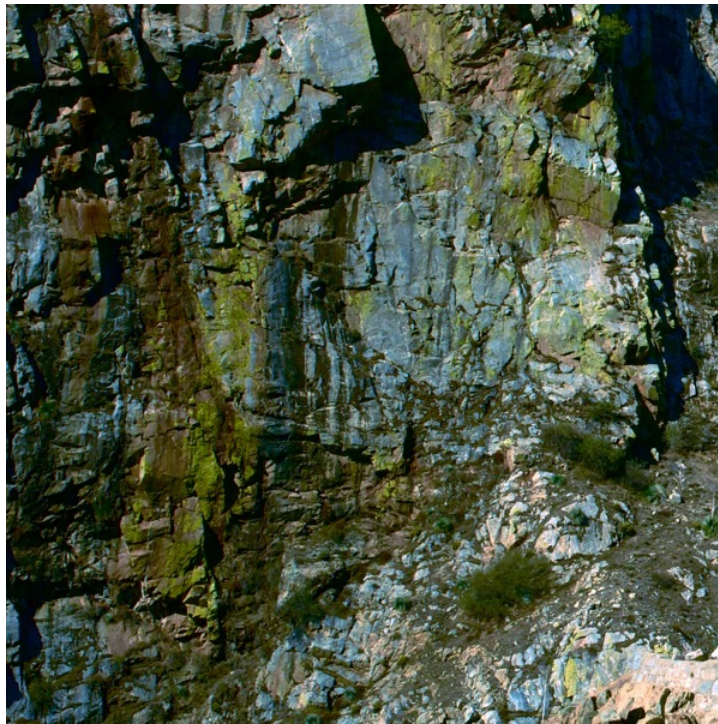


Figure 7. Metamorphic Rock and Kings Canyon Road (Highway 180) The metamorphic rock is remnants of a ancient mountain range – the Nevada Range, situated at the western edge of Laurasia, the Late Jurassic supercontinent of the north.



Figure 8. Phyllite in the Precambrian of Tennessee, USA. This is an outcrop of Metcalf Phyllite in the Great Smoky Mountains. It's one of many stratigraphic units in the ~50,000 feet thick Ocoee Supergroup. The Ocoee has considerable deposits of sandstone and shale originally deposited as sands and muds in an ancient ocean trench. Trenches form along subduction zones, where a tectonic plate composed of thin, heavy oceanic lithosphere dives down into the mantle below another tectonic plate of either oceanic lithosphere or thick, lightweight continental lithosphere. Rocks in the Metcalf Phyllite were originally shales, but have been metamorphosed to phyllites. Phyllite is a foliated, low to intermediate grade metamorphic rock dominated by mica. It often has wrinkled and crinkled foliation surfaces.



Figure 9. Slate in the Precambrian of Minnesota, USA. This is an outcrop of slate, a foliated metamorphic rock composed of clay minerals. Slate is the product of low-grade metamorphism of shale. The original shale bedding is visible in slate samples at this locality. The planar surfaces facing the viewer in the above photo are foliation planes.



Figure 10. Augen Gneiss. Gneiss is a high-grade, foliated metamorphic rock that consists of alternating bands of light- and dark-colored minerals (often quartz and biotite mica). The surface shown above consists of Precambrian-aged gneiss. The surrounding outcrop is gneiss with some shear zones and minor faults. Some epidote is present in bands and small pods. Notice the eye-shaped masses of quartz in the middle part of the photo. Gneiss with roughly eye-shaped mineral masses is called augen gneiss (augen is German for eyes).



Figure 11. Quartzite and schist near Kerguinou in Crozon, Brittany, France



Figure 12. The Vishnu Schist is a metamorphic complex that forms the basement rock of the Grand Canyon. It is a little over 1.7 billion years old.

Module Objectives

At the completion of this module you will be able to:

1. Summarize the factors that influence the nature of metamorphic rocks and the mechanisms for the formation of foliation, if present.
2. Classify metamorphic rocks on the basis of their texture and mineral content, and explain the origins of these differences.
3. Describe the various settings in which metamorphic rocks are formed and explain the links between plate tectonics and metamorphism.
4. Summarize the important processes of regional metamorphism, and explain how rocks that were metamorphosed at depths of 10 km or 20 km can now be found on Earth's surface.
5. Summarize the important processes of contact metamorphism and metasomatism, and explain the key role of hydrothermal fluids.

Activities Overview

See the Schedule of Work for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

Physical Geology by Steven Earle

- Chapter 7 (Metamorphism and Metamorphic Rock)

Module 8 Assignment: Metamorphic Rock Lab

10 points

After you complete the reading, you can start working on [Module 8 Assignment – Metamorphic Rock Lab](#)

Module 8 Quiz

10 points

Module 8 Quiz has 10 multiple-choice questions and is based on the content of the Module 8 readings and Assignment 8.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

[Your Questions and Concerns...](#)

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General course questions: If your question is of a general nature such that other students would benefit from the answer, then go to the discussions area and post it as a question thread in the “General course questions” discussion area.

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8.2: Metamorphic Rock Identification

Metamorphic Rocks

Metamorphic Rock Identification

Introduction

Rocks are made of minerals. Rocks can be a mixture of different kinds of minerals, a mixture of many grains of the same kind of mineral, or a mixture of different grains of rocks. When you split a rock into very small pieces, the pieces are different from each other. For example, when you break granite apart, you get small pieces of quartz (clear), feldspar (pink or white), and mica (black). When you split a mineral into pieces, you still have pieces of the same mineral. If you break a big chunk of quartz into smaller pieces, you still have pieces of quartz.

There are three basic rock types: Igneous, sedimentary, and metamorphic.

Metamorphic Rocks

Metamorphic rocks (changed rocks) are made when existing rocks are subjected to high temperatures and high pressures for long periods of time. Metamorphism (meta = change, morph = form) happens when molten rock intrudes other rocks and bakes the contact zone where the molten rock touches the preexisting rock. Metamorphism also happens when rocks are buried deeply during the process of mountain building. The kind of metamorphic rock made depends on the kind of original rock; for example, sandstone is turned to quartzite, shale is turned to slate, and limestone is turned to marble. Other kinds of metamorphic rock are named for the kinds of minerals present, the size of the grains and other textures. For example, mica schist has very thin layers of mica, and garnet gneiss (pronounced like nice) has garnet crystals in thick layers of quartz and feldspar. The amount of time, amount of pressure, and highness of temperature determine what types of metamorphic rocks are made.

How Metamorphic Rocks are Made

1. Pressure from the weight of overlying rocks or from stresses of mountain building rearranges the minerals in rocks into bands or rearranges the atoms of the minerals into new minerals.
2. Heat from the intrusion of a large igneous mass can metamorphose a large area.
3. Heat from the intrusion of a dike or sill or flow can bake the adjoining rocks in a contact metamorphic zone.

Composition

The mineral composition of the rock can be determined based on observations with a hand lens and if needed, physical or chemical tests. Start by identifying and list all visible minerals present in the rock.

Probable Parent Rocks

All metamorphic rocks are derived by the action of heat and/or pressure on pre-existing igneous, sedimentary, or metamorphic rocks. The pre-existing rock is called either the parent rock or the protolith. Your textbook incorrectly uses the term “source rocks” for the pre-existing rock. The term source rock used in sedimentary deposits to describe the rock from which petroleum is derived, or the rock that erodes to produce sediment and later sedimentary rock. Read the descriptions in your lab manual or textbook for the source rock of each of the metamorphic rocks that you identify. Indicate in the name(s) of the probable parent rock(s) in the last column of the metamorphic rock identification form.

Texture

The term texture refers to the size, shape, and boundary relationships of the minerals, particles, and other substances that make up a rock. There are two major textural groups in metamorphic rocks: Foliated and Non-Foliated.

Examples of Metamorphic Rock Textures

Texture	Characteristics	Rock Name
foliated (banded)	very thin layers	Slate
foliated (banded)	wavy layers with sheen	Phyllite
foliated (banded)	thin layers of mica	Schist

Texture	Characteristics	Rock Name
foliated (banded)	thick layers of quartz, feldspar, and mica	Gneiss
non-foliated (massive)	welded quartz sandstone	Quartzite
non-foliated (massive)	sugary to coarse crystals, fizzes in HCl acid	Marble
non-foliated (massive)	dense, black, fine grained, flint-like fracture	Hornfels

Foliated (Banded) Metamorphic Rocks

In this texture, the mineral crystals in the rock are aligned with each other. This alignment may be displayed as parallel planes along which the rock splits, by overlapping sheets of platy minerals such as micas, by the parallel alignment of elongate minerals such as amphiboles, or by alternating layers of light and dark minerals. Foliated texture is further subdivided based on the presence or absence of pronounced color banding in the rock. Rocks without distinct alternating bands of light and dark minerals are described as *nonlayered*, whereas rocks with alternating bands of dark and light minerals are described as *layered*. Layered is also referred to as gneissic foliation. Foliated textures are further described on the basis of the grain (crystal) size in the rock. Examples of complete descriptions of foliated metamorphic rocks include: foliated, nonlayered, very fine grained for slate, foliated, layered, coarse grained for gneiss, and foliated, nonlayered, fine grained for phyllite. Foliated textures produced by shearing and breaking, such as in a fault zone or a meteor impact crater, are referred to as *mylonitic*.

Foliated (Banded) Metamorphic Rock Table

Characteristics	Minerals	Rock Name
Very thin layers, like blackboards Very fine-grained Smooth, flat surfaces, from slaty cleavage Separate grains not visible Dense, brittle, clinking sound	Mica Quartz Clay (microscopic)	Slate
Very, very thin, irregular layers of mica Usually pale gray green Satin sheen to rock rather than individual flakes Fine to medium-grained Uneven surfaces Grains visible	Mica Quartz Other minerals	Phyllite
Thin, irregular layers of mica & platy minerals Usually pale gray green Medium-grained Uneven surfaces Grains visible	Mica (muscovite, biotite) Chlorite Talc Hornblende Quartz Garnet Feldspar	Schist
Thin, irregular layers of mica and platy minerals	Bluish color; mica, quartz	Blueschist
Thin, irregular layers of mica and platy minerals	Greenish color; mica, quartz, serpentine	Greenschist

Characteristics	Minerals	Rock Name
Thick bands, wavy, semi-continuous layers of white quartz, feldspar, and mica Medium to coarse-grained Banded, coarsely crystalline Large, crystalline grains	Feldspar Quartz Mica Hornblende Garnet	Gneiss

Non-Foliated Metamorphic Rocks

In this texture the mineral crystals in the rock have grown in many directions and do not show alignment. As a result, nonfoliated rocks commonly appear massive and structureless, with only a few lines of impurities through the rock. These rocks may break across, rather than around, mineral grains to produce a scaly surface on the specimen. Nonfoliated textures are further described on the basis of the grain (crystal) size in the rock. Examples of complete descriptions of nonfoliated metamorphic rocks include nonfoliated, medium grained for quartzite, or nonfoliated, coarse grained for marble.

Non-Foliated Metamorphic Rock Table

Characteristics	Former Rock	Rock Name
Very hard, smooth Stretched and welded cobbles and pebbles – Fractures through grains, not around them as in rougher conglomerate Composed of rock fragments, quartz, chert	Conglomerate	Meta-conglomerate
Very hard, smooth Welded sand grains – Fractures through grains, not around them as in rougher sandstone	Sandstone	Quartzite
Fizzes in dilute acid Medium to coarse-grained Sugary to crystalline Composed of calcite (CaCO_3)	Limestone	Marble
Very hard, flint-like fracture Smooth, very fine-grained Dark colored to black Very dense, compact	Claystone Slate Mudstone Shale	Hornfels
Black to brown Dense, highly altered plant remains Carbon, opaque, non-crystalline	Peat	Coal

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8.3: Assignment- Metamorphic Rock Lab

Module 8 Assignment

Metamorphic Rock Lab



Figure 1. Shiny Vishnu Schist in the Grand Canyon. The Vishnu Schist is a metamorphic complex that forms the basement rock of the Grand Canyon. It is a little over 1.7 billion years old.

Overview

You can start the activity after you have completed the reading assignment.

In this lab, you will study photos of several metamorphic rocks and determine their physical properties.

Instructions

A. Before you begin this activity, you may also wish to review the [Metamorphic Rock Identification](#) page. Some optional resources you can use are:

- [PCC Rock and Mineral Guide](#)
- [Geology.com Mineral Guide](#)
- [Geology.com Rock Guide](#)
- [Minerals A-Z](#), Minerals.net

B. Select each photo below to view the igneous rock samples larger. You can also view the images in Flickr by clicking the link, and zoom in on each of these samples in the picture to get a better view of their texture:

Select an image to view larger



Figure 2. Red slate (5.8 cm across at its widest).

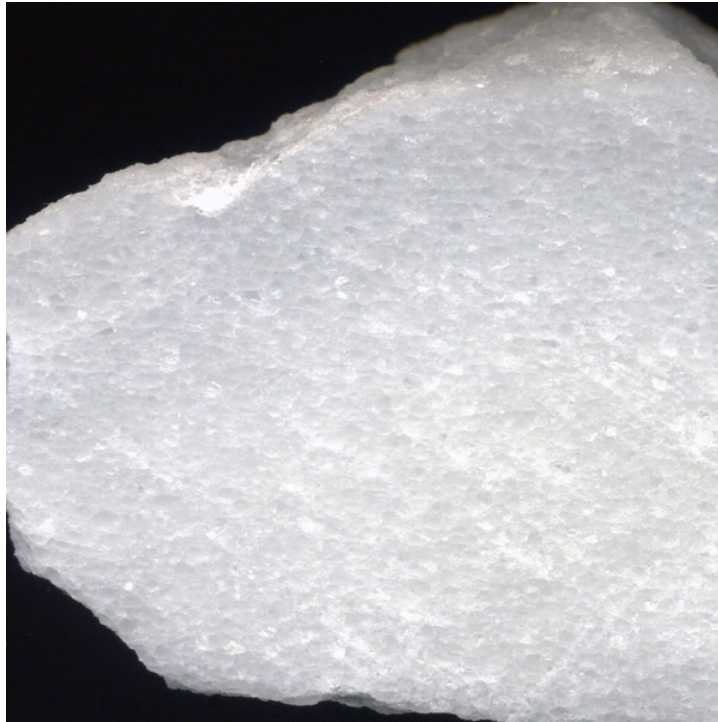


Figure 3. Marble from the Miocene of Colorado, USA. (6.2 cm across at its widest). The specimen shown above is from the Yule Marble, the state rock of Colorado, quarried near the town of Marble, Colorado, USA. Yule Marble formed by contact metamorphism of the Leadville Limestone (Mississippian). The igneous intrusion that metamorphosed limestone into marble is the Treasure Mountain Granite (Middle Miocene, 12 Ma). – James St. John



Figure 4. Quartzite (metaquartzite). Quartzite is a common, crystalline-textured, intermediate- to high-grade metamorphic rock. It forms by metamorphism of quartzose sandstones or siltstones. Quartzite can be entirely composed of interlocking quartz crystals, or the original sand grains may still be visible. This rock is hard ($H = 7$), will not bubble in acid (unlike marble), and can be almost any color.



Figure 5. Gneiss. Gneiss is a high-grade, foliated metamorphic rock. It differs from lower grade foliated metamorphics, such as slate, phyllite, and schist, by having alternating bands or stripes of light and dark minerals. Metamorphism has been so intense that minerals have self-segregated into discrete zones. Most gneisses form by metamorphism of schists or granites..



Figure 6. Muscovite Schist. The muscovite schist shown above is a common variety of mica schist.

- [Slate](#)
- [Marble](#)
- [Quartzite](#)
- [Gneiss](#)
- [Schist](#)

C. Determine the following characteristics to the best of your ability from the photos of the samples above:

1. Color
2. Texture (foliated or non-foliated?)
3. Probable mineral content
4. Probable parent rock
5. Was this rock a product of low-, medium-, or high-grade metamorphism?
6. Compare your personal observations with the information in the course Rock and Mineral Guide (above). How is each sample different (or similar) from the Guide?
7. For one of the rock samples of your choice, write a half-page summary describing the physical characteristics you can determine from the photo or from any personal sample you have collected. If using a personal sample, please include a photograph. For all the other samples above, include a table summarizing the characteristics you observed (1 – 6). You will be graded on this activity as described in the rubric below.

Grading Rubric

10 points: Report accurately summarized the metamorphic rock characteristics, spelling and grammar are correct and complete sentences are used, including a photograph. Characteristics of the other samples are included in a table and are accurate.

8 points: Report mostly captured the metamorphic rock characteristics, spelling and grammar are mostly correct and complete sentences are used, including a photograph. Characteristics of the other samples are included, but one or two details were missing.

5 points: Report missed two or more characteristics, included spelling and grammar errors, and/or did not include a photograph. Characteristics of the other samples are included, but over half of the samples and/or characteristics are missing.

2 points: Report was inaccurate, included significant spelling and grammar errors, and/or did not include a photograph. Characteristics of the other samples are not included.

0 points: Did not complete the assignment.

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CHAPTER OVERVIEW

9: Geologic Time

[9.1: Introduction](#)

[9.2: Assignment- Relative Dating and Cross Cutting Relationships](#)

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9.1: Introduction

Module 9

Geologic Time



Figure 1. There is about a 1.2 billion year gap in the rock – that is the Great Unconformity. Clear Creek trail, Grand Canyon National Park

Introduction

Geologic time is immense. The Earth has existed for approximately 4.6 billion years, and many geologic processes occur over timescales of millions of years. Given that it is unusual for a person to live over 100 years, grasping the immensity of geologic time is challenging. In this module, you will learn about ways in which relative time can be determined, and about techniques that can be used to estimate numerical ages of Earth materials. You will also learn about the units that are used to measure geologic time.

The amount of time that is involved in the carving of the landscape, the formation of rocks, or the movement of the continents is an important scientific question. Different hypotheses about the age of the Earth can essentially change our perspective of the workings of geologic events that molded the Earth. If the geologic time is relatively short then catastrophic events would be required to form the features we see on the surface of the Earth, whereas a vast amount of time allows the slow and steady pace that we can easily observe around us today.

Geologists have used many methods to reconstruct geologic time and mapping the major events in Earth's history as well as their duration. Scientists studying rocks were able to piece together a progression of rocks through time to construct the Geologic Time Scale below. This time scale was constructed by lining up in order rocks that had particular features such as rock types, environmental indicators, or fossils. Scientists looked at clues within the rocks and determined the age of these rocks in a comparative sense. This process is called relative dating, which is the process of determining the comparative age of two objects or events. For example, you are younger than your parents. It doesn't matter your age or your parents' age, as long as you can establish that one is older than the other. As time progressed, scientists discovered and developed techniques to date certain rocks,

as well as the Earth itself. They discovered the Earth was billions of years old (4.54 billion years old) and put a time frame to the geologic time scale. This process is called absolute dating, which is the process of determining the exact amount of time that has passed since an object was formed or an event occurred.

	Eon	Era	Period		Epoch	
P H A N E R O Z O I C		Cenozoic	Quaternary		Holocene	0 Yr.
					Pleistocene	15K Yr
			Tertiary	Neogene	Pliocene	1.8 Ma
					Miocene	5.3 Ma
				Paleogene	Oligocene	24 Ma
					Eocene	34 Ma
					Paleocene	55 Ma
		Mesozoic	Cretaceous			
			Jurassic		142 Ma	
			Triassic		202 Ma	
		Paleozoic	Permian		251 Ma	
			Pennsylvanian	Carboniferous	292 Ma	
			Mississippian		320 Ma	
			Devonian		354 Ma	
			Silurian		417 Ma	
			Ordovician		440 Ma	
			Cambrian		495 Ma	
				545 Ma		
Proterozoic	Pre-Cambrian (general)					
Archean						
Hadean						
2500 Ma						
4000 Ma						
4550 Ma						

Figure 2. The geologic time scale. “Ma” stands for millions of years [ago], while “K Yr” stands for thousands of years [ago].

Both absolute and relative dating have advantages and are still frequently used by geologists. Dating rocks using relative dating allows a geologist to reconstruct a series of events cheaply, often very quickly, and can be used out in the field on a rocky outcrop. Relative dating also can be used on many different types of rocks, where absolute dating is restricted to certain minerals or materials. However, absolute dating is the only method that allows scientists to place an exact age to a particular rock.

Select an image to view larger



Figure 3. These folded and crumpled strata are in the cliffs just to the north of Hartland Quay, Devon, UK. The rocks of Hartland Quay are the remains of a mountain range. Sedimentary rocks were deposited in a shallow sea during the Carboniferous period – about 320 million years ago. The layers are sequences of shales and mudstones representing the remains of sub-marine “avalanches” of sediments called turbidites. At the same time as the sands and mudstones were being deposited at Hartland, coals were being deposited in swamps, forming the South Wales coalfields. Plate tectonics caused the collision of two super continents with Hartland Quay in the middle. Devon was at the southern margin of a super-continent called Laurasia, which collided with the super-continent Pangaea – to the South. As these two mega-continent collided during the Variscan Orogeny the rocks at Hartland Quay were buckled and folded, producing the spectacular chevron shaped folds exposed in the cliffs today. The top surface was then eroded flat. – Simon Jones



Figure 4. Close up image of the layers of sediment at Hartland Quay of Figure 1.



Figure 5. Santa Elena Canyon, Big Bend, Texas. From 500 million year old rocks at Persimmon Gap to modern-day windblown sand dunes at Boquillas Canyon, geologic formations in Big Bend demonstrate amazingly diverse depositional styles over a vast interval of time.



Figure 6. Acasta Gneiss, Northwest Territory, Canada. At 3.96 billion years old, this gneiss is one of the oldest known Earth rocks. The Earth is 500 million years older still, but little record of that early time has survived our planet's geologic activity.



Figure 7. The Earth is very old — 4.5 billion years or more according to recent estimates. Most of the evidence for an ancient Earth is contained in the rocks that form the Earth's crust. The rock layers themselves — like pages in a long and complicated history — record the surface-shaping events of the past, and buried within them are traces of life —the plants and animals that evolved from organic structures that existed perhaps 3 billion years ago. Also contained in rocks once molten are radioactive elements whose isotopes provide Earth with an atomic clock. Within these rocks, 'parent' isotopes decay at a predictable rate to form 'daughter' isotopes. By determining the relative amounts of parent and daughter isotopes, the age of these rocks can be calculated. Thus, the results of studies of rock layers (stratigraphy), and of fossils (paleontology), coupled with the ages of certain rocks as measured by atomic clocks (geochronology), attest to a very old Earth!

Module Objectives

At the completion of this module you will be able to:

1. Apply basic geological principles to the determination of the relative ages of rocks.
 2. Explain the difference between relative and absolute age-dating techniques.
 3. Summarize the history of the geological time scale and the relationships between eons, eras, periods, and epochs.
 4. Understand the importance and significance of unconformities.
 5. Describe the applications and limitations of using isotopes, tree rings, and magnetic data for geological dating.
-

Activities Overview

See the Schedule of Work for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

Physical Geology by Steven Earle

- Chapter 8 (Measuring Geologic Time)

Module 9 Assignment: Relative Dating and Cross Cutting Relationships

10 points

After you complete the reading, you can start working on [Module 9 Assignment – Relative Dating and Cross Cutting Relationships](#)

Module 9 Quiz

10 points

Module 9 Quiz has 10 multiple-choice questions and is based on the content of the Module 9 readings and Assignment 9.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

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9.2: Assignment- Relative Dating and Cross Cutting Relationships

Module 9 Assignment

Relative Dating and Cross Cutting Relationships



Figure 1. Grand Canyon National Park preserves an iconic geologic landscape and resources ranging from 1,840 to 270 million years old, including diverse paleontological resources; unconsolidated surface deposits; a complex tectonic and erosion history; and Pliocene to Holocene volcanic deposits. The Colorado River established its course through the canyon about six million years ago, and likely evolved from pre-existing drainages to its current course. Geologic processes, including erosion of tributaries and slopes, and active tectonics continue to shape the canyon today. The geologic record in Grand Canyon is an important scientific chronicle and is largely responsible for its inspirational scenery.

Overview

Well known for its geologic significance, the Grand Canyon is one of the most studied geologic landscapes in the world. It offers an excellent record of three of the four eras of geological time, a rich and diverse fossil record, a vast array of geologic features and rock types, and numerous caves containing extensive and significant geological, paleontological, archeological and biological resources. It is considered one of the finest examples of arid-land erosion in the world. The Canyon, incised by the Colorado River, is immense, averaging 4,000 feet deep for its entire 277 miles. It is 6,000 feet deep at its deepest point and 15 miles at its widest. The image below shows the layers of rock that are exposed in the canyon.

Grand Canyon's Three Sets of Rocks

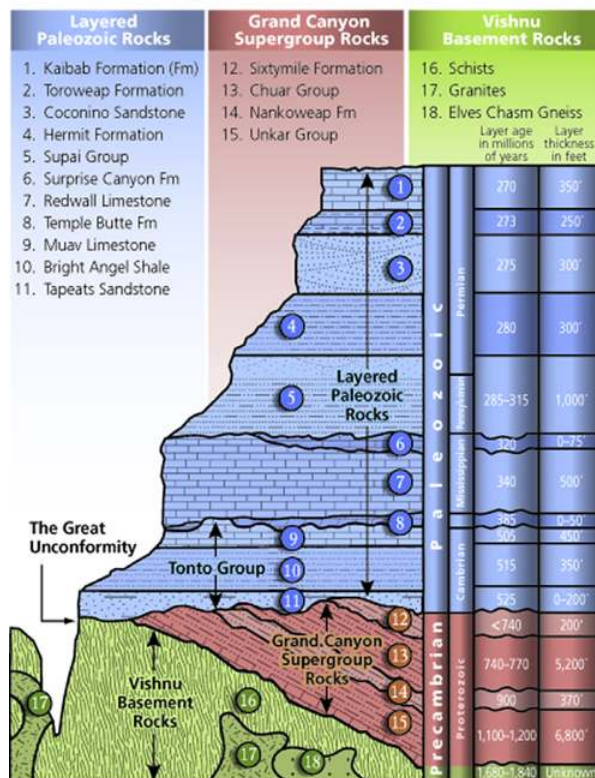


Figure 2. Diagram showing the placement, age and thickness of the rock units exposed in the Grand Canyon.

This is a geologic cross section (not drawn to scale) that shows the stratigraphy of the Grand Canyon. In other words, it represents what the rock layers would look like if you took a knife and sliced down through the Earth at a given location, like a piece of cake. You are viewing those layers from the “side” of the piece of cake in this image. Note that all three types of rock (sedimentary, metamorphic, and igneous) are present in this cross section. Note how the ages of the rock decrease in age from the bottom to the top. If it weren't already labeled, do you think you would be able to spot the Great Unconformity near the bottom of the canyon?

How Old is the Grand Canyon? (optional)

Listen to scientists talk about the age of the Grand Canyon and the controversy over the dating. Press the play button on the left of the page to listen. (Transcripts available on the left menu as well.)

How Old is the Grand Canyon?

Grand Canyon May be Older (and Younger) than you think.

Check out [Basic Answers to your Geologic Questions](#).

This accompanying informational document comes from the Grand Canyon Guide newspaper, published by the Grand Canyon National Park.

Instructions

You will be determining the relative order in which geological events occurred, as shown in this generic stratigraphic cross section (below). Stratigraphy is the study of the rock strata, or layers, and is usually applied to sedimentary (and sometimes volcanic) rocks.

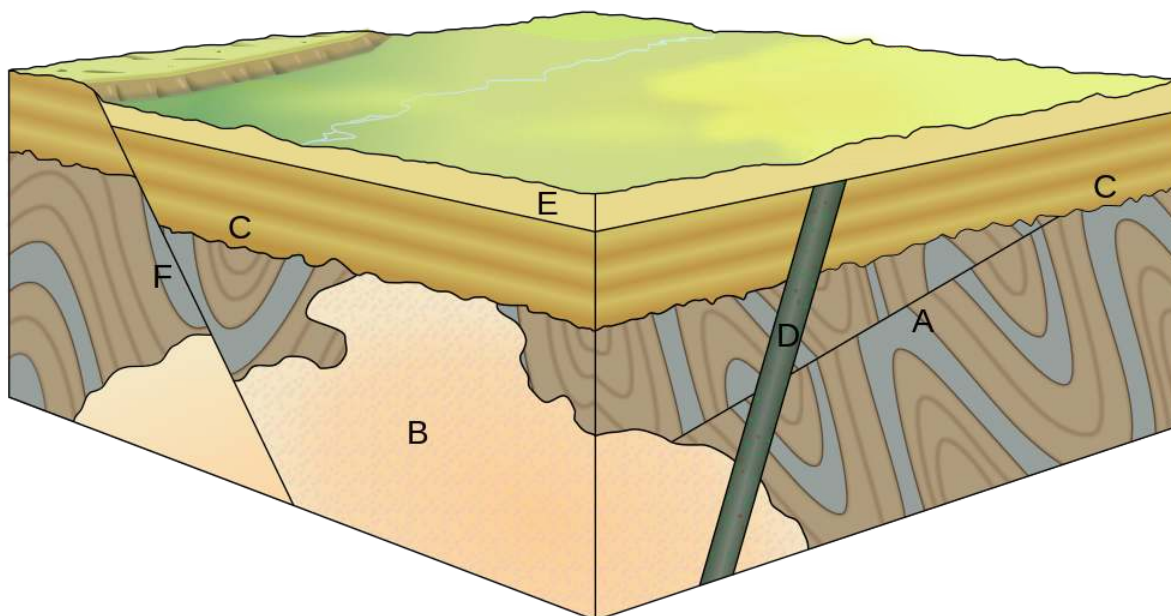


Figure 3. Diagram illustrating cross-cutting relations in geology. These relations can be used to give structures a relative age. Explanations: A – folded rock strata cut by a thrust fault; B – large intrusion (cutting through A); C – erosional angular unconformity (cutting off A & B) on which rock strata were deposited; D – volcanic dyke (cutting through A, B & C); E – even younger rock strata (overlying C & D); F – normal fault (cutting through A, B, C & E).

1. Study the 3-D cross section above. The cross section contains evidence of folding in layer G (a squeezing of the rock due to compression— we'll learn more about that in module 11) and faulting among the various rock layers.
2. What rock type(s) are represented in each of the layers B, G, D, E (sedimentary, igneous, or metamorphic)? Explain how you determined this.
3. What type of unconformity does C represent? Explain. (Hint: Your choices are disconformity, nonconformity, angular unconformity, or paraconformity.)
4. To which letter(s) or layer(s) of rock does the Principle of Superposition apply, and why? Explain.
5. Write the order in which each lettered event (A-H) occurred in the sequence, from oldest to youngest. (Hint: Remember that A and F are fault lines, D is a dike, and C is an unconformity.)
6. At what point in the sequence do you think the folding of unit G took place, and why? Explain.
7. In 3 – 4 sentences, describe how the Law of Cross Cutting Relations applies to the cross section and the sequence in which you ordered the events.
8. Do some searching on the Internet (or elsewhere) to find another simple geologic cross section of your choice.
 - Include an image of this cross section in your write-up, and describe the order in which events occurred in the section.
 - Please put labels on your cross section if it does not already have them, so that it is clear which events you are referring to.
 - Cite your source for the cross section, please!

Grading Rubric

10 points: All questions were answered thoroughly and accurately. Complete sentences were used to answer the sample questions.

8 points: All questions were answered and were mostly accurate. Only two or three minor errors.

5 points: Answers were too brief and 1 – 2 questions were unanswered.

2 points: Only very partial information provided.

0 points: Did not complete the assignment.

9.2: Assignment- Relative Dating and Cross Cutting Relationships is shared under a [CC BY 4.0](https://creativecommons.org/licenses/by/4.0/) license and was authored, remixed, and/or curated by Anne Huth.

CHAPTER OVERVIEW

10: Earthquakes

[10.1: Introduction](#)

[10.2: Discussion 4- Current Events in Geology](#)

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10.1: Introduction

Module 10

Earthquakes



Figure 1. Damage from the 2009 Padang earthquake, Indonesia.

Introduction

It was the deadliest day in the history of Mt. Everest. On April 25, 2015, a 7.8 magnitude earthquake hit Nepal. This triggered an avalanche that killed 19 climbers on Mt. Everest. In Nepal, over 8,800 people died, and many more were injured and made homeless. Hundreds of aftershocks (smaller earthquakes that follow a larger earthquake) have occurred since that day.

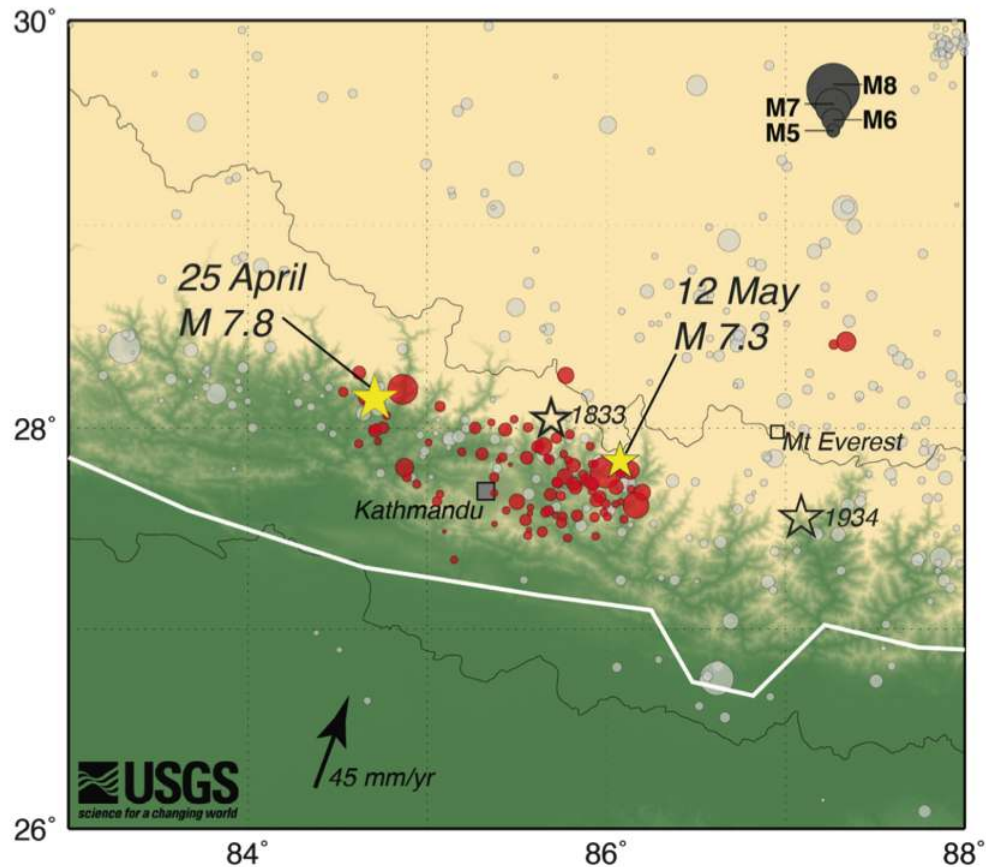


Figure 2. A map of the main earthquake to hit Nepal on April 25, 2015, along with a major aftershock on May 12, and numerous (>100) other aftershocks (shown in red). Note the magnitude scale in the upper right.

Earthquakes are not new to this region. A similar death toll was experienced in a 1934 earthquake, and many other smaller earthquakes have occurred within historical times. An 1833 quake of similar magnitude resulted in less than 500 deaths, though this was most likely due to two very large foreshocks (smaller earthquakes that precede the main earthquake) that sent most residents out of doors in alarm, which was safer for them. Worldwide, there have been much deadlier and stronger earthquakes in just this century (e.g. Haiti, 2010 – 316,000 dead; Sumatra, 2004 – 227,000 dead; a large number of deaths in each of these events was due to ground shaking and the other hazards that were created by the earthquake). Earthquakes give geologists valuable information about Earth's interior and about conditions at Earth's surface. As you have learned, most earthquakes occur at plate boundaries.

Select an image to view larger

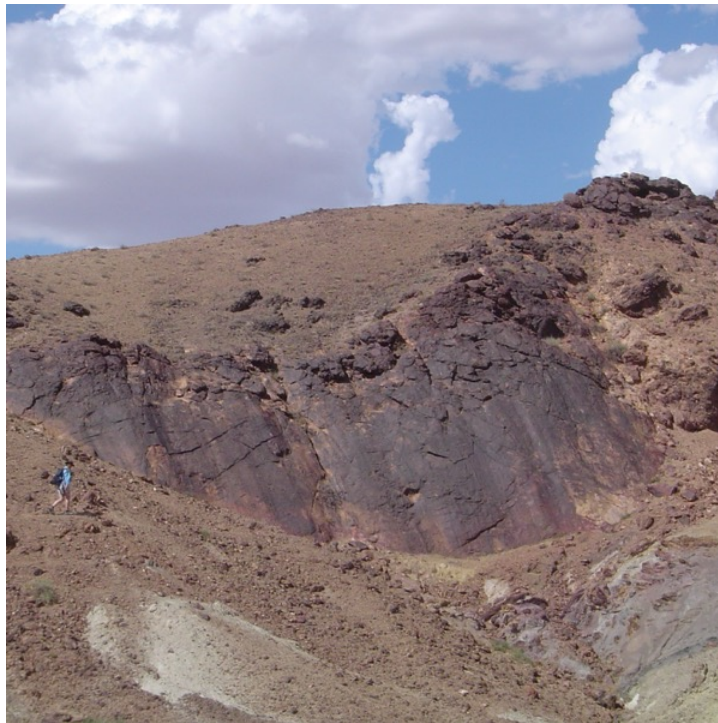


Figure 3. A fault scarp in the Gobi Desert of Mongolia. A fault scarp is an offset in the ground surface where one side of a fault has moved up or down relative to the other side, revealing the “face” of the fault.



Figure 4. River Road in Christchurch, New Zealand with earthquake damage from the February 22, 2011 event.



Figure 5. A boat and trash sit in the front parking lot of a church after a tsunami caused a great amount of structural damage to the island and its villages Oct. 1, 2009, in Pago Pago, American Samoa.



Figure 6. Housed in a vacuum under a protective dome inside a vault in the Santa Catalina Mountains north of Tucson, a seismometer similar to this one (which is located in Antarctica) registered the Nepal earthquake 15 minutes after the ground started shaking in the Himalayas.

Module Objectives

At the completion of this module you will be able to:

1. Explain how the principle of elastic deformation applies to earthquakes.
2. Describe how the main shock and the immediate aftershocks define the rupture surface of an earthquake, and explain how stress transfer is related to aftershocks.
3. Describe the relationship between earthquakes and plate tectonics.
4. Distinguish between earthquake magnitude and intensity, and explain some of the ways of estimating magnitude.
5. Describe how earthquakes lead to the destruction of buildings and other infrastructure, fires, slope failures, liquefaction, and tsunamis.
6. Discuss the value of earthquake predictions, and describe some of the steps that governments and individuals can take to minimize the impacts of large earthquakes.

Activities Overview

See the Schedule of Work for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

Physical Geology by Steven Earle

- Chapter 11 (Earthquakes)

Discussion 4

30 points, class participation

For this week's "Current Events in Geology" topic, you should earn 30 points towards the 150 points of class participation. It is important that you feel engaged in this class. Discussion topics are very flexible, and can cover anything in geology or a related field, including hydrology or water resources, environmental or climate science, paleontology, planetary geology, etc. This is a great opportunity for you to learn about topics in geology that interest YOU, and to see that many interesting things relating to geology are currently making headlines in the news. You are also helping your instructor to become aware of what is going on and to learn new things, so I appreciate your efforts and look forward to reading what you find!

Discussion 4 Instructions

Pay close attention to the Course Schedule for when each of your posts are due. Some are due earlier than others. Failure to post on time will result in lost points.

Module 10 Quiz

10 points

Module 10 Quiz has 10 multiple-choice questions and is based on the content of the Module 10 readings.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

Exam 2

75 points

The questions in this exam are "deep-thinking" questions designed to cultivate critical thinking based on what you have learned in the course up to this point. Each question will be worth 25 points (25 points x 3 questions = 75 points total). You will submit this exam in the Assignments tool.

Exam 2

Your Questions and Concerns...

Please contact me if you have any questions or concerns.

General course questions: If your question is of a general nature such that other students would benefit from the answer, then go to the discussions area and post it as a question thread in the "General course questions" discussion area.

Personal questions: If your question is personal, (e.g. regarding my comments to you specifically), then send me an email from within this course.

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10.2: Discussion 4- Current Events in Geology



Figure 1. Sunlight shines inside Antelope Canyons casting shadows on the curved walls, Page, Arizona.

Like Discussion 3, topics are very flexible, and can cover anything in geology or a related field, including hydrology or water resources, environmental or climate science, paleontology, planetary geology, etc.

For this discussion, you will write an initial post and reply to at least TWO of your classmates' posts. Follow the guidelines for each posting below:

Basic Guidelines for Initial Post

(15 points, required)

Click on "Start a New Thread". You need to include all of the following in your own thread:

1. Find a geology or geology-related article that is dated no earlier than 3 days before the discussion first opened (for example, if the discussion opens on March 10, then you would need to find an article dated March 7 or after).
2. Initial post must be made before 3 days (72 hours) before the discussion closes.
3. Start a New Thread in the discussion, and put the full title of your article in the "enter a subject" line. Do not just leave it blank. It is very important that other students can see the title without entering your thread, so that it is easy for them to search for what they find most interesting.
4. In your post, please include the following information:
 - What is the title of your article? On what date (day/month/year) was it published online?
 - What is the full URL of your web-based source? (copy the whole web address; we must be able to visit the site and read the full article)
 - Why did you find this particular article interesting? In other words, what caught your attention, thus leading you to choose to share it?
 - In your own words, write a brief summary of what happened or was learned. In other words, what significant finding is being reported? (your answer must be at least five complete and meaningful sentences long, and **MUST** be in your own words; you will not get credit for sentences that you just copy/paste from the article!)

Basic Guidelines for Replies to Students

(15 points, required)

1. You are free to make replies to students with regard to either a) your own article you may have posted for extra credit, or b) another student's article.
2. Each reply must contain 6 or 7 meaningful sentences directly related to article content. Phrases like "that is a great article!" and "I really liked your summary" do not count as meaningful content. However, these are still encouraging phrases in support of your peers so please feel free to include them in your post.
3. You must reply to at least 2 other students. (3, or more, for extra credit.)
4. If your replies are too short, you will need to make more than 2 replies to reach your full sentence count for the discussion (2 replies x 6 or 7 sentences each = 12-14 sentences required in each discussion).
5. Do not wait until the last day of the discussion to make your replies. You only receive credit for one reply (up to 10 points max) on the last day.
6. Reply early and often, and earning your full discussion points will be easy!

Extra Credit

(5 points, optional)

Make a third reply (or more!) to a student following the guidelines above.

Learning Outcomes

As a result of your participation in the discussion, you will become more aware of current events and news articles relating to topics in geology (i.e. become a more informed citizen). You will have some freedom in customizing this course to pursue your own interests in geology, including things not covered in the content of this course, by finding news articles on topics that relate to you.

Grading Rubric

Initial Post

20 points: Initial post met length and content requirements

15 points: Initial post needs minor improvements in length and content

10 points: Initial post needs major improvements in length or content

5 points: Initial post was made but with very little effort

0 points: Initial post was not made

Reply posts (each)

5 points: Reply was thoughtful, relevant, and met length requirements.

4 points: Reply needs minor improvements in relevancy and/or length.

2.5 points: Reply needs major improvements in relevancy and/or length.

1 points: Reply was made but with very little effort.

0 points: Reply was not made.

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CHAPTER OVERVIEW

11: Structural Geology

[11.1: Introduction](#)

[11.2: Assignment- Identifying Structural Features in a Geological Landscape](#)

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11.1: Introduction

Module 11

Structural Geology



Figure 1. A syncline in a roadcut in Sideling Hill, in Maryland. Synclines are folds that most often exhibit a concave shape, where the youngest rocks are in the middle of the fold and the oldest rocks on the outside of the fold.

Overview

The Earth is an active planet shaped by dynamic forces. Such forces can build mountains and crumple and fold rocks. As rocks respond to these forces, they undergo deformation, which results in changes in shape and/or volume of the rocks. The resulting features are termed geologic structures. This deformation can produce dramatic and beautiful scenery, as evidenced in the figure of above, which shows the deformation of originally horizontal rock layers.

Why is it important to study deformation within the crust? Such studies can provide us with a record of the past and the forces that operated then. The correct interpretation of features created during deformation is critical in the petroleum and mining industry. It is also essential for engineering. Understanding the behavior of deformed rocks is necessary to create and maintain safe engineering structures. When proper geological planning is not considered in engineering, disasters can strike.

For example, the Vajont Dam was constructed at Monte Toc, Italy in the early 1960s. The site was a poor choice for a dam because the valley was narrow, thorough geological tests were not performed, and the area surrounding the dam was prone to large landslides. The steep canyon walls were composed of limestone with solution cavities, not known for its stability, and shifting and fracturing of rock that occurred during the filling of the reservoir was ignored.



Figure 2. An image of the Vajont reservoir shortly after the massive landslide (you can see the scar from the landslide on the right, and the dam is located in the foreground on the left).

In 1963, a massive landslide in the area displaced much of the water in the dam, causing it to override the top of the dam and flood the many villages downstream, resulting in the deaths of almost 2,000 people.



Figure 3. View of the village of Longarone, which was below the dam, showing the extent of the damage after the 'wave of death' had passed through.

Select an image to view larger



Figure 4. Close up view of Sideling Hill syncline.

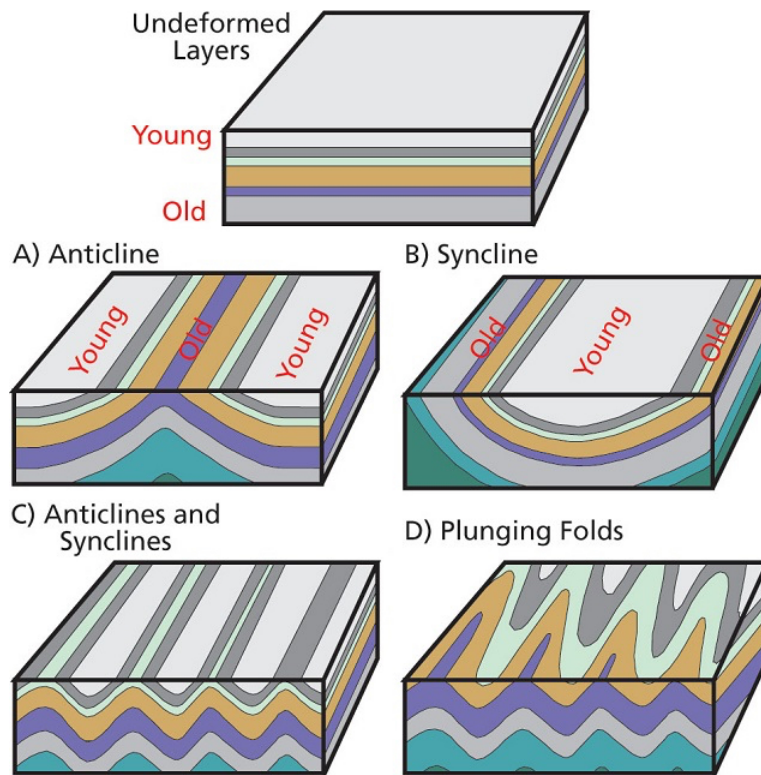


Figure 5. Diagram of different types of folds. Think of a stack of blankets on a table top that you push together so that they wrinkle up. Now imagine what would happen if you sliced the peaks of the folds so that the height was the same.



Figure 6. Chevron folds with flat-lying axial planes. Millook, North Cornwall, UK.



Figure 7. Migmatite in an exposed roadcut, showing tight plastic folds resulting from shearing and stretching in the migmatite. Adirondack Lowlands, New York.



Figure 8. Copper Creek Thrust Fault. The prominent linear feature from upper left to lower right is the Copper Creek Thrust Fault in Tennessee. Thrust faults are low-angle reverse faults, formed by compressional stress. They are common in mountain belts formed by tectonic collision – this example is in the Appalachian Mountains (= result of a collision between Africa and North America during the Pennsylvanian). The folded rocks above the fault are part of the Rome Formation (Middle Cambrian). The tilted rocks below the fault at lower left are Moccasin Formation limestones (Middle Ordovician).



Figure 9. Normal Faults. Five faults totaling 12 meters in offset. Honaker Trail Formation. In the footwall of the Moab Fault Zone.



Figure 10. Reverse Fault in Eagle Ford outcrop, West of Del Rio Texas. This part of the Eagle Ford, closer to the Sierra Madre Oriental, has been subjected to Laramide-era contraction.

Module Objectives

At the completion of this module you will be able to:

1. Describe the types of stresses that exist within the Earth's crust.
2. Explain how rocks respond to those stresses by brittle, elastic, or plastic deformation, or by fracturing.
3. Summarize how rocks become folded and know the terms used to describe the features of folds.
4. Describe the conditions under which rocks fracture.

5. Summarize the different types of faults, including normal, reverse, thrust, and strike-slip.
 6. Understand how measurements of strike and dip of a geological feature are determined.
-

Activities Overview

See the Schedule of Work for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

Physical Geology by Steven Earle

- Chapter 12 (Geological Structures)

Module 11 Assignment: Identifying Structural Features in a Geological Landscape

15 points

After you complete the reading, you can start working on [Module 11 Assignment – Identifying Structural Features in a Geological Landscape](#)

Module 11 Quiz

10 points

Module 11 Quiz has 10 multiple-choice questions and is based on the content of the Module 11 readings and Assignment 11.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once.

Note: that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

Your Questions and Concerns...

Please contact me if you have any questions or concerns.

General course questions: If your question is of a general nature such that other students would benefit from the answer, then go to the discussions area and post it as a question thread in the "General course questions" discussion area.

Personal questions: If your question is personal, (e.g. regarding my comments to you specifically), then send me an email from within this course.

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11.2: Assignment- Identifying Structural Features in a Geological Landscape

Module 11 Assignment

Identifying Structural Features in a Geological Landscape



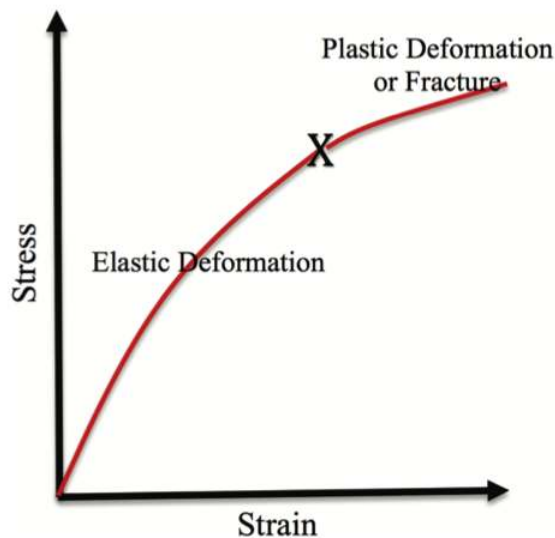
Figure 1. Swartberg Pass rock formation, South Africa

Overview

Stress versus Strain: A Review

Rocks change as they undergo stress, which is just a force applied to a given area. Since stress is a function of area, changing the area to which stress is applied makes a difference. For example, imagine the stress that is created both at the tip of high heeled shoes and the bottom of athletic shoes. In the high heeled shoe, the area is very small, so that stress is concentrated at that point, while the stress is more spread out in an athletic shoe. Rocks are better able to handle stress that is not concentrated in one point. There are three main types of stress: compression, tension, and shear. When compressional forces are at work, rocks are pushed together. Tensional forces operate when rocks pull away from each other. Shear forces are created when rocks move horizontally past each other in opposite directions. Rocks can withstand compressional stress more than tensional stress.

Applying stress creates a deformation of the rock, also known as strain. As rocks are subjected to increased stress and strain, they at first behave in an elastic manner, which means they return to their original shape after deformation (see figure below). This elastic behavior continues until rocks reach their elastic limit (point X on the figure below), at which point plastic deformation commences. The rocks may bend into folds, or behave in a brittle manner by fracturing (brittle behavior can be easily envisioned if you think of a hammer hitting glass), but regardless they do not return to their original shape when the stress is removed in plastic deformation. The resulting deformation from applied stress depends on many factors, including the type of stress, the type of rock, the depth of the rock and pressure and temperature conditions, and the length of time the rock endures the stress. Rocks behave very differently at depth than at the surface. Rocks tend to deform in a more plastic manner at depth, and in a more brittle manner near the Earth's surface.



A graph of strain versus stress. As stress and strain increase, rocks first experience elastic deformation that allows them to return to their original shape, until point X is reached. After this point, rocks will either experience plastic deformation or they will fracture, and they cannot return to their original shape.

Instructions

In this lab you will be applying what you have learned about folds and faults and identifying these features from photographs. I have also included unconformities in this lab as a review, because these are often confused with faults. You may wish to go back and review some of the information about unconformities that you learned in the module on Geologic Time.

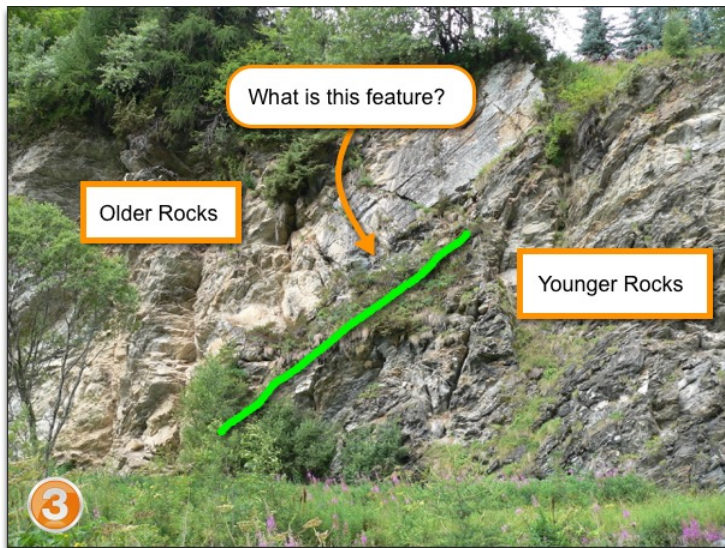
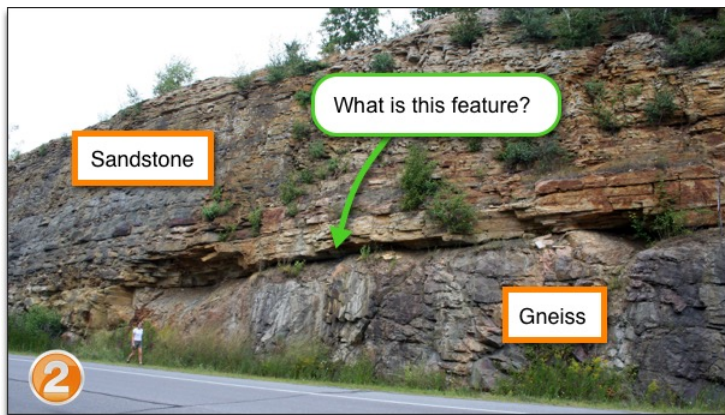
For each of the photographs below, please answer the following questions:

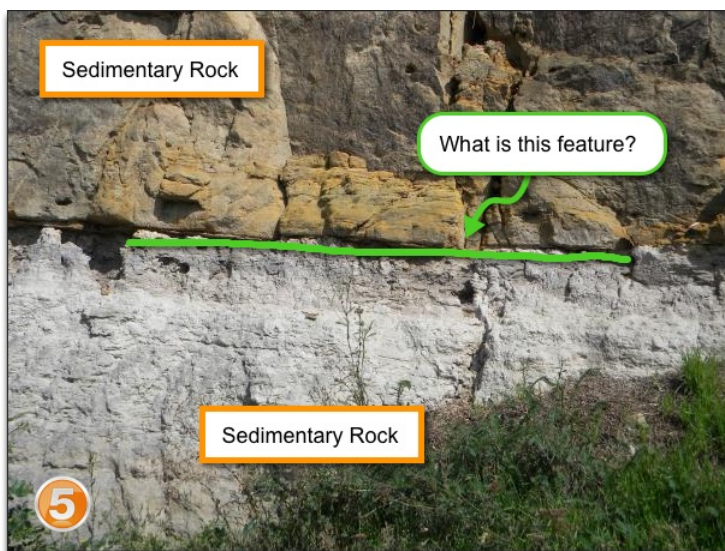
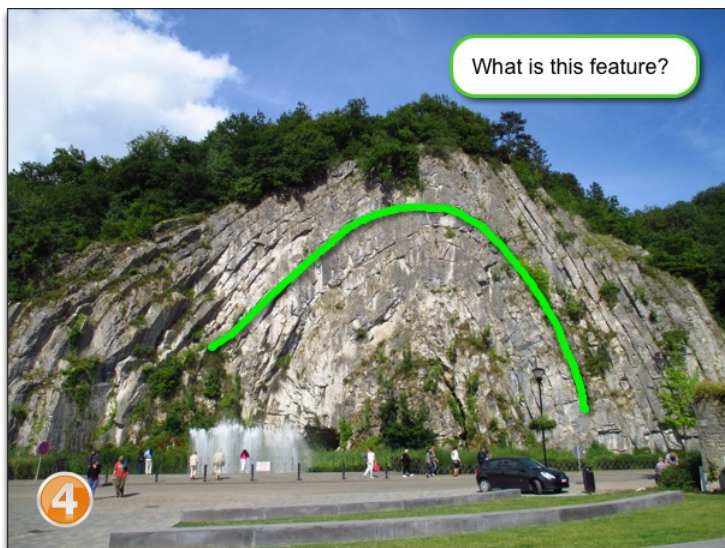
1. What type of feature is in the photograph? Is it a fold, a fault, or an unconformity?
2. After you have identified the type of feature, provide some more specifics on the feature. For example, if it is a fold, is it an anticline, syncline, or monocline? If it is a fault, is it a strike-slip, normal, or reverse (thrust) fault? If it is an unconformity, it is a nonconformity, a disconformity, or an angular unconformity?
3. Please describe in some detail how you were able to determine what type of feature was in the photograph— what visual cues did you use to help you?
4. If the feature is a fold or a fault, was it a result of tensional, compressional, or shear stress?

Your assessment should be between 1.5 to 2 pages in length.

An important note about folds:

Although **anticlines** most often occur “convex up” (meaning they look like a dome), their defining feature is that the oldest rocks will be at the center of the fold and the youngest rocks on the outside of the fold. If rocks have undergone extreme deformation and have completely overturned, it is possible to find an overturned anticline, in which case it appears “concave up,” but the oldest rocks are still in the middle. This is still considered an anticline, as they are truly defined by the placement of the oldest and youngest rocks. Conversely, a **syncline** is defined as having the youngest rocks at the center and the oldest rocks on the outside of the fold. These most often occur as a concave-upward fold, in which the layered strata are inclined up (resembling a smile). However, for the purpose of this lab, assume that the anticlines are convex-up and the synclines are concave-up.







Grading Rubric

15 points: All questions were answered thoroughly and accurately. Complete sentences were used to answer the sample questions.

12 points: All questions were answered and were mostly accurate. Only two or three minor errors.

8 points: Answers were too brief and 1 – 2 questions were unanswered

5 points: Only very partial information provided.

0 points: Did not complete the assignment.

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CHAPTER OVERVIEW

12: Streams and Floods

[12.1: Introduction](#)

[12.2: Assignment- Calculating and Assessing Flood Recurrence Intervals](#)

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12.1: Introduction

Module 12

Streams and Floods



Figure 1. Delta Ponds in Eugene, Oregon Delta Ponds is a 150-acre waterway site consisting of numerous ponds, channels, wetlands, and associated riparian areas. Up until the late 1800s, the Delta Ponds area was part of a river floodplain network of side channels, sloughs, and tributaries that provided a rich habitat well-suited for many native fish and wildlife species. Over time, flood control management, urbanization, and land use practices changed the area dramatically. The ponds, peninsulas and islands that are present today at Delta Ponds were formed by gravel extraction operations that took place in the 1950's and 60's. Perhaps the biggest change to the area was that following gravel mining, this former side-channel of the Willamette River became disconnected from the river. -Rick Obst

Introduction

Think about how many times a day you take water for granted—you assume the tap will be flowing when you turn on your faucet, you expect rainfall to water your lawn, and you may count on water for your recreation. Not only is water necessary for many of life's functions, it is also a considerable geologic agent. Water can sculpt the landscape dramatically over time both by carving canyons as well as depositing thick layers of sediment. Some of these processes are slow and result in landscapes worn down over time. Others, such as floods, can be dramatic and dangerous.

What happens to water during a rainstorm? Imagine that you are outside in a parking lot with grassy areas nearby. Where does the water from the parking lot go? Much of it will run off as sheet flow and eventually join a stream. What happens to the rain in the grassy area? Much of it will infiltrate, or soak into the ground. We will learn about both surface water and groundwater in the next two modules. Both are integral parts of the water cycle, in which water gets continually recycled through the atmosphere, to the land, and back to the oceans. This cycle, powered by the sun, operates easily since water can change form from liquid to gas (or water vapor) quickly under surface conditions. Both surface water and groundwater are beneficial for drinking water, industry, agriculture, recreation, and commerce. Demand for water will only increase as population increases, making it vital to protect water resources both above and below ground.

Select an image to view larger



Figure 2. Chesapeake Bay Virginia National Estuarine Research Reserve. Aerial view of Taskinas Creek area showing the very low gradient, meandering tidal streams.



Figure 3. Looking down a waterfall in Pant Glas, Scotland. The constant flow of water has cut the rock smooth and created small stepped pools.



Figure 4. Flash floods, like this one in the Gobi Desert of Mongolia, are common across the Southern United States, as well.



Figure 5. A weir was built on the Humber River (Ontario) to prevent a recurrence of a catastrophic flood.



Figure 6. Flooded street in Cedar Rapids, IA



Figure 7. USGS personnel monitoring flood waters in Waverly, Iowa.

Module Objectives

At the completion of this module you will be able to:

1. Explain the hydrological cycle and residence times of water in its various compartments.
2. Describe a drainage basin and different types of drainage patterns.
3. Explain how streams form, how they are graded, and how flow velocity and sediment size are related to erosion and deposition in a stream channel.

4. Describe the process of stream evolution and the types of environments where one would expect to find straight-channel, braided, and meandering streams.
 5. Describe examples of processes that lead to flooding.
-

Activities Overview

See the *Schedule of Work* for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

Physical Geology by Steven Earle

- Chapter 13 (Streams and Floods)

Module 12 Assignment: Calculating and Assessing Flood Recurrence Intervals

10 points

After you complete the reading, you can start working on [Module 12 Assignment – Calculating and Assessing Flood Recurrence Intervals](#)

Module 12 Quiz

10 points

Module 12 Quiz has 10 multiple-choice questions and is based on the content of the Module 12 readings and Assignment 12.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

Your Questions and Concerns...

Please contact me if you have any questions or concerns.

General course questions: If your question is of a general nature such that other students would benefit from the answer, then go to the discussions area and post it as a question thread in the “General course questions” discussion area.

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12.2: Assignment- Calculating and Assessing Flood Recurrence Intervals

Module 12 Assignment

Exploring Earth's layers and seismic-wave travel times



Figure 1. USGS scientists measuring September 2009 flooding, Springs Creek, Georgia

Overview

Flooding is a common and serious problem in our nation's waterways. Flood stage is reached when the water level in a stream overflows its banks. Floodplains are popular sites for development, with nice water views, but are best left for playgrounds, golf courses, and the like. Have you ever heard someone say that a flood was a 1 in 100 year flood? Does that mean that a flood of similar magnitude will occur every 100 years? No, it only means that, on average, we can expect a flood of this size or greater to occur within a 100 year period. One cannot predict that it will occur in a particular year, only that each year has a 1 in 100 chance of having a flood of that magnitude. It also does not mean that only 1 flood of that size can occur within 100 years.

In order to better understand stream behavior, the U.S. Geological Survey has installed thousands of stream gauges throughout the country, locations with a permanent water level indicator and recorder. Data from these stations can be used to make flood frequency curves, which are useful in making flood control decisions. In western Georgia, a dramatic flood event occurred in September, 2009 that resulted in 11 fatalities, over \$200 million in property damage, and closed Interstate 20 for a day. Rain fell from September 16-22, with a particularly intense period on September 20th. Use information below from a stream gauge located on Sweetwater Creek near Austell, Georgia, to create a flood frequency graph.

Instructions

Data from the chart below was collected from a USGS stream gage, and includes the 20 largest discharge events for Sweetwater Creek at station 02337000 from January 1, 2008 – May 1, 2015, excluding the dramatic 2009 flood. In order to create a flood frequency graph, first the recurrence interval must be calculated (one is calculated below for an example). A recurrence interval refers to the average time period within which a given flood event will be equaled or exceeded once. To calculate it, first determine the rank of the flood, with a 1 going to the highest discharge event and a 20 going to the lowest discharge event. Calculate the recurrence interval using the following equation:

$$RI = (n + 1)/m \quad (12.2.1)$$

where

- RI = Recurrence Interval (yrs)
- n = number of years of record (in this case, 2008 – 2015 = 8 individual years of record)
- m = rank of flood

Therefore, within this particular record of data, the recurrence interval for each flood would be calculated as:

$$RI = 9/m \quad (12.2.2)$$

USGS Stream Gage Data

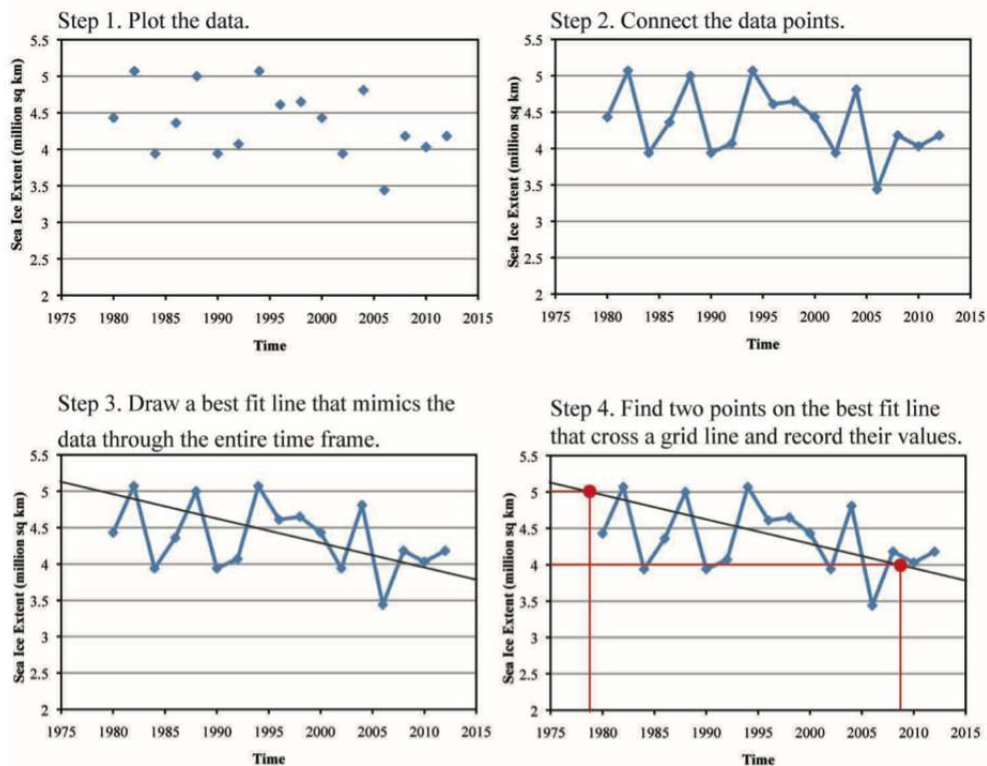
Peak Discharge Date	Discharge (cfs – cubic feet per second)	Rank (1-20)	Recurrence Intervals
87/27/2008	5,140		
3/2/2009	2,360		
10/13/2009	3,290		
11/12/2009	6,120	1	9
12/3/2009	2,860		
12/10/2009	2,170		
12/19/2009	3,830		
12/26/2009	2,650		
1/25/2010	2,500		
2/6/2010	3,680		
3/12/2010	2,350		
4/17/2011	3,100		
2/24/2013	2,060		
2/27/2013	2,190		
5/6/2013	3,610		
12/23/2013	3,790		
4/8/2014	4,170		
1/5/2015	3,970		
4/20/2015	2,940		

Flood Recurrence Intervals as Probabilities

Your results for recurrence interval will tell you the probability that a flood of a particular magnitude will occur in any given year. If you roll a single dice, the chance of rolling a 4 will be a 1-in-6 chance, because there are only 6 possible outcomes on the dice. You could roll the dice a second time, and your chances of it landing on a 4 are still the same (1 in 6). You can think about flood recurrence intervals in the same way. If you calculate a recurrence interval of 3 for a flood event with a discharge of 3,000 cfs, it means that particular flood has a 1-in-3 chance of occurring in any given year. Another way of thinking about it is to say that a flood event with a discharge of 3,000 cfs is a “3-year flood.” It does not mean, however, that a flood of this magnitude will only occur every 3 years. In fact, two or more 3-year floods could easily occur within weeks or months of each other, or the opposite could be true, where there could easily be 10 years or more between two floods of this magnitude. In the same way, if you roll a dice, it could land on a 4 twice in a row, even though it is still a 1-in-6 probability each time you roll the dice. The recurrence interval simply represents the chance that something will occur.

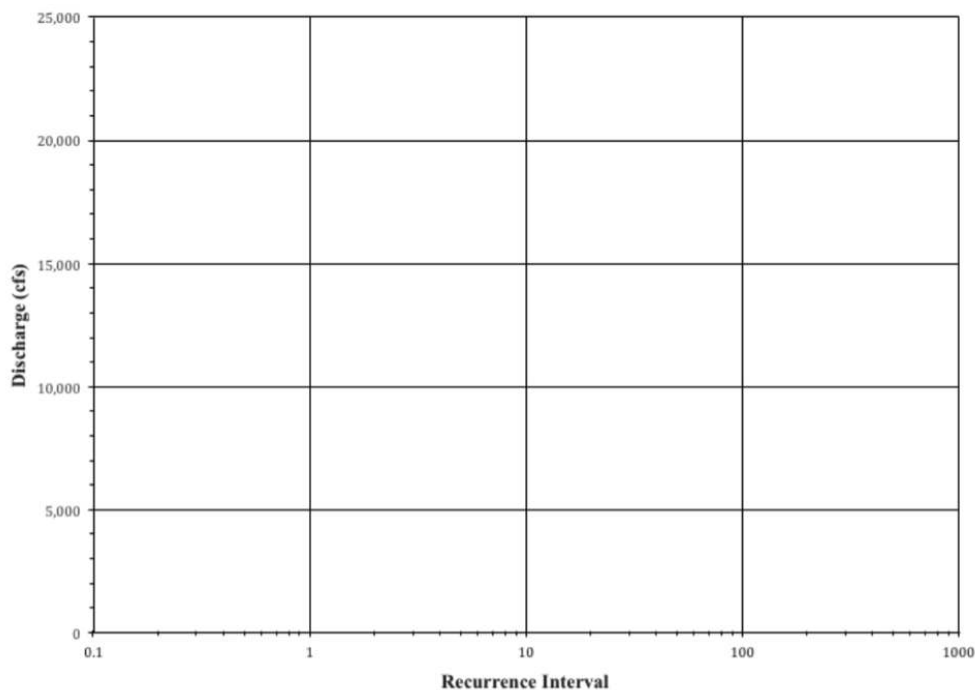
Graphing Your Results and Drawing Best-Fit Line

You will be graphing these data and drawing a “best fit line” through the points in order to calculate the slope of line and examine trends in the data. An example of this process is shown below using data of sea-ice extent from the assignment in the Climate Change module. Use a straight edge to draw a best-fit line (a straight line along the graph that shows the general direction that the group of points seem to be heading – it doesn’t have to hit every point on the graph) through the data after all the points have been plotted.



Example.

Now that you have completed the chart, plot the discharge against the recurrence interval on the graph template below. Please note that the x-axis (for recurrence interval) is in logarithmic scale and you may need to estimate where the data points fall. A logarithmic scale is non-linear, based on orders of magnitude. Draw a best-fit line through your data after all the points have been plotted. Make sure your best-fit line continues to the edge of the graph.



Template.

Interpreting your results

1. On which date did a flood event have a recurrence interval of 0.5?
 - a. 2/27/2013
 - b. 10/13/2009
 - c. 3/10/2011
 - d. 4/20/2015
2. Of the following dated flood events, which one would you expect to happen more often?
 - a. 8/27/2008
 - b. 2/24/2013
 - c. 2/6/2010
 - d. 12/23/2013
3. Observe your best-fit line. What approximate discharge would be associated with a 50-year recurrence interval?
 - a. 2,000 cfs
 - b. 4,750 cfs
 - c. 8,500 cfs
 - d. 14,000 cfs
4. Flood stage, or bankfull stage, on Sweetwater Creek occurs at a discharge of ~4,500 cfs. According to your best-fit line, what is the recurrence interval of such a discharge?
 - a. 0.5 years
 - b. 3 years
 - c. 25 years
 - d. 50 years
5. During the flood event of 9/23/2009, the discharge measured at this gaging station was 21,200 cfs. Note where this would plot on your graph. Would the recurrence interval for this flood plot at:
 - a. 100 years
 - b. 300 years
 - c. 700 years longer than
 - d. 1,000 years
6. Is it possible that a flood with a similar discharge to that of the event from 9/23/2009 could happen again in the next 20 years?
 - a. Yes
 - b. No

Grading

10 points: Accurately responded to each question, including a clearly drawn figure of Earth's interior, a well-written brief summary, and showing the math for each of the 3 calculations. Any sources used were cited.

8 points: Responded to each question, but may have addressed one or two incorrectly.

5 points: More than two questions missed or answered incorrectly; sources were not cited.

2 points: Only very partial information provided.

0 points: Did not complete the assignment.

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CHAPTER OVERVIEW

13: Groundwater

[13.1: Introduction](#)

[13.2: Assignment- Design Your Own Fieldtrip](#)

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13.1: Introduction

Module 13

Groundwater



Figure 1. Dead trees in the terraces of Canary Spring at Mammoth Hot Springs, Yellowstone National Park grew during inactivity of the mineral-rich springs, and were killed when calcium carbonate carried by spring water clogged the vascular systems of the trees. Crepuscular rays are seen in the steam emerging from the hot springs.

Introduction

We will be exploring groundwater and clearing up some of the misconceptions people have about groundwater and how it flows. For example, it is best not to envision groundwater as underground lakes and streams (which only occasionally exist in caves). Instead, think of groundwater slowly seeping from one minuscule pore in the rock to another. Have you ever been to the beach and dug a hole, only to have it fill with water from the base? If so, you had reached the water table, the boundary between the unsaturated and saturated zones. Rocks and soil just beneath the land's surface are part of the unsaturated zone, and pore spaces in them are filled with air. Once the water table is reached, then rocks and soil pore spaces are filled with water, in the saturated zone.

The water table is said to mimic topography, in that it generally lies near the surface of the ground (often tens of feet below the surface, though this can vary greatly with location). The water table rises with hills and sinks with valleys, often discharging into streams. The water table receives additional inputs as rainfall infiltrates into the ground (this is called recharge). Its position is dynamic; during droughts the water table lowers and during wet times, it rises.

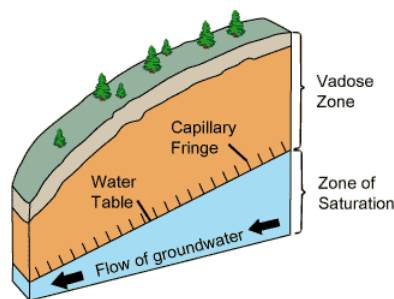


Figure 2. The water table is the boundary between the unsaturated zone and saturated zone.

Two important properties of groundwater that influence its availability and movement are porosity and permeability. Porosity refers to the open or void space within the rock. It is expressed as a percentage of the volume of open space compared to the total rock volume. Porosity will vary with rock type. Many rocks with tight interlocking crystals (such as igneous and metamorphic rocks) will have low porosity since they lack open space. Sedimentary rocks formed from well-sorted sediment tend to have high porosity because of the abundant spaces between the grains that compose them. To imagine this, envision a room filled from floor to ceiling with basketballs (similar to a rock composed completely of sand grains). Now add water to the room. The room will be able to hold a good deal of water, since the basketballs don't pack tightly due to their shape. That would be an example of high porosity.

Permeability refers to the ability of a geologic material to transport fluids. It depends upon the porosity within the rock, but also on the size of the open space and how interconnected those open spaces are. Even though a material is porous, if the open spaces aren't connected, water won't flow through it. Rocks that are permeable make good aquifers— geologic units that are able to yield significant water. Sedimentary rocks such as sandstone and limestone are good aquifers. Rocks that are impermeable make confining layers and prevent the flow of water. Examples of confining layers would be sedimentary rocks like shale (made from tiny clay and silt grains) or un-fractured igneous or metamorphic rock. In an unconfined aquifer, the top of the aquifer is the water table.

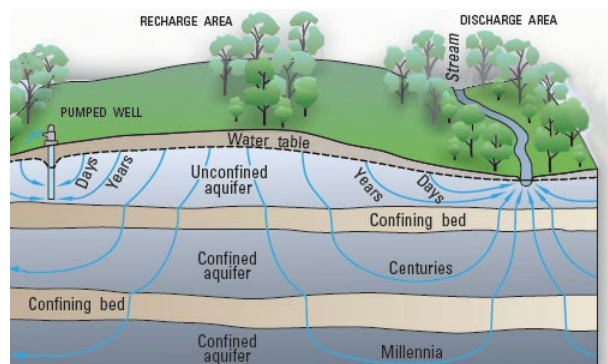


Figure 3. Groundwater flow in both confined and unconfined aquifers.

Groundwater generally flows from areas of higher elevation to lower elevation in the shallow subsurface. Note the flow paths in the figure above. Approximately 20% of the water used in the United States is groundwater, and this water has the potential to become contaminated, mostly from sewage, land fills, industry, and agriculture. The movement of groundwater helps spread the pollutants, making containment a challenge.

Module Objectives

At the completion of this module you will be able to:

1. Explain the concepts of porosity and permeability and the importance of these to groundwater storage and movement.
2. Define aquifers, aquitards, confining layers, and the differences between confined and unconfined aquifers.
3. Explain the concepts of hydraulic head, the water table, potentiometric surface, and hydraulic gradient, and apply the Darcy equation for estimating groundwater flow.
4. Describe the flow of groundwater from recharge areas to discharge areas, and the nature of flow in karst systems.
5. Explain how wells are used to extract groundwater, the implications of over-pumping a well, and how observation wells are used to monitor groundwater levels
6. Describe some of the ways that groundwater can become contaminated, and how contamination can be minimized.

Activities Overview

See the *Schedule of Work* for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

[Physical Geology by Steven Earle](#)

- Chapter 14 (Groundwater)

Module 13 Assignment: Design Your Own Field Trip

20 points

After you complete the reading, you can start working on [Module 13 Assignment – Design Your Own Field Trip](#)

Module 13 Quiz

10 points

Module 13 Quiz has 10 multiple-choice questions and is based on the content of the Module 13 readings and Assignment 13.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

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Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

Your Questions and Concerns...

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13.2: Assignment- Design Your Own Fieldtrip

Module 13 Assignment

Design Your Own Field Trip



Figure 1. Sunrise on Picacho Peak, Arizona

Overview

Many students choose a geology course because they enjoy the outdoors. Perhaps you are one of those people. Do you enjoy hiking, taking a picnic out to the mountains, or visiting National Parks? Or maybe you prefer taking long drives to enjoy the landscape around you or visiting museums? This assignment will encourage you to visit one of the parks, natural areas, or museums in your area as you design your own field trip!

Perhaps you have a favorite location you like to visit frequently that you would like to share with me. If you don't have a favorite place, or you are not accustomed to getting into the great outdoors, now is the time to start thinking about a local destination that intrigues you. This destination should have features that are related to the fields of geology, hydrology, astronomy, environmental science, or climate/atmospheric science.

This could be a museum, a park, a hiking trail, or a beautiful mountain drive, for example. If you don't know where to start, it is always a good idea to begin by asking your friends or family about places they might recommend. If you're not sure that your destination of choice is appropriate for this assignment, feel free to email your instructor to check in first.

Instructions

Step 1: Do a little research.

Before you begin planning your field trip, review some references (either online or at the library) that discuss the geology or natural history of the area you would like to visit. Read about your destination so you have a good idea of what to expect. Write down some notes for later.

Step 2: Map it out.

A map is always a helpful addition to any field trip. You can either create your own or use one that you find online. Just make sure that you cite your source in a caption under the map. If directions are needed to find this destination (particularly if it is not well known), be sure to include those as well.

Step 3: Get out and have some fun!

Take a notebook, any notes you made from your references, your map, and start exploring! A note for hikers or wilderness explorers: I encourage you to take a friend along, especially if you choose to hike in the wilderness.

Please take plenty of water, sunscreen, hat, cell phone, and emergency first aid. You are not required, nor is it recommended, to go out and explore any wilderness or remote areas for this course, particularly on your own. If you are accustomed to that type of activity and that is your preference, that is fine. But I am not asking you to put yourself in a situation where you might be vulnerable.

This should be a fun and safe activity that can incorporate friends and family if you wish!

Step 4: Tell the class about it.

Once you return home, write about your experiences! Tell us about where you visited, what you did while you were there, and some geological or natural history of the area. Don't skimp on this last part! Also include some details, such as:

- Where should one go first when they arrive?
- Are there particular field trip stops that you feel are most important?
- What should we expect at each stop?
- What geological (or related) feature are we looking at when we get to each stop?

Your write-up should be at least 2-3 pages, including photos, a map, and text. Most important, just be creative!

Submit to the Assignments tool and paste a copy into the Field Trip Discussion topic to share with the class.

Grading

20 points: Report summarized your experiences and included some background geological or natural history of the area. Spelling and grammar were correct and complete sentences were used. Photographs were included. Report was an appropriate length.

17 points: Report summarized your experiences and some geology of the area, photographs were included, but may need a little more discussion or length. Report may contain a few spelling or grammar errors.

15 points: Report is missing some detail on geology/natural history, or some necessary photographs. It included some spelling and grammar errors and may be missing some length.

10 points: Report was missing a good amount of detail on geologic or natural history of the area as well as length, did not include enough photographs, and may have significant spelling and grammar errors.

0 points: Did not complete the assignment.

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CHAPTER OVERVIEW

14: Mass Wasting and Glaciers

[14.1: Introduction](#)

[14.2: Assignment- A Virtual Field Trip Guide to Exploring the Volcanic History and Evidence of Mass Wasting at Sentinel Peak, Tucson, Arizona](#)

[14.3: Discussion- Climate Change](#)

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14.1: Introduction



Figure 1. Meltwater from Grinnell, Gem, and Salamander Glaciers feeds the teal lakes of Grinnell Valley in the Many Glacier area of Glacier National Park, Montana.

Introduction

Landslides

Landslides constitute a major geologic hazard because they are widespread, occur in all 50 states and U.S. territories, and cause \$1-2 billion in damages and more than 25 fatalities on average each year. Expansion of urban and recreational developments into hillside areas leads to more people that are threatened by landslides each year. Landslides commonly occur in connection with other major natural disasters such as earthquakes, volcanoes, wildfires, and floods.

The term landslide includes a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flows. Although gravity acting on an over-steepened slope is the primary reason for a landslide, there are other contributing factors:

- Erosion by rivers, glaciers, or ocean waves create over-steepened slopes.
- Rock and soil slopes are weakened through saturation by snowmelt or heavy rains.
- Earthquakes create stresses that make weak slopes fail.
- Earthquakes of magnitude 4.0 and greater have been known to trigger landslides.
- Volcanic eruptions produce loose ash deposits, heavy rain, and debris flows.
- Excess weight from accumulation of rain or snow, stockpiling of rock or ore, from waste piles, or from man-made structures may stress weak slopes to failure.

Slope material that become saturated with water may develop a debris flow or mud flow. The resulting slurry of rock and mud may pick up trees, houses, and cars, thus blocking bridges and tributaries causing flooding along its path.

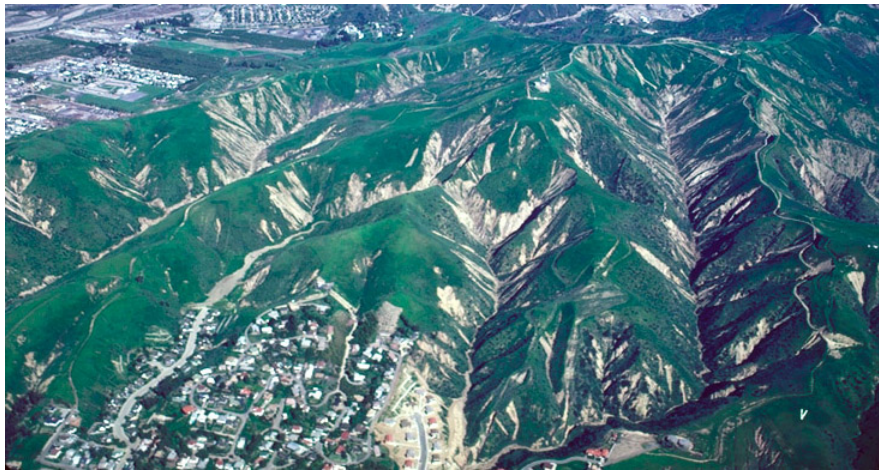


Figure 2. Debris flow scars formed in 1968-1969 in greater Los Angeles. The image taken months after the debris flows occurred.

Landslide Locations

Landslides occur in every state and U.S. territory. The Appalachian Mountains, the Rocky Mountains and the Pacific Coastal Ranges and some parts of Alaska and Hawaii have severe landslide problems. Any area composed of very weak or fractured materials resting on a steep slope can and will likely experience landslides.

Although the physical cause of many landslides cannot be removed, geologic investigations, good engineering practices, and effective enforcement of land-use management regulations can reduce landslide hazards.

– Excerpts from “Landslides 101,” Landslide Hazards Program, [U.S. Geological Survey](#)

Glaciers in Glacier National Park. Montana, USA

A glacier is a body of snow and ice of sufficient size and mass to move under its own weight. Glacier movement may be detected by the presence of crevasses, or cracks that form in the ice as the glacier moves. In Glacier National Park (GNP), USGS scientists define glaciers according to the commonly accepted guideline in which a body of ice has an area of at least 0.1 km² (100,000 m²), or about 25 acres. Below this size, the ice is generally stagnant and does not move, unless it is on a steep slope. Glaciers are dynamic, changing in response to temperature and precipitation. A glacier forms when winter snowfall exceeds summer melting. Glaciers retreat when melting outpaces accumulation of snow.

While the glaciers that carved GNP’s majestic peaks were part of a glaciation that ended about 12,000 years ago, the relatively small alpine glaciers that cling to mountainsides today are considered geologically new, having formed about 7,000 thousand years ago. These glaciers grew substantially during the Little Ice Age (LIA) that began around 1400 AD and reached their maximum size at the end of the LIA around 1850 AD. Their maximum sizes can be inferred from the mounds of rock and soil left behind, known as moraines. Aerial photography reveals moraines of over 150 glaciers that existed in Glacier National park at the end of the LIA. In 2015, only 26 active named glaciers remain.

Early park visitors and scientists noted that glaciers were retreating as early as 1914. The climate was already warming and glaciers were responding, but the industrial revolution added more carbon dioxide to the atmosphere, furthering glacier retreat. In Glacier National Park, as well as around the globe, glacier mass and extent has decreased during the 20th century in response to warmer temperatures.

– Excerpts from “[Retreat of Glaciers in Glacier National Park](#),” Northern Rocky Mountain Science Center, U.S. Geological Survey

Select an image to view larger



Figure 3. A view from a Washington Army National Guard helicopter shows the bypass (left) that has been created to facilitate emergency workers' efforts after a mile-long stretch of Highway 530 was affected by the landslide.



Figure 4. This photo shows one of the houses damaged by the 2005 Laguna Beach Landslide. The house experienced an undermining of the landslide but remained intact.



Figure 5. Talus cones on the north shore of Isfjorden, Svalbard, Norway.



Figure 6. Some people think these terraces were created by sheep! This is a splendid example of soil creep, or solifluction. When it is frosty, the moisture in the soil freezes and the ground expands because ice expands outwards at right angles to the slope. Then, when it thaws, the soil subsides vertically, creating these little terraces on grassy slopes.



Figure 7. This is not a glacier from Glacier National Park, but rather it is “Oberaargletscher,” as seen from Oberaar, Bern, Switzerland in July 2010.

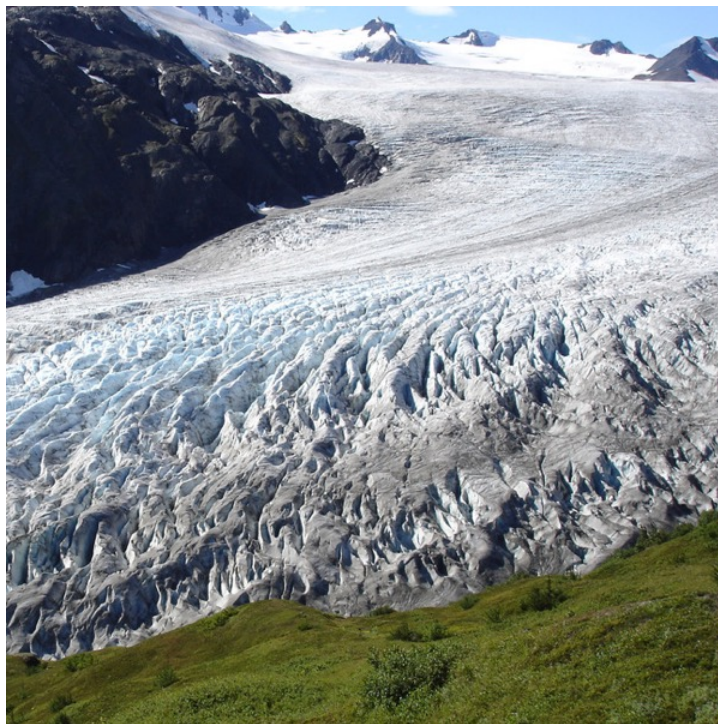


Figure 8. Exit Glacier in Kanai Fords National Park, Alaska



Figure 9. The Fox Glacier in New Zealand

Module Objectives

At the completion of this module you will be able to:

1. Explain how slope stability is related to slope angle, and how various factors influence the strength of materials on slopes.
2. Explain what types of events can trigger mass wasting, and the types of motion that can happen during mass wasting.
3. Describe the main types of mass wasting, the steps we can take to delay it, and some of the measures that can be taken to mitigate the risks associated with mass wasting.
4. Describe the timing and extent of Earth's past glaciations and the important geological events that led up to the Pleistocene glaciations.
5. Explain the differences between continental and alpine glaciation.
6. Identify the various landforms related to alpine glacial erosion, and various types of glacial lakes.

Activities Overview

See the Schedule of Work for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

Physical Geology by Steven Earle

- Chapter 15 (Mass Wasting)
- Chapter 16 (Glaciation)

Module 14 Assignment: A Virtual Field Trip Guide to Exploring the Volcanic History and Evidence of Mass Wasting at Sentinel Peak, Tucson, Arizona

20 points

After you complete the reading, you can start working on [Module 14 Assignment – A Virtual Field Trip Guide to Exploring the Volcanic History and Evidence of Mass Wasting at Sentinel Peak, Tucson, Arizona](#)

Discussion 5 – Climate Change

30 points (+5 points extra credit)

This week's discussion guidelines are different from the previous discussions. We will be having a conversation about climate change and the ways in which it might personally affect you or your family.

Discussion 5 Instructions

Check the Schedule of Work for Due Date.

Module 14 Quiz

10 points

Module 14 Quiz has 10 multiple-choice questions and is based on the content of the Module 14 readings and assignment.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

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14.2: Assignment- A Virtual Field Trip Guide to Exploring the Volcanic History and Evidence of Mass Wasting at Sentinel Peak, Tucson, Arizona



Figure 1. View from the top of Sentinel Peak

This field activity is significantly modified from work by J. Rasmussen, Ph.D., Pima Community College, with permission

Overview

Sentinel Peak, also known as “A Mountain”, is one of a number of peaks in the Tucson Mountains, located on the west side of the City of Tucson. There is a rich geologic history surrounding Sentinel Peak and the Tucson Mountains. Your mission will be to follow this guide, collect “virtual” evidence, and ultimately decide if Sentinel Peak (A Mountain) is a volcano! In addition, there is an interesting conglomerate layer and you will have an opportunity to decide what sort of mass wasting event might have caused its deposition. I have outlined a series of short stops (see below) that will guide you in this quest.



Figure 1. Summit of Sentinel Peak (A-Mountain). There are beautiful views of the city from the top!

Maps and Publications

Before you begin your virtual field trip, it will be a good idea to do a little background research on Sentinel Peak, and on the Tucson Mountains, in general. You will include this information in your final write-up, so spend some time reading about its geologic history. It is recommended to review the following documents to start your research:

[Map of bedrock geology of Sentinel Peak and Tumamoc Hill](#) (courtesy of AZGS)

[Field Guide to “A” Mountain and Surrounding Region](#) (courtesy of AZGS)

There is also a [ArcGIS Story Map](#) that you can review. This application will help you see where all the stops are on map imagery. Included is some of the text from this document so you will have descriptions of each rock formation to accompany your virtual field trip.

What you need

You will need the following items when you virtually visit Sentinel Peak:

1. [AZGS bedrock geology map](#)
2. [Table 1](#)
3. [Field Guide to “A” Mountain and Surrounding Region](#)

StoryMaps

StoryMap Stop # 1

Consult the geologic map on StoryMap.

StoryMap Stop # 2

Location: Stream channel (a dry wash) to the west of the parking lot. Note the caliche in the eroded stream bank. Caliche, also known as hardpan, is a calcium carbonate cement that forms within a few feet of the surface.



Figure 2. Caliche in stream channel at StoryMap #2. Look for white, highly weathered, crumbly material on the bank.

StoryMap Stop # 3

Location: Approximately 0.4 miles from Stop 1. Observe the dark, almost black, rocks scattered along the ground. This is an igneous rock called the basaltic andesite (Tb1 on the geologic map). If you crack open these rocks with a hammer, you would find a much lighter greyish color inside of them. The black on the outside is more of a varnish due to exposure in the desert environment.

- Describe this rock according to the characteristics listed in Table 1 for igneous rocks.



Figure 3. Basaltic andesite along trailhead at StoryMap Stop #3. Note the vesicular nature of the rock.

StoryMap Stops # 4 and 5

Location: Approximately 70 paces up the one-way road (to the southeast). On the left side of the road is an outcrop of conglomerate (Tc on the geologic map), which contains small pebbles of vesicular basalt in a matrix of silt, sand, and ash. This conglomerate may have been deposited by a mudflow or debris flow during an intense rainfall that resulted in a wet slurry of sand, mud, and volcanic clasts that it picked up along its path.



Figure 4. Volcanic conglomerate on the left side of the road, just after the fork.

- Describe this rock according to the characteristics listed in Table 1 for sedimentary rocks.
- In the questions at the end of this field activity, you are asked to take a closer look at the clast size and composition of the conglomerate.
- Please refer to Question 3 at end of this activity to guide you in your assessment of this formation while you are visiting this stop.



Figure 5. Volcanic clasts of vesicular basalt populate the conglomerate. The tip of the pen points to a basalt clast.

StoryMap Stops # 6 and 7

Location: Approximately 0.2 miles further up the road. On the left (north/northwest) side of the road you will find a tan- to white-colored igneous formation called tuff. This is the Tumamoc Tuff (Tt on the geologic map). After some observation, you may find fragments of pumice, and possibly some biotite and feldspar in the tuff. Can you spot these?



Figure 6. Tan material is Tumamoc tuff.

- Describe this rock according to the characteristics listed in Table 1 for igneous rocks.

Location: Approximately 10 paces up the road from where you observed the Tumamoc Tuff at Stop 4. Look for the contact between a pink- to grey-colored tuff and the tan tuff underneath. The pink/grey tuff is also part of the Tumamoc Tuff formation, but it is called a different member of the Tumamoc Tuff.



Figure 7. Pumice fragment embedded in the Tumuloc tuff.

- Describe this rock according to the characteristics listed in Table 1 for igneous rocks.

StoryMap Stops # 8 and 9

Location: Approximately 0.3 miles up the road to the parking area on the east side of the mountain, overlooking the city, and just under the “A” near the top.



Figure 8. Tumuloc basaltic andesite under the “A” near the top of the mountain.

Observe the rock formation at road level, under the A. This is basaltic andesite again, but part of a different formation called Tumuloc Basaltic Andesite (Tb2 on the geologic map). How is it different from the Tb1 formation you observed at Stop 2?

- Describe this rock according to the characteristics listed in Table 1 for igneous rocks.



Figure 9. Note the vascular nature of the rock, similar to the basaltic andesite at StoryMap Stop #3.

StoryMap Stop # 10

(Optional, for the purpose of observation only)

Location: Approximately 0.2 miles to the parking area. Here you will find another outcrop of Tumamoc Basaltic Andesite that is visible from the parking area, near the top of the peak. Look for the dark red-brown color rock near the top.

Now you are finished with your field work!



Figure 10: Though it is difficult to see in this photo, near the top is another outcrop of Tumamoc basaltic andesite, with the trailhead for the Sentinel Summit in the foreground.

Assignment

You will need to submit the following to the Assignments tool:

1. [Table 1](#) completed (this can be submitted as a separate document, and can be scanned in if you have hand-written your observations);
2. A short paragraph (3 – 5 sentences) addressing the origin of clasts in the conglomerate layer at Stop 3. Where did these materials come from if they were deposited by a mudflow or debris flow? How might you determine the original direction of flow in the conglomerate? What visual cues can you find that might help you determine this?

3. A short paragraph (3 – 4 sentences) on whether Sentinel Peak complies with the Law of Superposition, and why or why not;
4. A short paragraph (3 – 4 sentences) on whether Sentinel Peak is considered a volcano. What is your final assessment?

Please submit your observations to the Assignment 14 folder. You will need to upload two separate files— one with Table 1, and one with your written assessment addressing items 1 – 5 above.

Grading Rubric

20 points: Table was complete, photos were included, and paragraphs addressed the questions thoroughly.

17 points: Table was mostly complete, photos were included, and paragraphs addressed questions thoroughly but may have been a bit too brief.

15 points: Table was incomplete and a couple photos were missing. Paragraphs addressed questions but were too brief.

10 points: Only very partial information was given. Photos were not included, and paragraphs missing or too brief.

0 points: Assignment was not turned in.

14.2: Assignment- A Virtual Field Trip Guide to Exploring the Volcanic History and Evidence of Mass Wasting at Sentinel Peak, Tucson, Arizona is shared under a [CC BY 4.0](#) license and was authored, remixed, and/or curated by Anne Huth.

14.3: Discussion- Climate Change

Discussion 5

Climate Change



Figure 1. Aerial view of Lake Powell, showing the white ring left by dropping water levels, Page, Arizona.

Introduction

This week's discussion guidelines are different from the previous discussions.

We will be having a conversation about climate change and the ways in which it might personally affect you or your family. You should have some basic knowledge about the subject and can make educated post(s).

For this discussion, you will write an initial post and reply to at least TWO of your classmates' posts. Follow the guidelines for each posting below:

Basic Guidelines for Initial Post

(20 points, required)

1. Watch the following two NASA visualizations on how CO₂ concentrations change throughout the year in Earth's atmosphere:

[2-D model of CO₂ concentrations](#)

[3-D model of CO₂ concentrations](#)

2. Click on "Start a New Thread". You need to include all of the following in your own thread:

- Answer the following questions thoroughly. Each question should be addressed in the form of a paragraph (3-5 sentences each):
- Why do you think CO₂ concentrations are generally higher in the Northern Hemisphere?
- Why should we be concerned about climate change on a global scale?

- d. How might climate change affect you or your family personally, either presently or in the future?
- e. What are some actions you can reasonably take to curtail (reduce) CO₂ emissions in your life?

Initial post must be made before 3 days (72 hours) before the discussion closes.

Basic Guidelines for Replies to Students

(10 points, required)

1. Each reply must contain 6 or 7 meaningful sentences directly related to article content. Phrases like “that is a great article!” and “I really liked your summary” do not count as meaningful content. However, these are still encouraging phrases in support of your peers so please feel free to include them in your post.
2. You must reply to at least 2 other students. (3, or more, for extra credit.)
3. If your replies are too short, you will need to make more than 2 replies to reach your full sentence count for the discussion (2 replies x 6 or 7 sentences each = 12-14 sentences required in each discussion).
4. Do not wait until the last day of the discussion to make your replies. You only receive credit for one reply (up to 10 points max) on the last day.
5. Reply early and often, and earning your full discussion points will be easy!

Extra Credit

(5 points, optional)

Make a third reply (or more!) to a student following the guidelines above.

Learning Outcomes

As a result of your participation in the discussion, you will become more aware of others’ concerns with a changing climate. You will begin to think more broadly about how climate change affects Earth’s systems, features, and population on a global scale. You will practice critical thinking skills with regard to a current and relevant issue in geology and the scientific community in general.

Grading Rubric

Initial Post

20 points: Initial post met length and content requirements

15 points: Initial post needs minor improvements in length and content

10 points: Initial post needs major improvements in length or content

5 points: Initial post was made but with very little effort

0 points: Initial post was not made

Reply posts (each)

5 points: Reply was thoughtful, relevant, and met length requirements.

4 points: Reply needs minor improvements in relevancy and/or length.

2.5 points: Reply needs major improvements in relevancy and/or length.

1 points: Reply was made but with very little effort.

0 points: Reply was not made.

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CHAPTER OVERVIEW

15: Climate Change

[15.1: Introduction](#)

[15.2: Assignment- Changes in Extent of Sea Ice at the Poles](#)

[15.3: Exam 3 Information \(Final Exam\)](#)

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15.1: Introduction

Module 15

Climate Change



Figure 1. Melt streams on the Greenland Ice Sheet on July 19, 2015. Ice loss from the Greenland and Antarctic Ice Sheets as well as alpine glaciers has accelerated in recent decades.

Introduction

Climate is an average of the long-term weather patterns across a geographic area, which is a complicated metric controlled by factors within the lithosphere, atmosphere, cryosphere, hydrosphere, biosphere, and anthrosphere (the part of the environment that is influenced and modified mainly by human activity—sometimes also called the technosphere), as well as factors beyond our own planet. It is helpful to separate out humans from other life (anthrosphere verses biosphere) for several reasons, primarily because many of our activities are unique (industrialization, for instance) and it is helpful in understanding our role in climate change. Therefore, the science examining past, current, and future climate is extremely complex and interdisciplinary.

You may not think of climate as a geological field of study, but the history of climate is recorded within rocks, the current climate is altered by geologic events, and the future climate will be influenced by our use of geological resources such as fossil fuels. In addition to the complex nature of this subject, it is also one, if not the most, important scientific fields of study, both in terms of understanding the dynamics and implications of future climate change as well as attempting to combat or mitigate the potential effects.



Figure 2. In this photo you can see a collapsed block of ice-rich permafrost along Drew Point, Alaska. Coastal bluffs in this region can erode 20 meters/year (~65 feet). USGS scientists continually research the causes of major permafrost thaw and bluff retreat along the Arctic coast of Alaska. In addition, with the loss of sea ice to protect the beaches from ocean waves, salt water inundates the coastal habitats. You can learn more at: USGS Alaska Science Center: and USGS Pacific Coastal and Marine Science Center

Though the basic science behind climate and climate change has been well studied to a point of near consensus within the scientific community, there is still significant debate among the broader population. This is likely related to many factors beyond science, including economics, politics, the portrayal of the science by the media, and the overall public's scientific literacy. Gaining a better understanding of this issue is difficult given the enormous wealth of information and disparity in scientific literacy. This lab will explore this issue by examining climate data, as well as how we, as scientists or scientific-minded citizens, make interpretations and conclusions regarding data—how it is presented, and how it relates to our understanding of the world around us.

Module Objectives

At the completion of this module you will be able to:

1. Summarize the properties of greenhouse gases and their role in controlling the climate.
2. Explain the difference between climate forcing and climate feedbacks, and describe the mechanisms of climate forcing.
3. Describe the significance of both albedo and permafrost melting to climate.
4. Explain how extraction of fossil fuels and food production contribute to climate change.
5. Describe the role of climate change in sea-level rise.
6. Describe the link between climate change and the distribution of diseases and pests.
7. Examine ways in which we as individuals can limit our personal contribution to climate change.

Activities Overview

See the Schedule of Work for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

[Physical Geology by Steven Earle](#)

- [Chapter 19 \(Climate Change\)](#)

[Module 15 Assignment: Changes in Extent of Sea Ice at the Poles](#)

10 points

After you complete the reading, you can start working on [Module 15 Assignment – Changes in Extent of Sea Ice at the Poles](#)

[Module 15 Quiz](#)

10 points

Module 15 Quiz has 10 multiple-choice questions and is based on the content of the Module 15 readings and Assignment 15.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

[Exam 3: Final Exam](#)

75 points

The questions in this exam are “deep-thinking” questions designed to cultivate critical thinking based on what you have learned in the course up to this point. Each question will be worth 25 points (25 points x 3 questions = 75 points total).

[Exam 3 Instructions and Questions](#)

You will submit the results from your project in the Assignments folder labeled “Exam 3” by the end of this week (Module 15).

[Your Questions and Concerns...](#)

Please contact me if you have any questions or concerns.

General course questions: If your question is of a general nature such that other students would benefit from the answer, then go to the discussions area and post it as a question thread in the “General course questions” discussion area.

Personal questions: If your question is personal, (e.g. regarding my comments to you specifically), then send me an email from within this course.

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15.2: Assignment- Changes in Extent of Sea Ice at the Poles

Module 15 Assignment

Changes in Extent of Sea Ice at the Poles

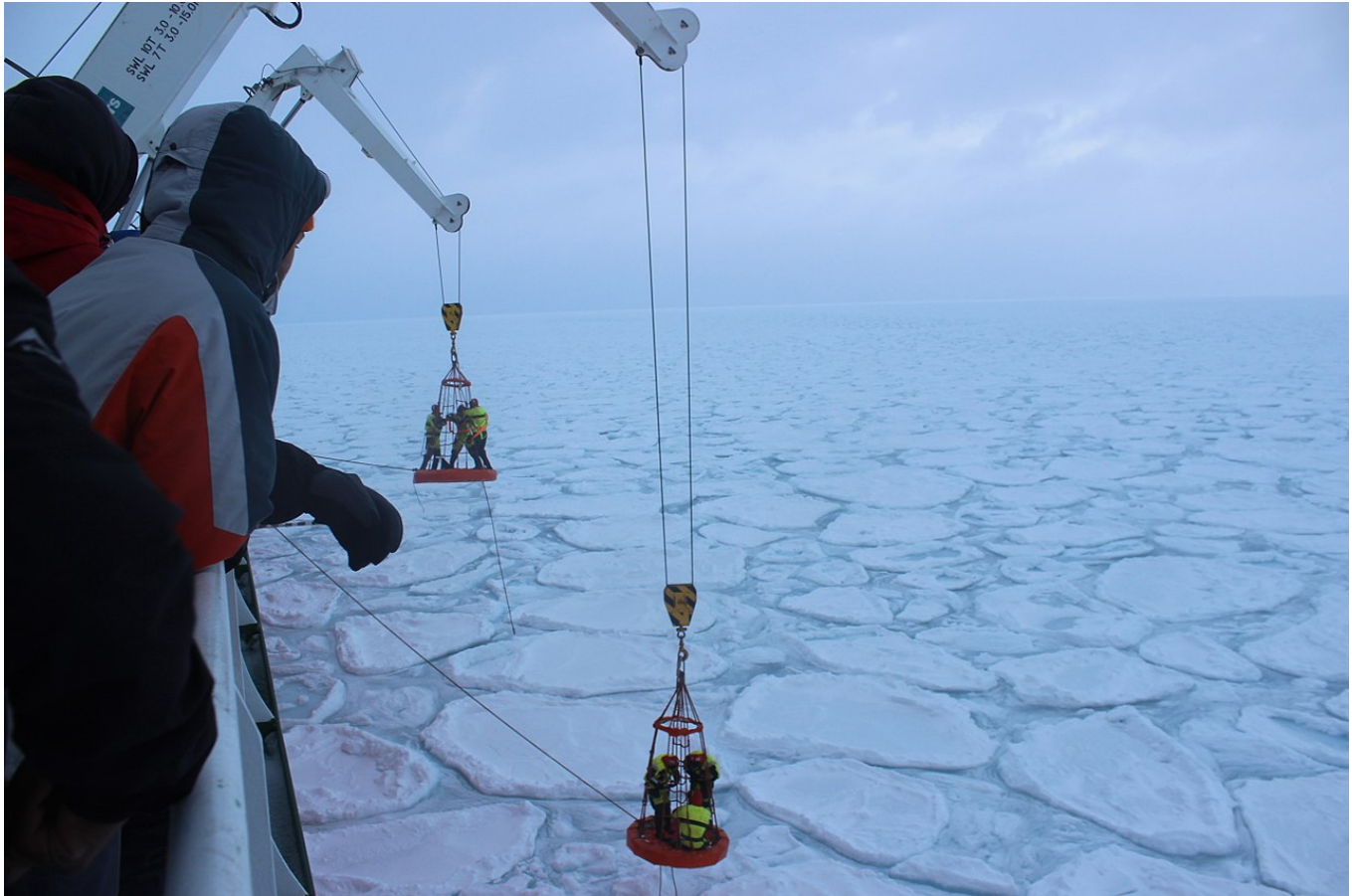


Figure 1. South African scientists work putting trackers on the ice in the Marginal Ice Zone of Antarctica on the Cape Agulhas II during a scientific cruise to the area in the winter of 2017

Overview

With regard to arguments supporting (or not supporting) climate change, climate scientists agree that climate change is happening and that it is indeed exacerbated by human activity. However, there are still a few skeptics and whole organizations outside of the field of climate science that are dedicated to debunking climate change. They might use real data to support their argument, but important data are often omitted or presented in such a way as to paint a very different or skewed picture of the evidence for or against climate change. In this lab activity, you will have an opportunity to explore and compare data presented from different points of view, including data presented in a widely circulated (but unattributed) article entitled “Antarctic Sea Ice for March 2010 Significantly Greater Than 1980,” which was published in April 2010 by a website called “[Global Warming Hoax](#)”. Feel free to visit the website and read the article before completing this lab, although it is not required.

How to Draw a Best Fit Line

All of the data provided in this lab originally come from the National Snow and Ice Data Center (NSIDC), housed at the University of Colorado, and can be freely downloaded at nsidc.org. You will be graphing these data and drawing a “best fit line” through the points in order to calculate the slope of line and examine trends in the data. An example of this process is shown below.

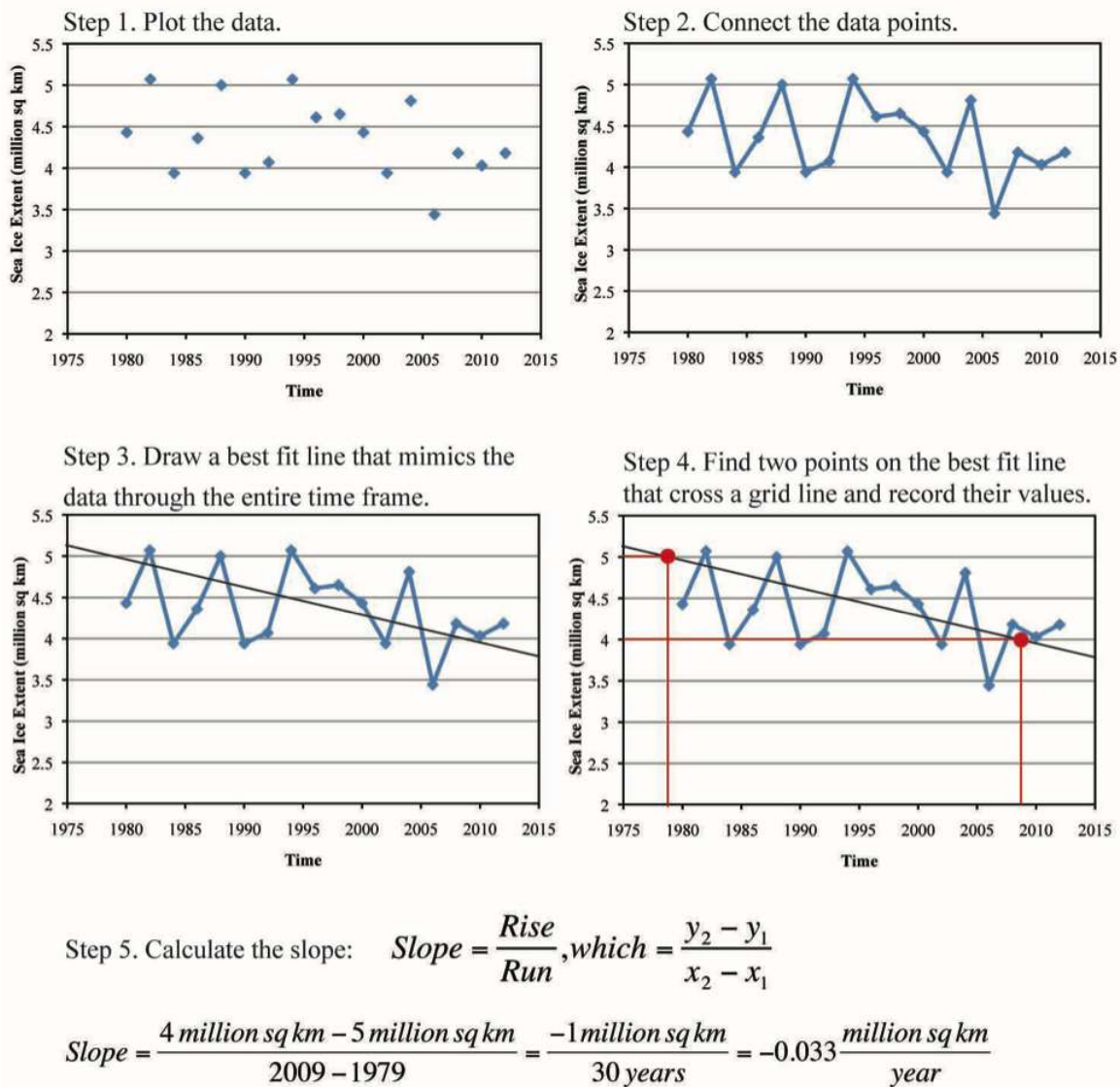


Figure 2.

Instructions

Part A – Original Data

The two data points on sea ice extent that are included in the Figure 2 were obtained from the article “Antarctic Sea Ice for March 2010 Significantly Greater Than 1980,” which was published on a website called “[Global Warming Hoax.](#)” The data, which is included to the left of the graph below, is the extent of Antarctic sea ice in millions of square kilometers as measured in March of 1980 and 2010. This data is accurate and is consistent with data that can be downloaded from NSIDC. To do this, follow the instructions on how to draw a best-fit line (above). In this case, steps two and three are the same and you can easily calculate slope using the original data.

- Based exclusively on the data provided and the graph, what conclusion would one make regarding climate change? Explain.
- Using the method illustrated in Figure 1, what is slope of the line of best fit for these two data points? Show all your work.
- Even though the above data are accurate, give and explain two reasons why this dataset might lead you to an incorrect conclusion regarding global climate change.
 - Reason #1:

b. Reason #2:

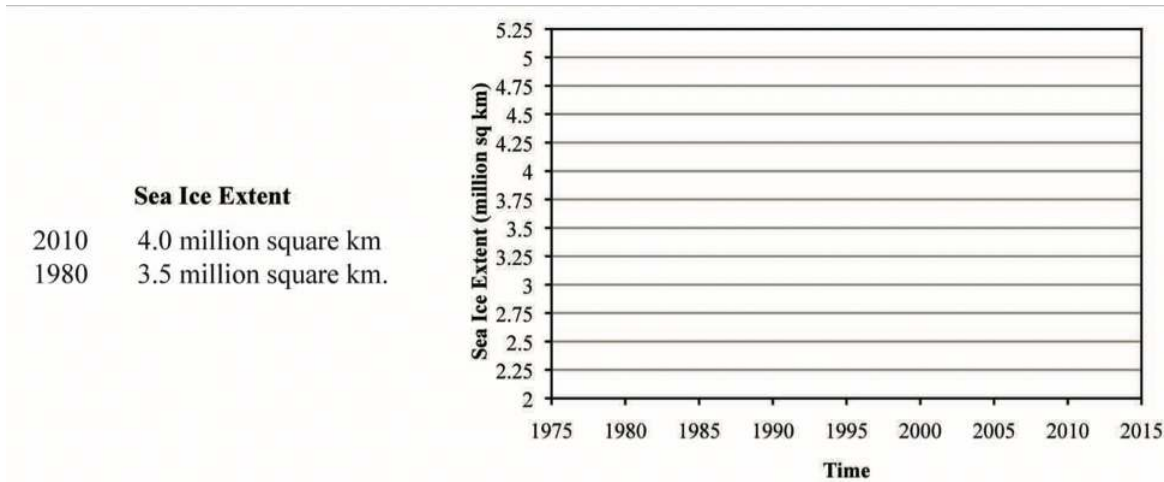


Figure 3. Sea Ice Extent

Part B – South Pole Sea Extent

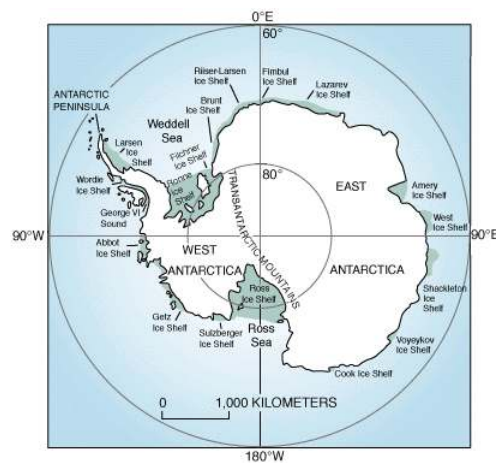


Figure 4. Map of Antarctica showing the extent of the polar ice cap and the extent of the floating ice shelves.

In part B, you will explore an expanded dataset of Antarctic sea ice extent measured during March 1980 through 2018, downloaded from NSIDC. Only the even-numbered years are presented, but the addition of odd years does not alter the trend in the data. Following the instructions for how to draw a best-fit line (above), graph the data, draw a line of best fit, and calculate the slope of the line.

Ice Extent – Southern Hemisphere

Year	Ice Extent, million square kilometers
1980	3.29
1982	4.29
1984	3.61
1986	3.7
1988	3.97
1990	3.97
1992	3.57
1994	4.55

Year	Ice Extent, million square kilometers
1996	4.18
1998	4.11
2000	4.09
2002	3.75
2004	4.53
2006	3.21
2008	5.28
2010	3.85
2012	4.55
2014	4.9
2016	4.07
2018	3.53

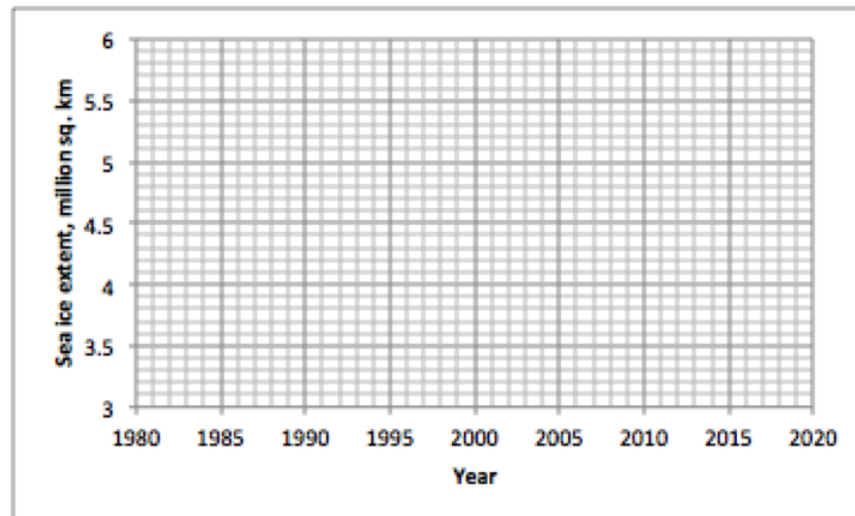


Figure 5. Sea ice extent in Southern Hemisphere measured in million square kilometers

1. What is the slope of the line of best fit you estimated for this data set? Show all your work.
2. What do these data tell you about how sea ice extent is changing in the southern hemisphere? How does your result for the extended dataset compare to the results from the data presented from the article presented in Part A?
3. What can you say about the data variability, or how wide of a range the data points cover, between the earlier years and the later years on the graph?
4. Please offer one suggestion for why the variability in sea ice extent has been changing between 1980 and 2018.

Part C – North Pole Sea Ice Extent



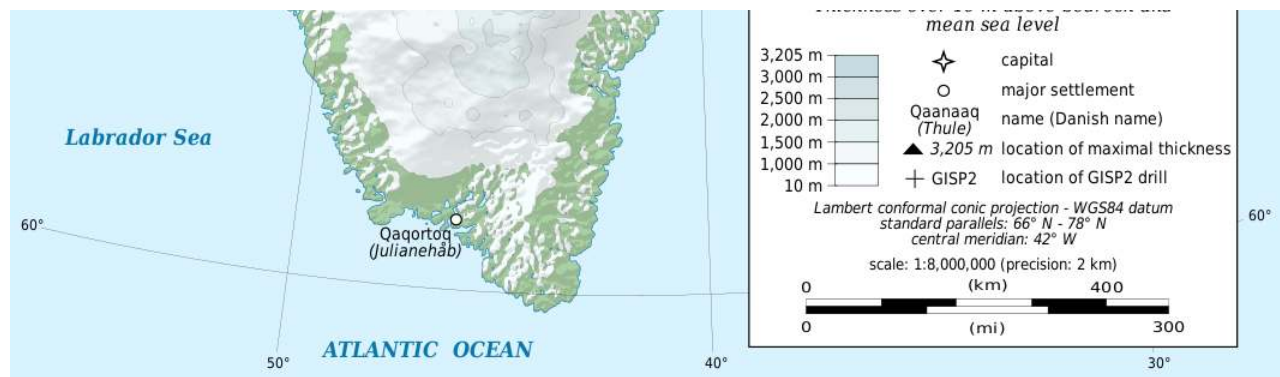


Figure 6. Map of Greenland showing the extent of the polar ice cap.

Next, we will examine the ice-extent patterns of the northern Arctic polar ice sheet that is located on Greenland. The ice-extent data are from March 1980 through 2018 for even-numbered years, also downloaded from NSIDC. Again, here you will graph the data, draw a line of best fit, and calculate the slope of the line.

Ice Extent – Northern Hemisphere

Year	Ice Extent, million square kilometers
1980	16.04
1982	16.04
1984	15.58
1986	15.91
1988	15.96
1990	15.87
1992	15.48
1994	15.55
1996	15.12
1998	15.6
2000	15.22
2002	15.35
2004	14.99
2006	14.42
2008	15.18
2010	15.14
2012	15.2
2014	14.76
2016	14.4
2018	14.3

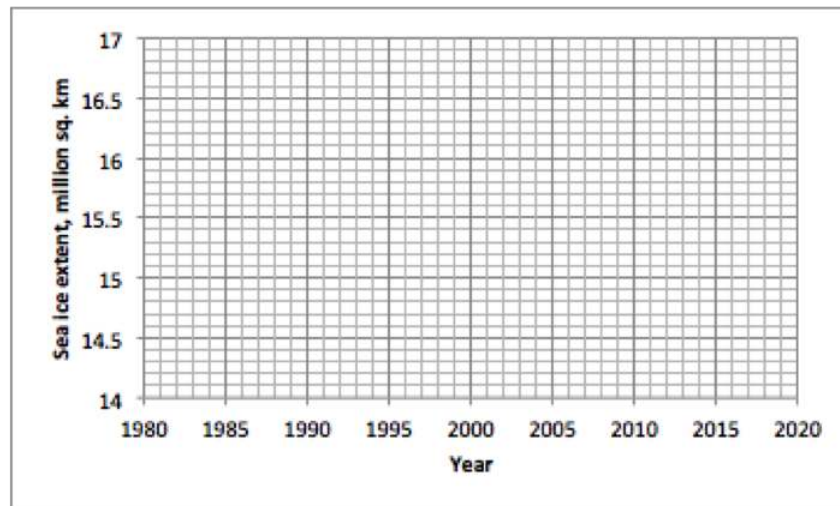


Figure 7. Sea ice extent in Northern Hemisphere measured in million square kilometers

1. What is the slope of the line of best fit you estimated for this data set? Show all your work.
2. What do these data tell you about how sea ice extent is changing in the northern hemisphere? How does your result for the North Pole compare to that of the South Pole (Part B)?
3. Explain why you might see a different trend, or slope of the best-fit line, when comparing the sea-ice extent data between the northern and southern hemispheres.

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15.3: Exam 3 Information (Final Exam)

Exam 3:

Final Exam



Figure 1. Limestone formations that resemble a forest of trees in Kunming, Yunnan, China, appropriately named the Stone Forest.

Overview

The questions in this exam are “deep-thinking” questions designed to cultivate critical thinking based on what you have learned in the course up to this point. Each question will be worth 25 points (25 points x 3 questions = 75 points total).

You will be asked to write a response to 3 of the 6 possible questions below. The specific three questions you will address will be chosen randomly based on the first letter of your last name. This will be announced on the course home page on the day the exam is due, so it is best to have outlines and/or full responses prepared in advance for all the questions.

Feel free to prepare your answers in advance to save you time on Exam day.

- As you review these questions, you are permitted to draft your answers ahead of time, as well as use reputable, high-quality resources outside of the textbook. Please cite any additional sources you used in your research.

Instructions

See the Schedule of Work for date of availability and due date.

You will be asked to write a response to 3 of the 6 possible questions below. The specific three questions you will address will be chosen randomly based on the first letter of your last name. This will be announced on the course home page on the day the exam is due, so it is best to have outlines and/or full responses prepared in advance for all the questions.

- Responses should be 3 – 4 paragraphs in length (where each paragraph consists of at least 5 – 6 sentences).
- Your response must directly answer the question posed. You will not be permitted to use tactics such as answering the question with more questions.
- All of your work should be in your own words, with no direct quotes from other sources.
- Do not include the original question in your document, because the plagiarism checker will detect this. Please aim for < 25% similarity to other sources in the plagiarism checker when you submit your document.

- Complete sentences with correct spelling and grammar will be expected.

Exam Questions

1. You are applying for a summer internship at the Nevada Geology Survey. At the interview, your future employer asks you to take a look at this simple cross section of Death Valley. What information can be derived from this cross section with regard to the formation of Death Valley? Include some discussion of the type of faulting present and any evidence you used to determine this. In addition, please address the larger “big-picture” tectonic setting that was at work in the formation of this valley, based on what you can conclude from the cross section, as well as what you have learned about plate tectonics and structural geology.

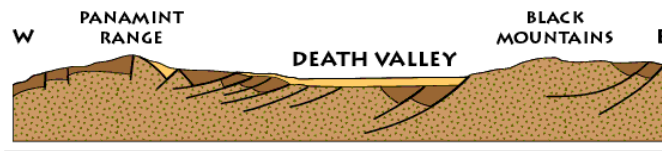


Figure 2. The deep Death Valley basin is filled with sediment (light yellow). Black lines show the location of the major faults.

2. You are hired as a consultant for the Center for Biological Diversity, which is concerned about a new, large housing development that will be situated adjacent to a nearby river and riparian area. The proposed development will draw water from its own drilled groundwater wells (approximately 10), rather than the public water supply. The cross section below shows the current water table in the river, the unconfined aquifer, and in a rancher’s nearby private well that he uses to provide water for his stock tank (the water table is represented by the dotted black line). Describe the predicted effects the proposed development and well field may have on the height of the water table, the rancher’s private well, and water level in the river. Use colored pencils to draw your predicted outcome with regard to changes to the water table in the figure below, including any cone(s) of depression that may result from groundwater withdrawal in new or existing wells. Include in your response some discussion as to why maintaining the current (pre-development) level of the water table is critical to the ecosystem.

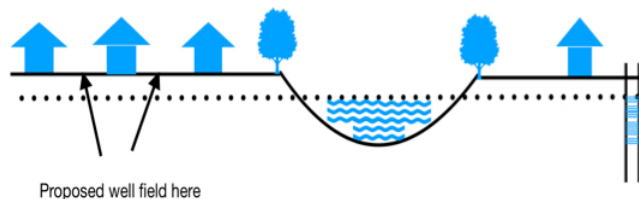


Figure 3. Rancher’s private well and homestead.

3. Recent and devastating forest fires in a national forest have removed a significant amount of vegetation across several hundred square kilometers around the perimeter of a steep canyon and popular recreation area in the Southwest. The climate models for the coming summer monsoon are predicting above-average monsoon precipitation. As a land manager for the Forest Service, you quickly realize that the canyon and nearby recreation area may become vulnerable to several geological and hydrological hazards. What specific hazards might the canyon experience during the coming summer, if the climate models are correct? Explain why you think the canyon is vulnerable to these specific hazards. What steps can you take to keep the public safe and avoid fatalities during the summer tourist season?
4. You have been hired as a tour guide for the American Museum of Natural History in New York City. The museum has recently acquired a piece of the Acasta Gneiss, dated at over 4 billion years old, and found in the Northwest Territories, Canada. The people in your tour are always asking the same questions: How can scientists figure out how old this rock is? What is “gneiss?” Why is this type of rock rare on Earth’s surface? Why is this continental rock so old compared to oceanic rocks? Being the professional that you are, you are able to answer each of their questions with confidence and clarity. What do you tell them?



Figure 4. A fragment of Acasta gneiss exhibited at the Natural History Museum in Vienna.

5. You are serving on the Intergovernmental Panel on Climate Change and are preparing an updated publication that will inform all levels of government and the public on the state of the global climate. As a key committee member, how would you summarize for the public the main drivers (causes) of climate warming? What scientific measurements have been made (either directly or by proxy) that have led to the conclusion that Earth is indeed warming? What recommendations would you make for changing habits or policy, on either a governmental or personal level (or both)? Include some discussion on the biggest concerns with regard to the effects of global warming on Earth's systems.
6. You are taking relatives to see the Grand Canyon for the very first time. Knowing that you have recently completed a rigorous course in geology, naturally they have lots of questions. At the Visitor Center, they spot the following display of all the rock formations in the canyon (see the key in the image caption). Your relatives ask you specific questions: What type of rocks are predominant in the canyon (igneous, metamorphic, sedimentary)? Which rock layer is the oldest and which is the youngest (and how do you know)? Relatively speaking, when did the Colorado River start carving out the canyon (after the deposition of which layer)? What caused the canyon to form? You feel compelled to brag a little about your new knowledge. Tell them everything you know

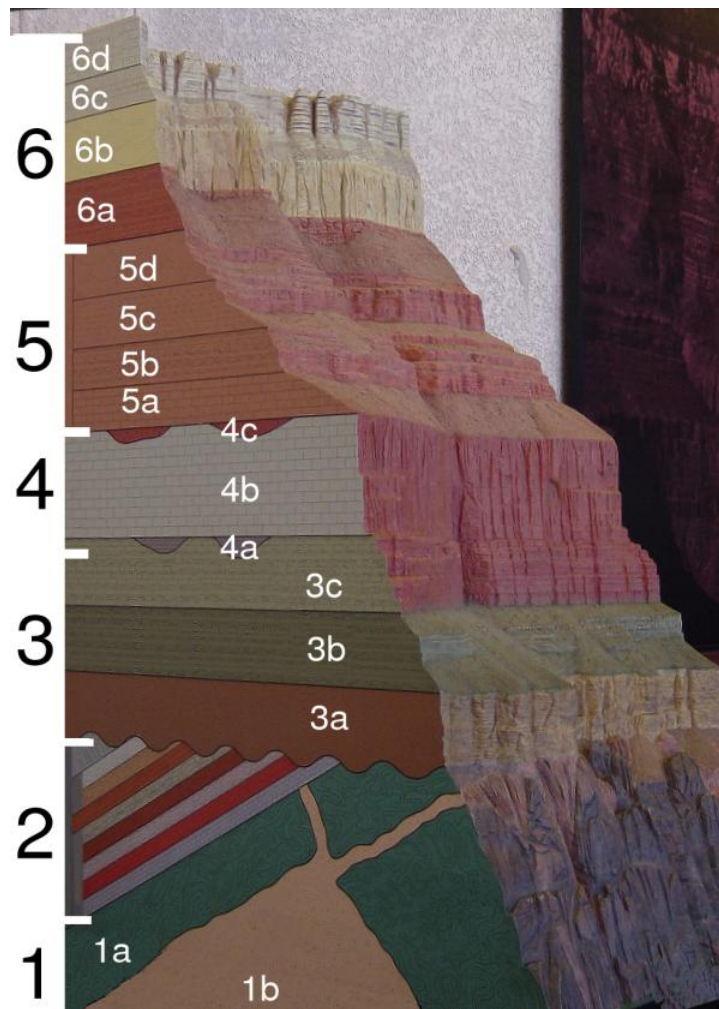


Figure 5. Cross section of the Grand Canyon, as shown in a display in the Grand Canyon Visitor Center. **Group 6** —Hermit, Coconino, Toroweap, and Kaibab (shale, sandstone, limestone). **Group 5** – Supai Group (mudstone, sandstone, limestone). **Group 4** – Temple Butte, Redwall, and Surprise Canyon Formations (conglomerate, sandstone, limestone). **Group 3** – Tonto Group (limestone, shale, and sandstone). **Group 2** – Grand Canyon Supergroup. **Group 1** – Vishnu Group (Vishnu Schist [1a] and Zoroaster Granite [1b]). Photo of an actual display in the Grand Canyon Visitor's Center.

Grading Rubric

Answers are worth 25 points each (3 answers x 25 points each = 75 points total). Points will be deducted for spelling errors, grammatical errors, or insufficient length. Points will be awarded for each answer according to the following rubric:

25 points: Answer addressed the question and illustrated your efforts at providing an accurate, in-depth, and thoughtful response. Answer was at least 3 – 4 paragraphs and contained few to no spelling or grammar errors.

20 points: Answer addressed the question and was an appropriate length, but may be lacking sufficient detail or contains a few inaccuracies. Significant effort was shown in the crafting of your response, despite the inaccuracies. Answer may contain a minor amount of spelling or grammar errors.

15 points: Answer was the appropriate length, but contained quite a few inaccuracies. Response seemed hurried or lacked depth or detail.

10 points: Answer did not adequately address the question. Response was hurried and showed lack of detail and knowledge on the subject. Length was insufficient.

5 points: Answer was insufficient in length (less than 1 – 2 paragraphs) and did not address the question with any effort or detail. Knowledge on the subject was not demonstrated. **0 points:** Response was not provided.

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CHAPTER OVERVIEW

16: Geologic History of North America

[16.1: Introduction](#)

[16.2: Physiographic Provinces of the United States of America](#)

[16.3: Assignment- Making North America](#)

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16.1: Introduction

Module 16

Geologic History of North America

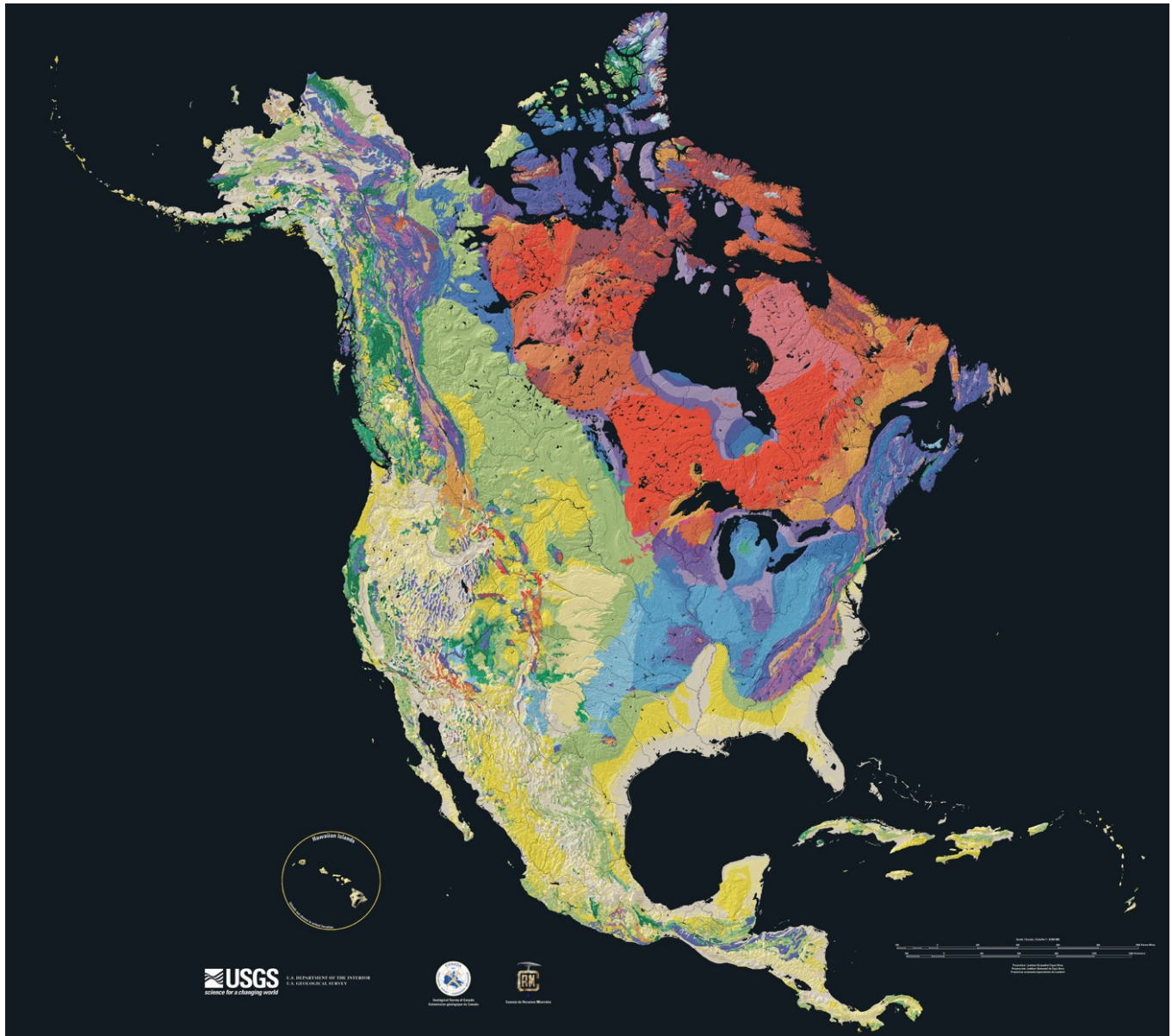


Figure 1. Relief map showing the varying age of bedrock underlying North America. This cartographic tapestry is woven from a geologic map and a shaded relief image. This combination reveals the geologic history of North America through the interrelation of rock type, topography and time. Regional surface processes as well as continent-scale tectonic events are exposed in the three dimensions of space and the fourth dimension, geologic time. From most recent to oldest, age is indicated by: yellow, green, blue, red. See the time scale in the gallery below.

Introduction

If you took a road trip across the continental United States of America you would see significant changes in the landscape in terms of the topography, rocks, soils, geological structures, and plant life that are evident even through the car window on the highway. Regions vary in their geologic history, from the rocky coastline of New England, to the plains of the Midwest, to the sharp peaks of the Rocky Mountains, to the volcanoes of the Pacific Northwest. These observable differences across the United States can be broken into physiographic provinces. Physiographic provinces are identifiable by their distinctive landforms, geologic features, and suites of rocks.

Select an image to view larger

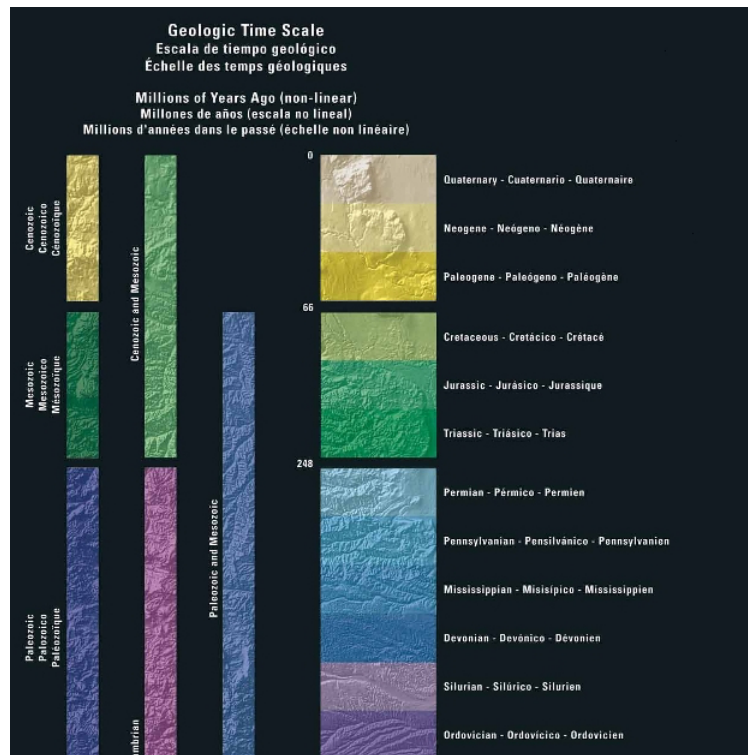


Figure 2. This is the time scale for the North America Tapestry of Time and Terrain map.

Module Objectives

At the completion of this module you will be able to:

1. Distinguish the different physiographic provinces of the United States based on their topography, geology, and other features.
2. Describe the tectonic origin of the major mountain ranges in the United States.
3. Explain why the central portion of the United States differs from the edges of the continent.

Activities

See the *Schedule of Work* for dates of availability and due dates.

Be sure to read through the directions for all of this module's activities before getting started so that you can plan your time accordingly. You are expected to work on this course throughout the week.

Read

[The Physiographic Provinces of the United States of America](#)

Investigate

Check out this interactive map from the National Park Service – click on a province to learn more.

[Physiographic Provinces Map](#)

Watch

Nova, [Making North America: Origins](#)

Module 16 Assignment: Making North America

10 points

After you complete the reading, you can start working on [Module 16 Assignment – Making North America](#)

Module 16 Quiz

10 points

Module 16 Quiz has 10 multiple-choice questions and is based on the content of the Module 16 readings and Assignment 16.

The quiz is worth a total of 10 points (1 points per question). You will have only 10 minutes to complete the quiz, and you may take this quiz only once. **Note:** that is not enough time to look up the answers!

Make sure that you fully understand all of the concepts presented and study for this quiz as though it were going to be proctored in a classroom, or you will likely find yourself running out of time.

Keep track of the time, and be sure to look over your full quiz results after you have submitted it for a grade.

Your Questions and Concerns...

Please contact me if you have any questions or concerns.

General course questions: If your question is of a general nature such that other students would benefit from the answer, then go to the discussions area and post it as a question thread in the “General course questions” discussion area.

Personal questions: If your question is personal, (e.g. regarding my comments to you specifically), then send me an email from within this course.

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16.2: Physiographic Provinces of the United States of America

Module 16

Physiographic Provinces of the United States of America

Introduction

The physiographic provinces of the United States of America can be broken into three different broad areas: Western, Central, and Eastern regions (Figure 1). Adjacent provinces will share features or will at least be affected by the geologic events that define the nearby region. The Western Provinces are shaped by relatively young events (Post-Paleozoic), which are mostly the result of an active plate tectonic margin (the western edge of the continent is also the edge of a tectonic plate).

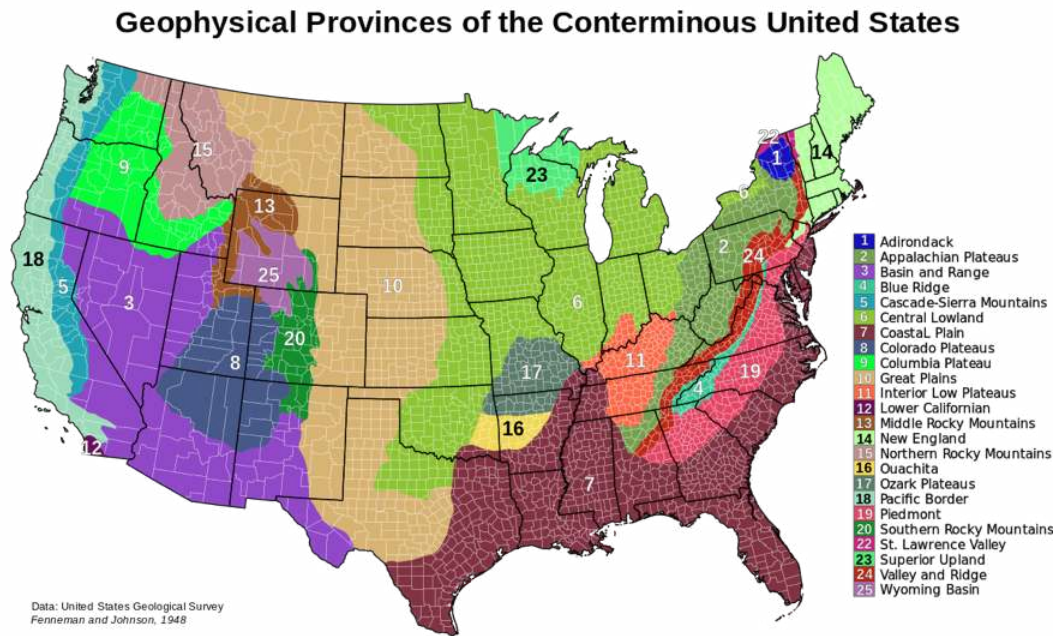


Figure 1. Geophysical Provinces of the Conterminous United States. Click to see larger.

The Eastern Provinces are a mix between young and old geologic events. Most of the individual provinces within this region result from the deformation of ancient mountain building as well as the recent passive sedimentary buildup observable today. Since the Central Provinces of the country has been largely shielded from tectonic activity, this area is flatter and less deformed than the coasts of the United States. Before the individual provinces are discussed in depth, it will be helpful to review the geologic time scale that was presented in earlier in this course.

Western U.S.

The geologic provinces in the Western United States occupy roughly a third of the country and stretch from the Rocky Mountains to the Pacific Ocean. We can group this tectonically active area into four types of provinces: the Rocky Mountains, the Coastal Pacific Mountain System, Interior Plateaus, and the extensional Basin and Range.

The Rocky Mountains are an immense range that stretches from New Mexico to Northern Canada. The Rocky Mountains first started to form during the Late Paleozoic, but their main growth occurred during the Laramide Orogeny during the Late Mesozoic and Early Cenozoic. An **orogeny** is a large-scale deformational event that is the result of the interaction between tectonic plates. In short, it is mountain building. The formation of this range differs from the Continent-Continent convergent boundaries, such as the Himalayas. The Rocky Mountains are the result of low-angle subduction, which caused deformation in the overlying plate. This striking mountain range is no longer active nor growing and has since been glaciated and eroded, which has rounded its highest peaks.

The Pacific Coast Mountains stretch from Mexico to the Arctic Circle in Alaska. Not only do the Pacific Coast Mountains differ significantly from the Rocky Mountains, but the mountain ranges within the Coastal Pacific Mountain System also differ amongst

themselves. The Sierra Nevada Range runs 400 miles across the middle of California and contains iconic features such as Yosemite's Half Dome, which is a mecca for mountain climbers (Figure 2). As with the Rocky Mountains, the Sierra Nevada Range is the byproduct of convergence and subduction. During the same time as the growth of the Rocky Mountains (Late Mesozoic), the subduction led to the formation of volcanoes and the intrusion of massive granite batholiths. The volcanoes have long since eroded away exposing the batholiths at the surface. The Sierra Nevada topography is relatively recent (within the last 5 million years), as these rocks have been deformed by extensional stress, creating large fault blocks that build the steep face of the range. The Cascade Range is the northern portion of the Pacific Coast Mountain Range that spans an area from Northern California to Canada. The Cascade Range is the result of modern subduction of the Juan de Fuca and Gorda Plates under the North American Plate. Whereas the Sierra Nevada range is the eroded exposed core of a Mesozoic chain of volcanoes, the Cascade Range is modern and active. This chain encompasses thousands of volcanoes, including well-known landmarks such as Mount Rainier and Mount Saint Helens.



Figure 2. Half Dome at Yosemite National Park, which is part of the Sierra Nevada Range. Click to see larger.

Between the Rocky Mountains and the Pacific Coast Mountain Range is a large broad area containing a great diversity of geologic features. The Northernmost portion between the Cascades and the Rocky Mountains is the Columbia Plateau. The Columbia Plateau is a large igneous province dominated by Cenozoic volcanic rocks that are a product of the Yellowstone Hotspot. This hotspot produced several massive, though infrequent, eruptions; the largest eruption covering over 50,000 square miles. The Yellowstone Hotspot is still active and supplies the heat that feeds the classic geysers and hot springs throughout Yellowstone National Park (Figure 3). Southeast of this province is the Colorado Plateau, which is a broad expanse that, considering its neighboring provinces, is remarkably undeformed. The Colorado Plateau is mostly composed of horizontal Paleozoic and Mesozoic sedimentary rocks that contain abundant fossils, including the massive bone beds of Dinosaur National Monument. During the Laramide Orogeny this area was dramatically uplifted, allowing rivers to erode downward thus producing immense canyons, such as Grand Canyon National Park. The southeastern portion of the expanse between the Rocky Mountain and Pacific Coast Ranges is called the Basin and Range Province. This area can easily be recognized by the abundant horsts and grabens, which you may remember are series of elevated plateaus and low basins produced from the extensional deformation and normal faults. There are multiple hypotheses for the source of the extension, which range from heating from the mantle to movement along the San Andreas Fault.



Figure 3. Hot Spring in Yellowstone National Park within the Columbia Plateau Province. Click to see larger.

Eastern U.S.

The physiographic provinces that occupy the eastern third of the country range from New England to Texas, wrapping around the Gulf of Mexico. These provinces can easily be split into three regions: (1) provinces associated with the building of the Appalachian Mountains, (2) provinces built by much older orogenies in the Northeast, and (3) provinces created from more recent passive accumulation of sediments along the coast.

The Appalachian Mountains are the product of multiple collisions with small island chains during the Paleozoic, culminating with a collision with the supercontinent of Gondwana during the formation of Pangaea. These ancient mountains have been significantly eroded down to rolling hills that span most of the Southeastern United States as seen in Great Smoky Mountains National Park (Figure 4). The Appalachian Mountains can be further divided into four distinctive physiographic provinces based on their topography and geology. The center of the Appalachian Mountains is called the Valley and Ridge Province, which is composed of highly folded and faulted sedimentary rock. Fossils within these rocks indicate that they are Paleozoic in age, with thick and resistant Pennsylvanian-age sandstones forming its ridges while weaker Devonian and Cambrian shales form its valleys. To the east of the Valley and Ridge is the Blue Ridge Province, which was uplifted along with the Valley and Ridge but is composed of much older igneous and metamorphic rock. Absolute dating of these rocks indicates that the Blue Ridge was formed during the Proterozoic and later deformed during the Middle Paleozoic. The topography between these two provinces differs with the more uniform rocks in the Blue Ridge producing random peaks, valleys, and ridges as opposed to the resistant and non-resistant rocks of the Valley and Ridge, which produce more uniformly parallel ridges.



Figure 4. Appalachian Mountains within Great Smoky Mountains National Park, which contains multiple physiographic provinces. Click to see larger.

Southeast of the Blue Ridge is the Piedmont Province, which is typified by much lower, rolling hills along with small isolated mountains such as Stone Mountain in Georgia (Figure 5). The Piedmont is composed of igneous and metamorphic rock from the cores of long eroded mountain chains ranging from the Proterozoic to the end of the Paleozoic period. On the adjacent west side of the Valley and Ridge province is the Appalachian Plateau, which is an uplifted and largely undeformed region analogous to the Colorado Plateau. The rocks in this province are similar in age and lithology to those in the Valley and Ridge, but the preservation of fossils is enhanced because of the absence of extensive folding and faulting. In addition, the Appalachian Plateau contains abundant geological resources, including coal in West Virginia and iron in Alabama.



Figure 5. Stone Mountain within the Piedmont Province. Click to see larger.

The physiographic provinces in the northeastern United States are very similar to the Piedmont and Blue Ridge Provinces. The New England Province is similar to the Piedmont in that it is composed of Late Proterozoic and Paleozoic intrusive igneous and metamorphic rocks. The major difference between these two provinces is in their history following exposure, with the New England Province showing extensive weathering and erosion from glaciers that is absent from its southeastern counterpart. The Adirondack Mountain Province located in upstate New York is similar to the Blue Ridge in that they are both composed of igneous and metamorphic rock. However, the Adirondacks are fairly unique considering that they are a circular rather than linear range of mountains. The rocks themselves are billion-year-old remnants of the building of a Proterozoic supercontinent called Rodinia. The actual mountains in the range are quite young and represent Late Cenozoic uplift, which exposed these ancient rocks.

The last eastern physiographic province is the Coastal Plain that spans a vast area along the Atlantic Ocean and Gulf of Mexico from New England to Texas. This province is composed of the sediment that has accumulated since the rifting of Pangaea when the eastern edge of the continent became tectonically inactive. The sediment was derived from the continent and was deposited in shallow marine sedimentary environments with abundant, mature sediment and marine fossils.

Central U.S.

The central third of the country is mostly flat, undeformed, and dominated by sequences of sedimentary rocks. We separate this broad expanse into two physiographic provinces based largely on the source of the sediment. The Interior Lowlands Province covers the Midwestern states and consists largely of undeformed Paleozoic marine rocks (limestones and shales) that have been since carved and shaped by the activity of glaciers and rivers. This description may not seem as geologically exciting as those to the east or west, but spectacular cave developments can occur in these marine limestones, such as those from Mammoth Cave, Kentucky (Figure 6). To the west of the Interior Lowlands Province is the Great Plains Province, which is composed of sediments

that eroded from the Rocky Mountains and are, therefore, substantially younger (Mesozoic and Cenozoic) with a higher proportion of clastic material. As with Interior Lowlands, the Great Plains have since been shaped by glaciers and rivers.



Figure 6. Mammoth Cave National Park in Central Kentucky. Click to see larger.

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16.3: Assignment- Making North America

Module 16 Assignment

The Making of North America



Overview

For this exercise, be aware that you will need to have viewed the NOVA episode “[Making North America: Origins](#)” which is available from PBS online. This video reveals and summarizes the unique and often surprising geologic history of North America, from evidence for vast shallow seas and sand dunes in the West; to the remnants of a rift zone around Lake Superior where the continent tried, without success, to break apart; to evidence left behind in Central Park of the majestic Taconic Mountains that once stood where the bustling metropolis of New York City is now.

Instructions

After watching the video, please choose one of the following questions, and write a one to one and a half page response based on what you learned from it (1.5 spacing, 12-point font, no title or headers). You are welcome to expand your knowledge with other sources as long as you include a reference list:

1. Describe the story of the North American continental craton that was called Laurentia. Include some discussion of the underlying geology of Lake Superior, and what it tells us about the geologic history of Laurentia.
2. The Manhattan schist is a geological remnant left behind in New York City that gives us clues about Manhattan’s exciting geologic history. What can we learn from it and other pieces of evidence left behind in the city?
3. Describe the geological evidence for major tectonic collisions across the United States. Include some discussion of the sand dunes in Utah, the jagged and near vertical sandstone slabs in Colorado, fossil evidence in northwestern North America, and the San Andreas fault.

Grading Rubric

15 points: Accurately responded to the question of your choice and followed length requirements. Reference list (if needed) was included.

12 points: Accurately responded to the question of your choice, but response might be a little short or the information contains some inaccuracies. Reference list (if needed) was included.

8 points: Response was too brief or inaccurate. Reference list (if needed) was omitted.

5 points: Only very partial information provided.

0 points: Did not complete the assignment.

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Glossary

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