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Laboratory Manual for Introductory Geology

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INTRODUCTORY

GEOLOGY

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TABLE OF CONTENTS

1

Introduction to Physical Geology
Bradley Deline

1.1 INTRODUCTION

The average introductory geology student's perception of geology normally involves the memorization of rocks and discussions of natural disasters, but Geology contains so much more. Geology is the study of our planet, which is vital to our everyday lives from the energy we use, to the growing of the food we eat, to the foundations of the buildings we live in, to the materials that are used to make everyday objects (metals and plastics). The ideal place to start this course is discussing the methods that are used to better understand our planet, the processes that shape it, and its history.

Science is not a set of facts to remember. Instead it is a method to discover the world around us. You are likely already familiar with the **Scientific Method**, but it is worthwhile to review the process. The first step of the scientific method is making an observation or learning the background surrounding the question in which you are interested. This can be done by taking classes on a subject matter as you are doing presently in geology or by simply taking careful notes about your surroundings. Based on your knowledge and observations, you can then make a **hypothesis**, which is a testable prediction on how something works. A hypothesis should be framed in a way that is easy to test and prove wrong. This might sound odd, but science works to rigorously disprove a hypothesis and only those that withstand the tests become accepted. The wonderful aspect of this definition of a hypothesis is that the testing results in a brand new observation that can then be used to formulate a new hypothesis. Therefore, whether the hypothesis is verified or rejected it will lead to new information. The next step is communication to other scientists. This allows other scientists to repeat the experiment as well as alter it in new and unthought-of ways that can then expand on the original idea. These few steps encompass the vast majority of the scientific method and the career of any individual scientist. As hundreds of related observations and tested hypotheses accumulate scientists can formulate a **theory**. The scientific meaning of a theory is an explanation for a natural phenomenon that is supported by a wealth of scientific

data. A theory is not yet a law because there still may be some debate on the exact workings of the theory or the reasons why a phenomenon occurs, but there is little debate on the existence of what is being described.

This leads us back to Geology, the scientific study of the Earth. There are aspects in geology that are directly testable, but others are not and geologists must become imaginative in discovering aspects about the earth and its history that we will never be able to directly observe. In this laboratory manual we will discuss the materials that make up the earth (Minerals and Rocks), earth processes both deep inside the earth (Folds and Faults) and on its surface (Rivers and Climate), as well as the theory that helps explain how the earth works (Plate Tectonics). A fundamental aspect of understanding the Earth is a grasp of Geologic Time (the subject of the first chapter), which helps us think about the rate and frequency of geologic events that have formed the planet that we know today.

1.1.2 Learning Outcomes

After completing this chapter, you should be able to:

- Discuss the importance of time in the study of Geology
- Discuss the difference between Relative Time and Absolute Time
- Apply Geologic Laws in the relative dating of geologic events
- Use fossils to date a rock unit
- Use ideas behind radiometric dating to date rock units

1.1.3 Key Terms

- Absolute Dating
- Angular Unconformity
- Carbon-14 Dating
- Daughter Atom
- Disconformity
- Geologic Laws
- Geologic Time Scale
- Half-life
- Index Fossils
- Isotope
- Law of Cross-Cutting

- Law of Faunal Succession
- Law of Original Horizontality
- Law of Superposition
- Nonconformity
- Parent Atom
- Potassium-Argon Dating
- Radiometric Dating
- Relative Dating
- Unconformity
- Uranium Dating

1.2 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 ques-

tion. 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 attempting to reconstruct geologic time trying to map 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** (Figure 1.1). 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 deter-

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
					65 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)				2500 Ma
Archean					4000 Ma
Hadean					4550 Ma

Figure 1.1 | The geologic time scale. Ma, Million years, K. Yr, Thousand years
Author: Bradley Deline
Source: Original Work
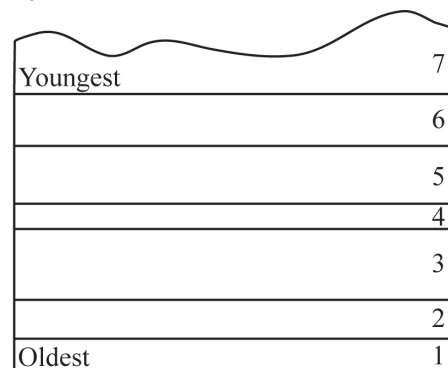**License:** CC BY-SA 3.0

mined 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 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.

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.

1.2.1 Relative Time and Geologic Laws

The methods that geologists use to establish relative time scales are based on Geologic Laws. A scientific law is something that we understand and is proven. It turns out that, unlike math, it is hard to prove ideas in science and, therefore, Geologic Laws are often easy to understand and fairly simple. Before we discuss the different geologic laws, it would be worthwhile to briefly introduce the different rock types. Sedimentary rocks, like sandstone, are made from broken pieces of other rock that are eroded in the high areas of the earth, transported by wind, ice, and water to lower areas, and deposited. The cooling and crystallizing of molten rock forms igneous rocks. Lastly, the application of heat and pressure to rocks creates metamorphic rocks. This distinction is important because these three different rock types are formed differently and therefore, need to be interpreted differently.

The **Law of Superposition** states that in an undeformed sequence of sedimentary rocks the oldest rocks will be at the bottom of the sequence while the youngest will be on top. Imagine a river carrying sand into an ocean, the sand will spill out onto the ocean floor and come to rest on top of the seafloor. This sand was deposited after the sand of the seafloor was already deposited. We can then create a relative time scale of rock layers from the oldest rocks at the bottom (labeled #1 in Figure 1.2) to the youngest at the top of an outcrop (labeled #7 in Figure 1.2).

Figure 1.2 | Block diagram showing the relative age of sedimentary layers based on the Law of Superposition.
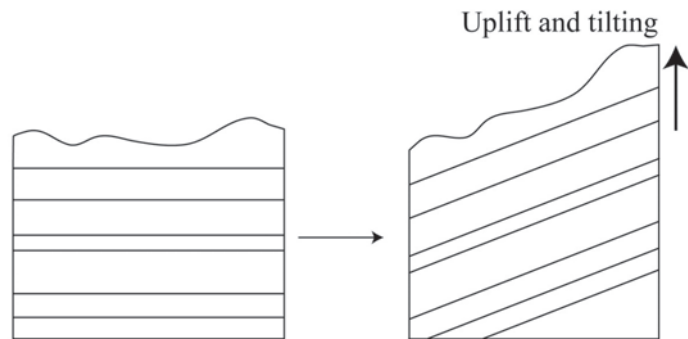**Author:** Bradley Deline
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The **Law of Original Horizontality** states that undeformed sedimentary rock are deposited horizontally. The deposition of sediment is controlled by gravity and will pull it downward. If you have muddy water on a slope, the water will flow down the slope and pool flat at the base rather than depositing on the slope itself. This means that if we see sedimentary rock that is tilted or folded it was first deposited flat, then folded or tilted afterward (Figure 1.3).

The **Law of Cross-Cutting** states that when two geologic features intersect, the one that cuts across the other is younger. In essence, a feature has to be present before something can affect it. For example, if a fault fractures through a series of sedimentary rocks those sedimentary rocks must be older than the fault (Figure 1.4).

One other feature that can be useful in building relative time scales is what is missing in a sequence of rocks. **Unconformities** are surfaces that represent significant weathering and erosion (the breakdown of rock and movement of sediment) which result in missing or erased time. Erosion often occurs in elevated areas like continents or mountains so pushing rocks up (called uplifting) results in erosion and destroying a part of a geologic sequence; much older rocks are then exposed at the earth's surface. If the area sinks (called subsidence), then much younger rocks will be deposited overtop of these newly exposed rocks. The amount of time missing can be relatively short or may represent billions of

Figure 1.3 | Sedimentary rocks are deposited horizontally such that if the layers are tilted or folded it must have occurred following deposition.
Author: Bradley Deline
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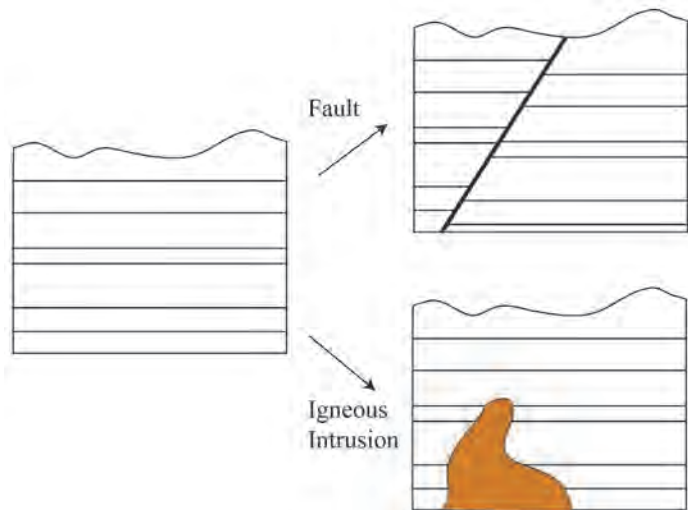
Figure 1.4 | Block diagrams showing the Law of Cross-Cutting. In both instances on the right the geological features (fault or Igneous intrusion) cut across the sedimentary layers and must then be younger.
Author: Bradley Deline
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years. There are three types of unconformities based on the rocks above and below the unconformity (Figure 1.5). If the type of rock is different above and below the unconformity it is called a **Nonconformity.** For example, igneous rock formed deep in the earth is uplifted and exposed at the surface then covered with sedimentary rock. If the rocks above and below the erosion surface are both sedimentary,

Nonconformity

Intrusion of igneous rock into sedimentary rocks

Uplift and erosion

Subsidence and deposition

Intrusive Igneous Rock
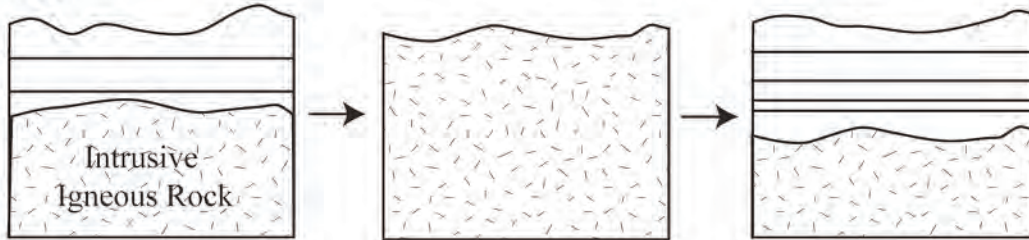
Angular Unconformity

Deposition of sedimentary rocks

Uplift, tilting, and erosion

Subsidence and deposition
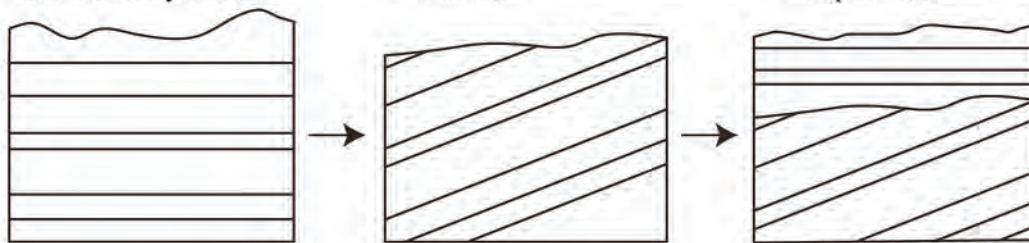
Disconformity

Deposition of sedimentary rocks

Uplift and erosion

Subsidence and deposition
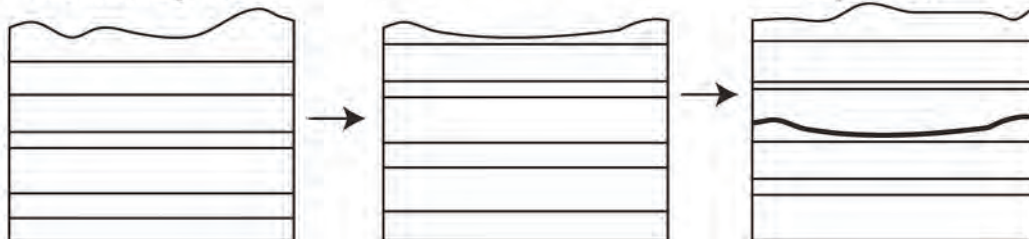
Figure 1.5 | Block diagrams showing the formation of the three types of Unconformities. The three unconformities differ based on the type of rock underneath the erosion surface.
Author: Bradley Deline
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then the orientation of the layers is important. If the rocks below the erosion surface are not parallel with those above, the surface is called an **Angular Unconformity**. This is often the result of the rocks below being tilted or folded prior to the erosion and deposition of the younger rocks. If the rocks above and below the erosion surface are parallel, the surface is called a **Disconformity**. This type of surface is often difficult to detect, but can often be recognized using other information such as the fossils discussed in the next section.

Using these principles we can look at a series of rocks and determine their relative ages and even establish a series of events that must have occurred. Common events that are often recognized can include 1) Deposition of sedimentary layers, 2) Tilting or folding rocks, 3) Uplift and erosion of rocks, 4) Intrusion of liquid magma, and 5) Fracturing of rock (faulting). Figures 1.6 and 1.7 show how to piece together a series of geologic events using relative dating.

Building a Relative Time Sequence
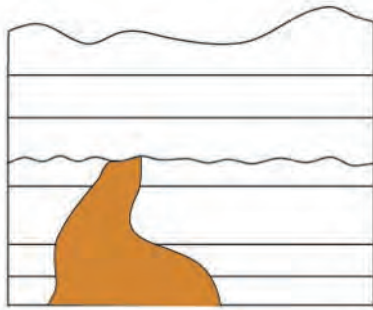
Step 1. Identify and number all of the sedimentary layers.

Step 2.Identify any other geologic events
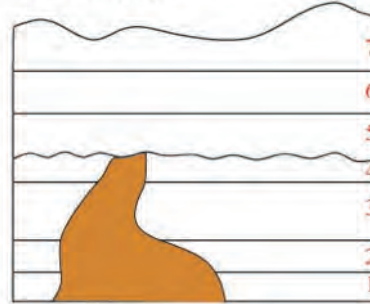
Disconformity
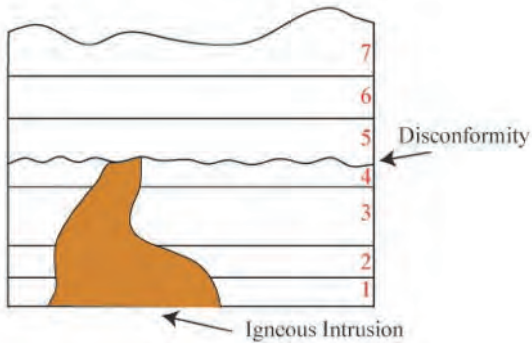
Igneous Intrusion

Step 3. Place the sedimentary Layers and geologic events in order based on the Geologic Laws.

1. Deposit sedimentary layers 1-4.
2. Igneous Intrustion.
3. Uplift and Erode - Disconformity.
4. Subsidence and Deposit layers 5-7.
5. Uplift and Erode.

Figure 1.6 | An example showing how to determine a relative dating sequence of events from a block diagram.
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Building a Relative Time Sequence
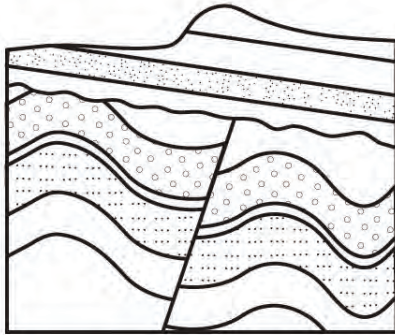
Step 1. Identify and number all of the sedimentary layers.

Step 2. Identify any other geologic events

- Tilting
- Angular Unconformity
- Folding
- Faulting
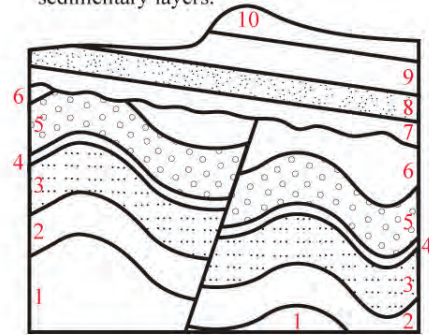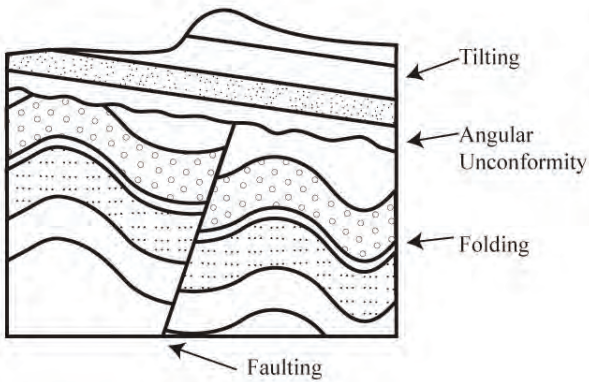
Step 3. Place the sedimentary Layers and geologic events in order based on the Geologic Laws.

1. Deposit sedimentary layers 1-6.
2. Fold and Fault layers 1-6.
3. Uplift and Erode - Angular Unconformity
4. Subsidence and Deposit layers 7-10
5. Tilt Layers 1-10.
6. Uplift and Erode.

Figure 1.7 | An example showing how to determine a relative dating sequence of events from a block diagram.
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1.3 LAB EXERCISE

Part A – Relative Time

Relative time is an important tool for geologist to quickly construct series of events, especially in the field. In the following section, apply what you have learned regarding relative time to the questions below.
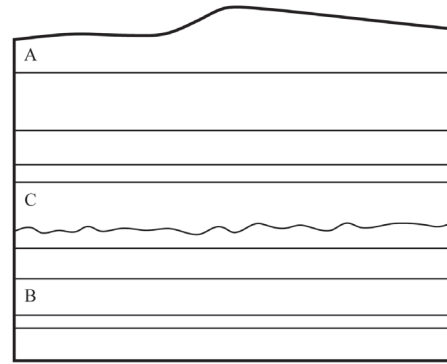
Figure 1.8 | Block diagram to use to answer questions 1 and 2.
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1. In Figure 1.8, which of the following rock layers is the **oldest**?

    a. A   b. B   c. C

2. Which Geologic Law did you use to come to the conclusion you made in the previous question?

    a. The Law of Superposition   b. The Law of Cross-Cutting

    c. The Law of Original Horizontality   d. Unconformities

Figure 1.9 | Block diagram to use to answer questions 3, 4, and 5. Unconformities are shown in brown.
Author: Bradley Deline
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3. In Figure 1.9, which of the following geologic structures is the **youngest**?

    a. A   b. B   c. C

4. Which Geologic Law did you use to come to the conclusion you made in the **previous question?**

    a. The Law of Superposition   b. The Law of Cross-Cutting

    c. The Law of Original Horizontality   d. Unconformities

5. Examine unconformities 1 and 2 indicated in Figure 1.9. Which of the following **statements about them is true?**

    a. The older unconformity is a Nonconformity, while the younger is an Angular Unconformity.

    b. The older unconformity is a Disconformity, while the younger is a Nonconformity.

    c. The older unconformity is a Nonconformity, while the younger is a Disconformity.

    d. The older unconformity is an Angular Unconformity, while the younger is a Disconformity.

6. Examine the Unconformity shown in Figure 1.10. What type of unconformity **is this?**

    a. Angular Unconformity

    b. Nonconformity

    c. Disconformity

Figure 1.10 | Block diagram to use to answer question 6.
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Examine Figure 1.11. Note that all of the layers in this block diagram are composed of sedimentary rock and the unconformities are colored in red. Using the geologic laws discussed earlier and following the examples shown in Figures 1.6 and 1.7, identify the geologic events that occurred in this area. Then place the following geologic events in the correct relative time sequence.
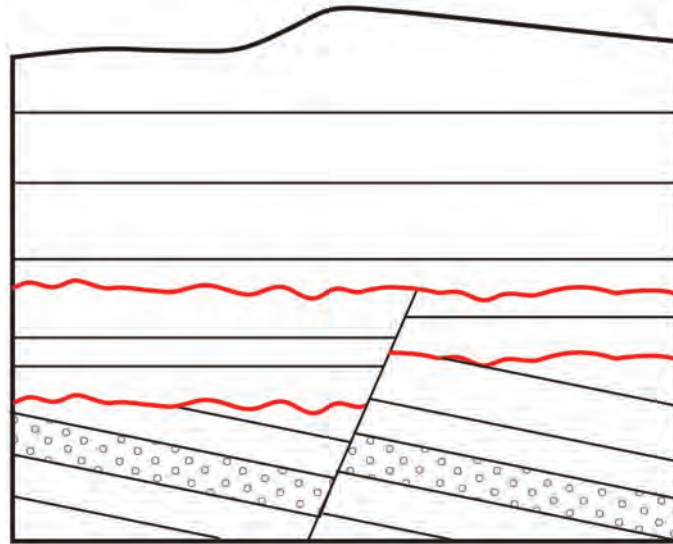
Figure 1.11 | Block diagram to use to answer questions 7, 8, and 9. Unconformities are shown in red.
Author: Bradley Deline
Source: Original Work
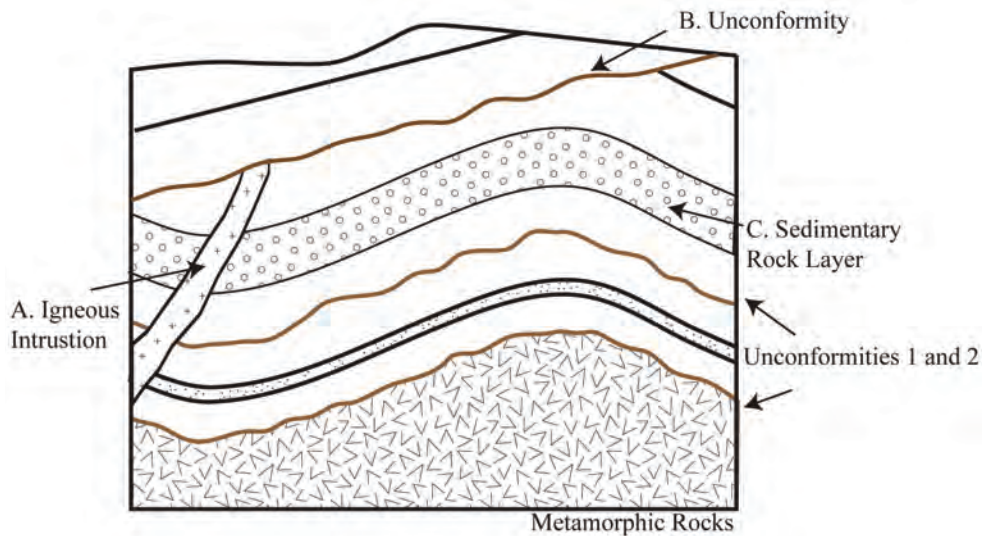**License:** CC BY-SA 3.0

a. Tilting.

b. Uplift and Erosion (Angular Unconformity).

c. Submergence and deposition of sedimentary layers 10-13.

d. Uplift and Erosion to current position.

e. Submergence and Deposition of sedimentary layers 7-9.

f. Uplift and Erosion (Disconformity)

g. Submergence and deposition of sedimentary layers 1-6.

h. Fault.
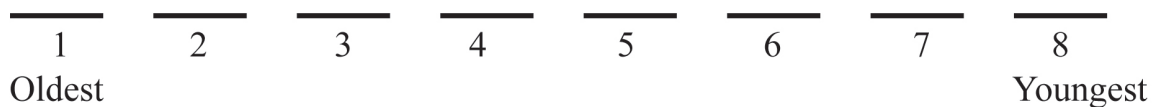
‾‾‾	‾‾‾	‾‾‾	‾‾‾	‾‾‾	‾‾‾	‾‾‾	‾‾‾
1	2	3	4	5	6	7	8

Oldest   Youngest

7. Which of the above geologic events is the second in the sequence?

    a. A   b. B   c. C   d. D

    e. E   f. F   g. G   h. H

8. Which of the above geologic events is the fifth in the sequence?

    a. A   b. B   c. C   d. D

    e. E   f. F   g. G   h. H

9. Which of the above geologic events is the seventh in the sequence?

    a. A   b. B   c. C   d. D

    e. E   f. F   g. G   h. H

1.4 FAUNAL SUCCESSION AND INDEX FOSSILS

Another useful tool in relative dating are fossils. Fossils are the preserved remains of ancient organisms normally found within sedimentary rocks. Organisms appear at varying times in geologic history and go extinct at different times. These organisms also change in appearance through time. This pattern of the appearance, change, and extinction of thousands of fossil organisms creates a recognizable pattern of organisms preserved through geologic time. Therefore, rocks of the same age likely contain similar fossils and we can use these fossils to date sedimentary rocks. This concept is called the **Law of Faunal Succession**.

Some fossils are particularly useful in telling time, these are called **Index Fossils**. These are organisms that we are likely to find because they were abundant when they were alive and were likely to become fossils (for example, having a robust skeleton). These organisms often have a large geographic range so they can be used as an index fossil in many different areas. However, they should also have a short geologic range (the amount of time an organism is alive on Earth), so we can be more precise in the age of the rock if we find the fossil. Index fossils are often the quickest and easiest way to date sedimentary rocks precisely and accurately.

1.5 LAB EXERCISE

Part B – Faunal Succession

The use of animals and their preserved remains (fossils) can help build a highly precise time sequence, often with a higher resolution than absolute dating. In the following section, use this principle to answer the following questions.

A group of geology students stops at a rocky outcrop in Northern Kentucky to examine the rocks and fossils. After looking at geologic maps they conclude that the rocks are Ordovician (~450 Million years old) in age. They make a collection of fossils to better date these rocks. After returning to school they identify the following fossils in order to establish the time frame in which each were alive. They hope to use the Law of Fossil Succession to then plot the ranges of the genera and determine the exact age of the rocks.

A. The sea lily *Ectenocrinus.*
Fulton-Fairmount

B. The trilobite *Isotelus.*
Fulton-Arnheim

C. The lampshell *Zygospria.*
McMicken- Fairmount

D. The snail *Cyclonema.*
McMicken- Fairmount

E. The lampshell
Vinlandostrophia.
Fairmount- Corryville

F. The bryozoan
Parvohallopora.
Southgate- Fairmount

G. The lampshell *Cincinnetina.*
Fulton- Fairmount

H. The edrioasteroid
Streptaster.
Southgate- Sunset

I. The clam *Ambonychia.*
Fairmount- Bellevue

The geologic range of *Ectenocrinus* (A) is plotted below. Using *Ectenocrinus* as an index fossil you can determine that the rock is from the Late Ordovician and was formed between the Fulton member of the Kope Formation and the Fairmount member of the Maysville Formation. Plot the geologic range of the remaining eight animals to narrow down when this rock was formed.
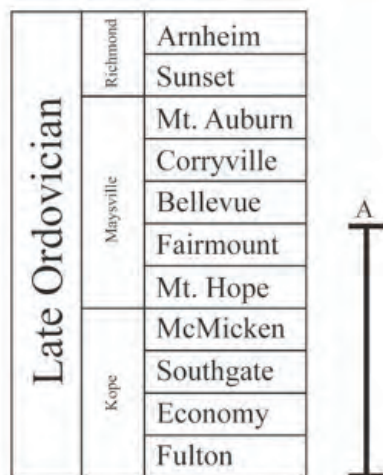
All pictures by B. Deline

Figure 1.12
Author: Bradley Deline
Source: Original Work
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10. Based on the assemblage of organisms (A-I) in this sample, what is the age of this rock?

    a. Economy   b. Southgate   c. McMicken   d. Mt. Hope

    e. Fairmount   f. Bellevue   g. Corryville   h. Mt. Auburn

11. Which organism was the *most* useful in coming to this conclusion (which is the best index fossil)?

    a. Isotelus   b. Zygospira   c. Cyclonema   d. Vinlandostrophia

    e. Parvohallopora   f. Cincinnetina   g. Streptaster   h. Ambonychia

12. Which organism was the *least* useful in coming to this conclusion (which is the worst index fossil)?

    a. Isotelus   b. Zygospira   c. Cyclonema   d. Vinlandostrophia

    e. Parvohallopora   f. Cincinnetina   g. Streptaster   h. Ambonychia

1.6 ABSOLUTE TIME AND RADIOMETRIC DATING

Absolute time is a method for determining the age of a rock or object most often using radiometric isotopes. Atoms are made of three particles, protons, electrons, and neutrons. All three of these particles are important to the study of geology: the number of protons defines a particular element, the number of electrons control how that element bonds to make compounds, and the number of neutrons changes the atomic weight of an element. **Isotopes** are atoms of an element that differ in the number of neutrons in their nucleus and, therefore, their atomic weight. If an element has too many or too few neutrons in its nucleus then the atom becomes unstable and breaks down over time, which is called **radioactive decay**. The process of radioactive decay involves the emitting of a particle from a radioactive atom, called the **parent atom**, which changes it to another element, called the **daughter atom**. We can study and measure the radioactivity of different elements in the lab and calculate the rate of decay. Though the rate of decay varies between isotopes from milliseconds to billions of years, all radiometric isotopes decay in a similar way. Radiometric decay follows a curve that is defined by a radiometric isotope's **half-life**. The half-life is defined as the amount of time it takes for half of the atoms of the radiometric parent isotope to decay to the daughter. The half-life is independent of the amount of atoms at a given time so it takes the same amount of time to go from 100% of the parent isotope remaining to 50% as it does to go from 50% of the parent isotope remaining to 25%. If we know the length of the half-life for a particular radio-

metric isotope and we measure the amount of parent and daughter isotope in a rock, we can then calculate the age of the rock, which is called **Radiometric Dating**. Given the shape of the decay curve, a material never runs out of the parent isotope, but we can only effectively measure the parent up to 10-15 half-lives.

1.7 LAB EXERCISE

Part C — Radiometric Dating

Complete the following chart by calculating the amount of parent isotope remaining for all of the given half-lives, then plot your findings on the graph (Figure 1.13). Make sure you connect the data points on the graph by drawing in the decay curve.

Use the completed chart and graph to answer the questions below.

Number of Half-lives	Amount of Parent Isotope Remaing
0	100%
1	50%
2	
3	
4	
5	
6	
7	
8	
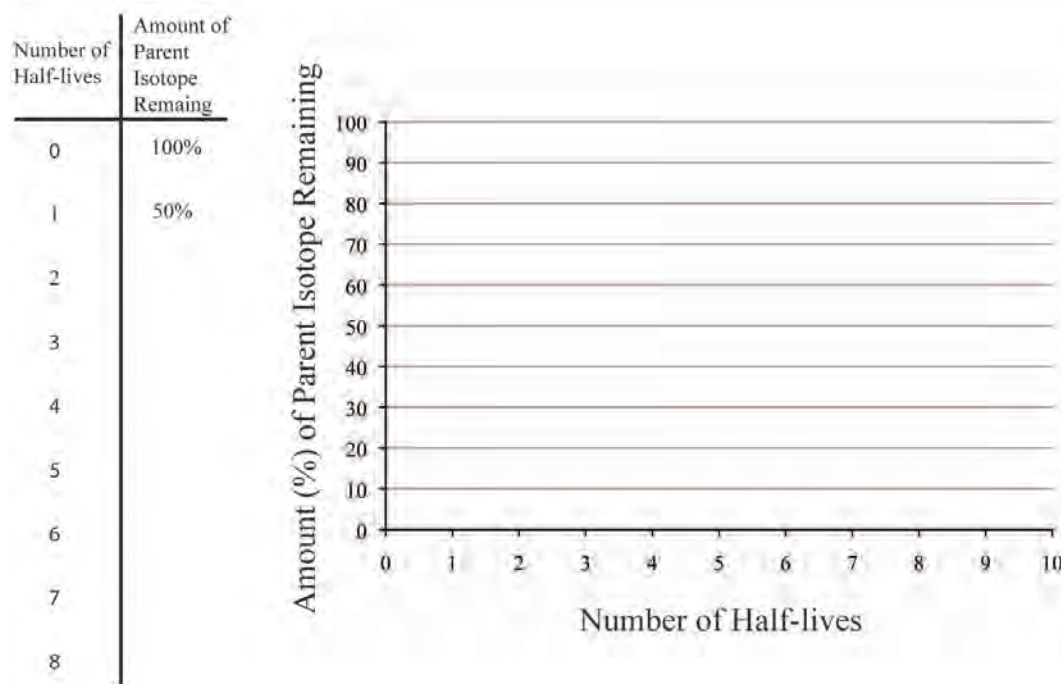
Figure 1.13
Author: Bradley Deline
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13. How much of the parent isotope would be remaining after 7 half-lives have passed?

    a. 6.25%   b. 1.56%   c. 0.78%   d. 0.39%

14. If a radiometric element has a half-life of 425 years, how old would a rock be that only had 3.125% of the parent isotope remaining?

    a. 2125 years   b. 1700 years   c. 2550 years   d. 3400 years

15. Based on your graph above, approximately how much of the parent isotope would be remaining after 3.5 half-lives?

    a. 16%   b. 12%   c. 4%   d. 8%

16. Based on your graph above, approximately how many half-lives have passed when only 35% of the parent isotope is remaining?

    a. 0.75   b. 1.5   c. 2.1   d. 2.5

1.8 DATING SYSTEMS

There are several different radiometric isotopes that are commonly used in absolute dating. Each of these systems have different uses within geology in that they require different materials and can date objects within specific time frames.

Carbon-14 dating is of limited use within geology, but is still the system that is familiar to most people. Carbon-14 (parent isotope) is found in organic material including bone, tissue, plants, and fiber. This isotope is found naturally in small amounts in the atmosphere within CO_2 and is incorporated into plants during photosynthesis and then filters throughout the food chain. You currently have Carbon-14 in your body that is decaying to Nitrogen-14 (daughter isotope), but you replace it whenever you eat. When an animal stops eating or a plant stops photosynthesizing, the radioactive carbon starts to decay without being replaced, which can be easily measured. Carbon-14 has a very short half-life of 5,730 years and can only be used to date materials up to approximately 70,000 years. Given the age of the Earth is 4.54 billion years, carbon-14 can only be used to date very recent materials.

Uranium dating involves a complex system of multiple isotopes that decay through a chain reaction until it reaches non-radiogenic lead. Surprising to most students, uranium can be found in many places, but it is normally in very miniscule amounts. Another issue with this system is that the daughter isotope, lead, is also found naturally in many different places, which makes it difficult to differentiate between lead formed from radiometric decay and lead found naturally in the environment. The mineral zircon solves both of these issues, by concentrating uranium and excluding lead from its mineral structure. Therefore, we use Uranium dating on zircons found within igneous rocks (such as volcanic ash or rocks formed deep in the earth). Uranium has a very long half-life of 4.5 billion years, which is more than long enough to date most rocks on Earth. It takes about one million years for the complex system to normalize such that Uranium dates of less than that are unreliable.

Potassium-Argon dating is also a useful method of dating rocks. Potassium decays into two separate daughter isotopes, Argon and Calcium. We measure the amount of Argon in the rocks because unlike calcium it is rare within minerals since it is a Noble Gas and doesn't normally bond with other elements. Therefore, any argon within a mineral is from the decay of potassium. The use of Argon also

has its drawbacks, for instance a gas can easily escape from a rock and, therefore, special care needs to be taken in the lab to prevent this. This system works well when there are multiple materials to examine that contain abundant potassium, like the rock granite that is full of potassium-rich pink minerals called feldspars. The half-life of Potassium is 702 million years, so it is similar to Uranium in that it is most useful dating older rocks.

With all of these methods there is still the chance for error such that it is best to think of any particular radiometric date as a scientific hypothesis that needs to be further tested. Error can come from the addition or subtraction of either parent or daughter isotopes in the rock following its formation. This can be done in several ways, most commonly through the adding of heat and pressure (metamorphism). There are ways to correct for these issues that allows the scientist to date both the rock and the metamorphic event as long as the geologic history is known.

As you may have guessed from the previous exercise, it is rare to find a rock that contains an amount of the parent remaining that falls exactly on one of the half-lives. In most cases we need to use a simple formula to calculate the age of a rock using the length of the half-life and the amount of parent remaining.

The formula is:

$$Age = -(\frac{t_{1/2}}{0.693})\ln(P)$$

$t_{1/2}$ = The length of the half-life in years

P = The amount of the parent remaining in decimal form. For example, if there is 50% of the parent remaining it would equal 0.5.

Let's work an example using the equation that we already know the answer to in advance. You have a sample of bone that has 25% of the Carbon-14 (Half-life= 5730 years) remaining, how old is the sample? We can answer this question in two ways:

1. We know that if there is 25% remaining, two half-lives have passed and with each half-life being 5730 the bone would be 11,460 years old.
2. We could use the above equation and insert both the length of the half-life and the amount of the parent remaining:

$$Age = -(\frac{5730}{0.693})\ln(0.25)$$

To solve the equation, take the Natural Log (ln) of 0.25 and multiply by the term in the parentheses (make sure to include the negative sign). If you do this you will get 11,460 as well.

1.9 LAB EXERCISE

Part D – Isotopic Systems

Using what you learned in the previous section regarding absolute dating, determine the most appropriate methods and the ages of the materials in the following questions.

17. An Archeologist finds some cotton cloth at a burial site and wants to determine the age of the remains. Which isotopic system should they use?

    a. Carbon-14   b. Uranium   c. Potassium-Argon

18. The Archeologist determines that there is 16.7% of the parent isotope remaining in the cloth sample. How old is the burial site? Hint: you can find the length of the half-life in the reading above.

    a. 13,559 years   b. 14,798 years   c. 16,743 years

    d. 1.66 billion years   e. 1.81 billion years   f. 2.05 billion

19. A geologist is trying to date a sequence of sedimentary rocks with abundant fossils and sandstones. Within the sequence is a distinctive clay layer that under closer inspection is fine-grained volcanic ash. Which of the following is the best way to obtain an absolute date for the sequence of rocks?

    a. Carbon date the fossils   b. Potassium-Argon date the sands

    c. Uranium date the Zircons in the ash   d. Identify the index fossils

20. The geologist determines there is 78.3% of the parent remaining in the sample that they examine. How old is the sequence of rocks? Hint: you can find the length of the half-life in the reading above.

    a. 187.5 million years   b. 247.8 million years   c. 390.7 million years

    d. 2.504 billion years   e. 1.588 billion years   f. 1.202 billion years

1.10 STUDENT RESPONSES

The following is a summary of the questions in this lab for ease in submitting answers online.

1. In Figure 1.8, which of the following rock layers is **oldest**?

   a. A   b. B   c. C

2. Which Geologic Law did you use to come to the conclusion you made in the previous question?

   a. The Law of Superposition   b. The Law of Cross-Cutting

   c. The Law of Original Horizontality   d. Unconformities

3. In Figure 1.9, which of the following geologic structures is **youngest**?

   a. A   b. B   c. C

4. Which Geologic Law did you use to come to the conclusion you made in the previous question?

   a. The Law of Superposition   b. The Law of Cross-Cutting

   c. The Law of Original Horizontality   d. Unconformities

5. Examine unconformities 1 and 2 indicated in Figure 1.9. Which of the following statements about them is true?

   a. The older unconformity is a Nonconformity, while the younger is an Angular Unconformity.

   b. The older unconformity is a Disconformity, while the younger is a Nonconformity.

   c. The older unconformity is a Nonconformity, while the younger is a Disconformity.

   d. The older unconformity is an Angular Unconformity, while the younger is a Disconformity.

6. Examine the Unconformity shown in Figure 1.10. What type of unconformity is this?

   a. Angular Unconformity   b. Nonconformity   c. Disconformity

7. Which of the above geologic events is the second in the sequence?

    a. A   b. B   c. C   d. D

    e. E   f. F   g. G   h. H

8. Which of the above geologic events is the fifth in the sequence?

    a. A   b. B   c. C   d. D

    e. E   f. F   g. G   h. H

9. Which of the above geologic events is the seventh in the sequence?

    a. A   b. B   c. C   d. D

    e. E   f. F   g. G   h. H

10. Based on the assemblage of organisms (A-I) in this sample, what is the age of
    this rock?

    a. Economy   b. Southgate   c. McMicken   d. Mt. Hope

    e. Fairmount   f. Bellevue   g. Corryville   h. Mt. Auburn

11. Which organism was the *most* useful in coming to this conclusion (which is the
    best index fossil)?

    a. Isotelus   b. Zygospira   c. Cyclonema   d. Vinlandostrophia

    e. Parvohallopora f. Cincinnetina g. Streptaster   h. Ambonychia

12. Which organism was the *least* useful in coming to this conclusion (which is the
    worst index fossil)?

    a. Isotelus   b. Zygospira   c. Cyclonema   d. Vinlandostrophia

    e. Parvohallopora f. Cincinnetina g. Streptaster   h. Ambonychia

13. How much of the parent isotope would be remaining after 7 half-lives have passed?

    a. 6.25%   b. 1.56%   c. 0.78%   d. 0.39%

14. If a radiometric element has a half-life of 425 years, how old would a rock be that only had 3.125% of the parent isotope remaining?

   a. 2125 years   b. 1700 years   c. 2550 years   d. 3400 years

15. **Based on your graph above, approximately how much of the parent isotope would be remaining after 3.5 half-lives?**

   a. 16%   b. 12%   c. 4%   d. 8%

16. **Based on your graph above, approximately how many half-lives have passed when only 35% of the parent isotope is remaining?**

   a. 0.75   b. 1.5   c. 2.1   d. 2.5

17. An Archeologist finds some cotton cloth at a burial site and wants to determine the age of the remains. Which isotopic system should they use?

   a. Carbon-14   b. Uranium   c.Potassium-Argon

18. **The Archeologist determines that there is 16.7% of the parent isotope remaining in the cloth sample. How old is the burial site? Hint: you can find the length of the half-life in the reading above.**

   a. 13,559 years   b. 14,798 years   c. 16,743 years

   d. 1.66 billion years   e. 1.81 billion years   f. 2.05 billion

19. **A geologist is trying to date a sequence of sedimentary rocks with abundant fossils and sandstones. Within the sequence is a distinctive clay layer that under closer inspection is fine-grained volcanic ash. Which of the following is the best way to obtain an absolute date for the sequence of rocks?**

   a. Carbon date the fossils   b. Potassium-Argon date the sands

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20. **The geologist determines there is 78.3% of the parent remaining in the sample that they examine. How old is the sequence of rocks? Hint: you can find the length of the half-life in the reading above.**

   a. 187.5 million years   b. 247.8 million years   c. 390.7 million years

   d. 2.504 billion years   e. 1.588 billion years   f. 1.202 billion years

2 Earth's Interior

Randa Harris and Bradley Deline

2.1 INTRODUCTION

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 1900's 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 throughout.

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.

2.1.1 Learning Outcomes

After completing this chapter, you should be able to:

- Determine the different layers of the Earth and the distinguishing properties of each layer

- Understand how seismic waves behave within the different layers of the Earth
- Understand how seismic tomography has been used to gain a better understanding of the Earth's interior
- Understand the Earth's magnetic field and how it changes over time
- Learn how to use the program Google Earth for geological applications

2.1.2 Key Terms

- Crust
- Inner Core
- Magnetic Field
- Mantle

- Outer Core
- Polar Wandering Curves
- Seismic Tomography
- Seismic Waves

2.2 INTERIOR OF THE EARTH

The study of seismic waves and how they travel through the Earth has been very useful in helping to determine the changes in density and composition within the Earth and in locating the boundaries between the inner core, outer core, mantle, and crust. **Seismic waves** are energy waves generated during earthquakes; two types known as P and S waves propagate through the Earth as wave fronts from their place of origin. P-waves are compressional waves that move back and forth like an accordion, while S-waves are shear waves that move material in a direction perpendicular to the direction of travel, much like snapping a rope. The velocity of both of these waves increases as the density of the materials they are traveling through increases. Because most liquids are less dense than their solid counterparts, and seismic velocity is dependent on density, then seismic waves will be affected by the presence of any liquid phase in the Earth's interior. In fact, S waves are not able to travel through liquids at all, as the side to side motion of S waves can't be maintained in fluids; because of this, we know that the outer core is liquid.
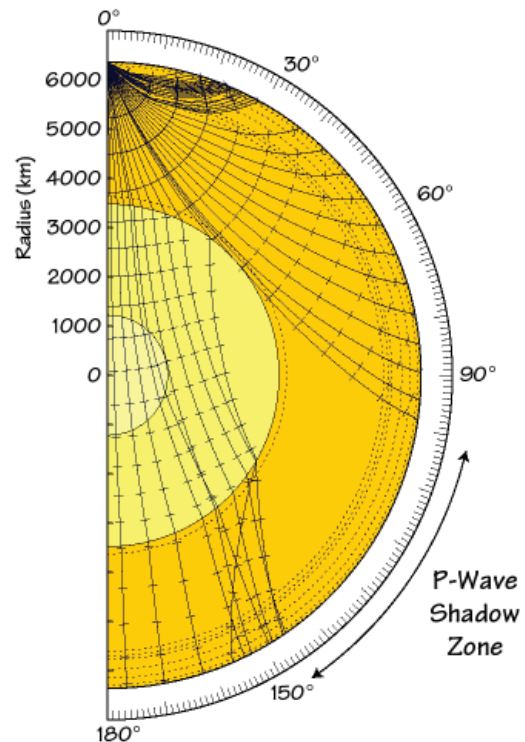
**Figure 2.1 |** A depiction of the P-wave shadow zone.
Author: USGS
Source: Wikimedia Commons
License: Public Domain

If the Earth was completely homogeneous, the P and S waves would flow in straight lines. They don't behave this way, however. As the waves travel through materials of different densities, they are refracted, or bent, as their direction and velocity alter. Sometimes these refractions can result in shadow zones, which are areas along the Earth where no seismic waves are detected. Due to the presence of a liquid outer core, a P-wave shadow zone exists from 103°-143° (see Figure 2.1) from the earthquake origination point (focus), and a larger S-wave shadow zone exists in areas greater than 103° from the earthquake focus.

Based on the way that the Earth travels through space, we know that the average density of the Earth is 5.52 g/cm³. When rocks at the Earth's surface are analyzed, we find that most crustal rocks have densities in the range of 2.5-3 g/cm³, which is lower than the Earth's average. This means that there must be denser material inside the Earth to arrive at that higher average density; in fact, the core region of the Earth is estimated to have a density of 9-13 g/cm³. The composition of the Earth's layers also changes with depth. The bulk Earth composition is mostly made up of iron (~32%), oxygen (~30%), silicon (~16%), and magnesium (15%). If you examine rocks at the Earth's surface, however, you will find that oxygen is the most abundant element by far (~47%), followed by silicon (~28%) and aluminum (~8%), and lesser amounts of iron, calcium, sodium, potassium, and magnesium. Minerals made from silicon and oxygen are very important and are called silicates. So, if iron is present in lower numbers in the crustal rocks, where has that iron gone? Much of it can be found in the core of the Earth, which accounts for the major increase in density there. Review Table 2.1 below for general information about each layer of the Earth, and note how much thicker continental crust is compared to oceanic crust. Examine Figure 2.2 for a depiction of the layers of the Earth.
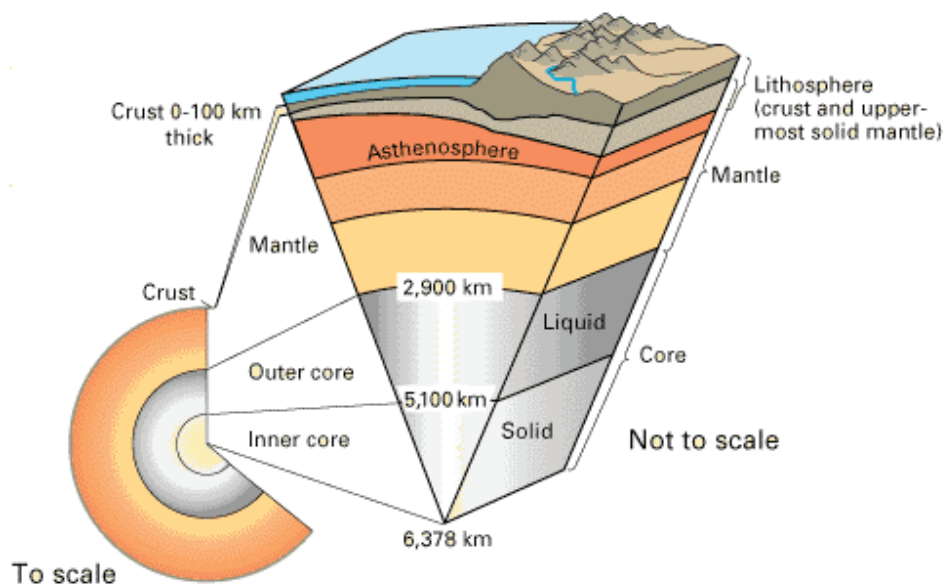
Figure 2.2 | A depiction of the inner layers of the Earth. Note that the image to the bottom left is to scale, while the image to the right is not.
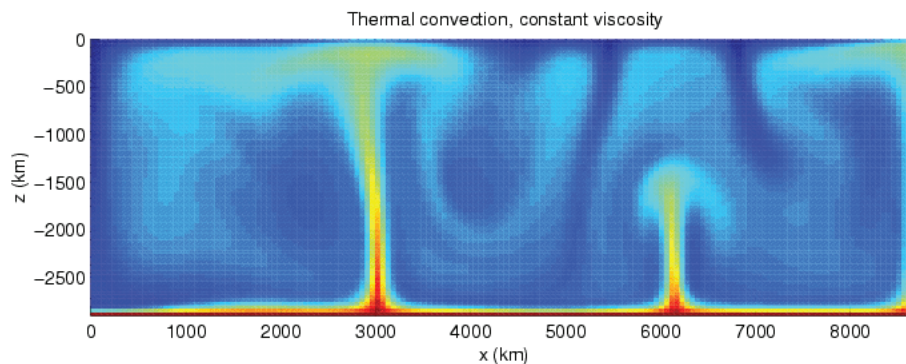**Author:** USGS
Source: USGS
License: Public Domain

Note that this figure includes the terms lithosphere and asthenosphere. The lithosphere is the outer, rigid part of the Earth made up of the upper mantle, oceanic crust, and continental crust. The asthenosphere is just beneath the lithosphere and, rather than being rigid, behaves plastically and flows.

Table 2.1

Earth's Layer	Density (g/cm3)	Thickness (km)	Composition
Continental Crust	~2.7-2.9	~20-70	Felsic rocks
Oceanic Crust	~3.0	~8-10	Mafic rocks
Mantle	~3.4-5.6	~2,885	Ultramafic rocks
Outer Core	~9.9-12.2	~2,200	Iron, some sulfur, nickel, oxygen, silicon
Inner Core	~12.8-13.1	~1,220	Iron, some sulfur and nickel

Relatively recent advances in imaging technology have been used to better understand the Earth's interior. **Seismic tomography** has been used to give a more detailed model of the Earth's interior. In CAT scans, x-rays are aimed at a person and rapidly rotated, generating cross-sectional images of the body. In a similar fashion, repeated scans of seismic waves are stacked to produce a three-dimensional image in seismic tomography. This technique has been used in many ways, from searching for petroleum near the Earth's surface to imaging the planet as a whole. Figure 2.3 depicts an image of the mantle created from seismic tomography.

Figure 2.3 | A model of thermal convection in the mantle, created using seismic tomography. This model depicts areas of cool mantle material in blue and areas of warm mantle material in red. The thin red areas represent rising plumes.
Author: User "Harroschmeling"
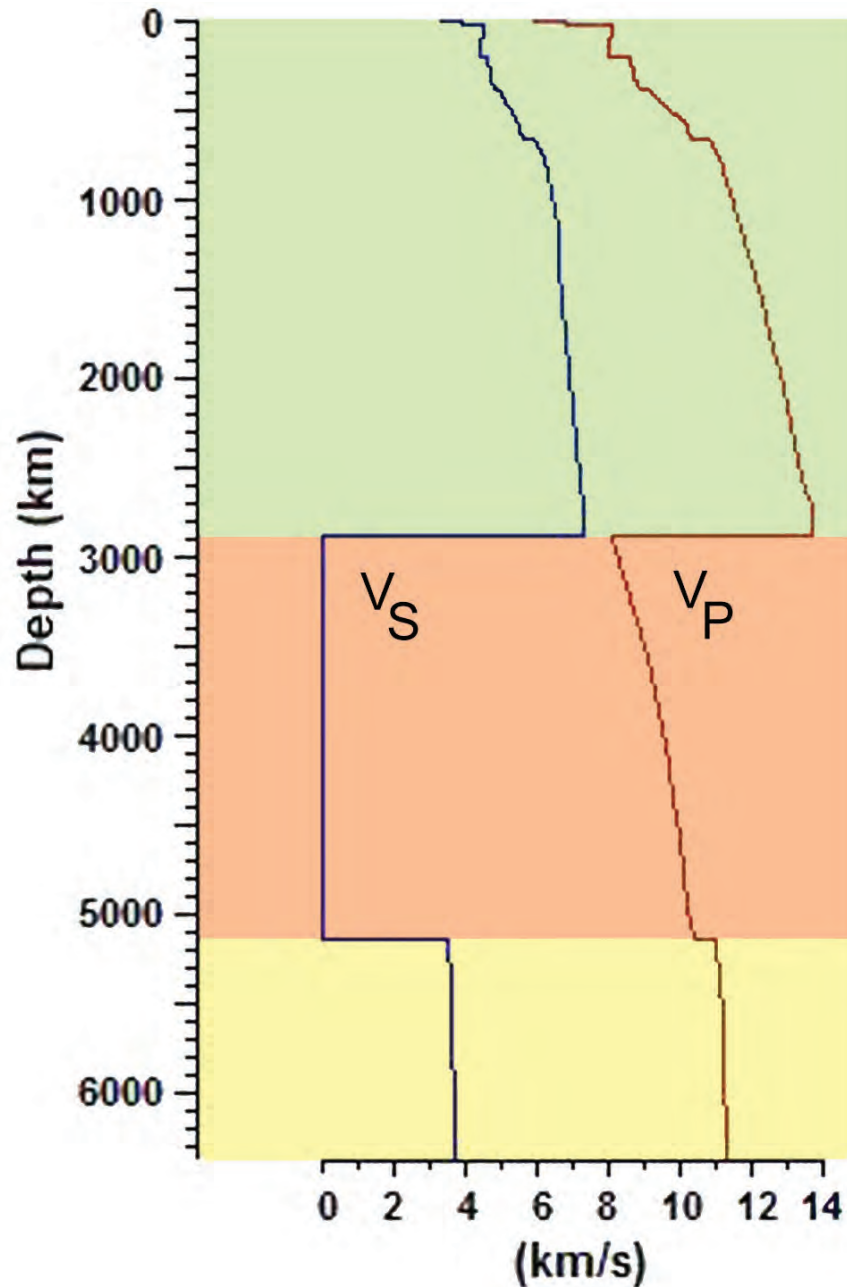**Source:** Wikimedia Commons
License: CC BY-SA 3.0

2.3 LAB EXERCISE

Part A – Interior of the Earth

The following graph (Figure 2.4) displays seismic velocities (in kilometers per second) of P and S waves with depth (measured in kilometers) inside the Earth. Examine the graph closely and answer the following questions.

Figure 2.4 | Graph of seismic velocity with depth within the Earth's Interior.
Author: User "Actualist"
Source: Wikimedia Commons
**License:** CC BY-SA 3.0

1. Observe the velocities of the waves on the graph. Which one travels faster?

    a. P waves   b. S waves

2. Inspect the P wave velocities. Where do the P wave velocities abruptly change?

    a. ~20 km   b. ~2,900 km   c. ~5,100 km   d. All of the above

3. **In which zones do the P wave velocities appear to be steadily increasing?**

    a. ~20–2,900 km   b. ~2,900-5,100 km   c. ~5,100-6,400 km   d. Both a & b

4. Observe the S wave velocities. Where do the S wave velocities abruptly change?

    a. ~20 km   b. ~2,900 km   c. ~5,100 km   d. All of the above

5. At ~2,900 km, the S wave velocity falls to 0. Why?

    a. S waves can't travel through solids, and this depth is where the solid inner core exists.

    b. S waves can't travel through liquids, and this depth is where the liquid outer core exists.

    c. S waves can't travel through solids, and this depth is where the solid mantle exists.

    d. S waves entered the shadow zone.

    Observe closely the changes in seismic wave velocity. You may add lines to your graph to denote the abrupt changes. Label each zone with the internal layers of the Earth and answer the following questions.

6. The zone from ~0-20 km represents the Earth's:

    a. crust   b. mantle   c. inner core   d. outer core

7. The zone from ~20-2,900 km represents the Earth's:

    a. crust   b. mantle   c. inner core   d. outer core

8. The zone from ~2,900-5,100 km represents the Earth's:

    a. crust   b. mantle   c. inner core   d. outer core

9. The zone from ~5,100-6,400 km represents the Earth's:

    a. crust   b. mantle   c. inner core   d. outer core

2.4 EARTH'S MAGNETIC FIELD

The thermal and compositional currents moving within the liquid outer core, coupled with the Earth's rotation, produce electrical currents that are responsible for the Earth's magnetic field. The shape of the magnetic field is similar to that of a large bar magnet. The ends of the magnet are close to, but not exactly at, the geographic poles on Earth. The north arrow on a compass, therefore, does not point to geographic north, but rather to magnetic north. The magnetic field plays a role in making the Earth hospitable to humans. Solar wind sends hot gases called plasma to Earth, and the magnetic field deflects most of this plasma. Without the work of the magnetic field, these damaging rays would harm life on the planet. As the solar wind approaches the Earth, the side of the Earth's magnetic field closest to the Sun gets pushed in, while the magnetic field on the opposite side away from the sun stretches out (Figure 2.5). You may have heard of the Aurora Borealis or "Northern Lights." Solar storms can create disturbances within the magnetic field, producing these magnificent light displays (Figure 2.6).
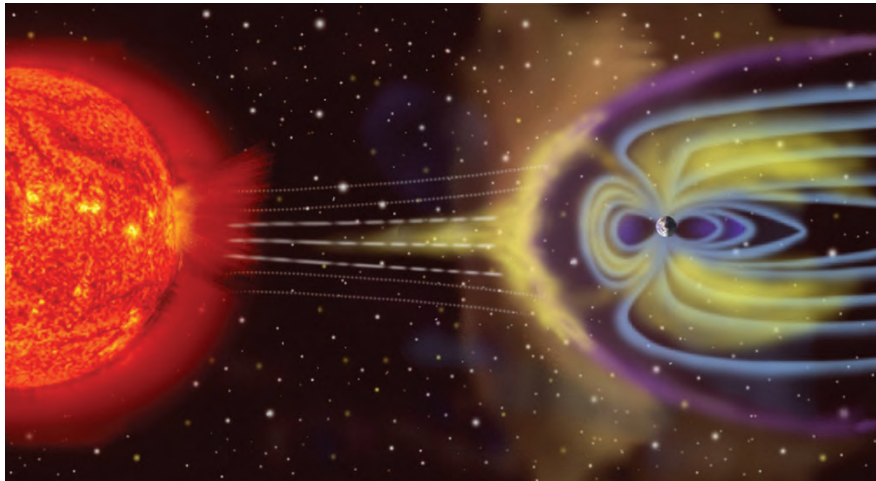
Figure 2.5 | Solar wind interacting with the Earth's magnetic field.
Author: NASA
Source: Wikimedia Commons
License: Public Domain

The magnetic field changes constantly and has experienced numerous reversals of polarity within the past, although these reversals are not well understood. Study of past reversals relies on paleomagnetism, the record of remnant magnetism preserved within certain rock types. Iron-bearing minerals that form from lava can align with the Earth's magnetic field and thus provide a record of the magnetic field in the Earth's past. However, this preserved magnetism could be lost if the mineral in the rocks has not been heated above a temperature known as the Curie point (a temperature above which minerals lose their magnetism). Essentially, the iron atoms "lock" into position, pointing to the magnetic pole. This records the alignment of the magnetic field at that time (we currently are in a normal polarity, in which north on a compass arrow aligns closely with geographic north, or the North Pole). If the magnetic field was stationary, all of the magnetic

Figure 2.6 | An example of the beautiful Aurora Borealis, light displays created by solar storm interaction with the Earth's magnetic field.
**Author**: User "Soerfm"
Source: Wikimedia Commons
License: CC BY-SA 3.0

minerals would point in the same direction. This is not the case, however. Reversals occur rather frequently on the geologic time scale.

Not only do magnetic poles reverse over geologic time, they also wander. Paleomagnetic data show that the magnetic poles move systematically, wandering across the globe. **Polar wandering curves** have been created to display the migration of the poles across the Earth's surface over time. Apparent polar wander refers to the perceived movement of the Earth's paleomagnetic poles relative to a continent (the continent remains fixed) (Figure 2.7). As you will learn in the Plate Tectonics chapter, polar wandering curves provide excellent evidence of the theory that the plates move, as curves for different continents do not agree on the magnetic pole locations. They all converge on the current pole location at present day, however.
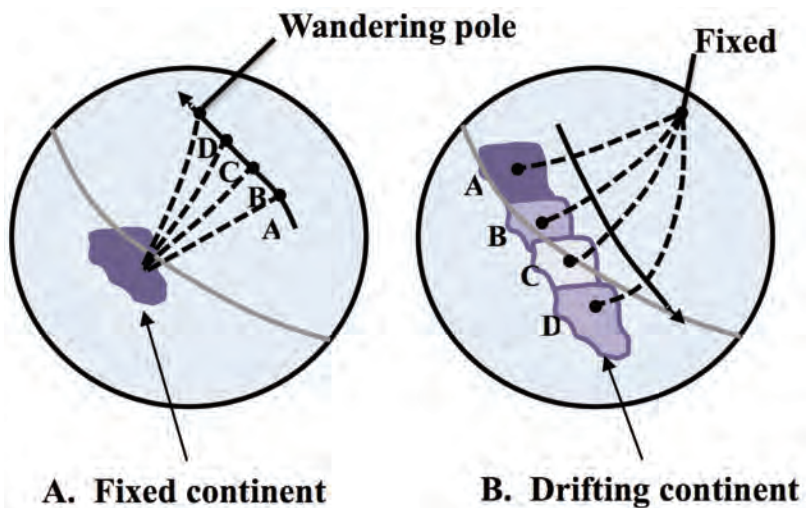
Figure 2.7 | If continents are fixed, as in A in the figure, the pole must be wandering. However, the pole is relatively fixed around the pole (with some movement), so the drifting continent (B) is the correct model.
Author: Randa Harris
**Source:** Original Work
License: CC BY-SA 3.0

2.5 LAB EXERCISE

Part B – Earth's Magnetic Field

You will use the polar map given (Figure 2.8) to plot the changing locations of the magnetic pole over time. To view the polar map, imagine that you are above the North Pole looking down on it. 90° N latitude is directly in the center of the map, and the lines of latitude, measured in 2 degree increments, spread out in circles from the center. Values of longitude are also given, and are represented as lines that radiate out from the center in increments of 30 degrees. A scale bar, in kilometers, is provided. To familiarize yourself with the map, first practice plotting some of the locations given. The first two, A and B, have been done for you. You will be plotting actual locations of the magnetic North Pole over time ranging from 1400-1900 AD onto Figure 2.8. The table below includes the year and latitude and longitude (as degrees from 0 to 360) for each location. Once you have completed this, answer the questions that follow. Remember that 1,000 meters = 1 kilometer.

Point	Year	Latitude	Longitude
A	—	87.7	160.3
B	—	85.6	6.6
C	1400	84.8	228.3
D	1500	86.3	301.5
E	1600	85.6	316.7
F	1700	81.1	307.1
G	1800	81.1	297.1
H	1900	82.3	288.2
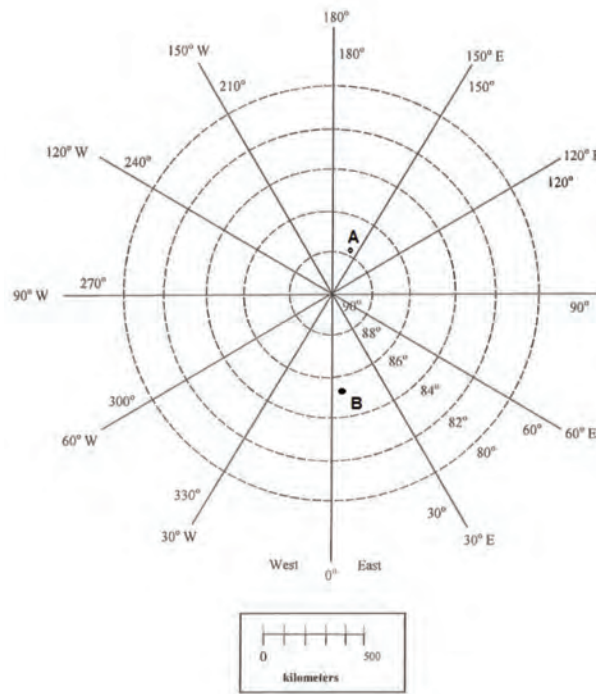
Figure 2.8 | Add the magnetic pole locations to this polar map and answer the questions below.
Author: NASA
Source: NASA
License: Public Domain

10. Measure the distance, using the bar scale, between the pole in 1400 and 1500 (locations C and D). How far did the pole move?

    a. ~50 km   b. ~150 km

    c. ~600 km   d. ~1,000 km

11. How far (in km) did the pole move in one year during this time period?

    a. 0.5 km   b. 1.5 km   c. 6 km   d. 10 km

12. How far did the pole move in meters in one year during this time period?

    a. 1,500 m   b. 500 m   c. 10,000 m   d. 6,000 m

13. Approximately how far did the pole move per day?

    a. <1 m   b. ~16 m   c. ~20 m   d. ~12 m

14. Measure the distance, using the bar scale, between the pole in 1400 and 1700 (locations C and F). How far did the pole move?

    a. ~50 km   b. ~150 km   c. ~600 km   d. ~1,000 km

15. Do pole movements tend to be steady every 100 years or variable?

    a. movements are steady   b. movements are variable

2.6 GOOGLE EARTH INTRODUCTION

Google Earth is a great tool to visualize and explore many of the geologic features that we will discuss in this class. This program is free and easy to use. This first Google Earth assignment will focus on familiarizing you with the program and some of the tools that we will use in later labs. Note that the optimal way to view geology is to go outside. Since that is not an option for an online class, the next best thing is using Google Earth. This is a practical and useful program that has many applications.

NOTICE: Google Earth updates versions periodically. If this occurs the instructions in the labs for this chapter may refer to the older version of the program. If you think this has occurred please let your instructor know.

If Google Earth is not already installed on the computer you are using**, then** please do the following:

1. Go to http://earth.google.com

2. Click on the Download Google Earth tab at the top of the page, **review** the Privacy Policy, and click Agree and Download to download the latest version.

3. Save the file to **your** desktop**,** open it and follow the instructions to install.

4. Open Google Earth.

Before we begin the assignment, let's first familiarize ourselves with Google Earth. Read each step and spend a few minutes trying things out, which will make things easier later. Also note that the Mac and PC versions of Google Earth are a little different.

You will use this program extensively throughout the course. Take the time to learn how to navigate it now.

Step 1 – Navigation

Watch each of the tutorial videos at: http://www.google.com/earth/learn/beginner.html#navigation. It is important that you dedicate time to review these virtual resources to help you better **understand Google Earth and its capabilities**. These will be key to mastering the tool. Navigating in Google Earth can be done in two ways:

First**,** you can use the Search panel in the upper left **hand side of the screen**. Just type in a location, address, or coordinate and it will zoom into the position (give it a try **now**).

The second approach is that you can also navigate manually:

- To move position you can left click with the mouse and drag the map or click on the hand icon in the upper right corner.

- You can zoom in and out using the mouse wheel, by right clicking and dragging the mouse up or down, or by sliding the lowest bar in the upper right corner.

- Click and hold the mouse wheel in order to rotate the map (left and right) or tilt the scenery (up and down). This can also be done using the arrows surrounding the eye icon in the upper right corner.

Along the bottom of the image it gives several important pieces of information:

1. Latitude and Longitude

2. Elevation in reference to sea level

3. Eye altitude, which indicates how zoomed in or out you are.

For example, let's check out Niagara Falls. In the Search panel in the upper left, type in Niagara Falls, NY. To better tell where the Falls are, you want to zoom out a little bit. Notice your eye altitude along the bottom right. Use the minus button for the zoom until you are at ~10,000' eye altitude. Check your latitude (~43°04'39"N – read as 43 degrees, 4 minutes, and 57 seconds North) and longitude (~79°04'28"W). It will move as you move your cursor across the screen, as will your elevation. If you want to see a picture of the Falls, just click on one of the many photo icons to see one. Note that the river is headed in a general northerly route – you can zoom in close to see the actual Falls.

Also important to understand with navigation is the concept of bearing. A bearing is the compass direction as measured between two points. It can be expressed as an azimuth
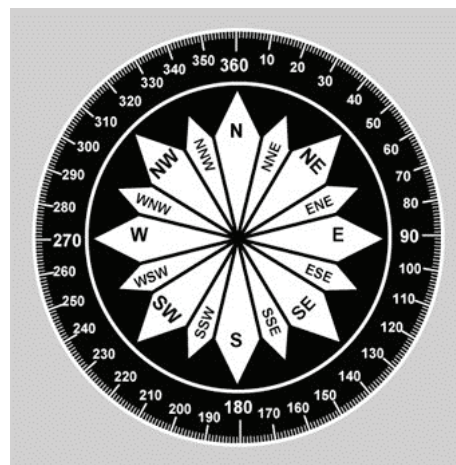
Figure 2.9 | A compass displaying the degrees.
Author: FAA
Source: Wikimedia Commons
License: Public Domain

bearing in degrees between 0 and 360, as along a circle. 0 and 360 degrees would be north, 90 degrees would be east, south would be 180 degrees, and west would be 270 degrees (Figure 2.9).

Bearing can be useful in determining how to get from point A to point B. To measure a bearing in Google Earth, follow this procedure. You want the bearing from point A to point B. Locate point A. Select the Ruler tool. Measure from A to B. In the last line in the Ruler tool box, read the Heading in degrees – that is measuring bearing (Tip: when point A is very far from point B, it can be helpful to add a placemark. Once at point A, choose the item in the menu bar right above the image that looks like a yellow pushpin. That is a placemark. Place it at point A. Also add a placemark at point B. Zoom out far enough that you can see both placemarks, then use the ruler tool to measure the heading between them. This works well for measuring headings across the entire United States). Let's practice getting a bearing again with Niagara Falls. For this example, point A will be the Scotiabank Convention Center located at 43004'34.08"N and 79005'05.98"W. Point B will be the name label for Goat Island (located across the river, just before the Falls begin). The bearing from point A to point B is ~74 degrees.

Step 2 – Measuring

In order to examine features, we will need to be able to measure them, which is easily managed in Google Earth. Measuring is done using the Ruler Tool, which can be accessed either by clicking the ruler icon in the toolbar above the image or by selecting from the menu across the top Tools, then Ruler.

There are two options with the ruler tool, line and path. The line option (which is the default option) gives the distance and direction between two points; notice the pull down menu that gives 11 different options for units of measurements. To make a measurement, after you have selected the ruler tool, you simply click on two different points. The path option gives the distance for a set of two or more points giving the ability to measure a distance that isn't a straight line.

NOTE: When measuring features you want to use the Map Length – using the ground length can lead to an incorrect answer.

Gradient will often be measured for this and future labs. Gradient is similar to slope which indicates how steep or flat an area is. It is calculated as the difference in elevation divided by the horizontal distance. When calculating gradient, maintain the same units in the numerator and denominator.

Gradient = change in elevation/horizontal distance

Let's practice again at Niagara Falls. First move the image slightly higher to fully see the start of the white water, just before the Falls begin (do this by left clicking the mouse and using the hand to move the image). With the eye altitude

still at ~10,000', let's measure the distance across the river right at the start of the whitewater before the Falls (where the whitewater stops). First click your ruler icon, then select a point on one side of the river, then move your mouse straight across to the other side. In feet, this should measure ~4,800 feet (don't stop at the island – measure all the way to the other river bank). Using the pull-down menu, you can change the feet to miles, and the result should be ~0.9 miles. Now let's practice gradient across the actual Falls. Position your cursor over the actual Falls, and zoom in to an eye altitude of ~1,000 feet. Hold your cursor over the top of the Falls and record the elevation (remember, this is located along the bottom bar). Now move your cursor to the bottom of the Falls and record the elevation. The change in elevation (highest-lowest) will be your numerator. Use the Ruler tool to measure the distance between the two places – this will be your horizontal distance (the denominator). There will be variation in this answer depending on your exact spot along the Falls, but results should be similar to this:

$$\text{Gradient} = (500' - 325') / 75' = 175'/75' = 2.3$$

Step 3 – Changing the Options

For a few tasks it will be important to change some of the default settings on Google Earth in order to see a feature better or make your work easier. These changes can all be made by going to Tools in the menu bar across the top, then Options in the PC version (for the MAC, go to Google Earth, then Preferences).

1. **Changing the unit for Elevation – From the 3D view tab, in the middle** of the box there is a section entitled "Units of Measurement" that you **can change between metric and English units.**

2. Exaggerating Features – Since differences in elevations are much **smaller than geographic distances it is sometimes hard to see features.** To exaggerate features (that is, make a mountain look taller than it **actually is in order to see it better), click on the 3D view tab, in the** lower left side at the "Terrain" section of the box, look for "Elevation Exaggeration (also scales 3D buildings and trees)". If you want to **exaggerate a feature increase this value up to 3. To view the area** **without any exaggeration, return the value to the default of 1.**

2.7 LAB EXERCISE

Part D – Google Earth

Answer the following questions using the skills discussed above. In order to prepare you for examining geologic features in Google Earth, let's first examine a more familiar area, Washington, D.C.

16. Search for the "Washington Monument" and zoom into ~3,000 feet eye altitude. What is the latitude of the monument?

    a. 38° 53'N   b. 38° 53'S   c. 77° 02'E   d. 77° 02'W

17. What is the longitude of the monument?

    a. 38° 53'N   b. 38° 53'S   c. 77° 02'E   d. 77° 02'W

18. Zoom into an eye altitude of ~500 feet. Locate the base of the monument (the base is square and is located in the center of the circle). What is the elevation of **the base of the monument in feet?**

    a. 15 feet   b. 40 feet   c. 65 feet   d. 80 feet

19. What is the elevation of the base of the monument in meters?

    a. 40 meters   b. 25 meters   c. 12 meters   d. 7 meters

20. How big is the base (area) of the Washington Monument in square feet? (Hint – make sure the 3D Buildings is selected in the Layers box, located in the lower left of the screen. Also, area is measured in square feet, so make sure you are multiplying two measurements.)

    a. ~1040 feet^2 b. ~3100 feet^2 c. ~4700 feet^2 d. ~6030 feet^2

21. If you were standing at the Washington Monument, what direction would you **need to walk to go to the United States Capitol Building?**

    a. North   b. East   c. South   d. West

22. **The direction system is useful, but imprecise. It is better to use a bearing. If you** were standing at the Washington Monument, what bearing would you need to walk to go to the Smithsonian National Museum of Natural History, which houses many important geological specimens (Hint: Many of the buildings on the National Mall **are part of the Smithsonian – make sure you get the correct building!)?**

    a. 30°   b. 75°   c. 90°   d. 260°

23. If you decided instead to walk from the Washington Monument to the White House, how far would you have to walk, in miles (assume you could walk right **to the entrance of the building)?**

    a. 0.56 miles   b. 0.78 miles   c. 1.20 miles   d. 1.87 miles

24. How far is this distance in kilometers?

    a. 0.5 kilometers   b. 0.9 kilometers   c. 1.4 kilometers   d. 1.9 kilometers

25. Overall, would you be walking uphill or downhill?

    a. No change in elevation   b. Slightly uphill   c. Slightly downhill

26. How much does the elevation change in feet?

    a. 0 feet   b. 10 feet   c. 20 feet   d. 30 feet

27. What is the gradient of your walk?

    a. ~0.003   b. ~0.05   c. ~0.5   d. ~1

28. You decide to start walking from the Washington Monument to the White House, but as soon as you start a Park Ranger yells at you for walking on the grass. How far would the walk be (in miles) if you stayed on the sidewalks? **There are many possible routes – try to take one of the shortest routes possible.**

    a. 0.5 miles   b. 0.8 miles   c. 2 miles   d. 5 miles

29. Now, let's look at a geologic feature. Put 36 05 35.38 N 113 14 43.70 W into the search bar and zoom out to an eye altitude of ~25,000 feet. This is the Grand Canyon. If you started out in Washington, D.C., what bearing would you need **to travel in to go to the Grand Canyon?**

    a. 210°   b. 245°   c. 275°   d. 315°

30. **The Grand Canyon is an extraordinarily steep area. If you go from the river at** the bottom of the Canyon (36 05 35.38 N 113 14 43.70 W) straight north up the canyon rim (the area that flattens out above the red layers of rock – 36 06 10.12 N 113 14 48.88 W), what is the gradient of the Grand Canyon? (**Hint: You can tilt the image, which will make the flat rim easier to see, by either pressing down on the middle mouse wheel and moving the mouse forward and backward or by clicking on the arrows above and below the eye in the upper right hand portion of the window.**)

    a. 0.214   b. 0.673   c. 0.976   d. 1.245

2.8 STUDENT RESPONSES

1. Observe the velocities of the waves on the graph. Which one travels faster?

    a. P waves   b. S waves

2. Inspect the P wave velocities. Where do the P wave velocities abruptly change?

    a. ~20 km   b. ~2,900 km   c. ~5,100 km   d. All of the above

3. **In which zones do the P wave velocities appear to be steadily increasing?**

    a. ~20–2,900 km b. ~2,900-5,100 km c. ~5,100-6,400 km d. Both a & b

4. Observe the S wave velocities. Where do the S wave velocities abruptly change?

    a. ~20 km   b. ~2,900 km   c. ~5,100 km   d. All of the above

5. At ~2,900 km, the S wave velocity falls to 0. Why?

    a. S waves can't travel through solids, and this depth is where the solid inner core exists.

    b. S waves can't travel through liquids, and this depth is where the liquid outer core exists.

    c. S waves can't travel through solids, and this depth is where the solid mantle exists.

    d. S waves entered the shadow zone.

6. The zone from ~0-20 km represents the Earth's:

    a. crust   b. mantle   c. inner core   d. outer core

7. The zone from ~20-2,900 km represents the Earth's:

    a. crust   b. mantle   c. inner core   d. outer core

8. The zone from ~2,900-5,100 km represents the Earth's:

    a. crust   b. mantle   c. inner core   d. outer core

9. The zone from ~5,100-6,400 km represents the Earth's:

    a. crust   b. mantle   c. inner core   d. outer core

10. Measure the distance, using the bar scale, between the pole in 1400 and 1500 (locations C and D). How far did the pole move?

    a. ~50 km   b. ~150 km   c. ~600 km   d. ~1,000 km

11. How far (in km) did the pole move in one year during this time period?

    a. 0.5 km   b. 1.5 km   c. 6 km   d. 10 km

12. How far did the pole move in meters in one year during this time period?

    a. 1,500 m   b. 500 m   c. 10,000 m   d. 6,000 m

13. Approximately how far did the pole move per day?

    a. <1 m   b. ~16 m   c. ~20 m   d. ~12 m

14. Measure the distance, using the bar scale, between the pole in 1400 and 1700 (locations C and F). How far did the pole move?

    a. ~50 km   b. ~150 km   c. ~600 km   d. ~1,000 km

15. Do pole movements tend to be steady every 100 years or variable?

    a. movements are steady   b. movements are variable

16. Search for the "Washington Monument" and zoom into ~3,000 feet eye altitude. What is the latitude of the monument?

    a. 38 53'N   b. 38 53'S   c. 77 02'E   d. 77 02'W

17. What is the longitude of the monument?

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    a. 30   b. 75   c. 90   d. 260

23. If you decided instead to walk from the Washington Monument to the White House, how far would you have to walk, in miles (assume you could walk right to the entrance of the building)?

    a. 0.56 miles   b. 0.78 miles   c. 1.20 miles   d. 1.87 miles

24. **How far is this distance in kilometers?**

    a. 0.5 kilometers   b. 0.9 kilometers   c. 1.4 kilometers   d. 1.9 kilometers

25. **Overall, would you be walking uphill or downhill?**

    a. No change in elevation   b. Slightly uphill   c. Slightly downhill

26. **How much does the elevation change in feet?**

    a. 0 feet   b. 10 feet   c. 20 feet   d. 30 feet

27. What is the gradient of your walk?

    a. ~0.003   b. ~0.05   c. ~0.5   d. ~1

28. You decide to start walking from the Washington Monument to the White House, but as soon as you start a Park Ranger yells at you for walking on the grass. How far would the walk be (in miles) if you stayed on the sidewalks? **There are many possible routes – try to take one of the shortest routes possible.**

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   a. 0.214   b. 0.673   c. 0.976   d. 1.245

3 Topographic Maps

Karen Tefend and Bradley Deline

3.1 INTRODUCTION

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 average sea level (a.s.l.) or mean sea level (m.s.l). 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.

3.1.1 Learning Outcomes

After completing this chapter, you should be able to:

- Recognize topographic patterns and geologic patterns
- Read and construct contour lines
- Determine gradients
- Read map scales and convert fractional scales
- Construct a topographic profile

3.1.2 Key Terms

- Bar Scale
- Benchmarks
- Contour Interval

- Contour Line
- Equator
- Fractional (Ratio) Scale

- **Gradient**
- **Hachure Marks**
- **Index Contour**
- **Latitude**
- **Longitude**
- **Prime Meridian**
- **Relief**
- **Topographic Profile**
- **Verbal Scale**
- **Vertical Exaggeration**

3.2 MAP ORIENTATION AND SCALE

All topographic maps produced by the U.S. Geological Survey (U.S.G.S) are oriented with north at the top of the map. Therefore if you locate a position on the map, and move towards the top of the map you are moving in a northerly direction, and if you are moving to the bottom of the map, you are moving towards the south. Any movement to the right will be towards the east, and a movement towards the left will be towards the west. These maps are oriented with their sides oriented parallel to lines of longitude, which are imaginary lines that circle the globe and are oriented so that they pass through the north and south geographic poles . Starting with the 0° longitude line (known as the Prime Meridian) that passes through the town of Greenwich, England, these lines increase up to 180° in both directions east and west of the Prime Meridian (Figure 3.1). It may help to visualize longitude lines if you think of an orange, which when peeled will show the sections of orange oriented like longitude lines that section the Earth. All longitude lines converge at the navel of the orange (or the geographic north and south poles of the Earth).
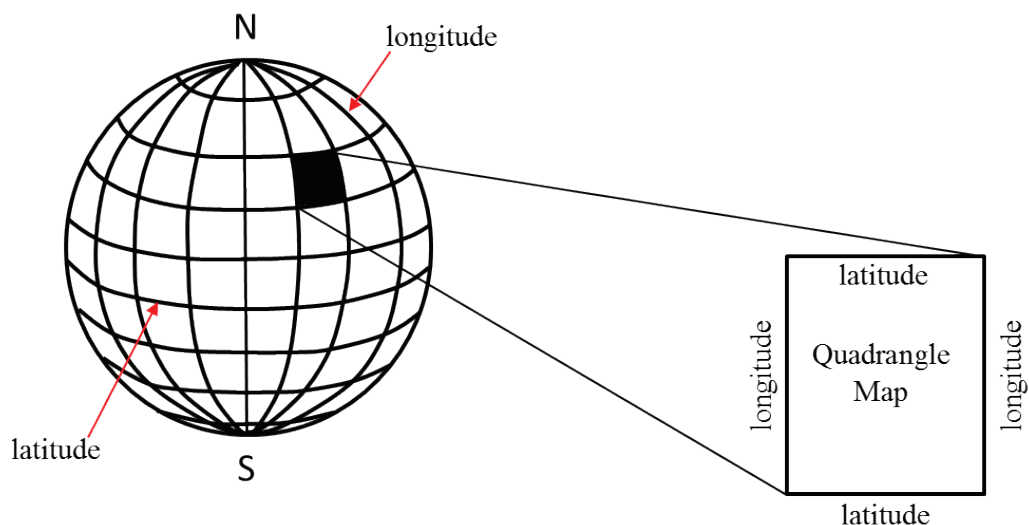
Figure 3.1 | Latitude and Longitude grid system of the Earth.
Author: Karen Tefend
Source: Original Work
License: CC BY-SA 3.0

The top edge and bottom edges of a topographic map are oriented so that they are parallel to lines of **latitude**, which are imaginary lines that circle the globe and

are oriented at right angles to the Earth's axis. The 0° latitude line is the Earth's **Equator**; latitude lines increase up to 90° north or 90° south of the Equator, so that the North Pole has a latitude of 90°N, and the South Pole has a latitude of 90°S.

This grid system of latitude and longitude allows a position on the Earth to be uniquely defined, provided that the values for latitude are always identified by their position N or S of the Equator, and longitude is identified as E or W of the Prime Meridian. A degree of latitude or longitude represents a large distance on the Earth, therefore degrees have been further subdivided into minutes (a minute **of distance is not the same as a minute of time!), and these minutes of distance** are further subdivided into seconds. There are 60 minutes (60') of distance in 1° of latitude or longitude, and there are 60 seconds (60") of distance in one minute. **An example of a precise location on the Earth's surface would be 33°34'22"N, 85°05'46"W** (the author's location at the time of writing this chapter!), which is read as "33 degrees, 34 minutes, 22 seconds north latitude, and 85 degrees, 5 minutes, 46 seconds west longitude."

The latitude and longitude coordinates of each topographic map are found at the corners of the map. Often these maps represent an area of the Earth that is smaller than one degree of distance. For example a common topographic map will show only 7.5 minutes of distance (7' 30") for both latitude and longitude; in this case, the top and bottom edges of a map will represent a distance of 7.5 minutes of latitude, and the left and right edges of the map will represent a distance of 7.5 minutes of longitude. Because the degree of distance is unchanging on the map, a
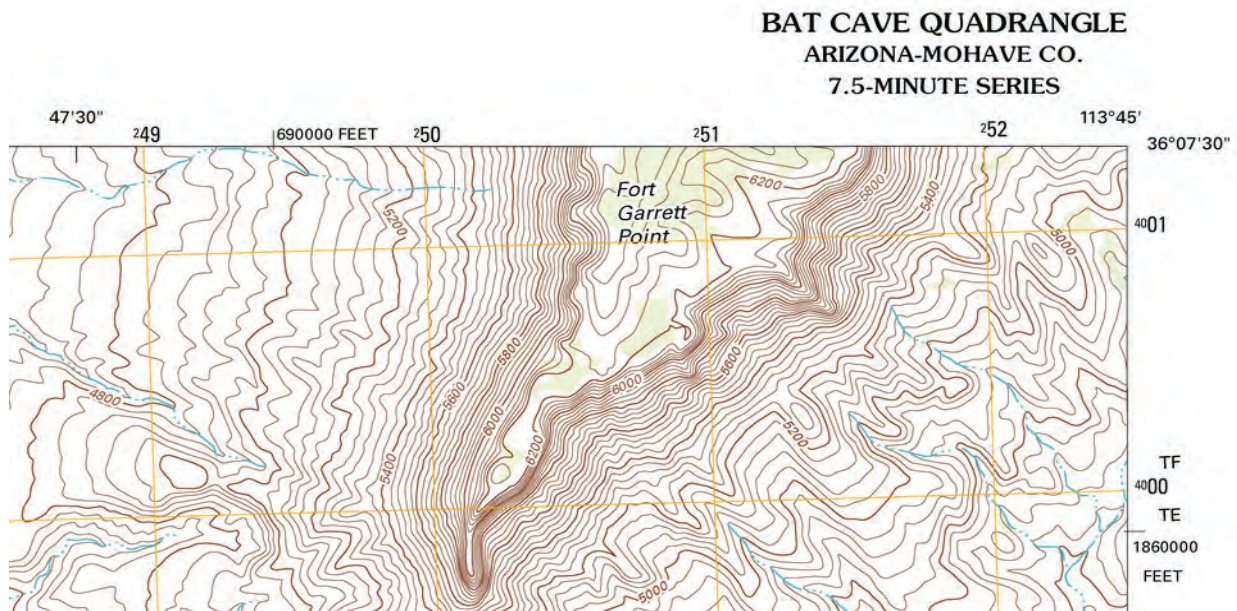
Figure 3.2 | This is the top right corner of a topographic map covering an area of 7′ and 30″ of latitude and longitude. Note that the coordinates are written out completely in the corner of the map, but shorthand notation is used for the longitude coordinate on the top edge of the map (47′30″). Since the number increased towards the left (by a distance of 2′30″), we know that these are west longitude numbers (meaning the longitude at that tick mark is 113°47′30″ W), since only lines of longitude located west of the Prime Meridian increase with distances to the left.

Author: USGS

Source: USGS

License: Public Domain

shorthand notation of just the change in minutes and seconds is labelled at certain positions on the map's edge. Only at the corners of the map will the degrees be included for the latitude and longitude coordinates. See the example above, which shows the top right corner of a 7.5 minute map or 7.5 minute quadrangle (the shape of most topographic maps). Additional numbers other than latitude and longitude are also shown on the edges of the map; these are a different grid system and will not be explained here.

Remember that the top and bottom edges of a topographic map are oriented parallel to lines of latitude. In Figure 3.2, the top edge of the map is a latitude line, so the coordinates that are changing as you move along the top of the map (in an East-West direction), must be longitude coordinates, since the latitude should not change. The bottom edge of this map is not shown, but you can predict what the latitude on the bottom edge should be: this map is of a region in Arizona, and since Arizona is located north of the Equator the latitude lines should increase from the bottom of the map, towards the top of the map (as all latitude lines increase as you move north of the Equator). For a 7.5-minute map, the increase in latitude from the bottom corner to the top corner should be exactly 0°7'30"N. This gives the bottom corner of the map a latitude of 36°00'00"N.

All maps are a scaled down version of the region of the world that they depict; if this were not the case, then the map that a person must carry would be the exact same size as a city (if it is a city map) or the size of a state (if it is a state map). Imagine trying to carry around with you a map of the entire country! The word "scale" refers to the amount of reduction, and all maps provide a map scale to indicate how much the area on the map has been reduced. Map scales are provided so that a map reader can determine exactly how much distance is actually represented on their map, or to measure the distance between two points on a map, or even to calculate the gradient of a hill or river. The two commonly used map scales on a topographic map are the **bar scale** (or **graphical scale**) and the **fractional scale** (also known as a **ratio scale**).

In Figure 3.3 there are three bar scales; each bar is a graphical representation of distance on the map, and it is up to the map reader to decide if they want to measure distances in kilometers, meters, miles, or feet. To find the distance between

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
NORTH AMERICAN VERTICAL DATUM OF 1988
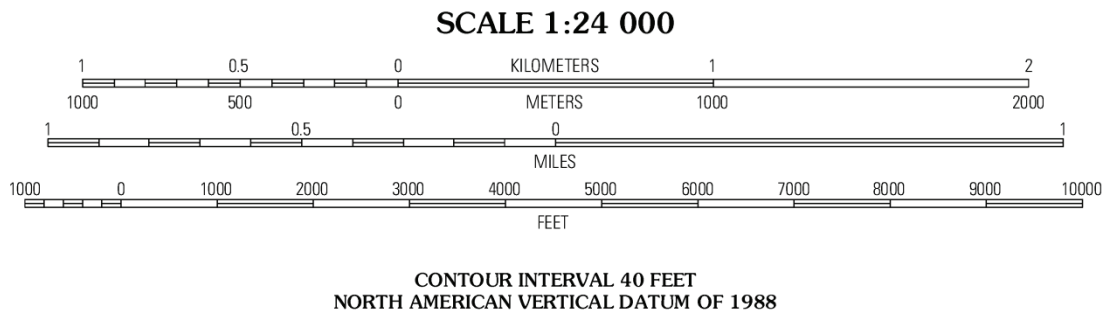
Figure 3.3. Map scales typically located on the bottom of a topographic map. Note that the bar scales start at zero in the interior of each bar for kilometers, miles, and feet. The bar to the left of zero is further subdivided for more accurate distance determinations.
Author: USGS
Source: USGS
License: Public Domain

any two points on a map, a person could use a piece of paper to transfer the two points down to the bar scale and read the distance directly from the bar scale. Notice that each bar scale has the starting point (zero) within the interior of the scale, and not on the end of each scale (Figure 3.3).

The other type of map scale is the fractional scale; in the Figure 3.3 the fractional scale is 1:24,000. No units are reported as this ratio of 1 to 24,000 is valid for any unit of measure, provided that it is the same unit. For example, if using inches, then this map scale indicates that 1 inch on the map is actually covering 24,000 inches of ground (the distance between two locations in the real world). Or if using centimeters, then 1 centimeter on the map is actually covering 24,000 centimeters of ground. If our map was the same size as the area that it is representing (say for example, a map of the room you are currently sitting in), then the fractional scale of your map would be 1:1, and your map would be the exact same size as your room! This brings us again to the definition of a map, which is a scaled down version of a region that it is made to represent; maps that are greatly scaled down (greatly reduced) are called small scale maps even though they represent large sections of the Earth. For example, a 1:500,000 map will show a large section of the Earth, but small details are lost (such as building locations or small streets), whereas a 1:12,000 map is a large scale map even though it shows a much smaller region of the Earth's surface, but details can be seen (such as buildings, roads, and other landmarks). Placing your fingertip on the surface of a small scale map may cover an area of several miles, but placing your fingertip on a large scale map (such as 1:12,000) may cover only 1/10 of a mile.

One advantage to using a fractional or ratio scale is that any unit of measure can be used, and conversions are easy to make when needed. For example, for a 1:12,000 map 1 inch on the map is equal to 12,000 inches on the Earth's surface, and since there are 12 inches in 1 foot, we can also say that 1 inch on the map is equal to 1000 feet on the Earth's surface (convert the 12,000 inches to feet by multiplying by the conversion factor 1ft/12in). Simply verbalizing this scale by saying "on this map, 1 inch represents 1000 feet" is a third type of map scale, which for obvious reasons is called a **verbal scale**. Writing the phrase "1 inch equals 1000 feet" is a way of adding a verbal scale to your map.

Table 3.1 | Some useful conversion factors:

1 foot = 12 inches	1 meter = 3.28 feet
1 mile = 5280 feet	1 mile = 63,360 inches
1 kilometer = 1000 meters	1 kilometer = 0.62 miles

Remember that since conversion factors are equalities, such as 1 foot = 12 inches, then dividing one by the other (1ft/12in) gives you 1, and since multiplying anything by 1 does not change any value, all we really are doing is changing the units. Therefore the calculation 5.5 ft x (12in/1foot) will allow 5.5 ft to be expressed as inches, which in this case would be 66 inches.

3.3 LAB EXERCISE

Part A – Practice Questions (non-graded)

The following problems are for practice; answers to these questions are provided at the end of the chapter.

1. A 15 minute quadrangle map of a region within the United States with a longitude of 76°00'00" in the right corner of the map, will read what longitude in the left corner?

2. A 15 minute quadrangle map of a region within the United States with a latitude of 43°15'00" in the top corner of the map, will read what latitude in the bottom corner?

3. A fractional scale of 1:24,000 means that 1 inch = _____feet.

4. A fractional scale of 1:24,000 means that 1 foot = _____kilometers.

3.4 CONTOUR LINES

Contour lines allow a vertical dimension to be added to a map and represent elevations above sea level. Since each individual contour line connects points of equal elevation, then following that line in the real world means that you are staying at the same elevation while walking along that imaginary line. If you were to move off that line, you are either walking up or down in elevation. Imagine if you are on a small circular island in the ocean, and you walk from the shore up to 10 feet above the shoreline. If you were to walk around the island and stay exactly 10 feet above shore, you would be walking a contour line that represents 10ft of elevation above sea level. If you move off that line, you are either moving uphill or downhill. If you could walk uphill another 10ft and again stay at that elevation (now 20ft above sea level) while circling the island, then you are now walking the 20ft contour line. The vertical change in elevation between these two adjacent contour lines is called the **contour interval**, which in this case is 10 feet. If you were to transfer these imaginary lines onto a map, you would see three lines forming concentric circles that represent 0 ft (the seashore or sea level), 10ft and 20ft, and your map would look like a bull's eye pattern. Congratulations, you've made your first topographic map!

A topographic map will have contour lines shown as brown lines, and all maps will have a contour interval that is specific for that map. However, the elevations represented by the contour lines are not always labeled on each line (see Figure 3.2). Instead, every 5th contour line is labelled with an elevation, and is darkened; such a contour line is called an **index contour**. The use of index contours allows a map to be visually more appealing, especially when the contour lines are numerous and closely spaced to one another.

To determine the elevation of each contour line you must first know the contour interval for the map. By using the values of two adjacent index contours, one can easily calculate the contour interval between each line. For example, there are 4 contour lines between the 5200ft and 5400ft index contours (see Figure 3.2), which means that there are 4 contour lines separating the 200ft of elevation between the index contours into 5 sections. Dividing this 200ft elevation change between the index contours by 5 gives a contour interval of 40 ft (just as cutting a ruler in half creates two 6 inch pieces, or dividing the ruler into 3 evenly spaced cuts yields four 3 inch pieces). To verify this, locate the 5200ft index contour on the western side of the map in Figure 3.2, and increase the elevation by 40ft each time you cross a contour line while traveling east (to the right) towards the 5400ft contour line. Luckily there is no need to do this calculation to find the contour interval on a complete topographic map, as all topographic maps give the contour interval at the bottom of the map near the bar and fractional scales (see Figure 3.3). The contour interval must be obeyed for each contour line on a map; for example if the contour interval is 50 ft, then an example of possible contour lines on such a map could be 50ft, 100ft, 150ft, 200ft, etc.

You may be wondering why some contour lines are closely spaced in some areas of a map (such as the central portion of the map in Figure 3.2) and why they are farther apart in other areas of a map (such as the western part of the map in Figure 3.2). Imagine yourself again on the circular island in the ocean, and you are standing 10ft above sea level (on the 10ft contour line). If you want to walk up the hill to reach the 20ft elevation, how far did you have to walk? It depends on how steep the hill is; if it is a gentle slope you may have to walk a long time before you reach a higher elevation of 20ft. On a topographic map, the contour lines for this hill would be spaced far apart. However, if the hill's slope is very steep, you do not need to walk as far up the hill to reach a 20ft elevation, and the contour lines representing such a steep slope will be closely spaced on a topographic map. Recall that a slope (**gradient**) is the change in elevation divided by the distance; you can easily calculate the slope of your hill or any region on a topographic map if you know the change in elevation between two points, and if you know the distance between those same two points. Gradients are usually reported in feet per mile (ft/mile), but other units are also used. Remember to use the contour lines to determine the elevations, and the bar scale on your map to measure the distance.

In addition to contour lines, topographic maps will also have **benchmarks** (actual surveyed points) in various locations on your map. These surveyed points

are exact elevations above sea level and are commonly used to mark the elevations of mountains, hilltops, road intersections and airport runways. These benchmarks are rarely located on a contour line and instead are usually identified by a black "x" or identified with the letters "BM" and with the elevations included in black numbers (as opposed to the brown numbers on index contours). Benchmark locations will normally be found in the area between contour lines; for example a benchmark of 236ft will be found somewhere between the 230ft and 240ft contour line (if the contour interval is 10ft), or between the 235ft and 240ft contour line (if the contour interval is 5ft).

In addition to obeying the set contour interval for a map, contour lines should never branch (split) or simply end inside of the mapped region. Instead these lines are continuous, although they can continue off the edge of the map. Contour lines also never touch or overlap, unless certain rare instances occur, such as if there is a vertical or overhanging cliff. In the case of a vertical cliff, the contour lines will appear to merge.

The entire third dimension (elevation) represented by the contour lines on a topographic map is called the **relief**, and is easily determined if you can find the highest and lowest contour line elevations and subtract the two values to determine the vertical relief represented in the map. The hardest part is finding these highest and lowest elevations on the map. Start by finding the highest index contour line and continue counting lines until you reach the lowest contour line. In Figure 3.2, the highest contour line is the line that runs through the letter "r" in Fort (of Fort Garrett Point). This same contour line circles back and goes through the letter "o" in Fort. The elevation of this line is 6360ft (based on the contour interval of 40ft). Recall that this is only a small portion of a 7.5 minute map (or quadrangle), and because of this, some of the index contours appear to be missing the identifying elevation numbers, but it is still easy to identify the index contours because all index contours are in bold (darkened lines). To find the lowest elevation on the map, find the lowest index contour line and continue counting lines in the downhill direction. An easy way to determine which way is downhill is to find a water feature on the map; water is colored blue on topographic maps, and flowing water such as a river or stream is a blue line. A dashed blue line such as in Figure 3.2 implies that the stream is dry part of the year (this is called an intermittent stream). Since water collects in low spots, such as a basin (where ponds, lakes, or oceans are found) or a valley (such as a stream or river valley), then the contour lines should represent decreasing elevation as you move towards a water feature on a map. Referring back to Figure 3.2, it is apparent that the highest portion of the map is the central portion where Fort Garrett Point is located, and that any point west, south and east of this is a downhill direction. Note all of the streams are flowing away from this Fort Garrett Point region. The lowest elevation will be a contour line that is crossing the stream just before leaving the map area. Close examination of the contour lines reveals that the lowest contour line is in the lower right corner of the map; the contour line that is crossing the stream in this portion of the map represents an elevation of 4560ft.

So for this small portion of the 7.5 minute map shown in Figure 3.2, the relief of the map region is 6360ft (highest contour) – 4560ft (lowest contour) = 1800ft.

An interesting feature regarding flowing water such as streams and rivers is that they erode the landscape and as a result the topography of the land is affected; we see this as a deflection of the contour lines on a map as they cross flowing water. Notice in Figure 3.2 that the contour lines form a "v" shape as they cross the water, and that the pointed end of this "v" is pointing in the upstream direction. We can use this to easily determine which way water is flowing without even paying attention to the elevation of the contour lines. **Notice in Figure 3.2 that the contour lines that cross the streams are pointing toward the central hill (Fort Garrett Point), which means that the streams are all flowing away from the central portion of this map and towards the edges of the map region.**

3.5 LAB EXERCISES

Part B - Practice Questions

For Questions 5 through 9, refer to Figure 3.4 below, which shows a hill, an intermittent stream, and two index contours (darkened contour lines). Assume the contour interval for this map is 5ft, and the index contour that is crossing the **stream has an elevation of 70ft.**

5. Which way is the stream flowing, to the **North to the South?**

6. What is the elevation of the highest **contour on this portion of the map?**

70 ft.

Figure 3.4 | Portion of the 7.5 minute
Quadrangle of Bat Cave, Arizona
Author: USGS
Source: USGS
License: Public Domain

7. Calculate the relief of this map (Hint: Review the "Contour Lines" section in this chapter for assistance calculating relief).

8. Calculate the gradient of the stream between the highest and lowest contour lines that you can see cross the stream. These two contour lines are 2 miles apart.

9. The hill in the above diagram has a slightly steeper side on which side of the hill, the west or east side?

You have learned that the spacing between contour lines indicates the slope of the Earth's surface, and that the shape of the contour line as it crosses flowing water can indicate the slope direction. You have also learned that enclosed (circular) **contour lines indicate a hill or mountain. However, sometimes there are circular** depressions (for example, a sinkhole) found on the Earth's surface and these depressions may appear as hilltops on a topographic map unless a new convention is used. Contour lines with small perpendicular lines (called **hachure marks**) are **used for such depressions on a topographic map. The contour interval for the map** is still obeyed when contouring a depression. The only difference is that the ha- **chure marks on the contour lines indicate that you should count down in elevation, not up, as you move towards the center of the hachured contour circles.** However, if there is a depression at the top of a hill or mountain (for example, a volcanic crater), then the first contour line that is hachured must be the same elevation of **the closest contour line that is not hachured. The reason for the repeat is that a person climbing the hill will reach the highest contour line, and walk a little higher** still, before descending into the depression (crater), and will therefore encounter the same elevation line while descending (see Figure 3.5).
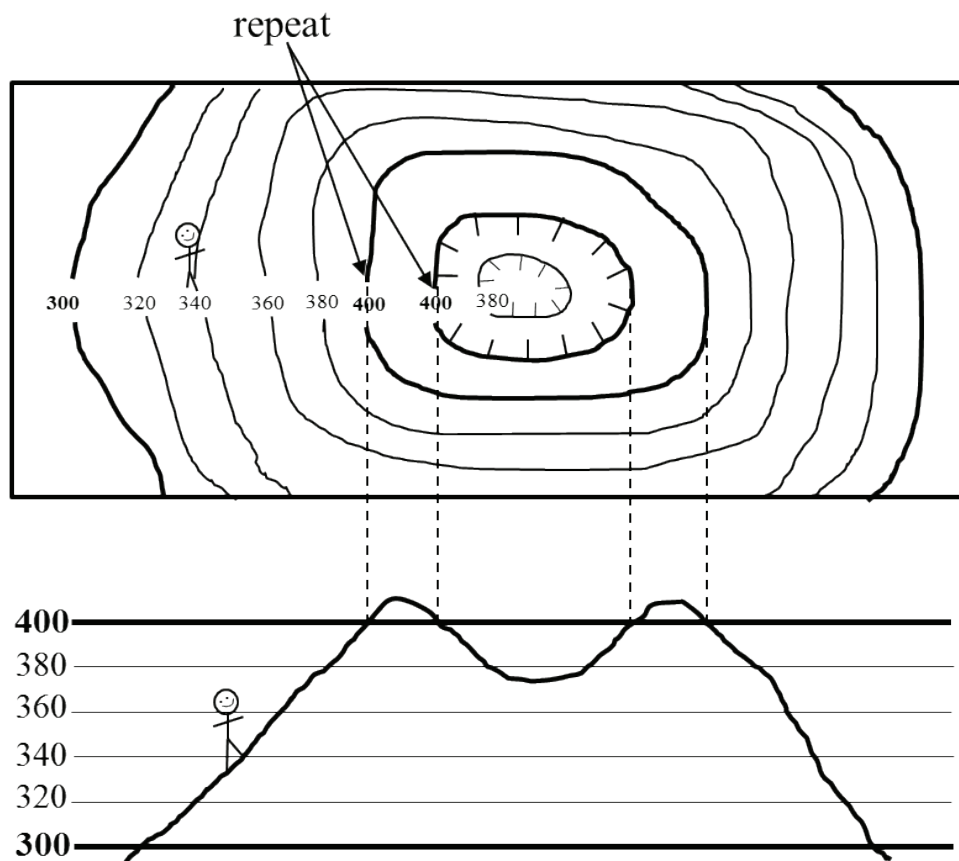
Figure 3.5 | Contours and hachured contours for a depression at the top of a hill. Notice that the first hachured depression is a repeat of the closest non-hachured contour line.
Author: Karen Tefend
Source: Original Work
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3.6 DRAWING CONTOUR LINES AND TOPOGRAPHIC PROFILES

Constructing a topographic map by drawing in contours can be easily done if a person remembers the following rules regarding contour lines: 1) contour lines represent lines connecting points of equal elevation above sea level; 2) contour lines never cross, split or die off; 3) contour intervals must be obeyed, therefore the contour line elevations can only be multiples of the contour interval; and 4) contour lines make a "v" pattern as they cross streams and rivers, and the "v" always points towards the upstream direction.

As you draw a contour line on a map you will notice that the elevations on one side of your line will be lower elevations, and elevations on the other side of your line will be higher elevations. Once your contour lines are drawn, you will notice that you had to draw some lines closer together in some areas and wider apart in other areas, and that you may have even enclosed an area by drawing a contour line in a circular pattern. These circular patterns indicate hilltops, like in the diagram below (Figure 3.6). To illustrate what these hills look like in profile (or, how they would look if you saw them while standing on the ground and looking at them from a distance), you can draw what is known as a topographic profile. Essentially a topographic profile is a side image of a topographic map, but the image is only a representation of the area shown on the line on the topographic map (line A-B on Figure 3.6). To construct a profile, you need graph paper, a ruler and a pencil. You want to have the y-axis of the graph paper represent the elevations of the contour lines that intersect your drawn line (line A-B in this case). By using a ruler, you can transfer these elevation points from your topographic map straight down onto your graph paper such as shown in Figure 3.6. Be sure to only plot those elevations that are at the intersection of the contour line with line A-B. Once your points are plotted on the graph paper, you simply connect the dots. As a rule, hill tops will be slightly rounded to show a slight increase in elevation to represent the crest of the hill, but be careful not to draw the hill top
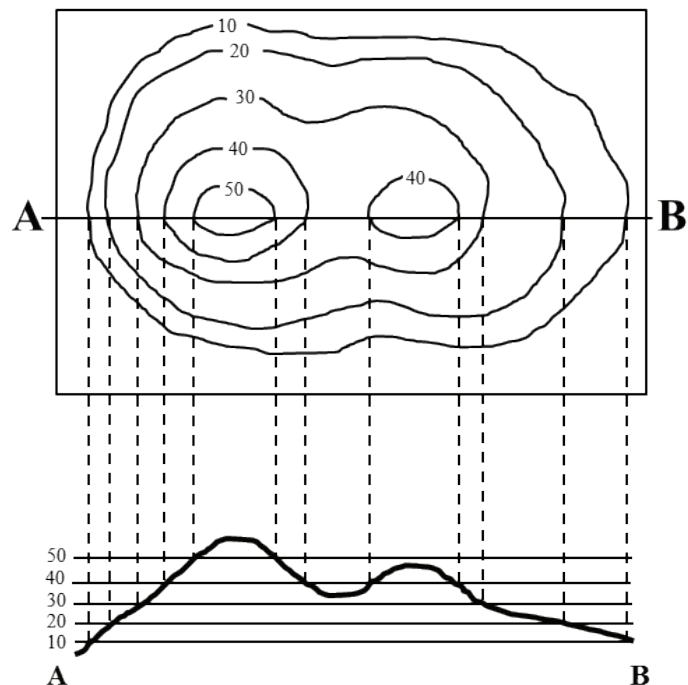
Figure 3.6 | Contour map and topographic profile of two hills and a valley between them.
Author: Karen Tefend
Source: Original Work
License: CC BY-SA 3.0

too high on your graph paper. For example, the first hill on the left has a top contour line of 50ft. Because there isn't a 60ft contour line on this hill top, we know that the hill's highest point (the crest) is some elevation between 50 and 60ft. When connecting the points on your graph paper in the area between the two hills in the Figure 3.6, you again want to round out the area to represent the base of your valley between the hills, but be careful not to make the valley floor too deep, as according to the topographic map the elevation is below 40ft, but not as low as 30ft.

If you examine the graph showing the topographic profile in Figure 3.6, can you image what would happen to your profile if we changed the spacing for elevations on the y-axis? When the vertical dimension of your graph is different from the horizontal dimension on your map, you may end up with a graph that shows a **vertical exaggeration**, and the features of the Earth represented by your topographic profile may be deformed such as in Figure 3.7.

Sometimes vertical exaggeration is desired, but in some cases you may not want it. To avoid having your profile distorted so that it accurately conveys what the surface of the Earth really looks like in profile, you will want both the vertical and horizontal scales to match. For example, if your map scale is 1 inch = 50 ft, then one inch on your graph's y-axis should only represent 50ft of elevation. If the topographic map in Figure 3.6 has a fractional scale of 1:12,000 then 1 inch is equal to 12,000 inches or

Figure 3.7 | A stretched profile (from Figure 3.6) to demonstrate what vertical exaggeration can do to an image. Notice how much steeper the slopes are in this image.
Author: Karen Tefend
Source: Original Work
License: CC BY-SA 3.0

1000ft; this 1inch = 1000ft equivalency is for the horizontal scale. When we hold a ruler to the y-axis of the topographic profile in Figure 3.6, we see that 0.5 inches = 50ft, which means 1 inch = 100ft on the vertical scale. To calculate the vertical exaggeration in the topographic profile shown in Figure 3.6 we divide the horizontal scale by the vertical scale: (1000ft/1inch)/(100ft/inch) = 10. Therefore the topographic profile in Figure 3.6 represents a profile of the map surface (along the A-B line) that has been vertically exaggerated by 10 times (10X).

Answers to Practice Lab Exercises, Parts A and B

1. 76°15'00" W longitude
2. 43°00'00" N latitude
3. 2000 ft
4. 1 ft = 24,000 ft, and 24,000 ft x (1km/3280ft) = 7.32 km
5. South

6. 95 ft (this is the index contour at the top of the hill)
7. 95 ft – 65 ft = 30 ft
8. (80ft – 65 ft)/2miles = 7.5 ft/mile
9. East

3.7 LAB EXERCISE

Part C - Topographic Maps

This is a graded activity. The following pages must be printed and completed by the student, and <u>mailed</u> to the instructor in order to be scored. Alternatively, you may scan the activity and send it electronically to the instructor; unreadable scans will not be accepted, so be sure to send in legible work. Please remember to include your name in the provided blank.

Name_____

3.8 TOPOGRAPHIC MAPS LAB ASSIGNMENT

Note: This lab is in color. Therefore, if you print it out in black and white please refer back to the electronic copy to avoid confusion.

This Lab Assignment is to be mailed to your Instructor at the contact address recorded in the Syllabus. Make sure that you use additional postage if needed. There is no online assessment for the Topographic Maps Lab.

Complete the entire assignment and mail to your instructor postmarked by the assignment deadline. **You should make an extra copy to practice on and mail in a clean and neat version for grading. Make sure to include your name on every page and staple all of the pages together.**

Please take advantage of all of the resources available to you. Be sure to read the corresponding lecture which contains directions to work out the solutions to the problems below. You should also review the instructional videos located in the unit content area within the course for additional assistance. Finally, check the Topographic Map Unit Discussion forum and the tutor talk area for additional resources and hints.

3.8.1 Topographic Maps Lab

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

1. (10 pts) The following topographic map (Map 3.1) 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 the map below. (Note: elevation is meters above sea level, which makes sea level = ____m).

Map 3.1
Author: Brad Deline
Source: Original Work
License: CC BY-SA 3.0

2. (10 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 the following map (Map 3.2). Complete Map 3.2 by adding in **the contour lines using a** <u>contour interval of 100 meters</u>. **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 the problem 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.**
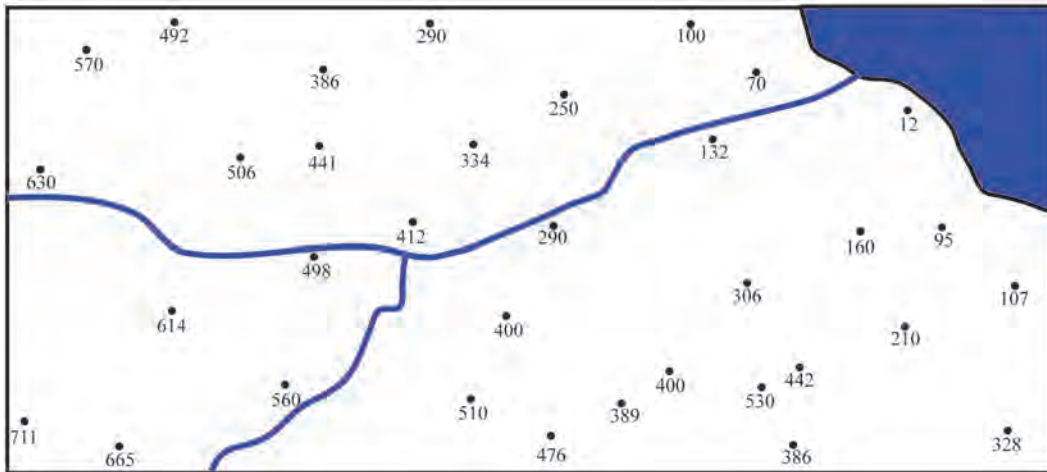
Map 3.2
Author: Brad Deline
Source: Original Work
License: CC BY-SA 3.0

For questions 3-7 refer to the Map 3.3. The following topographic map shows **an interesting and informative geological feature called a drumlin, which is a pile** **of sediment left behind by a retreating glacier.**
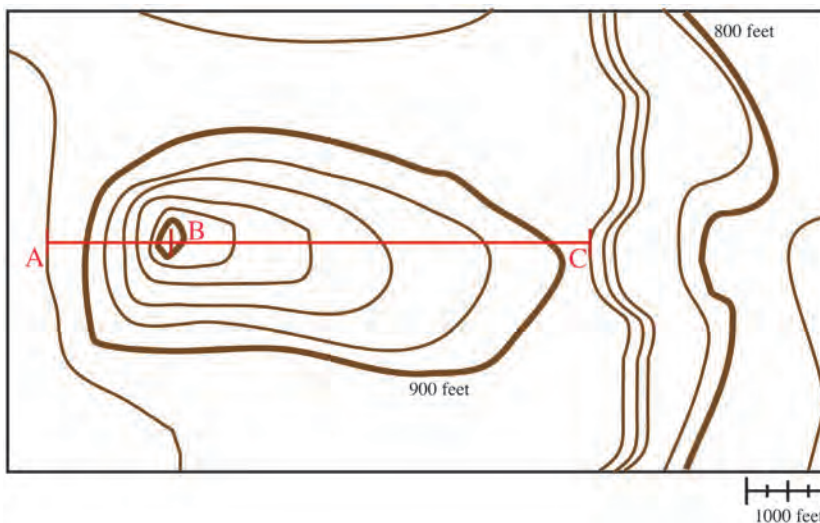
Map 3.3
Author: Brad Deline
Source: Original Work
License: CC BY-SA 3.0

3. (2 pts) What is the contour interval on Map 3.3?

4. (2 pts) What is the regional relief on Map 3.3?

5. (5 pts) Using the contour lines on Map 3.3, which area along the red line is **steeper A to B or B to C? Explain how you came to this conclusion.**

6. (5 pts) What is the gradient from A to B and B to C on Map 3.3? Show your work.

7. (2 pts) Drumlins can be used to determine the direction of movement in the **glacier with the glacier moving toward the shallower side of the structure. Using** your previous answers for Map 3.3, what direction was the glacier traveling? Note: unless indicated otherwise, assume that North is up (towards the top of **the map).**

8. (20 pts) Construct a topographic profile from A to A' on the graph paper below.
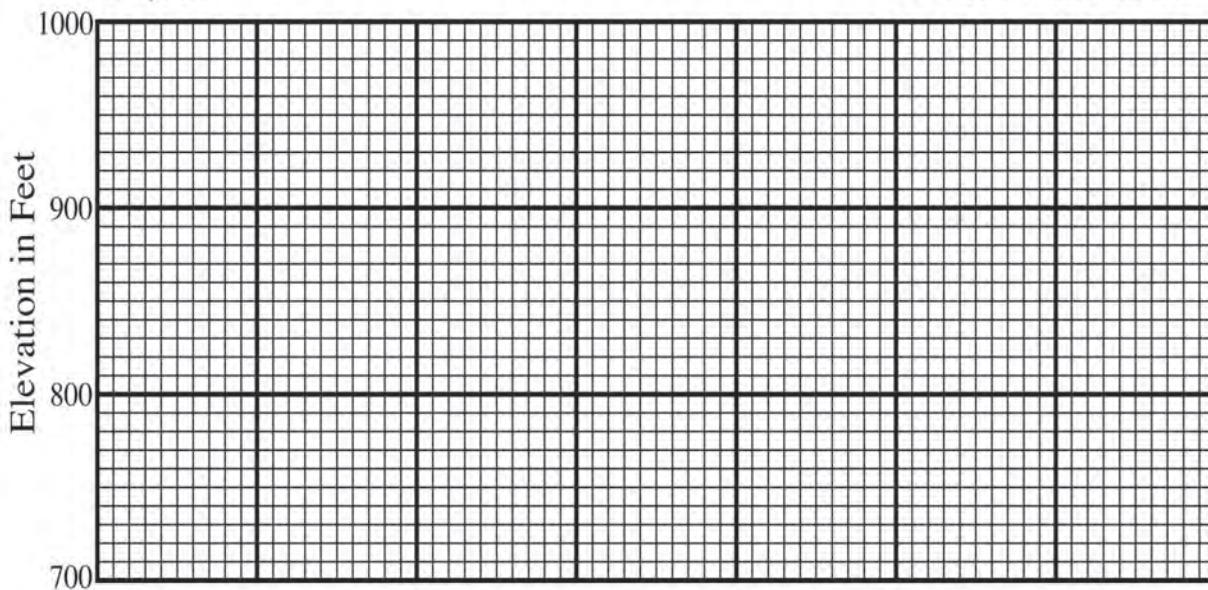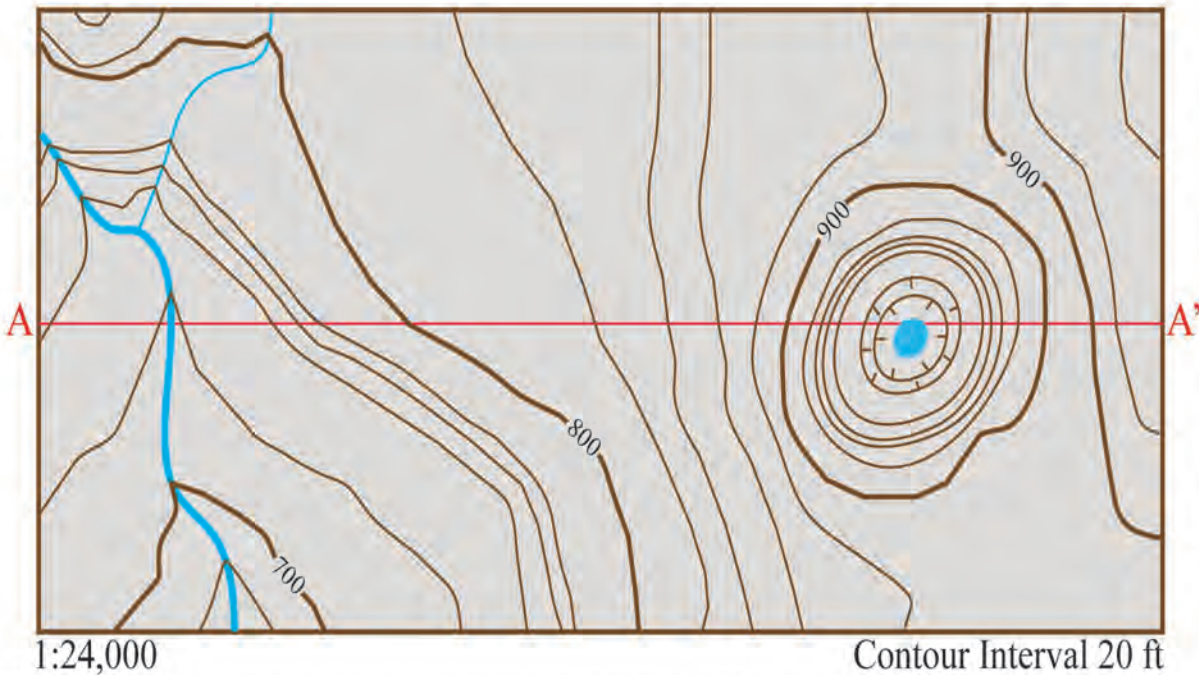
Map 3.4
Author: Brad Deline
Source: Original Work
License: CC BY-SA 3.0

9. (5 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.

For this part of the lab you will need to use Maps 3.5 and 3.6 (appearing at the end of this chapter). Following Maps 3.5 and 3.6 is a Map Key that you can use to identify the various symbols found on topographic maps.Also, note that the maps are in color and the colors have significance in terms of the symbols.

Questions 10-18: Rome North Quadrangle (27 pts)

10. (2 pts) What is the ratio scale of this map?

11. (2 pts) Explain in a sentence how this type of scale works.

12. (2 pts) What is the latitude on the north edge of the map?

13. (2 pts) What is the longitude on the east edge of the map?

14. (6 pts) Find Big Dry Creek, which is north of Rome. What direction does that river flow? Explain two reasons why you came to this conclusion.

15. (2 pts) Examine the large Ridge in the Northwestern portion of the map. What **is the tallest point in this ridge? How tall is it?**

16. (2 pts) How much higher is that point from Lake Conasauga?

17. (5 pts) What is the gradient between Lake Conasauga and the tallest point in the ridge? Show your work (Hint: zooming out will let you see both features on **the map at the same time and may make it easier to measure).**

18. (4 pts) How would the gradient change if you measured from Swan Lake to the tallest point in the ridge rather than Lake Conasauga? Explain why.

Questions 19-22: Grand Tetons (12 pts)

19. (3 pts) Explain why this map is referred to as a 7.5 minute map?

20. (3 pts) What is the relief on this map?

21. (2 pts) Does Taggert Creek flow into Taggert Lake or Lake Taminah? What direction does the creek flow?

22. (4 pts) Garnet Canyon (a little to the west of the word Garnet) is a common camping location for hikers and mountain climbers at the Grand Teton's National Park. Examine the topography surrounding Garnet Canyon and the Middle Teton. What would be the easiest and safest route from Garnet Canyon to the top of the Middle Teton? Explain why. (Drawing a simple map will help).

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U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

The National Map
US Topo

ROME NORTH QUADRANGLE
GEORGIA-FLOYD CO.
7.5-MINUTE SERIES

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
NORTH AMERICAN VERTICAL DATUM OF 1988

This map was produced to conform with the
National Geospatial Program US Topo Product Standard, 2011.
A metadata file associated with this product is draft version 0.6.16
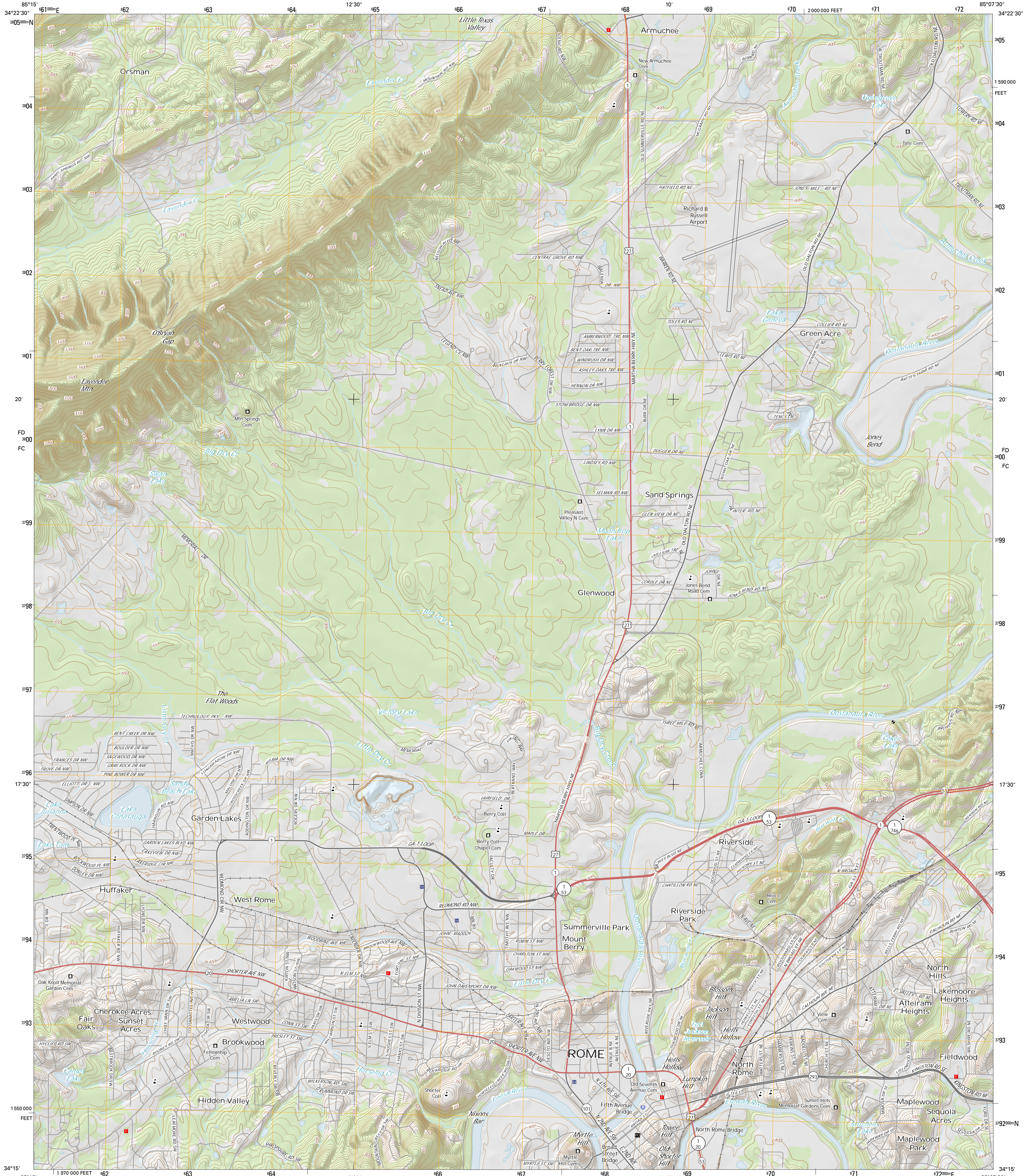
Produced by the United States Geological Survey
North American Datum of 1983 (NAD83)
World Geodetic System of 1984 (WGS84). Projection and
1 000-meter grid: Universal Transverse Mercator, Zone 16S
10 000-foot ticks: Georgia Coordinate System of 1983 (west
zone)

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reservations may not be shown. Obtain permission before
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Imagery.....................................NAIP, August 2010
Roads..HERE, ©2013
Names...GNIS, 2013
Hydrography..............National Hydrography Dataset, 2010
Contours...............National Elevation Dataset, 2009
Boundaries..............Multiple sources: see metadata file 1972 - 2013

ROAD CLASSIFICATION

Expressway   Local Connector
Secondary Hwy   Local Road
Ramp   4WD

Interstate Route   US Route   State Route

QUADRANGLE LOCATION
GEORGIA

ADJOINING QUADRANGLES
1 Summerville
2 Armuchee
3 Plainville
4 Rock Mountain
5 Shannon
6 Livingston
7 Rome South
8 Wax

ROME NORTH, GA
2014

Place names on map
Orsman
Armuchee
New Armuchee Cem
Little Texas Valley
Richard B Russell Airport
Green Acre
Lake Geneva
Jones Bend
O'Bryan Gap
Lavender Mtn
Sand Springs
Glenwood
Jones Bend Road Cem
Oostanaula River
Garden Lakes
Huffaker
West Rome
Riverside
Riverside Park
Summerville Park
Mount Berry
North Hills
Lakemoore Heights
Afteiram Heights
Cherokee Acres
Sunset Acres
Fair Oaks
Westwood
Brookwood
Hidden Valley
ROME
North Rome
Hells Hollow
Fieldwood
Maplewood Acres
Sequoia Acres
Maplewood Park
Kingston Rd NE
Tower Hill
Myrtle Hill

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GRAND TETON QUADRANGLE
WYOMING—TETON CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)

TARGHEE NATIONAL FOREST

GRAND TETON NATIONAL PARK

Table Mountain
Battleship Mountain
Horricane Pass
Schoolroom Glacier
Icefloe Lake
Middle Teton
Grand Teton
Mount Owen
East Prong
Teewinot Mountain
Teepee Pillar
Disappointment Peak
Amphitheater Lake
Surprise Lake
Delta Lake
Glacier Gulch
Glacier Falls
Bannock Falls
Bradley Lake
Cleft Falls
Spalding Falls
South Teton
Cloudveil Dome
Nez Perce
Shadow Peak
Kit Lake
Snowdrift Lake
Lake Taminah
Shoshoko Falls
Avalanche Canyon
Taggart Canyon Creek
Taggart Lake
Sunset Lake
The Wall
Veiled Peak
Mount Wister
South Fork
Spring
Basin Lakes
Sheep Steps
Buck Mountain
Timberline Lake
Static Peak
Mount Meek Pass
Death Canyon
Rimrock Lake
Prospectors Mountain
Forget-me-not Lake
Coyote Lake
Open Canyon
Mount Hunt
Mount Hunt Divide
Phelps Lake
White Grass Ranger Station
White Grass Ranch
Stewart Draw
Landing Strip
JACKSON HOLE
SNAKE RIVER
J Y Ranch
R Lazy S Ranch
TETON VILLAGE

SCALE 1:24000

CONTOUR INTERVAL 80 FEET
DOTTED LINES REPRESENT 40-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

Mapped, edited, and published by the Geological Survey

Control by USGS and USC&GS

Topography by photogrammetric methods from aerial
photographs taken 1967. Field checked 1968

Polyconic projection. 1927 North American datum
10,000-foot grid based on Wyoming coordinate system,
west zone
1000-meter Universal Transverse Mercator grid ticks,
zone 12, shown in blue

Fine red dashed lines indicate selected fence lines
Where omitted, land lines have not been established

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR WASHINGTON, D.C. 20242
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
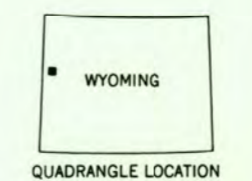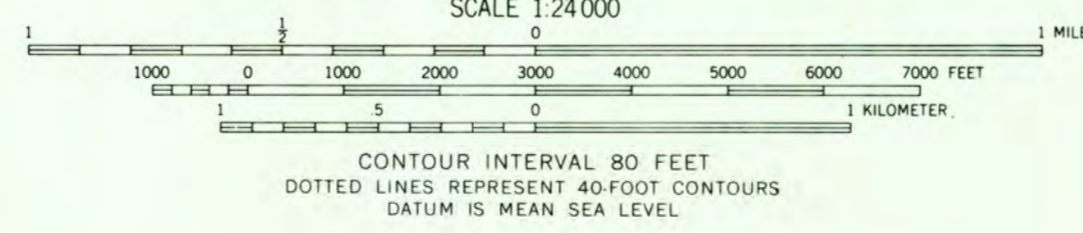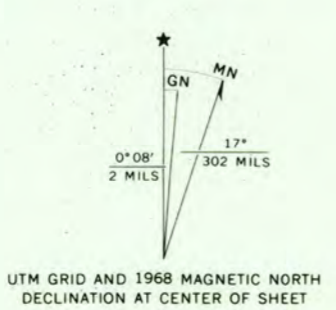
ROAD CLASSIFICATION

Secondary highway, all weather,   Light-duty road, all weather,
hard surface   improved surface

Unimproved road, fair or dry
weather

WYOMING

QUADRANGLE LOCATION
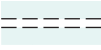
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AMS 3871 III NE—SERIES V874

MAR 1 1973
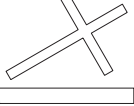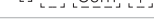
BATHYMETRIC FEATURES

Area exposed at mean low tide; sounding datum line***	
Channel***	
Sunken rock***	

BOUNDARIES

National	
State or territorial	
County or equivalent	
Civil township or equivalent	
Incorporated city or equivalent	
Federally administered park, reservation, or monument (external)	
Federally administered park, reservation, or monument (internal)	
State forest, park, reservation, or monument and large county park	
Forest Service administrative area*	
Forest Service ranger district*	
National Forest System land status, Forest Service lands*	
National Forest System land status, non-Forest Service lands*	
Small park (county or city)	

BUILDINGS AND RELATED FEATURES
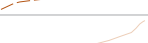
Building	
School; house of worship	
Athletic field	
Built-up area	
Forest headquarters*	
Ranger district office*	
Guard station or work center*	
Racetrack or raceway	
Airport, paved landing strip, runway, taxiway, or apron	
Unpaved landing strip	
Well (other than water), windmill or wind generator	
Tanks	
Covered reservoir	
Gaging station	
Located or landmark object (feature as labeled)	
Boat ramp or boat access*	
Roadside park or rest area	
Picnic area	
Campground	
Winter recreation area*	
Cemetery	

COASTAL FEATURES
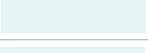
Foreshore flat	
Coral or rock reef	
Rock, bare or awash; dangerous to navigation	
Group of rocks, bare or awash	
Exposed wreck	
Depth curve; sounding	
Breakwater, pier, jetty, or wharf	
Seawall	
Oil or gas well; platform	

CONTOURS
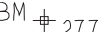
Topographic

Index	6000
Approximate or indefinite	
Intermediate	
Approximate or indefinite	
Supplementary	
Depression	
Cut	
Fill	
Continental divide	

Bathymetric

Index***	
Intermediate***	
Index primary***	
Primary***	
Supplementary***	

CONTROL DATA AND MONUMENTS

Principal point**	3-20
U.S. mineral or location monument	▲ USMM 438
River mileage marker	Mile 69

Boundary monument

Third-order or better elevation, with tablet	BM □ 9134 BM 277
Third-order or better elevation, recoverable mark, no tablet	□ 5628
With number and elevation	67 □ 4567

Horizontal control

Third-order or better, permanent mark	△ Neace Neace
With third-order or better elevation	BM △ 52 Pike BM393
With checked spot elevation	△ 1012
Coincident with found section corner	△ Cactus Cactus
Unmonumented**	

CONTROL DATA AND MONUMENTS – *continued*

Vertical control

Third-order or better elevation, with tablet	BM × 5280
Third-order or better elevation, recoverable mark, no tablet	× 528
Bench mark coincident with found section corner	BM + 5280
Spot elevation	× 7523

GLACIERS AND PERMANENT SNOWFIELDS

- Contours and limits
- Formlines
- Glacial advance
- Glacial retreat

LAND SURVEYS

Public land survey system

Range or Township line	
Location approximate	
Location doubtful	
Protracted	
Protracted (AK 1:63,360-scale)	
Range or Township labels	R1E T2N R3W T4S
Section line	
Location approximate	
Location doubtful	
Protracted	
Protracted (AK 1:63,360-scale)	
Section numbers	1 - 36 1 - 36
Found section corner	
Found closing corner	
Witness corner	WC
Meander corner	MC
Weak corner*	

Other land surveys

Range or Township line	
Section line	
Land grant, mining claim, donation land claim, or tract	
Land grant, homestead, mineral, or other special survey monument	▫
Fence or field lines	

MARINE SHORELINES

- Shoreline
- Apparent (edge of vegetation)***
- Indefinite or unsurveyed

MINES AND CAVES

Quarry or open pit mine	⚒
Gravel, sand, clay, or borrow pit	⚒
Mine tunnel or cave entrance	
Mine shaft	
Prospect	X
Tailings	Tailings
Mine dump	
Former disposal site or mine	

PROJECTION AND GRIDS

Neatline	39°15' 90°37'30"
Graticule tick	55'
Graticule intersection	
Datum shift tick	

State plane coordinate systems

Primary zone tick	640 000 FEET
Secondary zone tick	247 500 METERS
Tertiary zone tick	260 000 FEET
Quaternary zone tick	98 500 METERS
Quintary zone tick	320 000 FEET

Universal transverse metcator grid

UTM grid (full grid)	273
UTM grid ticks*	269

RAILROADS AND RELATED FEATURES

- Standard guage railroad, single track
- Standard guage railroad, multiple track
- Narrow guage railroad, single track
- Narrow guage railroad, multiple track
- Railroad siding
- Railroad in highway
- Railroad in road
- Railroad in light duty road*
- Railroad underpass; overpass
- Railroad bridge; drawbridge
- Railroad tunnel
- Railroad yard
- Railroad turntable; roundhouse

RIVERS, LAKES, AND CANALS

- Perennial stream
- Perennial river
- Intermittent stream
- Intermittent river
- Disappearing stream
- Falls, small
- Falls, large
- Rapids, small
- Rapids, large
- Masonry dam
- Dam with lock
- Dam carrying road

RIVERS, LAKES, AND CANALS – *continued*

Perennial lake/pond	
Intermittent lake/pond	
Dry lake/pond	Dry Lake
Narrow wash	
Wide wash	Wash
Canal, flume, or aqueduct with lock	
Elevated aqueduct, flume, or conduit	
Aqueduct tunnel	
Water well, geyser, fumarole, or mud pot	○ ○
Spring or seep	•

ROADS AND RELATED FEATURES

Please note: Roads on Provisional-edition maps are not classified as primary, secondary, or light duty. These roads are all classified as improved roads and are symbolized the same as light duty roads.

Primary highway	
Secondary highway	
Light duty road	
Light duty road, paved*	
Light duty road, gravel*	
Light duty road, dirt*	
Light duty road, unspecified*	
Unimproved road	
Unimproved road*	
4WD road	
4WD road*	
Trail	
Highway or road with median strip	
Highway or road under construction	Under Const
Highway or road underpass; overpass	
Highway or road bridge; drawbridge	
Highway or road tunnel	
Road block, berm, or barrier*	
Gate on road*	
Trailhead*	

SUBMERGED AREAS AND BOGS

Marsh or swamp	
Submerged marsh or swamp	
Wooded marsh or swamp	
Submerged wooded marsh or swamp	
Land subject to inundation	Max Pool

SURFACE FEATURES

Levee	Levee
Sand or mud	
Disturbed surface	
Gravel beach or glacial moraine	Gravel
Tailings pond	Tailings Pond

TRANSMISSION LINES AND PIPELINES

Power transmission line; pole; tower	
Telephone line	Telephone
Aboveground pipeline	
Underground pipeline	Pipeline

VEGETATION

Woodland	
Shrubland	
Orchard	
Vineyard	
Mangrove	Mangrove

* USGS-USDA Forest Service Single-Edition Quadrangle maps only.

In August 1993, the U.S. Geological Survey and the U.S. Department of Agriculture's Forest Service signed an Interagency Agreement to begin a single-edition joint mapping program. This agreement established the coordination for producing and maintaining single-edition primary series topographic maps for quadrangles containing National Forest System lands. The joint mapping program eliminates duplication of effort by the agencies and results in a more frequent revision cycle for quadrangles containing National Forests. Maps are revised on the basis of jointly developed standards and contain normal features mapped by the USGS, as well as additional features required for efficient management of National Forest System lands. Single-edition maps look slightly different but meet the content, accuracy, and quality criteria of other USGS products.

** Provisional-Edition maps only.
Provisional-edition maps were established to expedite completion of the remaining large-scale topographic quadrangles of the conterminous United States. They contain essentially the same level of information as the standard series maps. This series can be easily recognized by the title "Provisional Edition" in the lower right-hand corner.

*** Topographic Bathymetric maps only.

Topographic Map Information

For more information about topographic maps produced by the USGS, please call:
1-888-ASK-USGS or visit us at http://ask.usgs.gov/