1 Introduction to Physical Geology

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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 question. Different hypotheses about the age of the earth can essentially change our perspective of the workings of geologic events that molded the Earth. If the geologic time is relatively short then catastrophic events would be required to form the features we see on the surface of the earth, whereas a vast amount of time allows the slow and steady pace that we can easily observe around us today.

Geologists have used many methods 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	Age (top – base)
PHANEROZOIC	Cenozoic	Quaternary		Holocene	0 Yr. – 15K Yr
				Pleistocene	15K Yr – 1.8 Ma
		Tertiary	Neogene	Pliocene	1.8 Ma – 5.3 Ma
				Miocene	5.3 Ma – 24 Ma
			Paleogene	Oligocene	24 Ma – 34 Ma
				Eocene	34 Ma – 55 Ma
				Paleocene	55 Ma – 65 Ma
	Mesozoic	Cretaceous			65 Ma – 142 Ma
		Jurassic			142 Ma – 202 Ma
		Triassic			202 Ma – 251 Ma
	Paleozoic	Permian			251 Ma – 292 Ma
		Pennsylvanian	Carboniferous		292 Ma – 320 Ma
		Mississippian			320 Ma – 354 Ma
		Devonian			354 Ma – 417 Ma
		Silurian			417 Ma – 440 Ma
		Ordovician			440 Ma – 495 Ma
		Cambrian			495 Ma – 545 Ma
Proterozoic	Pre-Cambrian (general)				545 Ma – 2500 Ma
Archean					2500 Ma – 4000 Ma
Hadean					4000 Ma – 4550 Ma

Figure 1.1 | The geologic time scale. Ma, Million years, K. Yr, Thousand years
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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).

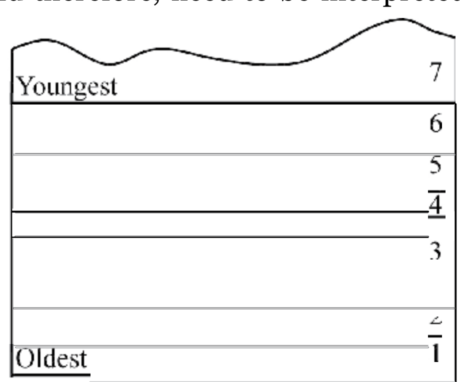

Figure 1.2 | Block diagram showing the relative age of sedimentary layers based on the Law of Superposition.
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The **Law of Original Horizontality** states that undeformed sedimentary rock are deposited horizontally. The deposition of sediment is controlled 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).

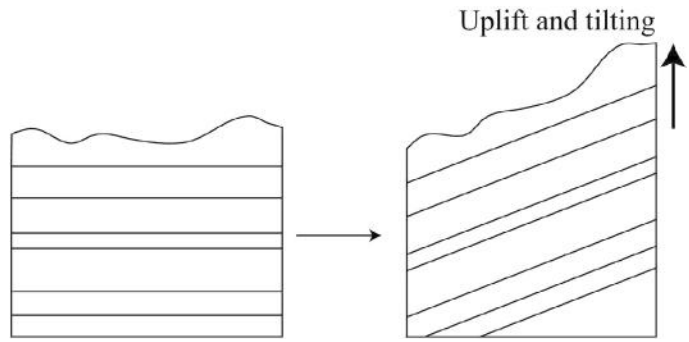

Figure 1.3 | Sedimentary rocks are deposited horizontally such that if the layers are tilted or folded it must have occurred following deposition.
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One other feature that can be useful in building relative time scales is what is missing in a sequence 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 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,

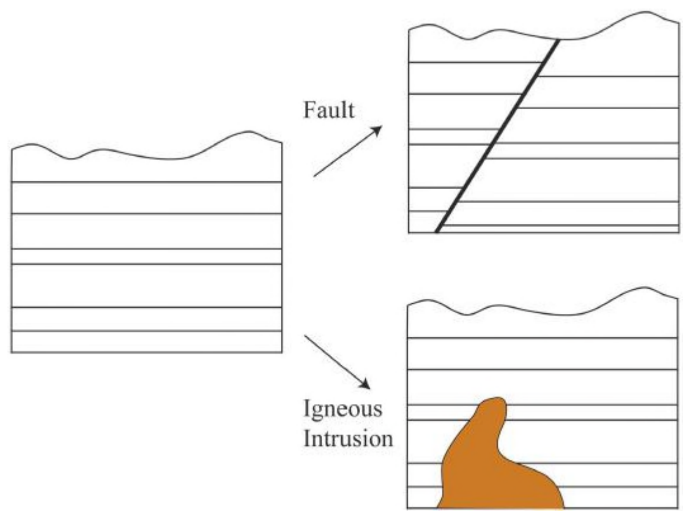

Figure 1.4 | Block diagrams showing the Law of Cross-Cutting. In both instances on the right the geological features (fault or Igneous intrusion) cut across the sedimentary layers and must then be younger.
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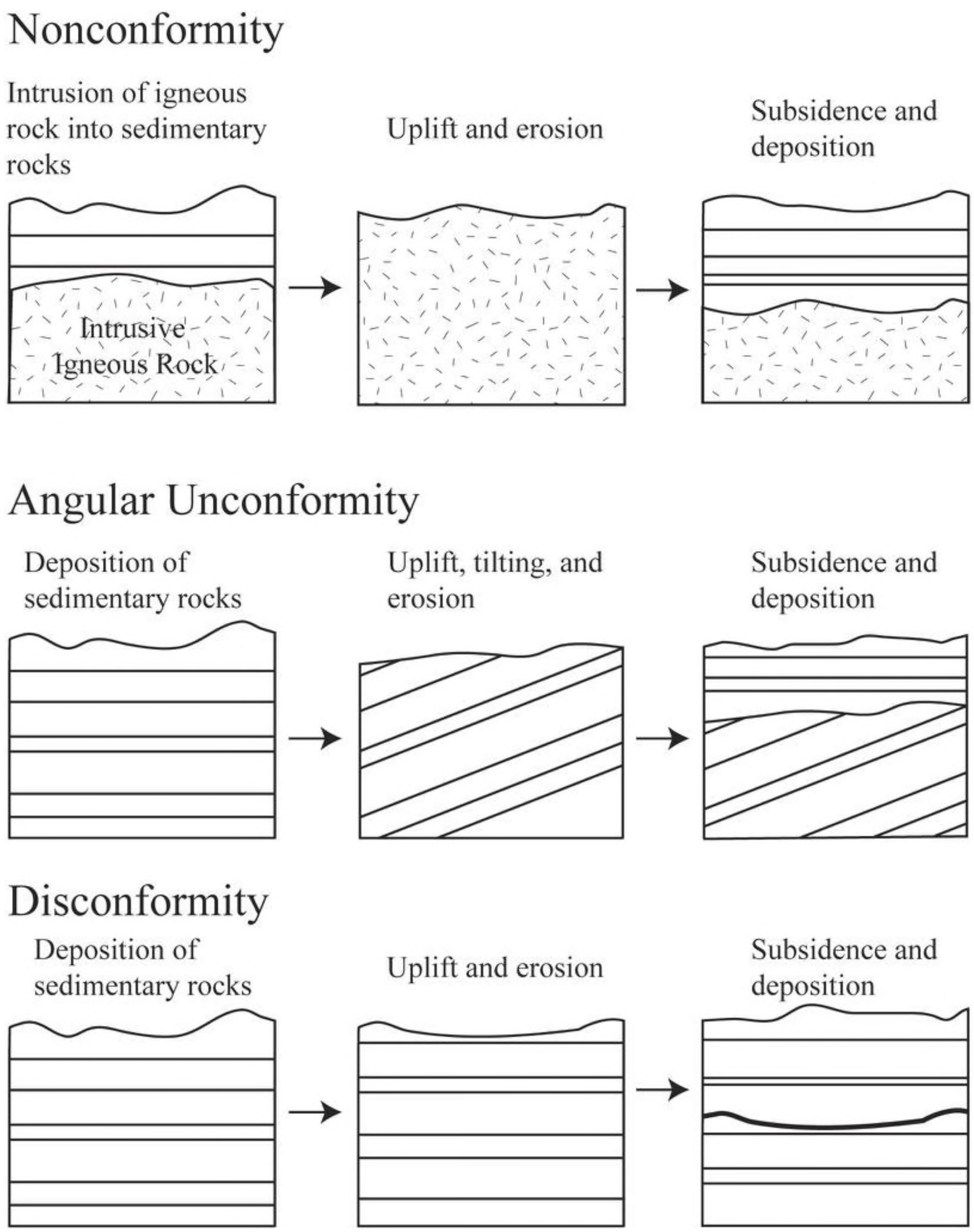

Figure 1.5 | Block diagrams showing the formation of the three types of Unconformities. The three unconformities differ based on the type of rock underneath the erosion surface.
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then the orientation of the layers is important. If the rocks below the 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.

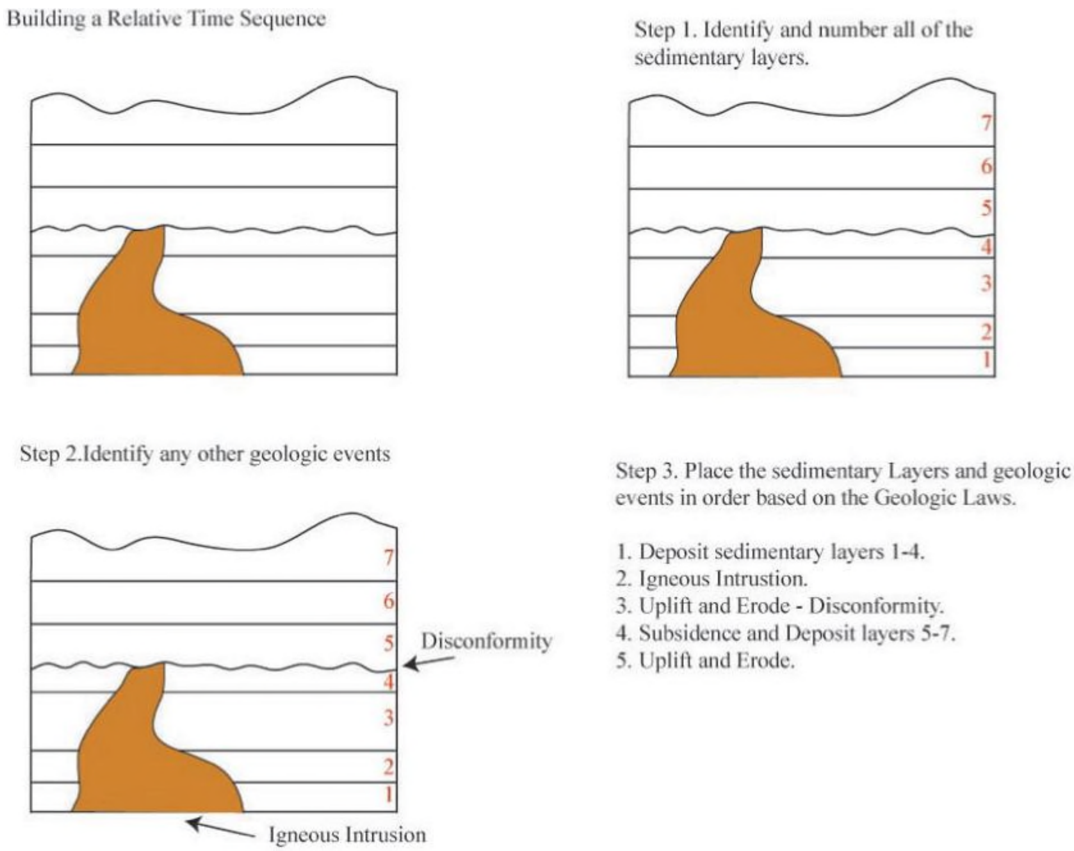

Figure 1.6 | An example showing how to determine a relative dating sequence of events from a block diagram.
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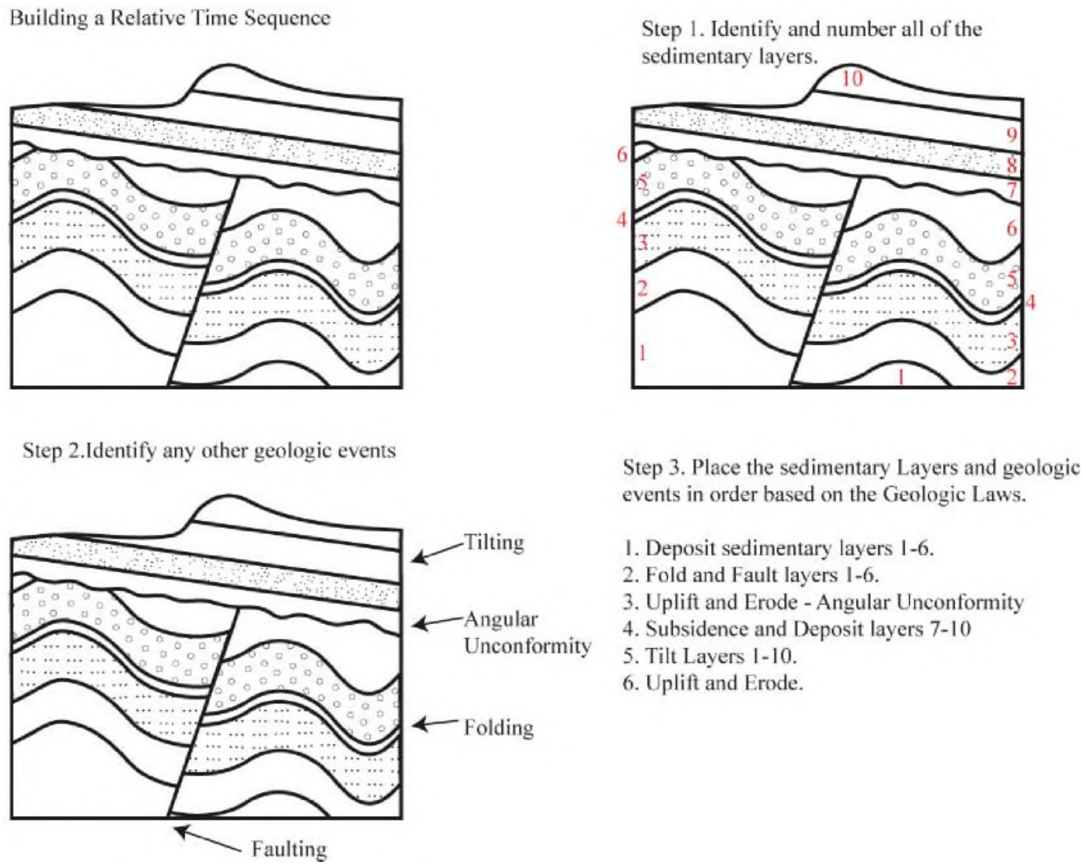

Figure 1.7 | An example showing how to determine a relative dating sequence of events from a block diagram.
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1.3 LAB EXERCISE

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.

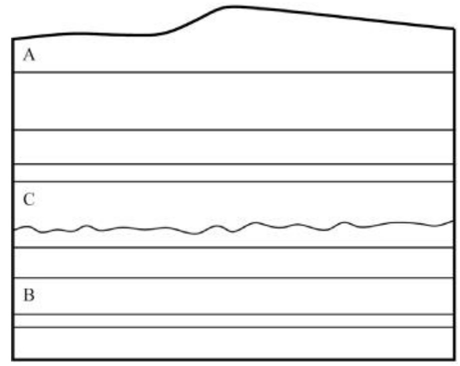

Figure 1.8 | Block diagram to use to answer questions 1 and 2.
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1. In Figure 1.8, which of the following rock layers is the **oldest**?

a. A b. B c. C

0. 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

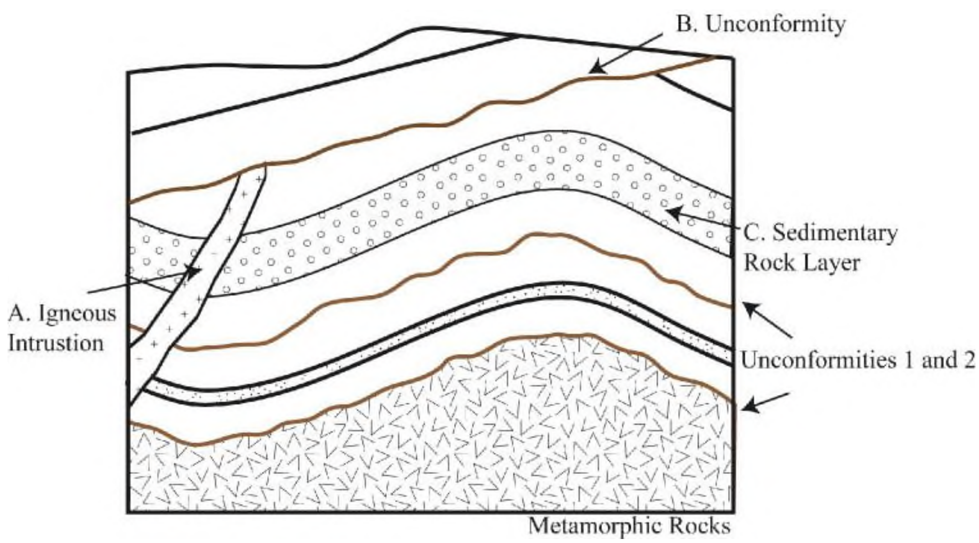

Figure 1.9 | Block diagram to use to answer questions 3, 4, and 5. Unconformities are shown in brown.
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1. In Figure 1.9, which of the following geologic structures is the **youngest**?

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

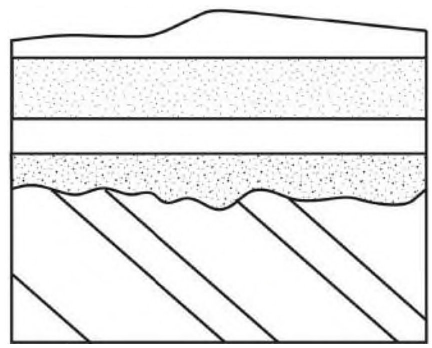

Figure 1.10 | Block diagram to use to answer question 6. **Author:** Bradley Deline **Source:** Original Work **License:** CC BY-SA 3.0

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.

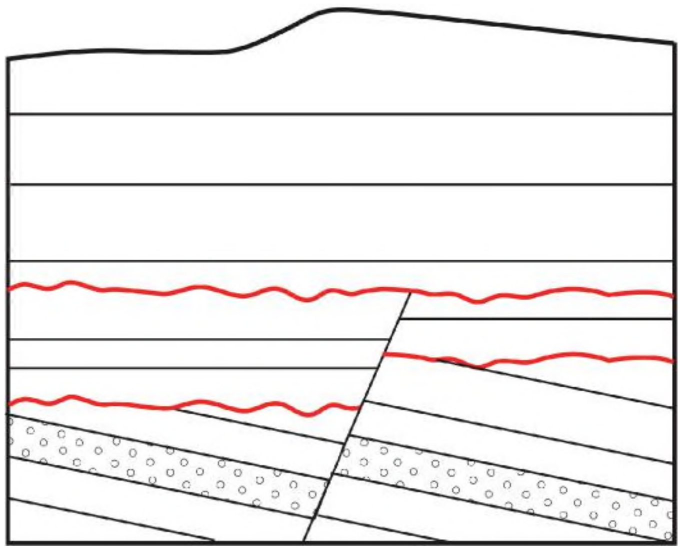

Figure 1.11 | Block diagram to use to answer questions 7, 8, and 9. Unconformities are shown in red.
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a. Tilting.

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.

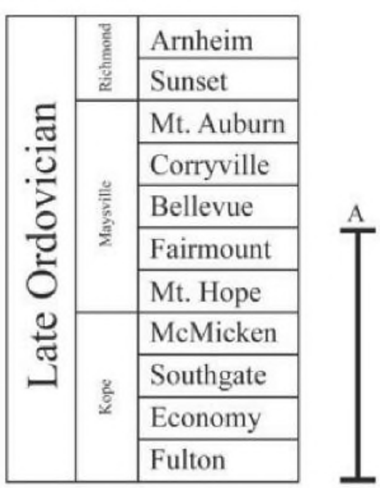

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Figure 1.12 Author: Bradley Deline **Source:** Original Work **License:** CC BY-SA 3.0

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 radiometric 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.

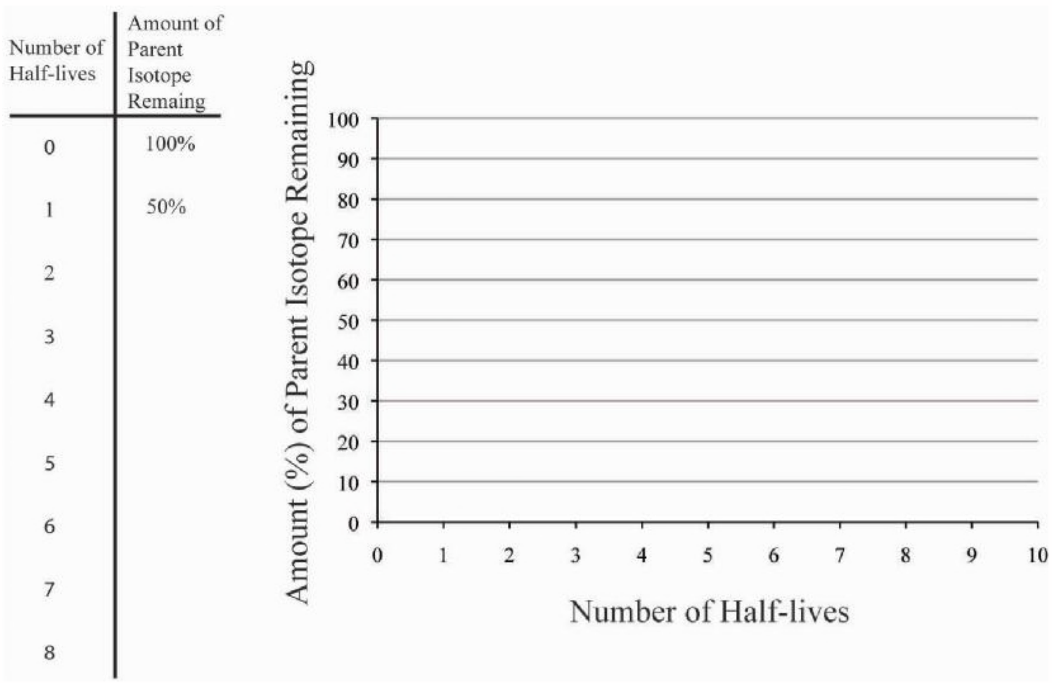

Figure 1.13
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13. How much of the parent isotope would be remaining after 7 half-lives have passed?

    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:

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

$t_{1/2}$ = 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:

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

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

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