LAB 7: RELATIVE DATING AND GEOLOGICAL TIME

Lab Structure

Recommended additional work	None
Required materials	Pencil

Learning Objectives

After carefully reading this chapter, completing the exercises within it, and answering the questions at the end, you should be able to:

- Apply basic geological principles to the determination of the relative ages of rocks.
- Explain the difference between relative and absolute age-dating techniques.
- Summarize the history of the geological time scale and the relationships between eons, eras, periods, and epochs.
- Understand the importance and significance of unconformities.
- Explain why an understanding of geological time is critical to both geologists and the general public.

Key Terms

- Eon
- Era
- Period
- Relative dating
- Absolute dating
- Isotopic dating
- Stratigraphy
- Strata
- Superposition
- Original horizontality
- Cross-cutting
- Inclusions
- Faunal succession
- Unconformity
- Angular unconformity
- Disconformity
- Nonconformity
- Paraconformity

Time is the dimension that sets geology apart from most other sciences. Geological time is vast, and Earth has changed enough over that time that some of the rock types that formed in the past could not form today. Furthermore, as we've discussed, even though most geological processes are very, very slow, the vast amount of time that has passed has allowed for the formation of extraordinary geological features, as shown in Figure 7.0.1.

Figure 7.0.1: Arizona's Grand Canyon is an icon for geological time; 1,450 million years are represented by this photo. The light-coloured layered rocks at the top formed at around 250 Ma, and the dark rocks at the bottom (within the steep canyon) at around 1,700 Ma.

We have numerous ways of measuring geological time. We can tell the relative ages of rocks (for example, whether one rock is older than another) based on their spatial relationships; we can use fossils to date sedimentary rocks because we have a detailed record of the evolution of life on Earth; and we can use a range of isotopic techniques to determine the actual ages (in millions of years) of igneous and metamorphic rocks. We will explore the use of fossils in dating sedimentary rocks, and interpreting past changes in climate and depositional environment through geologic time in the subsequent geology course, GEOL 1103 – Earth Through Time.

But just because we can measure geological time doesn't mean that we understand it. One of the biggest hurdles faced by geology students—and geologists as well—in mastering geology, is to really come to grips with the slow rates at which geological processes happen and the vast amount of time involved. The problem is that our lives are short and our memories are even shorter. Our experiences span only a few decades, so we really don't have a way of knowing what 11,700 years means. What's more, it's hard for us to understand how 11,700 years differs from 65.5 million years, or even from 1.8 billion years. It's not that we can't comprehend what the numbers mean—we can all get that figured out with a bit of practice—but even if we do know the numerical meaning of 65.5 Ma, we can't really appreciate how long ago it was.

You may be wondering why it's so important to really "understand" geological time. One key reason is to fully appreciate how geological processes that seem impossibly slow can produce anything of consequence. For example, the slow movement of tectonic plates that over geological time can travel many thousands of kilometres!

One way to wrap your mind around geological time is to put it into the perspective of single year, as we did in Table I1 the introductory chapter, because we all know how long it is from one birthday to the next. At that rate, each hour of the year is equivalent to approximately 500,000 years, and each day is equivalent to 12.5 million years. It's worth repeating: on this time scale, the earliest ancestors of the animals and plants with which we are familiar did not appear on Earth until mid-November, the dinosaurs disappeared after Christmas, and most of Canada was periodically locked in ice from 6:30 to 11:59 p.m. on New Year's Eve. As for people, the first to inhabit Alberta got here about one minute before midnight, and the first Europeans arrived about two seconds before midnight.

Media Attributions

- Figure 7.0.1: © Steven Earle. CC BY.

7.1 The Geological Time Scale

Perhaps the most important contributor to geology, ideas of geological time, and the first person to create a geological map, was William Smith. Smith worked as a surveyor in the coal-mining and canal-building industries in southwestern England in the late 1700s and early 1800s. While doing his work, he had many opportunities to look at the Paleozoic and Mesozoic sedimentary rocks of the region, and he did so in a way that few had done before. Smith noticed the textural similarities and differences between rocks in different locations, and more importantly, he discovered that fossils could be used to correlate rocks of the same age. Smith is credited with formulating the **principle of faunal succession** (the concept that specific types of organisms lived during different time intervals), and he used it to great effect in his monumental project to create a geological map of England and Wales, published in 1815. For more on William Smith, including a large-scale digital copy of the famous map, see the William Smith Wikipedia page.

Inset into Smith's great geological map is a small diagram showing a schematic geological cross-section extending from the Thames estuary of eastern England all the way to the west coast of Wales. Smith shows the sequence of rocks, from the Paleozoic rocks of Wales and western England, through the Mesozoic rocks of central England, to the Cenozoic rocks of the area around London (Figure 7.1.1). Although Smith did not put any dates on these—because he didn't know them—he was aware of the **principle of superposition** (the idea, developed much earlier by the Danish theologian and scientist Nicholas Steno, that young sedimentary rocks form on top of older ones), and so he knew that this diagram represented a stratigraphic column. And because almost every period of the Phanerozoic is represented along that section through Wales and England, it is a primitive geological time scale.

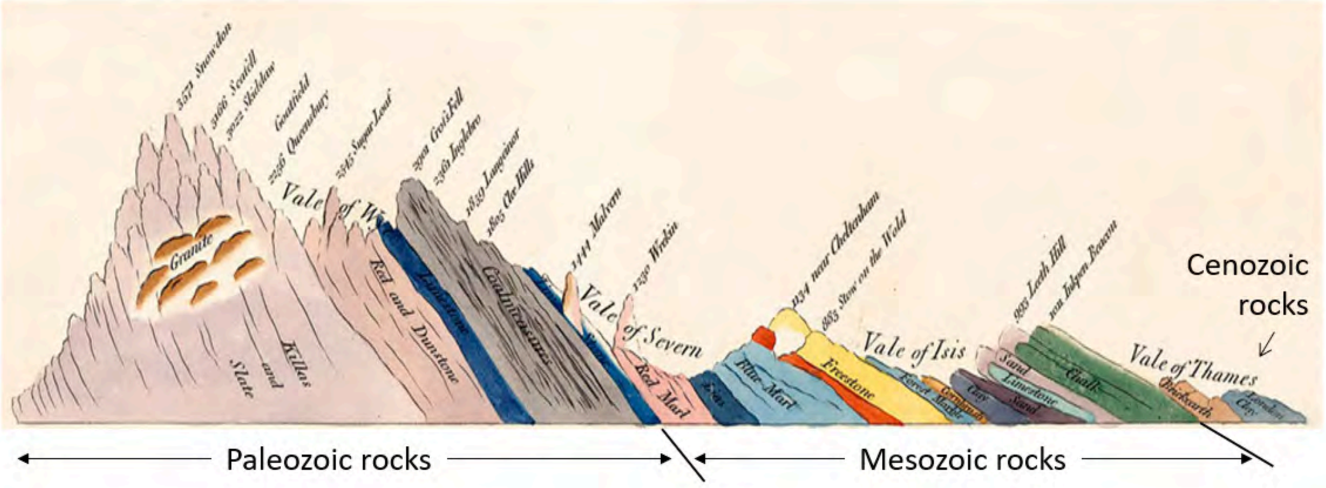

Figure 7.1.1: William Smith's "Sketch of the succession of strata and their relative altitudes," an inset on his geological map of England and Wales (with era names added).

Smith's work set the stage for the naming and ordering of the geological periods, which was initiated around 1820, first by British geologists, and later by other European geologists. Many of the periods are named for places where rocks of that age are found in Europe, such as Cambrian for Cambria (Wales), Devonian for Devon in England, Jurassic for the Jura Mountains in France and Switzerland, and Permian for the Perm region of Russia. Some are named for the type of rock that is common during that age, such as Carboniferous for the coal- and carbonate-bearing rocks of England, and Cretaceous for the chalks of England and France.

The early time scales were only relative because 19th century geologists did not know the ages of the rocks. That information was not available until the development of **isotopic dating** techniques early in the 20th century.

The geological time scale is currently maintained by the International Commission on Stratigraphy (ICS), which is part of the International Union of Geological Sciences. The time scale is continuously being updated as we learn more about the timing and nature of past geological events. You can view the 2020 version of the ICS time scale online. It would be a good idea to print a copy (in colour) to put on your wall while you are studying geology.

Geological time has been divided into four **eons**: Hadean (4570 to 4850 Ma), Archean (3850 to 2500 Ma), Proterozoic (2500 to 540 Ma), and Phanerozoic (540 Ma to present). As shown in Figure 7.1.2, the first three of these represent almost 90% of Earth's history. The last one, the Phanerozoic (meaning "visible life"), is the time that we are most familiar with because Phanerozoic rocks are the most common on Earth, and they contain evidence of the life forms that we are familiar with to varying degrees.

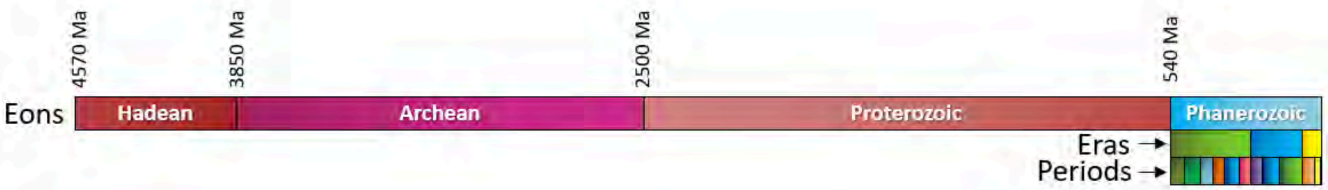

Figure 7.1.2: The four eons of Earth's history.

The Phanerozoic eon—the past 540 Ma of Earth's history—is divided into three **eras**: the Paleozoic ("early life"), the Mesozoic ("middle life"), and the Cenozoic ("new life"), and each of these is divided into a number of **periods** (Figure 7.1.3). Most of the organisms that we share Earth with evolved at various times during the Phanerozoic.

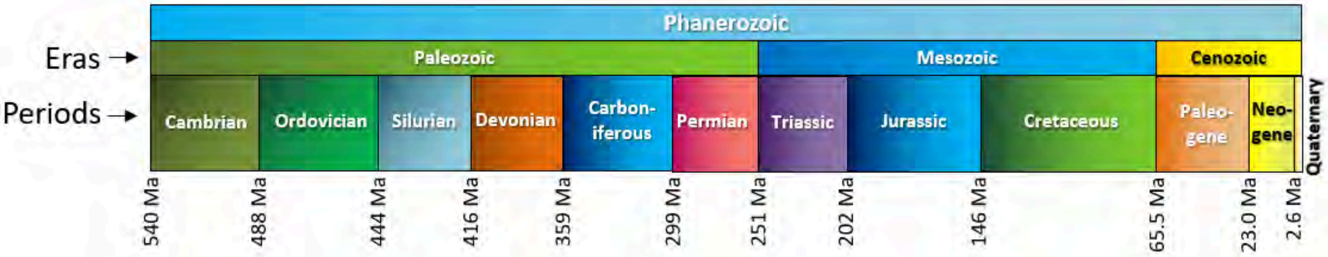

Figure 7.1.3: The eras (middle row) and periods (bottom row) of the Phanerozoic eon.

The Cenozoic era, which represents the past 65.5 Ma, is divided into three **periods**: Paleogene, Neogene, and Quaternary, and seven **epochs** (Figure 7.1.4). Dinosaurs became extinct at the start of the Cenozoic, after which birds and mammals radiated to fill the available habitats. Earth was very warm during the early Eocene and has steadily cooled ever since. Glaciers first appeared on Antarctica in the Oligocene and then on Greenland in the Miocene, and covered much of North America and Europe by the Pleistocene. The most recent of the Pleistocene glaciations ended around 11,700 years ago. The current epoch is known as the **Holocene**. Epochs are further divided into **ages** (a.k.a. stages), but we won't be going into that level of detail here.

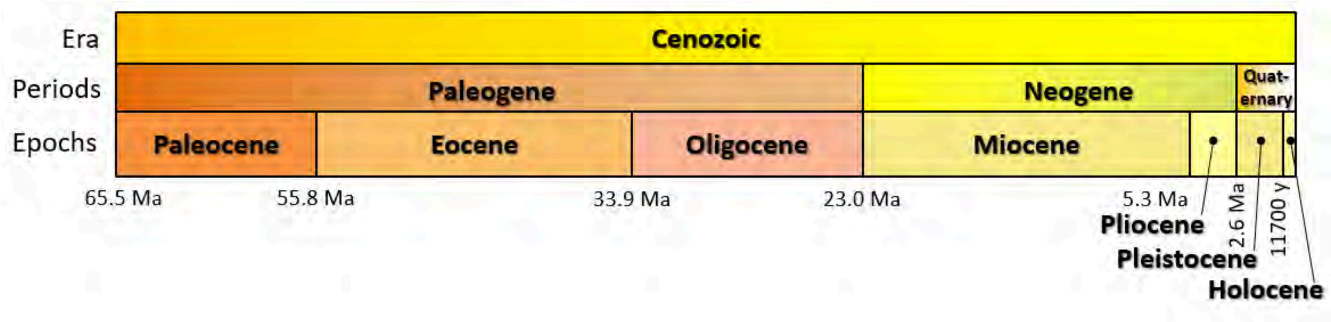

Figure 7.1.4: The periods (middle row) and epochs (bottom row) of the Cenozoic era.

Most of the boundaries between the periods and epochs of the geological time scale have been fixed on the basis of significant changes in the fossil record. For example, as already noted, the boundary between the Cretaceous and the Paleogene coincides exactly with a devastating mass extinction. That's not a coincidence. The dinosaurs and many other types of organisms went extinct at this time, and the boundary between the two periods marks the division between sedimentary rocks with Cretaceous organisms (including dinosaurs) below, and Paleogene organisms above.

Media Attributions

- Figure 7.1.1: "Sketch of the succession of strata and their relative altitudes" by William Smith. Adapted by Steven Earle. Public domain.
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7.2 Relative Dating Methods

There are two main ways in which geologists have built an understanding of geological time by dating geological materials: absolute dating and relative dating.

Absolute dating uses isotopic dating of rocks, or the minerals in them, based on the fact that we know the decay rates of certain unstable **isotopes** of elements and that these rates have been constant over geological time. It was only in the early part of the 20th century, when isotopic dating methods were first applied, that it became possible to discover the absolute ages of the rocks containing fossils. In most cases, we cannot use isotopic techniques to directly date fossils or the sedimentary rocks they are found in, but we can constrain their ages by dating igneous rocks that cut across sedimentary rocks, or volcanic layers that lie within sedimentary layers.

Relative dating, on the other hand, is the simplest and most intuitive way of dating geological features by examining the spatial relationships between them. There are a few simple rules for doing this, called the **principles of stratigraphy**. [1]

Through careful observation over the past few centuries, geologists have discovered that the accumulation of sediments and sedimentary rocks, as well as the eruption of some extrusive igneous rocks, takes place according to some important geological principles, as follows:

- The **principle of original horizontality** is that sediments accumulate in essentially horizontal layers, called **beds**. The implication is that tilted sedimentary beds observed to day must have been subjected to tectonic forces (Figure 7.2.1, right).
- The **principle of superposition** is that sedimentary layers are deposited in sequence, and that unless the entire sequence has been turned over by tectonic processes, the layers at the bottom are older than those at the top.
- The **principle of inclusions** is that any rock fragments in a sedimentary layer must be older than the layer. For example, the cobbles in a conglomerate must have been formed before the conglomerate was formed. Another example of this principle is shown in Figure 7.2.1 (left).
- The **principle of faunal succession** is that there is a well-defined order in which organisms have evolved through geological time, and therefore the identification of specific fossils in a rock can be used to determine its age. We won't be covering fossils in any detail in this book as they are covered in the subsequent geology course (GEOL 1103), but they are extremely important for understanding sedimentary rocks. Of course, fossils can be used to date sedimentary rocks, but equally importantly, they tell us a great deal about the depositional environment of the sediments and the climate at the time. For example, they can help to differentiate marine versus terrestrial environments; estimate the depth of the water; detect the existence of currents; and estimate average temperature and precipitation.
- The **principle of cross-cutting relationships** is that a body or discontinuity that cuts across a stratum must have formed after that stratum. For example, a fault that cuts across sedimentary **strata** must be be younger than the strata. The analogy to remember is that of a sandwich: the sandwich must be made before it can be cut. The strata must exist before the fault can cut across them. An example of this is given in Figure 7.2.2, which shows three different sedimentary layers. The lower sandstone layer is disrupted by two **faults**, so we can conclude that the faults are younger than that layer. But the faults do not appear to continue into the coal seam, and they certainly do not continue into the upper sandstone. So we can infer that coal seam is younger than the faults (because it cuts them off), and of course the upper sandstone is youngest of all, because it lies on top of the coal seam.

Figure 7.2.1: (left) Rip-up clasts of shale embedded in Gabriola Formation sandstone, Gabriola Island, B.C. The pieces of shale were eroded as the sandstone was deposited, so the shale is older than the sandstone. (right) The Triassic Sulphur Mt. Formation near Exshaw, Alberta. Bedding is defined by differences in colour and texture, and also by partings (gaps) between beds that may otherwise appear to be similar. The beds in the Sulphur Mt. Formation have been tilted by tectonic forces. Using the principle of original horizontality, we can infer that this tilting happened after the rocks formed.

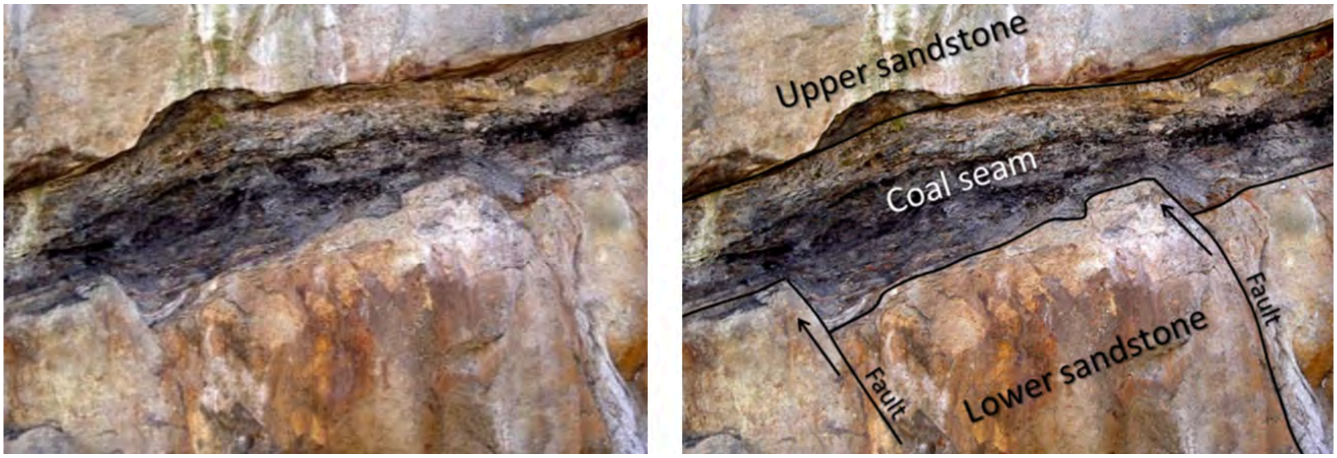

Figure 7.2.2: Superposition and cross-cutting relationships in Cretaceous Nanaimo Group rocks in Nanaimo, B.C. The coal seam is about 50 centimetres thick. The sequence of events is as follows: a) deposition of lower sandstone, b) faulting of lower sandstone, c) deposition of coal seam and d) deposition of upper sandstone. [Image description]

Practice Exercise 7.1 Cross-Cutting Relationships

Figure 7.2.3

The outcrop shown here (at Horseshoe Bay, B.C.) has three main rock types:

1. Buff/pink felsic intrusive igneous rock present as somewhat irregular masses trending from lower right to upper left
2. Dark grey metamorphosed basalt
3. A 50 centimetres wide light-grey felsic intrusive igneous dyke extending from the lower left to the middle right – offset in several places

Using the principle of cross-cutting relationships outlined above, determine the relative ages of these three rock types.

(The near-vertical stripes are blasting drill holes. The image is about 7 metres across.)

See Appendix 2 for Practice Exercise 7.1 answers.

One final important concept in the understanding of geologic time is the notion of missing segments of the rock record, recognized by unconformities. An **unconformity** represents an interruption in the process of deposition of sedimentary rocks. Recognizing unconformities is important for understanding time relationships in sedimentary sequences. An example of an unconformity is shown in Figure 7.2.4. The Proterozoic rocks of the Grand Canyon Group have been tilted and then eroded to a flat surface prior to deposition of the younger Paleozoic rocks. The difference in time between the youngest of the Proterozoic rocks and the oldest of the Paleozoic rocks is close to 300 million years. Tilting and erosion of the older rocks took place during this time, and if there was any deposition going on in this area, the evidence of it is now gone.

Figure 7.2.4: The great angular unconformity in the Grand Canyon, Arizona. The tilted rocks at the bottom are part of the Proterozoic Grand Canyon Group (aged 825 to 1,250 Ma). The flat-lying rocks at the top are Paleozoic (540 to 250 Ma). The boundary between the two represents a time gap of nearly 300 million years.

There are four types of unconformities, as summarized in Table 7.1, and illustrated in Figure 7.2.5.

Table 7.1 The characteristics of the four types of unconformities

Unconformity Type	**Description**
Nonconformity	A boundary between non-sedimentary rocks (below) and sedimentary rocks (above)
Angular unconformity	A boundary between two sequences of sedimentary rocks where the underlying ones have been tilted (or folded) and eroded prior to the deposition of the younger ones (as in Figure 7.2.4)
Disconformity	A boundary between two sequences of sedimentary rocks where the underlying ones have been eroded (but not tilted) prior to the deposition of the younger ones
Paraconformity	A time gap in a sequence of sedimentary rocks that does not show up as an angular unconformity or a disconformity

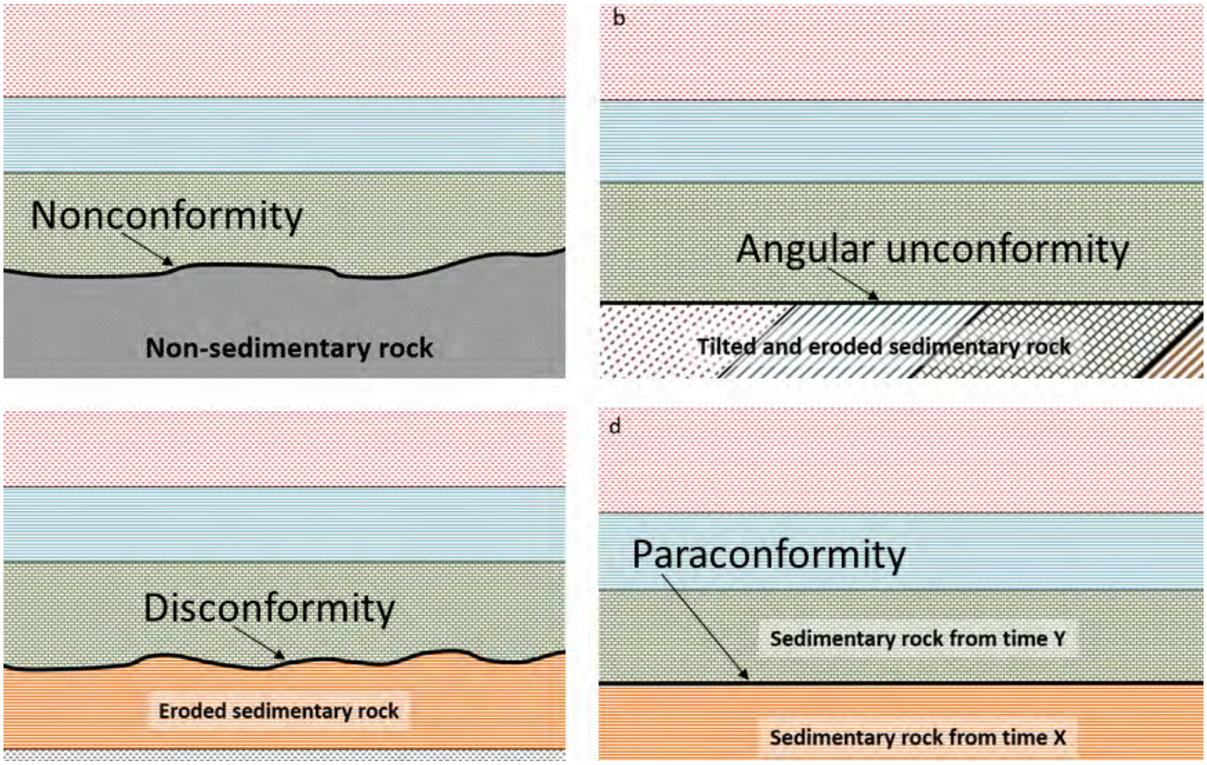

Figure 7.2.5: The four types of unconformities: (a) a nonconformity between older non-sedimentary rock and sedimentary rock, (b) an angular unconformity, (c) a disconformity between layers of sedimentary rock, where the older rock has been eroded but not tilted, and (d) a paraconformity where there is a long period (typically millions of years) of non-deposition between two parallel layers.

Key Takeaways

A common misconception when students think about unconformities is that an unconformity represents "*missing time*". This is not the case: time continued to pass, it cannot be "*missing*". What is "*missing*" is the record of this time in the stratigraphy of a given area, what geologists refer to as the rock record. For example, in the rock record of the southern plains of Alberta, the **contact** between the Jurassic Ellis **Group** and the Mississippian Rundle Group is an unconformity that represents over 150 million years! We can form two hypotheses to explain this missing section of the rock record in southeastern Alberta:

1. No sediments were deposited in this area during that 150 million years, meaning that the unconformity represents a period of **non-deposition**, and/or
2. Any sediments that were deposited during that 150 million years were eroded away before the deposition of the Ellis Group during the Jurassic, meaning that the unconformity represents a period of **erosion.**

Image Description

Figure 7.2.2 image description: The photograph shows three different sedimentary layers. The lower sandstone layer is disrupted by two faults, so we can conclude that the faults are younger than that layer. But the faults do not appear to continue into the coal seam, and they certainly do not continue into the upper sandstone. So we can infer that coal seam is younger than the faults (because it cuts them off), and of course the upper sandstone is youngest of all, because it lies on top of the coal seam.

[Return to Figure 7.2.2]

Media Attributions

- Figures 7.2.1, 7.2.2, 7.2.3, 7.2.4, 7.2.5: © Steven Earle. CC BY.

Notes

1. Stratigraphy is the branch of geology that deals with the formation, composition, sequence, and correlation of stratified rocks. Broadly speaking that includes all types of rock (igneous, sedimentary, and metamorphic), but often stratigraphers focus their studies on only sedimentary strata.

Lab 7 Exercises

Figure A represents two road cuts, or cliff faces, exposed along a road way. You can see that at first glance, the road cuts look almost identical as they both expose the same four types of rock: granite, sandstone, limestone, and shale.

1. As a quick review from Labs 4, 5, and 6, how did each of these rocks form? Briefly summarize the origin of each rock in the table below.

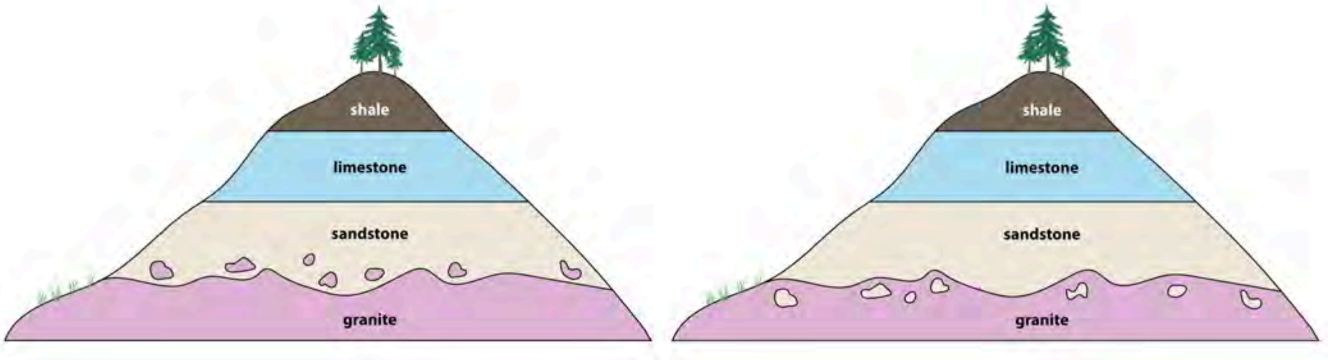

Figure A

Rock Type	**Granite**	**Sandstone**	**Limestone**	**Shale**
Origin				

2. Examine the two road cuts carefully, and using the principles of stratigraphy, write a point-form **geologic history** for each road cut. A geologic history is a written sequence of events that describes what geological processes happened in the past to produce the stratigraphy in a given area, like a timeline. Your geologic history should use proper terms to describe each event. For example, we would say that a sedimentary rock was deposited and then lithified. We would not say that a sedimentary rock "intruded" or "erupted" because these terms are reserved for intrusive and extrusive igneous rocks, respectively. If there are any unconformities present, identify which type (review Figure 7.2.6) and briefly describe what the unconformity represents. This might include: a period of uplift and erosion, a period of non-deposition, or both.

Youngest Event	**Road Cut A (left)**	**Road Cut B (right)**
	•	•
	•	•
	•	•
	•	•
	•	•
Oldest Event	•	•

3. Do the two road cuts share the same geologic history? Why or why not?

4. Which key principle of stratigraphy helped you determine the difference between the two road cuts?

Road cuts and naturally-occurring cliffs provide us with a view into the subsurface to help us understand the nature of the layers of rock beneath our feet. Another way to visualize the subsurface is using a block diagram, or **block model** (Figure B). The top of the diagram shows the plan view, or map view, of the Earth's surface. The sides of the diagram show two different cross-sectional views down into the subsurface. These vertical cross-sections illustrate the geology below the surface.

We can see in Figure B, for example, that at the surface there is an active volcano (venting steam) that is connected at depth to a shallow magma chamber (E). The letters shown in this diagram, and in all the figures in this lab, are randomly assigned. In Figure B, layers G, H, J, and K are all sedimentary. Units B, C, D, E, L, and M are igneous.

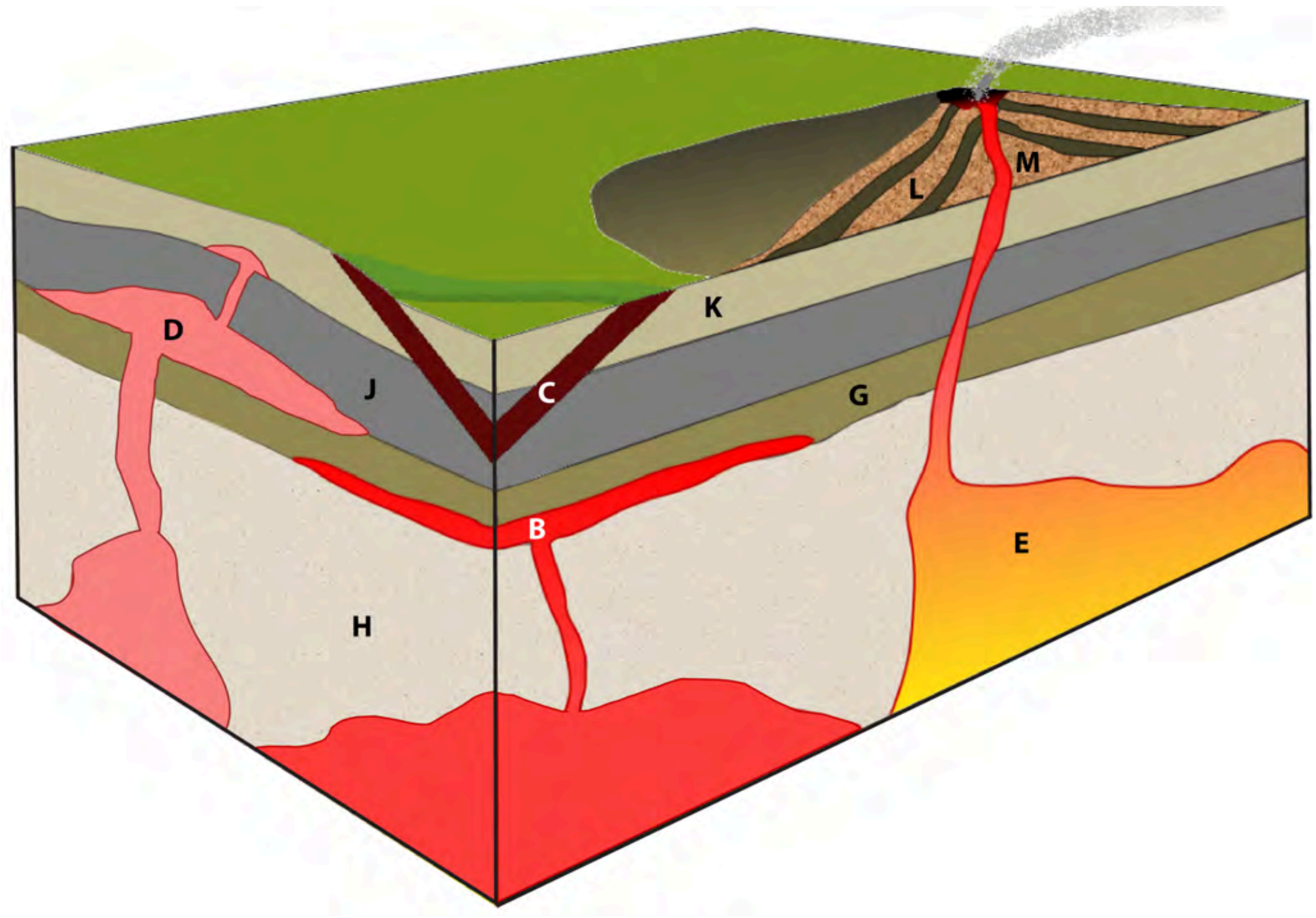

Figure B

5. Write a point-form geologic history for Figure B in the table below. Specify which stratigraphic principle(s) you used to justify the position of each event in the timeline.

Youngest Event	**Geologic History of Figure B**	**Justification** (which principle of stratigraphy did you use?)
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
Oldest Event	•	•

6. Write a point-form geologic history for Figure C in the table below. Specify which stratigraphic principle(s) you used to justify the position of each event in the timeline. If there are any unconformities present, identify which type and briefly describe what the unconformity represents. This might include: a period of uplift and erosion, a period of non-deposition, or both. All the units in Figure C are sedimentary rocks, except B which represents an erosional surface.

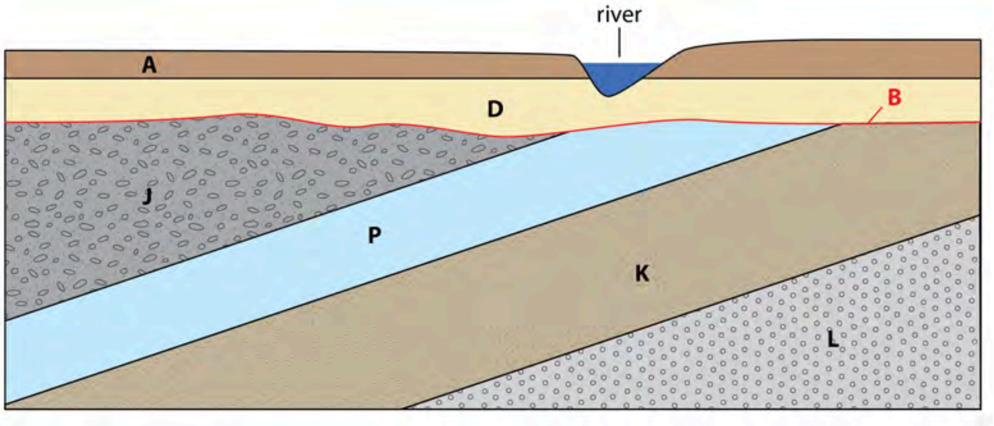

Figure C

Youngest Event	**Geologic History of Figure C**	**Justification**
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
Oldest Event	•	•

7. In the space below, write a short paragraph (<150 words) describing the geologic history for Figure D using complete sentences. To describe the sequence of sedimentary rocks, you may want to use the term "overlain", as in "the Pennsylvanian conglomerate is overlain by the Permian shale", or as an adjective, "the overlying Permian shale". Unit D is a basalt dyke (a type of igneous intrusion), and the line labeled as F is a **fault**. Read more about faulting in section 10.3.

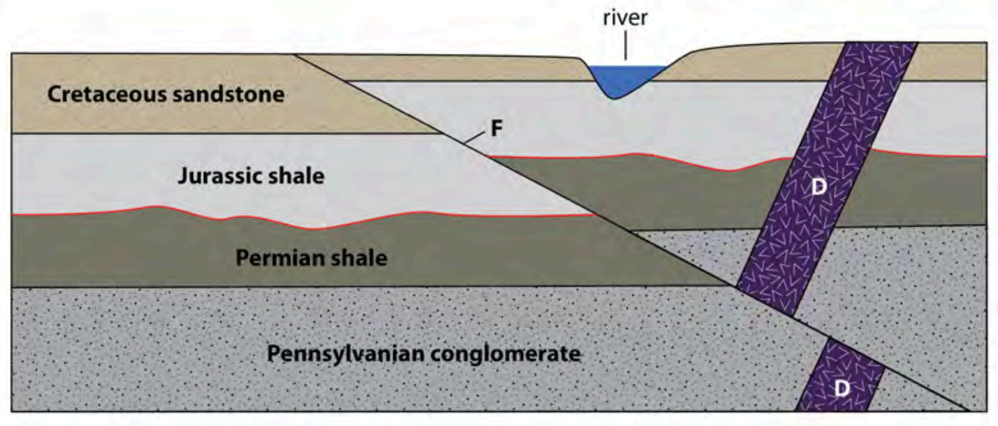

Figure D

8. Write a point-form geologic history for Figure E in the table below. Specify which stratigraphic principle(s) you used to justify the position of each event in the timeline. Unit J is a granite pluton and sill (two types of igneous intrusion), and the line labeled as F is a **fault**. Read more about faulting in section 10.3.

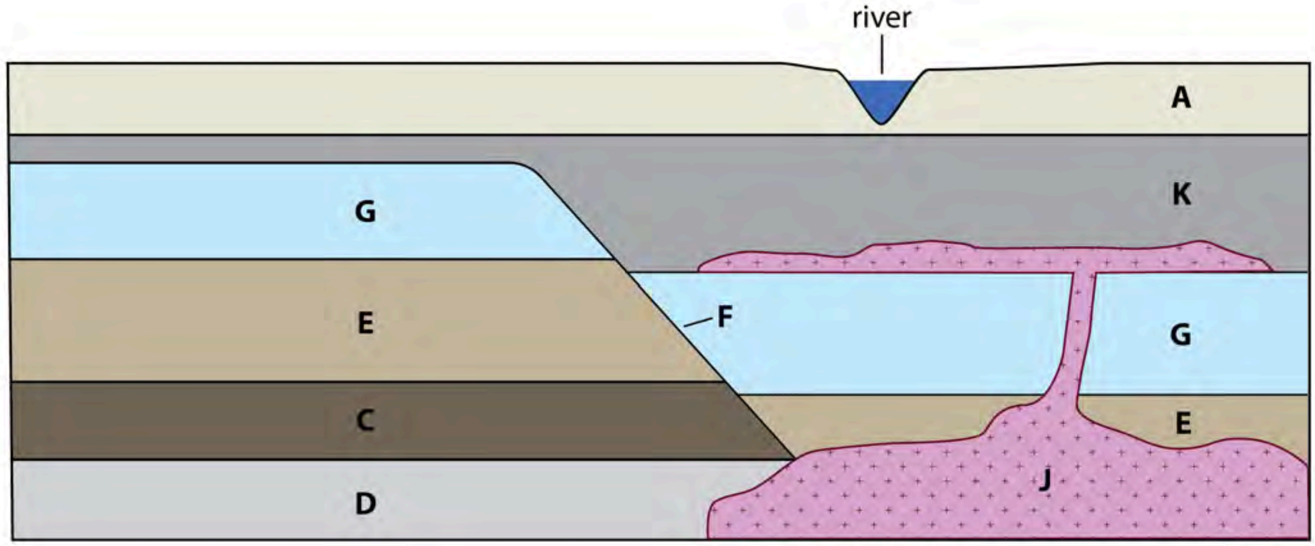

Figure E

Youngest Event	Geologic History of Figure E	Justification
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
Oldest Event	•	•

9. Write a point-form geologic history for Figure F in the table below. Specify which stratigraphic principle(s) you used to justify the position of each event in the timeline. If there are any unconformities present, identify which type and briefly describe what the unconformity represents. Unit L represents a rhyolite dome formed by felsic lava. Letter A refers to the surface denoted by the red line. Letter F represents a fault plane. All other letters refer to sedimentary rocks. Note that units B, C, and D have been folded into **anticlines** and **synclines**. Read more about folds in section 10.2.

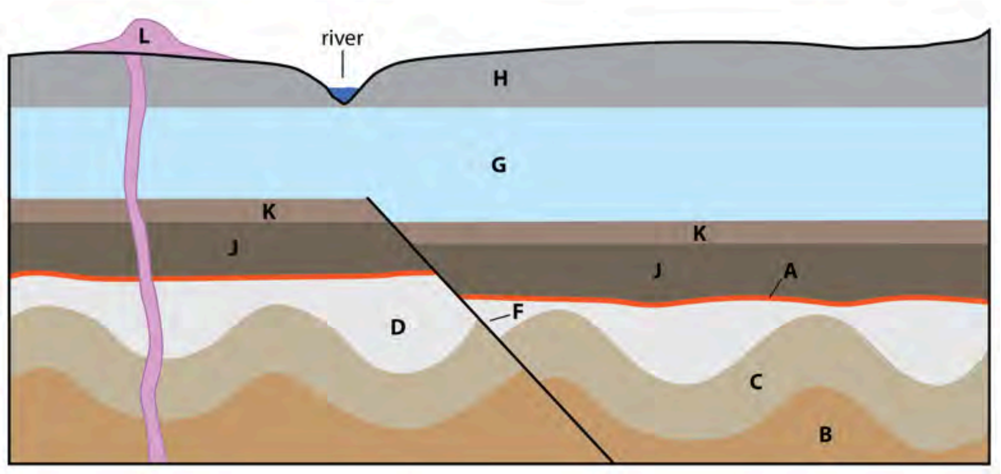

Figure F

Youngest Event	**Geologic History of Figure F**	**Justification**
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
	•	•
Oldest Event	•	•

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Summary

The topics covered in this chapter can be summarized as follows:

Section	Summary
7.1 The Geological Time Scale	The work of William Smith was critical to the establishment of the first geological time scale early in the 19th century, but it wasn't until the 20th century that geologists were able to assign reliable dates to the various time periods. Geological time is divided into eons, eras, periods, and epochs and the geological time scale is maintained and updated by the International Commission on Stratigraphy.
7.2 Relative Dating Methods	We can determine the relative ages of different rocks by observing and interpreting relationships among them, and applying the principles of stratigraphy. Gaps in the geological record are represented by various types of unconformities.
Lab 7 Exercises	The principles of stratigraphy can be applied to determine the geologic history of an area. Road cuts, cliff faces, and cross-sections give us an excellent insight into the geology of the subsurface, and the sequence of geologic events responsible for the strata observed can be solved like a puzzle. Keep in mind, that these stratigraphic principles can also be applied to relationships displayed in any outcrop, hand sample, and even in thin section! For example, using the principle of inclusions: a microscopic fluid inclusion within a crystal of quartz must be older than the quartz itself.