EXERCISE 6

Determining Geologic Ages

The recognition of the vastness of geologic time and the ability to establish the sequence of geologic events that have occurred at various places at different times are among the great intellectual achievements of science. To accomplish the task of deciphering Earth's history, geologists have formulated several laws, principles, and doctrines that can be used to place geologic events in their proper sequence (Figure 6.1). Also, using the principles that govern the radioactive decay of certain elements, scientists are now able to determine the age of many Earth materials with reasonable accuracy. In this exercise you will investigate some of the techniques and procedures used by Earth scientists in their search to interpret the geologic history of Earth.

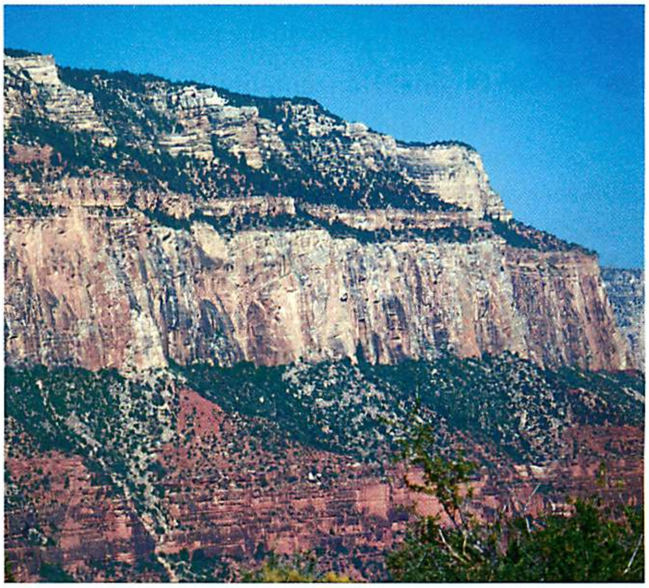


Figure 6.1 In any sequence of underformed sedimentary rocks, the oldest rock is always at the bottom and the youngest is at the top. (Photo by E. J. Tarbuck)

Objectives

After you have completed this exercise, you should be able to:

1. List and explain each of the laws, principles, and doctrines that are used to determine the relative ages of geologic events.
2. Determine the sequence of geologic events that have occurred in an area by applying the techniques and procedures for relative dating.
3. Explain the methods of fossilization and how fossils are used to define the ages of rocks and correlate rock units.
4. Explain how the radioactive decay of certain elements can be used to determine the age of Earth materials.
5. Apply the techniques of radiometric dating to determine the numerical age of a rock.
6. Describe the geologic time scale and list in proper order some of the major events that have taken place on Earth since its formation.

Materials

ruler
calculator

Materials Supplied by Your Instructor

fossils and fossil questions (optional)
meterstick or metric tape measure
5-meter length of adding-machine paper

Terms

relative dating
uniformitarianism
original horizontality
superposition
inclusion
unconformity
cross-cutting
fossil
fossil succession
radiometric date
half-life
eon
era

Relative Dating

Relative dating, the placing of geologic events in their proper sequence or order, does not tell how long ago something occurred, only that it preceded one event and followed another. Several logical doctrines, laws, and principles govern the techniques used to establish the relative age of an object or event.

Doctrine of Uniformitarianism

First proposed by James Hutton in the late 1700s, this doctrine states that the physical, chemical, and biological laws that operate today have operated throughout Earth's history. Although geologic processes such as erosion, deposition, and volcanism are governed by these unchanging laws, their rates and intensities may vary. The doctrine is often summarized in the statement, "The present is the key to the past."

Principle of Original Horizontality

Sediment, when deposited, forms nearly horizontal layers. Therefore, if we observe beds of sedimentary rocks that are folded or inclined at a steep angle, the implication is that some deforming force took place after the sediment was deposited (Figure 6.2).

Law of Superposition

In any sequence of undeformed sedimentary rocks (or surface deposited igneous rocks such as lava flows and layers of volcanic ash), the oldest rock is always at the bottom and the youngest is at the top. Therefore, each layer of rock represents an interval of time that is more recent than that of the underlying rocks (see Figure 6.1).

Figure 6.2 Uplifted and tilted sedimentary strata in the Canadian Rockies. (Photo by E. J. Tarbuck)

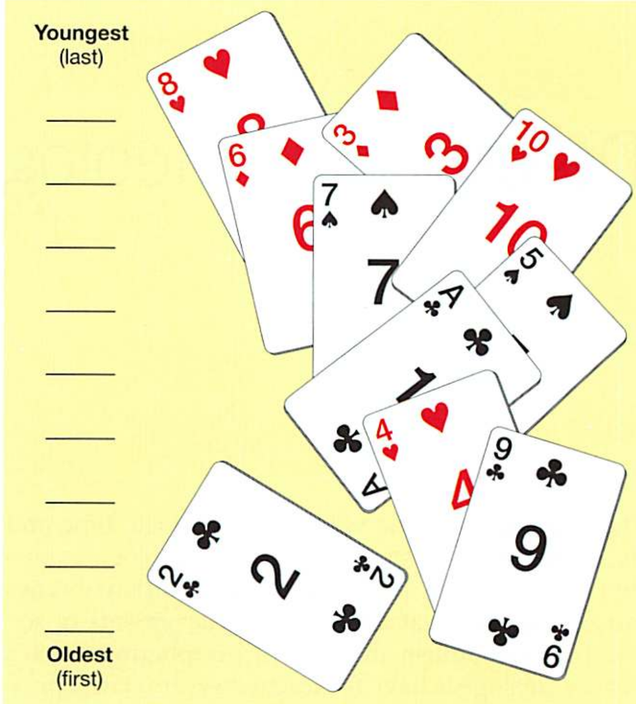


Figure 6.3 Sequence of playing cards illustrating the law of superposition.

Assume the playing cards shown in Figure 6.3 are layers of sedimentary rocks viewed from above.

1. In the space provided in Figure 6.3, list the order, first (oldest) to last (youngest), in which the cards were laid down.
2. Were you able to place all of the cards in sequence? If not, which one(s) could not be "relative" dated and why?

____

____

Figure 6.4 illustrates a geologic cross section, a side view, of the rocks beneath the surface of a hypothetical region. Use Figure 6.4 to answer questions 3 and 4.

3. Of the two sequences of rocks, A–D and E–G (A–D, E–G), was disturbed by crustal movements after its deposition. Circle your answer. What law or principle did you apply to arrive at your answer?

____

4. Apply the law of superposition to determine the relative ages of the *undisturbed* sequence of sedimentary rocks. List the letter of the oldest rock layer first.

Oldest _______________ Youngest

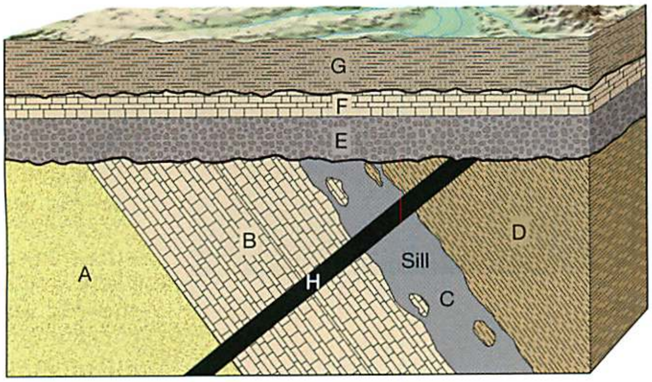


Figure 6.4 Geologic block diagram of a hypothetical region showing igneous intrusive features (C and H) and sedimentary rocks.

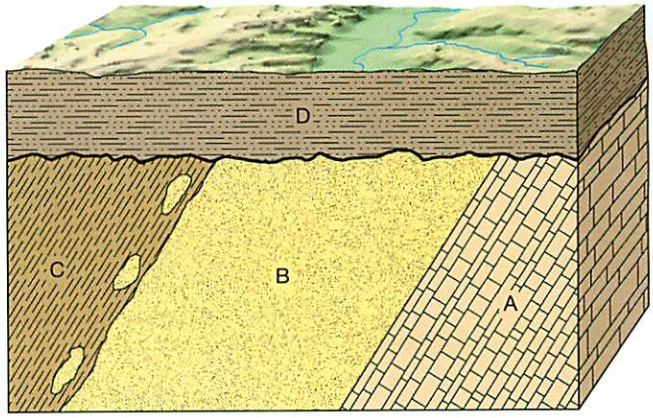


Figure 6.6 Geologic block diagram showing sedimentary rocks.

Inclusions

Inclusions are pieces of one rock unit that are contained within another unit (Figure 6.5). The rock mass adjacent to the one containing the inclusions must have been there first in order to provide the rock fragments. Therefore, the rock containing the inclusions is the younger of the two.

Refer to Figure 6.6 to answer questions 5 and 6. The sedimentary layer B is a sandstone. Letter C is the sedimentary rock, shale.

5. Identify and label the inclusions in Figure 6.6.
6. Of the two rocks B and C, rock (B, C) is older. Circle your answer.

Unconformities

As long as continuous sedimentation occurs at a particular place, there will be an uninterrupted record of the material and life forms. However, if the sedimentation process is suspended by an emergence of the area from below sea level, then no sediment will be deposited and an erosion surface will develop. The result is that no rock record will exist for a part of geologic time. Such a gap in the rock record is termed an **unconformity**. An unconformity is typically shown on a cross-sectional (side view) diagram by a wavy line (∿∿∿). Several types of unconformities are illustrated in Figure 6.7.

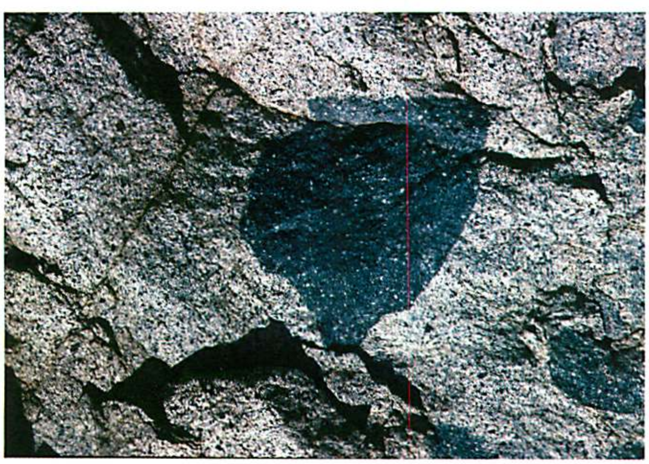


Figure 6.5 Inclusions are fragments of one rock enclosed within another. (Photo by E. J. Tarbuck)

7. Identify and label an example of an angular unconformity and a disconformity in Figure 6.4.

Principle of Cross-Cutting Relationships

Whenever a fault or intrusive igneous rock cuts through an existing feature, it is younger than the structure it cuts. For example, if a basalt dike cuts through a sandstone layer, the sandstone had to be there first and, therefore, is older than the dike (Figure 6.8).

Figure 6.9 is a geologic cross section showing sedimentary rocks (A, B, D, E, F, and G), an igneous intrusive feature called a *dike* (C), and a *fault* (H). Use Figure 6.9 to answer questions 8–11.

8. The igneous intrusion C is (older, younger) than the sedimentary rocks B and D. Circle your answer.
9. Fault H is (older, younger) than the sedimentary beds A–E.
10. The relative age of fault H is (older, younger) than the sedimentary layer F.
11. Did the fault occur before or after the igneous intrusion? Explain how you arrived at your answer.

____

____

12. Refer to Figure 6.4. The igneous intrusion H is (older, younger) than rock layer E and (older, younger) than layer D. Circle your answers.
13. Refer to Figure 6.4. What evidence supports the conclusion that the igneous intrusive feature

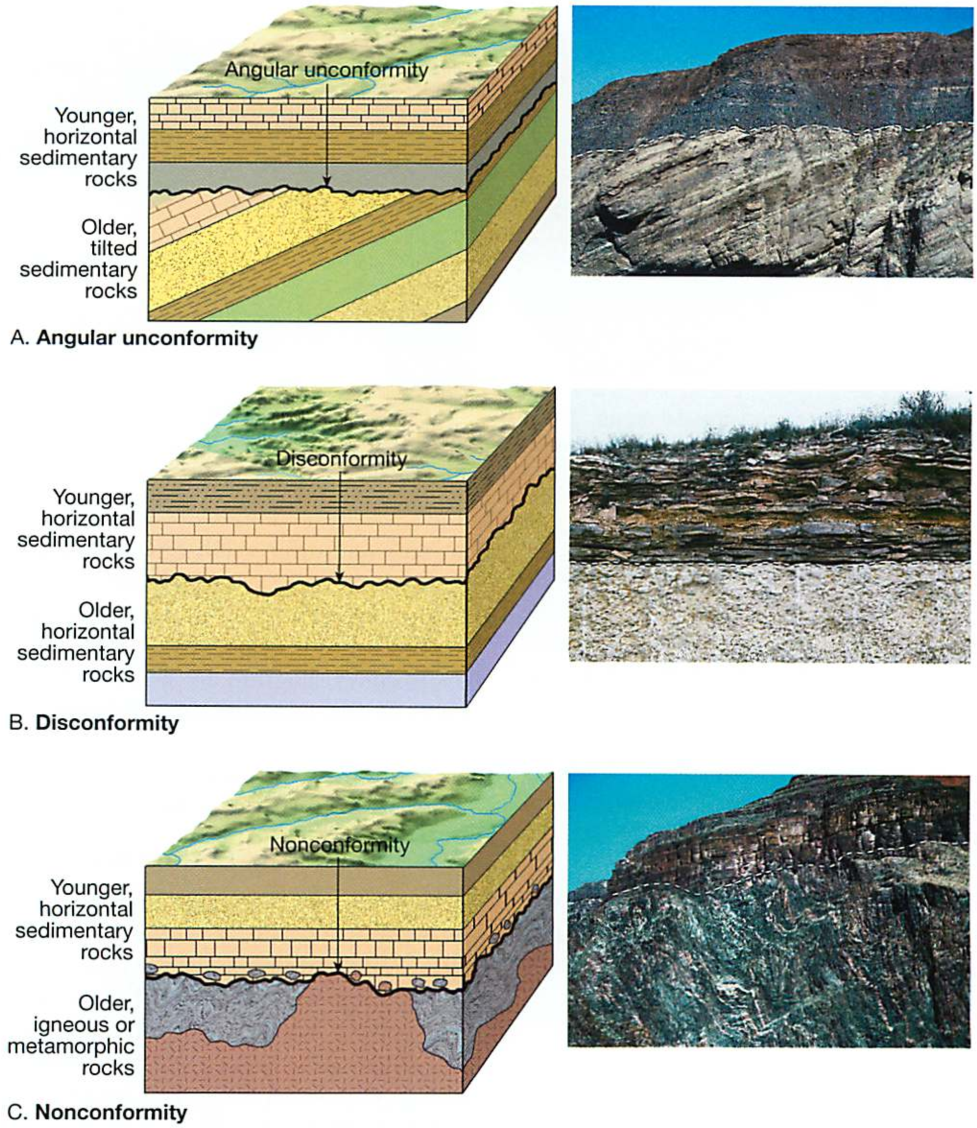


Figure 6.7 Three common types of unconformities. On the diagrams, wavy dashed lines mark the unconformity.

Figure 6.8 This basalt dike (black) is younger than the sandstone layers that it cuts through. (Photo by E. J. Tarbuck)

called a *sill*, C, is more recent than both of the rock layers B and D and older than the igneous intrusion H?

Fossils and the Principle of Fossil Succession

Fossils (Figure 6.10) are among the most important tools used to interpret Earth's history. They are used to define the ages of rocks, correlate one rock unit with another, and determine past environments on Earth.

Earth has been inhabited by different assemblages of plants and animals at different times. As rocks form, they often incorporate the preserved remains of these organisms as fossils. According to the principle of **fossil succession**, fossil organisms succeed each other in a definite and determinable order. Therefore, the time that a rock originated can frequently be determined by noting the kinds of fossils that are found within it.

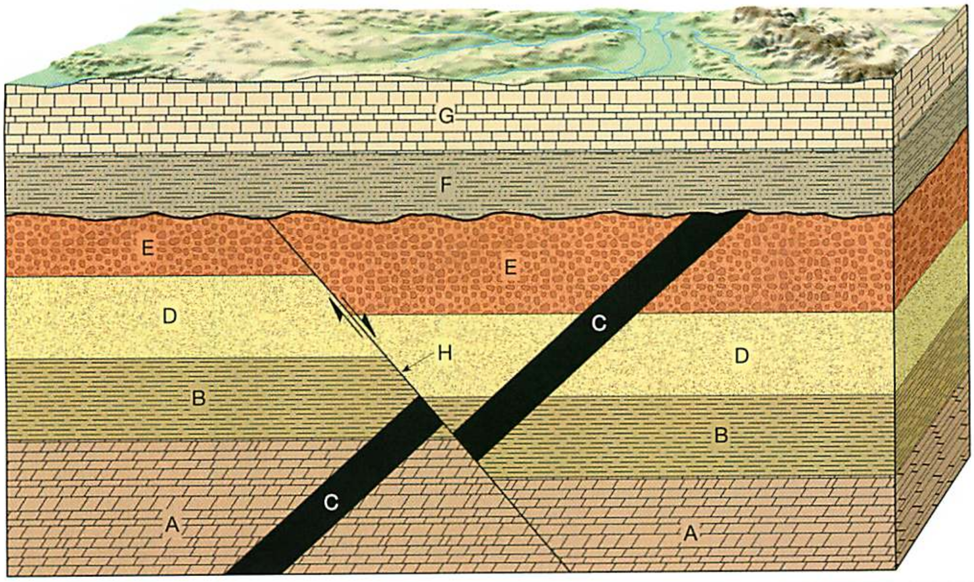
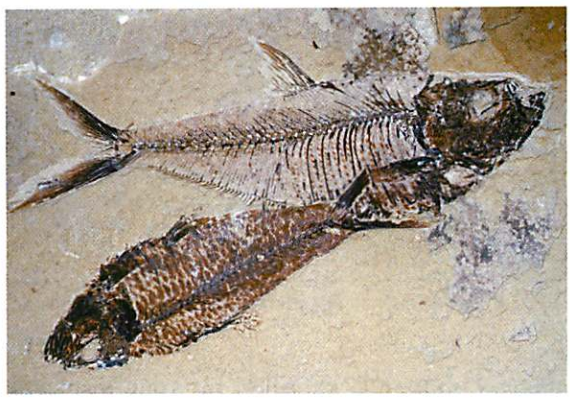


Figure 6.9 Geologic block diagram of a hypothetical area showing an igneous intrusion (C), a fault (H), and sedimentary rocks.

A.



B.

C.

D.

Figure 6.10 Various types of fossilization. In photo **A.** the mineral quartz now occupies the internal spaces of what was once wood. **B.** is the replica of fish after the carbonized remains were removed. In photo **C.** mineral matter occupies the hollow space where a shell was once located. **D.** is a track left by a dinosaur in formerly soft sediment. (Photos by E. J. Tarbuck)

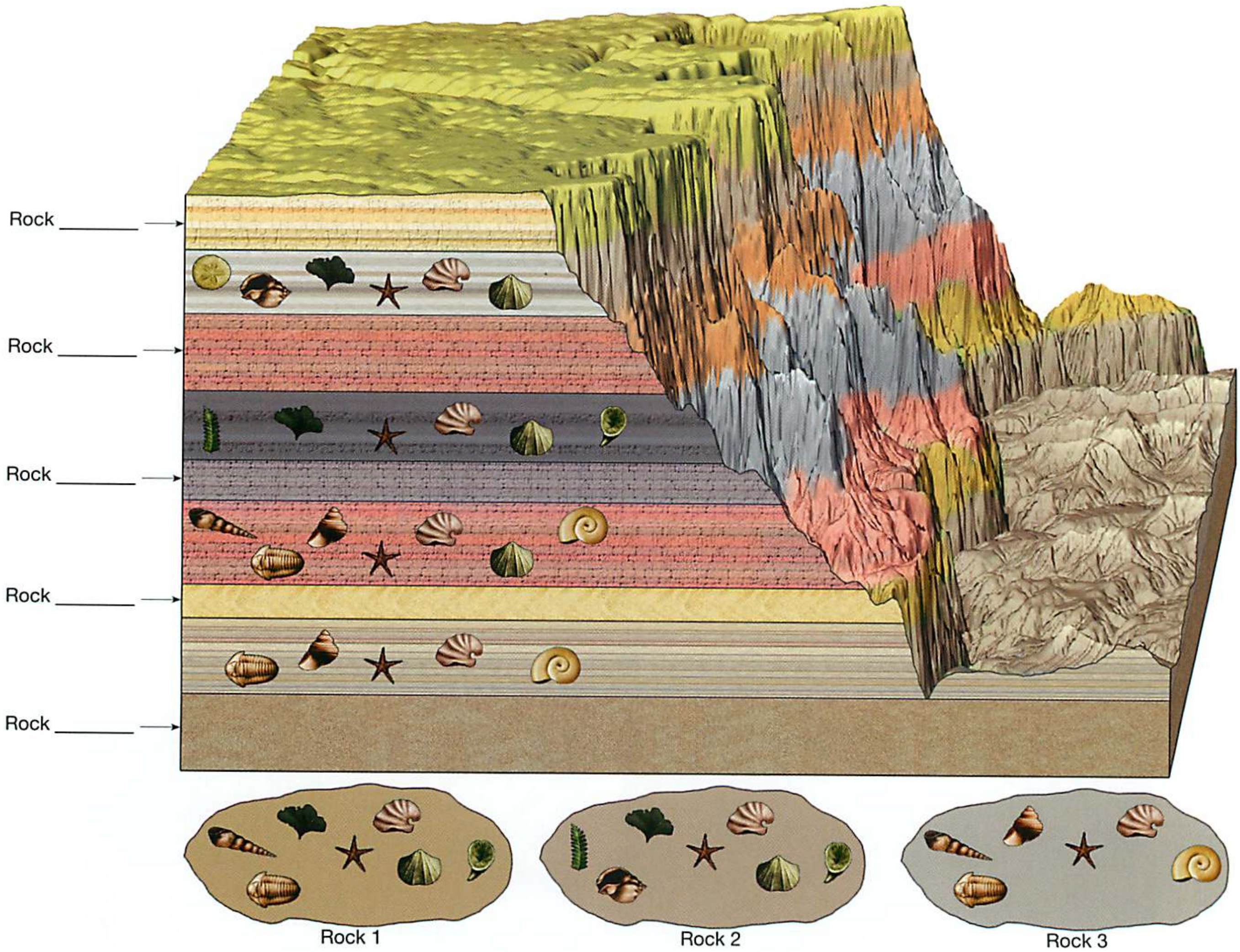


Figure 6.11 Layered sequence of sedimentary rocks with fossils and three separate rocks containing similar fossils.

Using the materials supplied by your instructor, answer questions 14 and 15.

14. At the discretion of your instructor, there may be several stations with fossils and questions set up in the laboratory. Following the specific directions of your instructor, proceed to the stations.

15. What are the conditions that would favor the preservation of an organism as a fossil?

____

____

16. Refer to Figure 6.10. Select the photo, A, B, C, or D, that best illustrates each of the following methods of fossilization or fossil evidence.

Petrification: The small internal cavities and pores of the original organism are filled with precipitated mineral matter. Photo: _______

Cast: The space once occupied by a dissolved shell or other structure is subsequently filled with mineral matter. Photo: _______

Impression: A replica of a former fossil left in fine-grained sediment after the fossilizing material, often carbon, is removed. Photo: _______

Indirect evidence: Traces of prehistoric life, but not the organism itself. Photo: _______

Figure 6.11 shows a sequence of undeformed sedimentary rocks. Each layer of rock contains the fossils illustrated within it. The three rocks, Rocks 1, 2, and 3, illustrated below the layered sequence were found nearby and each rock contains the fossils indicated. Answer question 17 using Figure 6.11.

17. Applying the principle of fossil succession, indicate the proper position of each of the three rocks relative to the rock layers by writing the words Rock 1, Rock 2, or Rock 3 at the appropriate position in the sequence.

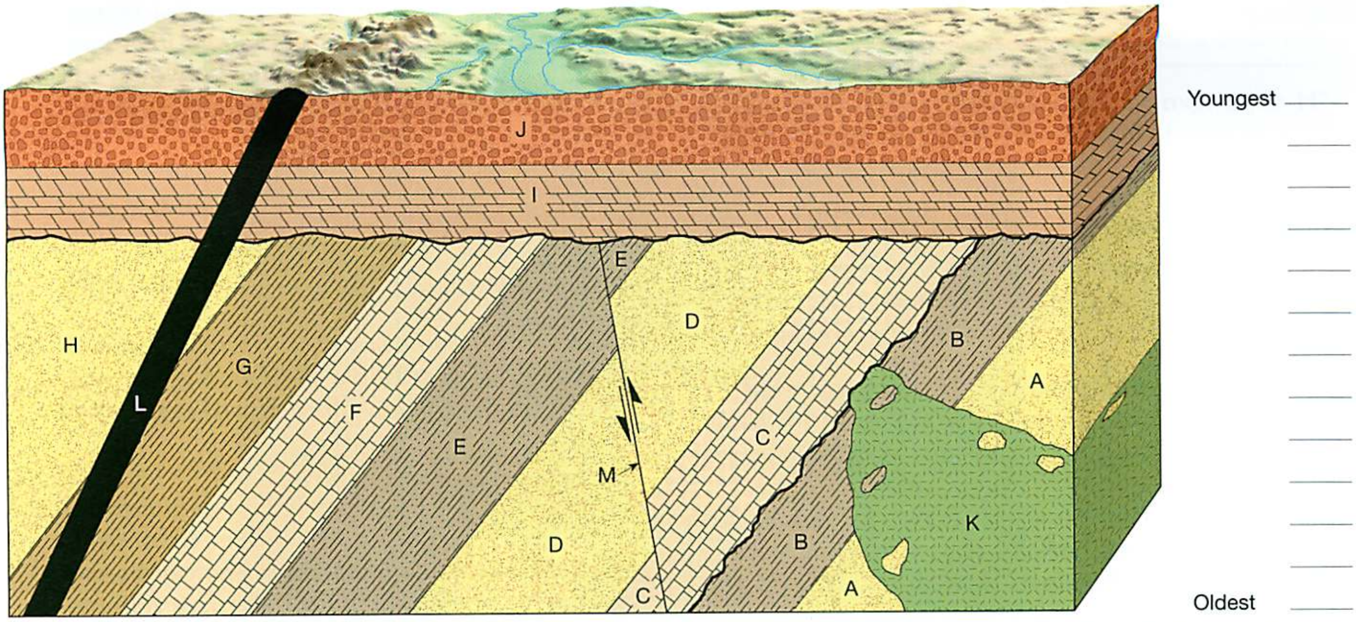


Figure 6.12 Geologic block diagram of a hypothetical area showing igneous intrusive features (K and L), a fault (M), and sedimentary rocks.

Applying Relative Dating Techniques

Geologists often apply several of the techniques of relative dating when investigating the geologic history of an area.

Figure 6.12 is a geologic cross section of a hypothetical area. Letters K and L are igneous rocks. Letter M is a fault. All the remaining letters represent sedimentary rocks. Using Figure 6.12 to complete questions 18–24 will provide insight into how the relative geologic history of an area is determined.

18. Identify and label the unconformities indicated in the cross section.

19. Rock layer I is (older, younger) than layer J. Circle your answer. What law or principle have you applied to determine your answer?

    ____

    ____

20. The fault is (older, younger) than rock layer I. Circle your answer. What law or principle have you applied to determine your answer?

    ____

    ____

    ____

21. The igneous intrusion K is (older, younger) than layers A and B. Circle your answer. What two laws or principles have you applied to determine your answer?

    ______________ and ______________

22. The age of the igneous intrusion L is (older, younger) than layers J, I, H, G, and F.

23. List the entire sequence of events, in order from oldest to youngest, by writing the appropriate letter in the space provided on the figure.

24. Explain why it was difficult to place the fault, letter M, in a specific position among the sequence of events in Figure 6.12.

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    ____

    ____

    ____

    ____

    ____

    ____

The Geologic Time Scale

Applying the techniques of geologic dating, the history of Earth has been subdivided into several different units which provide a meaningful time frame within which the events of the geologic past are arranged. Since the span of a human life is but a "blink of an eye" compared to the age of Earth, it is often difficult to comprehend the magnitude of geologic time. By completing questions 36–41, you will be better able to grasp the great age of Earth and appreciate the sequence of events that have brought it to this point in time.

36. Obtain a piece of adding machine paper slightly longer than 5 meters and a meterstick or metric measuring tape from your instructor. Draw a line at one end of the paper and label it "PRESENT." Using the following scale, construct a time line by completing the indicated steps.

SCALE

1 meter = 1 billion years
10 centimeters = 100 million years
1 centimeter = 10 million years
1 millimeter = 1 million years

Step 1. Using the geologic time scale, Figure 6.14, as a reference, divide your time line into the **eons** and **eras** of geologic time. Label each division with its name and indicate its absolute age.

Step 2. Using the scale, plot and label the plant and animal events listed in Figure 6.14 on your time line.

After completing your time line, answer questions 37–41.

37. What fraction or percent of geologic time is represented by the Precambrian eon?

Approximately _______ of geologic time.

38. Suggest a reason(s) why approximately 542 million years ago was selected to mark the end of Proterozoic eon and the beginning of the Paleozoic era.

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____

39. Write a brief statement outlining the various life forms that have existed on Earth through time.

____

____

____

40. How many times longer is the whole of geologic time than the time represented by recorded history, about 5,000 years?

Geologic time is ________ times longer than recorded history.

41. For what fraction or percent of geologic time have land plants been present on Earth?

Approximately ________ of geologic time.

Geologic Time on the Internet

Apply what you have learned in this exercise to write a geologic interpretation of a rock outcrop and to explore the fossil record by completing the corresponding online activities on the *Applications & Investigations in Earth Science* website at http://prenhall.com/earthsciencelab

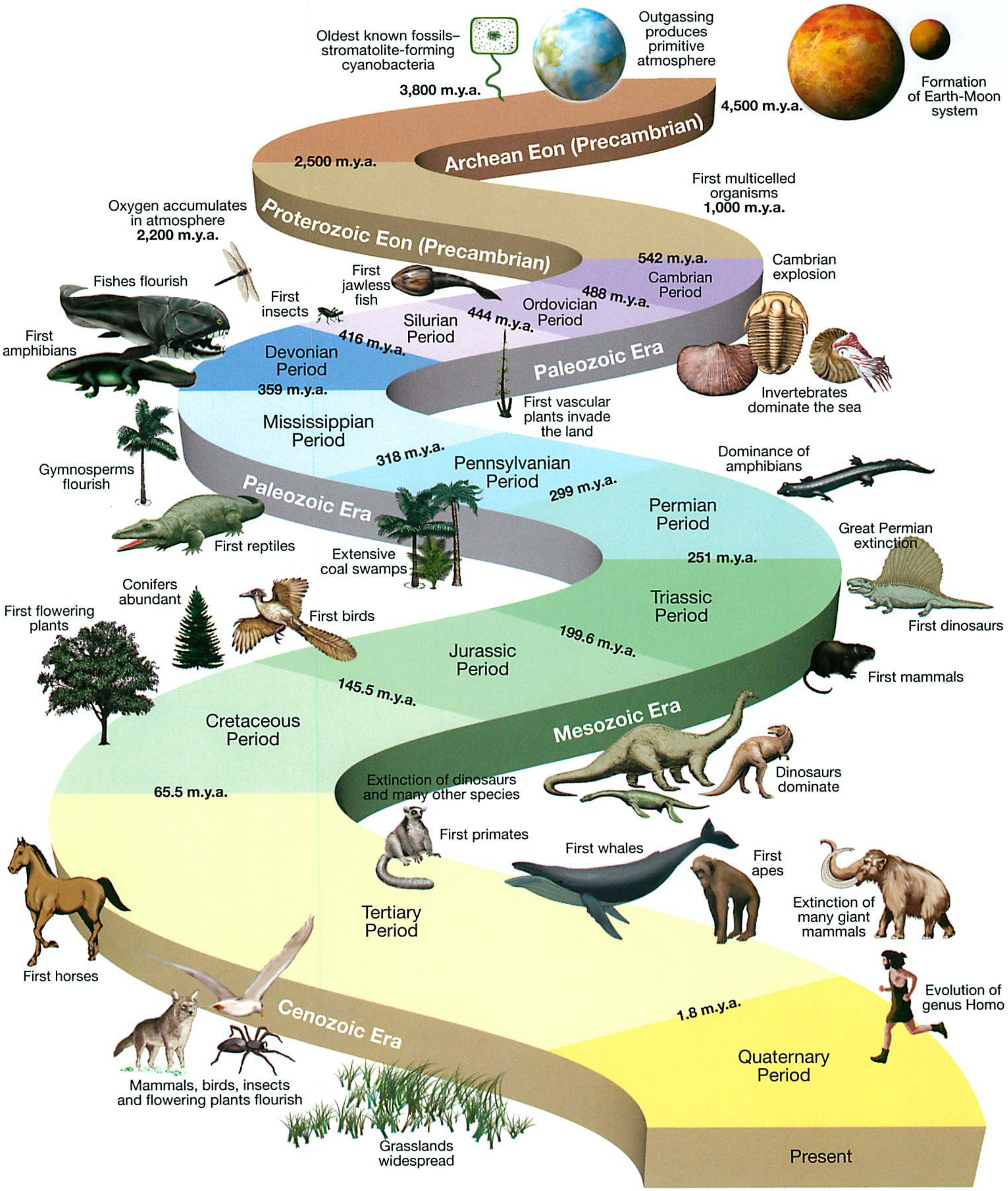

Figure 6.14 The geologic time scale. (Data from the Geologic Society of America)

Notes and calculations.

Determining Geologic Ages

Date Due: ______________________

Name: ______________________

Date: ______________________

Class: ______________________

After you have finished Exercise 6, complete the following questions. You may have to refer to the exercise for assistance or to locate specific answers. Be prepared to submit this summary/report to your instructor at the designated time.

1. Determine the sequence of geologic events that have occurred at the hypothetical area illustrated in Figure 6.15. List your answers from oldest to youngest in the space provided by the figure. Letters M and N are faults, J, K, and L are igneous intrusions, and all other layers are sedimentary rocks.

2. The following questions refer to Figure 6.15.

   a. What type of unconformity separates layer G from layer F?

   ____

   b. Which law, principle, or doctrine of relative dating did you apply to determine that rock layer H is older than layer I?

   ____

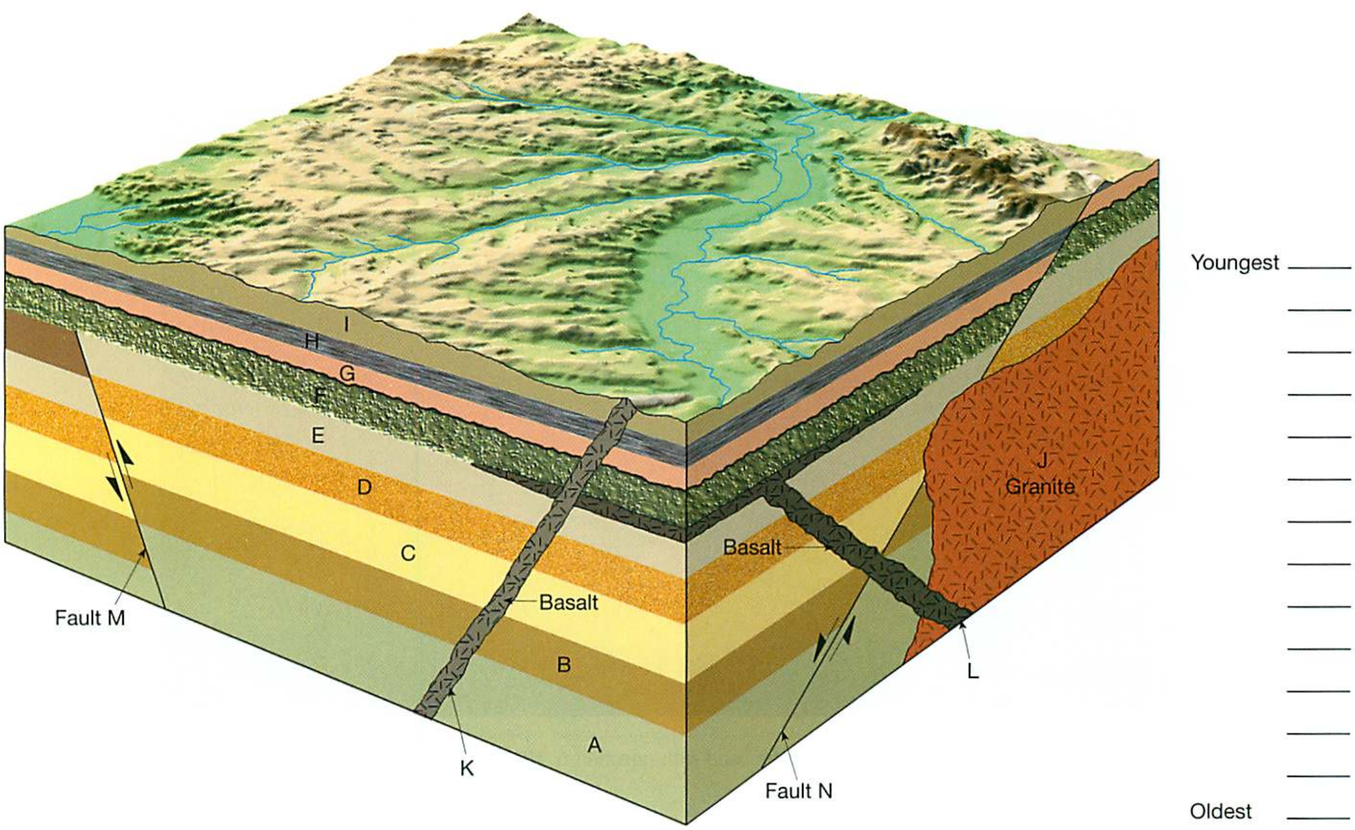

Figure 6.15 Geologic block diagram of a hypothetical region.

c. Which law, principle, or doctrine of relative dating did you apply to determine that fault M is older than rock layer F?

____

d. Explain why you know that fault N is older than the igneous intrusion J.

____

e. If rock layer F is 150 million years old and layer E is 160 million years old, what is the approximate age of fault M?

_______ million years

f. The analysis of samples from layers G and F indicates the following proportions of parent isotope to the daughter product produced from it. If the half-life of the parent is known to be 75 million years, what are the ages of the two layers?

	PARENT	DAUGHTER	AGE
Layer G:	50%	50%	_______
Layer F:	25%	75%	_______

g. What absolute time interval is represented by the unconformity at the base of rock layer G?

From ________ to ________ million years

3. List the sequence of geologic events that you determined took place in the area represented by Figure 6.12, question 23, in the exercise.

Oldest ______________________________ Youngest

4. What fraction of time is represented by each of the following geologic eons?

Phanerozoic eon: _____ Precambrian eon: _____

5. How many meters long would the time line you constructed in the exercise, question 36, have been if you had used a scale of 1 millimeter equals 1,000 years?

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6. Examine the photograph in Figure 6.16 closely. Applying the principles of relative dating, describe as accurately as possible the relative geologic history of the area.

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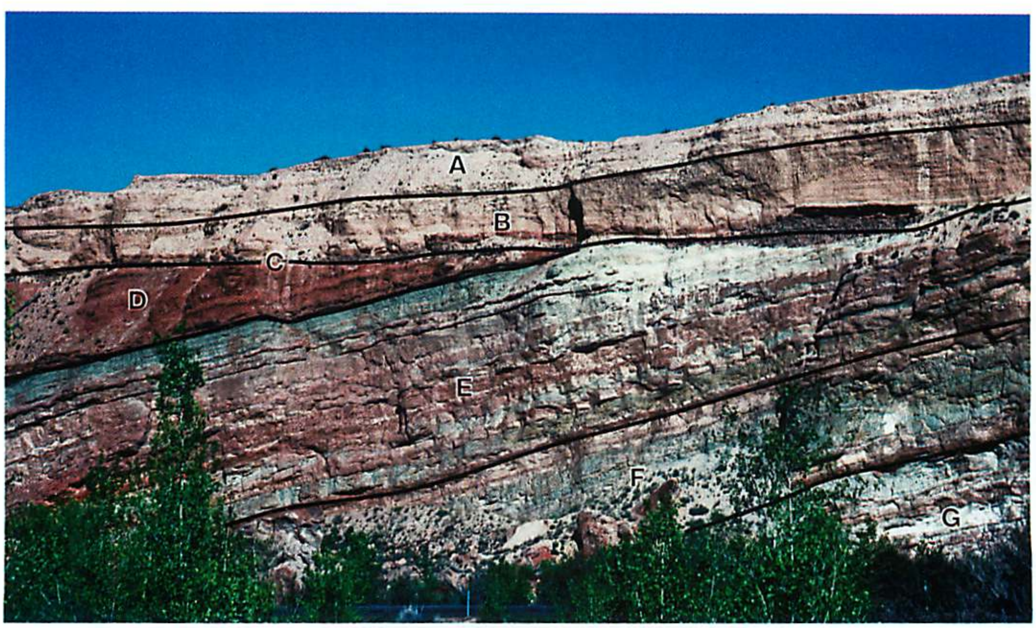

Figure 6.16 Photo of sedimentary beds to be used with question 6. (Photo by E. J. Tarbuck)