LABORATORY **8**

Dating of Rocks, Fossils, and Geologic Events

CONTRIBUTING AUTHORS
Jonathan Bushee • *Northern Kentucky University*
John K. Osmond • *Florida State University*
Raman J. Singh • *Northern Kentucky University*

Fossil ferns, 310 million years old, from the Pennsylvanian (Carboniferous) System of rocks, Pottsville, Pennsylvania (x1). (Richard M. Busch)

BIG IDEAS

Geologists use relative and absolute dating techniques to infer the ages of geologic features and events in geologic history. Relative age dating is the process of determining what happened first, second, and so on, in relation to other geologic features and events. Absolute age dating is the process of determining when something formed or happened in exact units of time such as days, months, or years. The "geologic time scale" is a chart showing the chronological sequence (relative ages) of named rock units and cooresponding divisions of relative time arranged next to a scale of absolute age in years.

FOCUS YOUR INQUIRY

THINK About It How can you tell relative age relationships among the parts of geologic cross sections exposed in outcrops?

THINK About It How can geologic cross sections be interpreted to establish the relative ages of rock units, contacts, and other geologic features?

THINK About It How are fossils used to tell geologic time and infer Earth's history?

THINK About It How do geologists determine the absolute age, in years, of Earth materials and events?

THINK About It How are relative and absolute dating techniques used to analyze outcrops and infer geologic history?

ACTIVITY

8.1 Geologic Inquiry for Relative Age Dating

THINK About It | **How can you tell relative age relationships among the parts of geologic cross sections exposed in outcrops?**

OBJECTIVE Identify features of geologic cross sections exposed in outcrops, infer their relative ages, and suggest rules for relative age dating.

PROCEDURES

1. **Before you begin**, do not look up definitions and information. Use your current knowledge, and complete the worksheet with your current level of ability. Also, this is **what you will need** to do the activity:

   ____ Black or blue pen
   ____ Activity 8.1 Worksheet (p. 217) and pencil

2. **Complete the worksheet in a way that makes sense to you.**
3. **After you complete the worksheet**, be prepared to discuss your observations, interpretations, and inferences with others.

ACTIVITY

8.2 Determining Sequence of Events in Geologic Cross Sections

THINK About It | **How can geologic cross sections be interpreted to establish the relative ages of rock units, contacts, and other geologic features?**

OBJECTIVE Apply principles of relative age dating to analyze and interpret sequences of events in geologic cross sections.

PROCEDURES

1. **Before you begin**, read the Introduction and Relative Age Dating Based on Physical Relationships. Also, this is **what you will need:**

   ____ dark (black or blue) pen
   ____ Activity 8.2 Worksheet (p. 219) and pencil

2. **Then follow your instructor's directions** for completing the worksheets.

Introduction

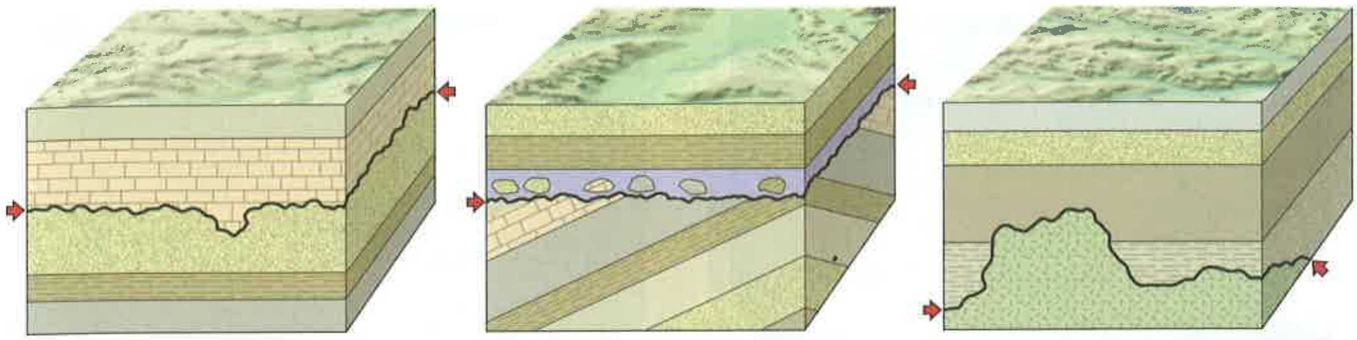
If you could dig a hole deep into Earth's crust, you would encounter the **geologic record,** layers of rock stacked one atop the other like pages in a book. As each new layer of sediment or rock forms today, it covers the older layers of the geologic record beneath it and becomes the youngest layer of the geologic record. Thus, rock layers form a *sequence* from oldest at the bottom to youngest at the top. They also have different colors, textures, chemical compositions, and **fossils** (any evidence of ancient life) depending on the environmental conditions under which they were formed. Geologists have studied sequences of rock layers wherever they are exposed in mines, quarries, river beds, road cuts, wells, and mountain sides throughout the world. They have also *correlated* the layers (traced them from one place to another) across regions and continents. Thus, the geologic record of rock layers is essentially a stack of stone pages in a giant natural book of Earth's history. And like the pages in any old book, the rock layers have been folded, fractured (cracked), torn (faulted), and even removed by geologic events.

Geologists tell time based on relative and absolute dating techniques. **Relative age dating** is the process of determining when something formed or happened in relation to other events. For example, if you have a younger brother and an older sister, then you could describe your relative age by saying that you are younger than your sister and older than your brother. **Absolute age dating** is the process of determining when something formed or happened in exact units of time such as days, months, or years. Using the example above, you could describe your absolute age just by saying how old you are in years.

Geologists "read" and infer Earth's history from rocky outcrops and geologic cross sections by observing rock layers, recognizing geologic structures, and evaluating age relationships among the layers and structures. The so-called *geologic time scale* is a chart of named intervals of the geologic record and their ages in both relative and absolute time. It has taken thousands of geoscientists, from all parts of the world, more than a century to construct the present form of the geologic time scale.

Relative Age Dating Based on Physical Relationships

A geologist's initial challenge in the field is to subdivide the local sequence of sediments and bodies of rock into mappable units that can be correlated from one site to the next. Subdivision is based on color, texture, rock type, or other physical features of the rocks, and the mappable units are called **formations.** Formations can be subdivided into *members*, or even individual strata. Surfaces between any of these kinds of units are **contacts.**



Disconformity
In a succession of rock layers (sedimentary strata or lava flows) parallel to one another, the disconformity surface is a gap in the layering. The gap may be a non-depositional surface where some layers never formed for a while, or the gap may be an erosional surface where some layers were removed before younger layers covered up the surface.

Angular unconformity
An angular unconformity is an erosional surface between two bodies of layered sedimentary strata or lava flows that are not parallel. The gap is because the older body of layered rock was tilted and partly eroded (rock was removed) before a younger body of horizontal rock layers covered the eroded surface.

Nonconformity
A nonconformity is an erosional surface between older igneous and/or metamorphic rocks and younger rock layers (sedimentary strata or lava flows). The gap is because some of the older igneous and/or metamorphic rocks were partly eroded (rock was removed) before the younger rock layers covered the eroded surface.

FIGURE 8.1 Three kinds of unconformities. Unconformities are surfaces that represent gaps (missing layers) in the geologic record; analogous to a gap (place where pages are missing) in a book. Red arrows point to the unconformity surface (bold black line) in each block diagram.

Laws for Determining Relative Age

Geologists use six basic laws for determining relative age relationships among bodies of rock based on their physical relationships. They are as follows:

- **Law of Original Horizontality**—*Sedimentary layers (**strata**) and lava flows were originally deposited as relatively horizontal sheets, like a layer cake.* If they are no longer horizontal or flat, it is because they have been displaced by subsequent movements of Earth's crust.
- **Law of Lateral Continuity**—*Lava flows and strata extend laterally in all directions until they thin to nothing (pinch out) or reach the edge of their basin of deposition.*
- **Law of Superposition**—*In an undisturbed sequence of strata or lava flows, the oldest layer is at the bottom of the sequence and the youngest is at the top.*
- **Law of Inclusions**—*Any piece of rock (clast) that has become included in another rock or body of sediment must be older than the rock or sediment into which it has been incorporated.* Such a clast (usually a rock fragment, crystal, or fossil) is called an **inclusion.** The surrounding body of rock is called the **matrix** (or groundmass). Thus, an inclusion is older than its surrounding matrix.
- **Law of Cross Cutting**—*Any feature that cuts across a rock or body of sediment must be younger than the rock or sediment that it cuts across.* Such cross cutting features include fractures (cracks in rock), faults (fractures along which movement has occurred), or masses of magma (*igneous intrusions*) that cut across preexisting rocks before they cooled. When a body of magma intrudes preexisting rocks, a narrow *zone of contact metamorphism* usually forms in the preexisting rocks adjacent to the intrusion.

Unconformities

Surfaces called **unconformities** represent gaps in the geologic record that formed wherever layers were not deposited for a time or else layers were removed by erosion. Most contacts between adjacent strata or formations are *conformities*, meaning that rocks on both sides of them formed at about the same time. An unconformity is a rock surface that represents a gap in the geologic record. It is like the place where pages are missing from a book. An unconformity can be a buried surface where there was a pause in sedimentation, a time between two lava flows, or a surface that was eroded before more sediment was deposited on top of it.

There are three kinds (FIGURE 8.1). A **disconformity** is an unconformity between *parallel* strata or lava flows. Most disconformities are very irregular surfaces, and pieces of the underlying rock are often included in the strata above them. An **angular unconformity** is an unconformity between two sets of strata that are not parallel to one another. It forms when new horizontal layers cover up older layers folded by mountain-building processes and eroded down to a nearly level surface. A **nonconformity** is an unconformity between younger sedimentary rocks and subjacent metamorphic or igneous rocks. It forms when stratified sedimentary rocks or lava flows are deposited on eroded igneous or metamorphic rocks.

Relative Age Dating Examples

Analyze and evaluate FIGURES 8.2–8.9 to learn how the above laws of relative age dating are applied in cross sections of Earth's crust. These are the kinds of two-dimensional cross sections of Earth's crust that are exposed in road cuts, quarry walls, and mountain sides. *Be sure that you consider all of these examples before proceeding.*

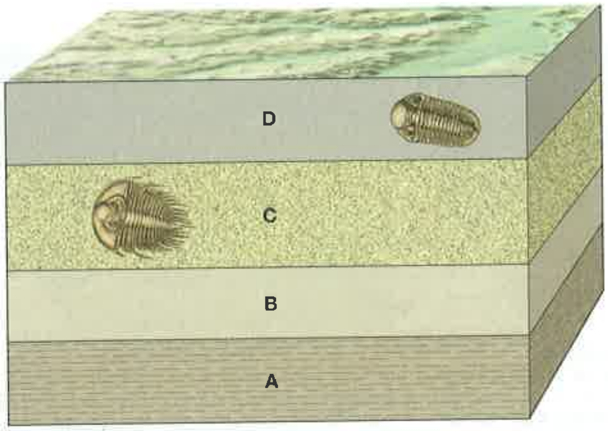


FIGURE 8.2 Law of superposition in horizontal strata. This is a sequence of strata that has maintained its original horizontality and does not seem to be disturbed. Therefore, Formation **A** is the oldest, because it is on the bottom of a sedimentary sequence of rocks. **D** is the youngest, because it is at the top of the sedimentary sequence. The sequence of events was deposition of **A, B, C,** and **D,** in that order and stacked one atop the other.

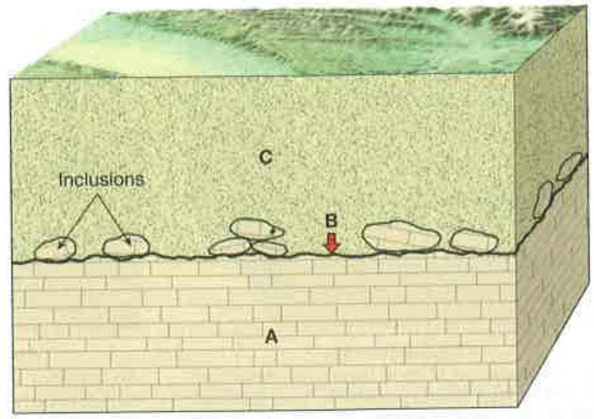


FIGURE 8.3 Inclusions on a disconformity. These strata are all horizontal. Limestone **A** is older, because it is on the bottom of a sequence of strata. Sandstone **C** is younger, because it is on top of the limestone and has inclusions (fragments of older rock) of the older limestone. Contact **C** is unconformable, because some of the limestone layers were eroded (making a gap in the rock layers) and became inclusions in the overlying sandstone. An unconformity between parallel strata, like this one, is a disconformity.

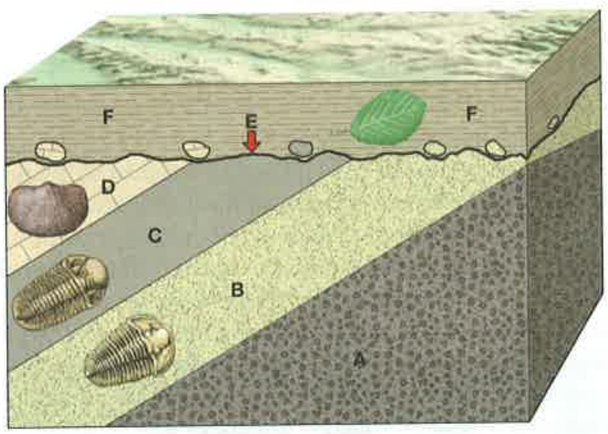


FIGURE 8.4 Angular unconformity. This is another sequence of strata, some of which do not have their original horizontality. Formation **A** is the oldest, because it is at the bottom of the sedimentary sequence. Formation **F** is youngest, because it forms the top of the sequence. Tilting and erosion of the sequence occurred after **D** but before deposition of Formation **F. E** is an angular unconformity.

The sequence of events began with deposition of **A, B, C,** and **D,** in that order and stacked one atop the other. The sequence of **A–D** was then tilted, and its top was eroded **(E)**. Siltstone **F** was deposited horizontally on top of the erosional surface **(E),** which is now an angular unconformity.

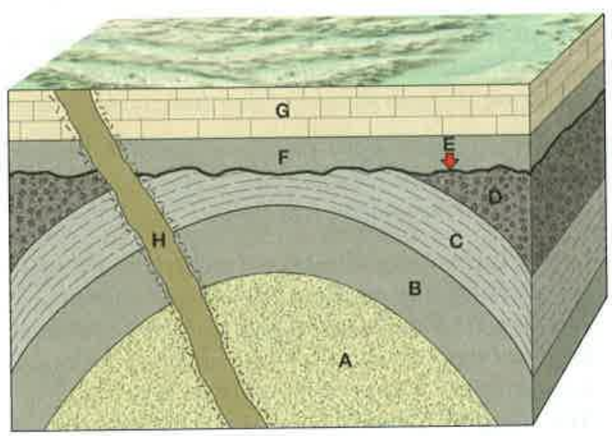
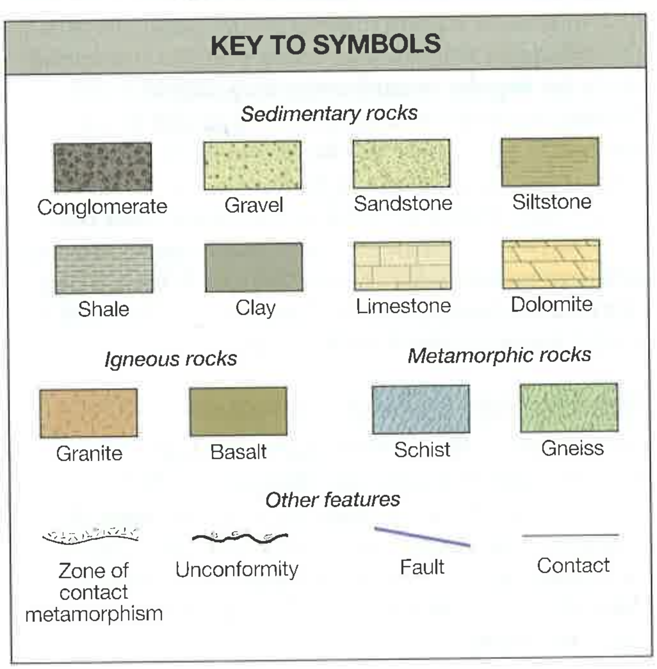


FIGURE 8.5 Law of cross-cutting. The body of igneous rock **H** is the youngest rock unit, because it cuts across all of the others. (When a narrow body of igneous rock cuts across strata in this way, it is called a **dike.**) **A** is the oldest formation because it is at the bottom of the sedimentary rock sequence that is cut by **H.** Folding and erosion occurred after **D** was deposited, but before **F** was deposited. **E** is an angular unconformity.

The sequence of events began with deposition of formations **A** through **D** in alphabetical order and one atop the other. That sequence was folded, and the top of the fold was eroded. Formation **F** was deposited horizontally atop the folded sequence and the erosional surface, which became angular unconformity **E. G** was deposited atop **F.** Lastly, a magma intruded across all of the strata and cooled to form basalt dike **H.**



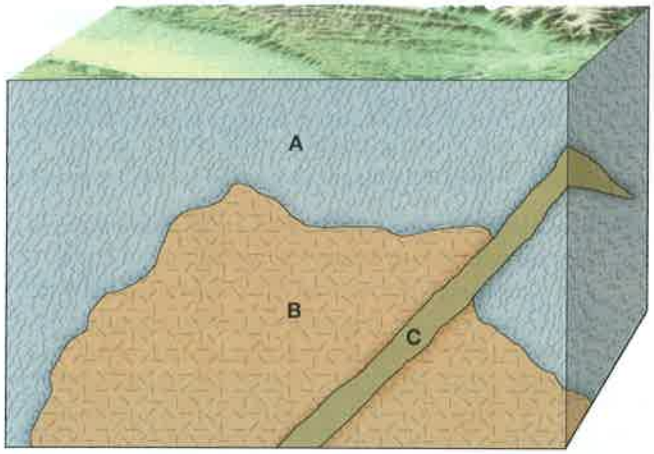


FIGURE 8.6 Igneous intrusions and cross-cutting. The body of granite **B** must have formed from the cooling of a body of magma that intruded the preexisting rock **A,** called **country rock.** The country rock is schist **A** containing a zone of contact metamorphism adjacent to the granite. Therefore, the sequence of events began with a body of country rock **A.** The country rock was intruded by a body of magma, which caused development of a zone of contact metamorphism and cooled to form granite **B.** Lastly, another body of magma intruded across both **A** and **B.** It caused development of a second zone of contact metamorphism and cooled to form basalt dike **C.**

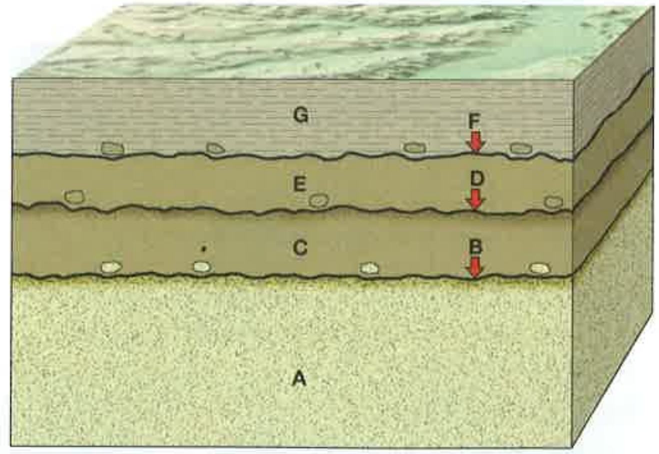


FIGURE 8.8 Disconformities. Notice that this is a sequence of strata and basalt lava flows (that have cooled to form the basalt). There are zones of contact metamorphism beneath both of the basalt lava flows **(C, E).** The sequence of events must have begun with deposition of sandstone **A,** because it is on the bottom. A lava flow was deposited atop **A** and cooled to form basalt **C.** This first lava flow caused development of the zone of contact metamorphism in **A** and the development of disconformity **B.** A second lava flow was deposited atop **C** and cooled to form basalt **E.** This lava flow caused the development of a zone of contact metamorphism and a disconformity **D.** An erosional surface developed atop **E,** and the surface became a disconformity **F** when shale **G** was deposited on top of it.

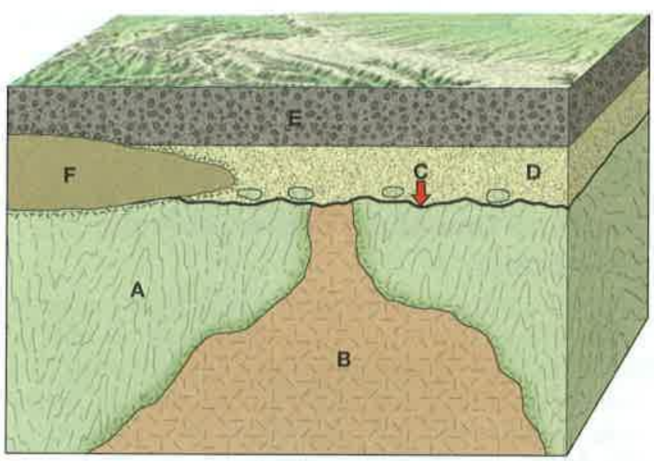


FIGURE 8.7 Nonconformity. At the base of this rock sequence there is gneiss **A,** which is separated from granite **B** by a zone of contact metamorphism. This suggests that a body of magma intruded **A,** then cooled to form the contact zone and granite **B.** There must have been erosion of both **A** and **B** *after* this intrusion (to form surface **C**), because there is no contact metamorphism between **B** and **D.** Formation **D** was deposited horizontally atop the eroded igneous and metamorphic rocks, forming nonconformity **C.** After **E** was deposited, a second body of magma **F** intruded across **A, C, D,** and **E.** Such an intrusive igneous body that is intruded along (parallel to) the strata is called a **sill (F).**

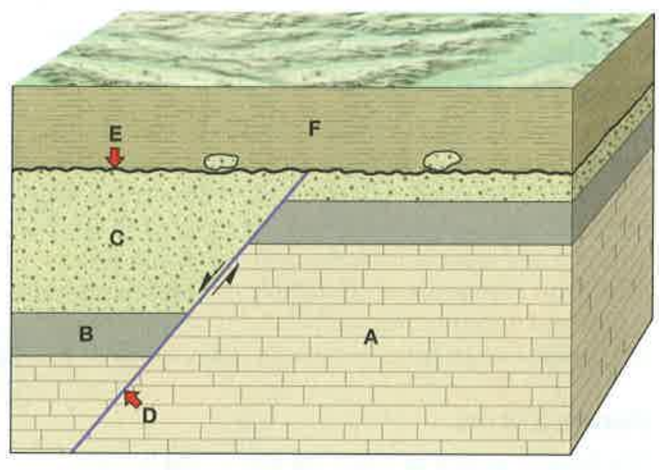


FIGURE 8.9 Cross-cutting by a fault. This is a sequence of relatively horizontal strata: **A, B, C,** and **F. A** must be the oldest of these formations because it is on the bottom. **F** is the youngest of these formations because it is on top. Formations **A, B,** and **C** are cut by a fault, which does not cut **F.** This means that the fault **D** must be younger than **C** and older than **F. E** is a disconformity. The sequence of events began with deposition of formations **A, B,** and **C,** in that order and one atop the other. This sequence was then cut by fault **D.** After faulting, the land surface was eroded. When siltstone **F** was deposited on the erosional surface, it became disconformity **E.**

ACTIVITY

8.3 Using Index Fossils to Date Rocks and Events

THINK About It | **How are fossils used to tell geologic time and infer Earth's history?**

OBJECTIVE Use index fossils to determine the relative ages (eras, periods) of rock bodies and infer some of Earth's history.

PROCEDURES

1. **Before you begin**, read Relative Age Dating Based on Fossils below. Also, this is **what you will need:**
   ____ calculator
   ____ Activity 8.3 Worksheet (p. 221) and pencil
2. **Then follow your instructor's directions** for completing the worksheets.

Relative Age Dating Based on Fossils

The sequence of strata that makes up the geologic record is a graveyard filled with the fossils of millions of kinds of organisms that are now extinct. Geologists know that they existed only because of their fossilized remains or the traces of their activities (like tracks and trails).

Principle of Fossil Succession and Index Fossils

Geologists have also determined that fossil organisms originate, co-exist, or disappear from the geologic record in a definite sequential order recognized throughout the world, so *any rock layer containing a group of fossils can be identified and dated in relation to other layers based on its fossils.* This is known as the **Principle of Fossil Succession.** A fossilized organism that can be used to identify the relative age of rock layers is called an **index fossil**.

Range Zones

The interval of rock in which the index fossil is found is called its **range zone** and corresponds to a particular interval of geologic time. The range zones of some well-known Phanerozoic index fossils are presented on the right side of FIGURE 8.10. Relative ages of the rocks containing these fossils are presented as *periods* and *eras* on the left side of FIGURE 8.10.

By noting the range zone of a fossil (vertical black line), you can determine the corresponding era(s) or period(s) of time in which it lived. For example, all of the different species of dinosaurs lived and died during the Mesozoic Era of time, from the middle of the Triassic Period to the end of the Cretaceous Period. Mammals have existed since late in the Triassic Period. If you found a rock layer with bones and tracks of both dinosaurs and mammals, then the age of the rock layer would be represented by the overlap of the dinosaur and mammal range zones (i.e., Middle Triassic to Late Cretaceous). Notice that FIGURE 8.10 also includes the following groups:

- **Brachiopods** (pink on chart): marine invertebrate animals with two symmetrical seashells of unequal size. They range throughout the Paleozoic, Mesozoic, and Cenozoic Eras, but they were most abundant in the Paleozoic Era. Only a few species exist today, so they are nearly extinct.
- **Trilobites** (orange on chart): an extinct group of marine arthropods (animals related to lobsters). They are only found in Paleozoic rocks, so they are a good index fossil for the Paleozoic Era and its named subdivisions.
- **Mollusks** (pink on chart): phylum of snails, cephalopods (squid, octopuses), and bivalves (oysters, clams; two asymmetrical shells of unequal size).
- **Plants** (dark green on chart).
- **Reptiles** (pale green on chart): the group of vertebrate animals that includes lizards, snakes, turtles, and dinosaurs. **Dinosaurs** are only found in Mesozoic rocks, so they are an index fossil for the Mesozoic and its subdivisions.
- **Mammals** (gray on chart): the group of vertebrate animals (including humans) that are warm blooded, nurse their young, and have hair.
- **Amphibians** (brown on chart): the group of vertebrate animals that includes modern frogs and salamanders.
- **Sharks** (blue on chart): a group of fish with teeth but no hard bones.

Rock and Time Units of the Geologic Time Scale

The geologic time scale in FIGURE 8.10 shows the ranges of index fossils in relation to named units of time and rock plus a scale of absolute ages in millions of years. Notice that there are two levels of named time and rock units in FIGURE 8.10. Long **eras** of time are subdivided into shorter **periods** of time. As noted in the table below, an era of time corresponds with an **erathem** of rock containing its characteristic index fossils. A period of time corresponds with a **system** of rock containing its characteristic index fossils.

Rock Units (Division of the Geologic Record)	Corresponding Geologic Time Units
Eonothem of rock	Eon of time (longest)
Erathem of rock	Era of time
System of rock	Period of time
Series of rock	Epoch of time

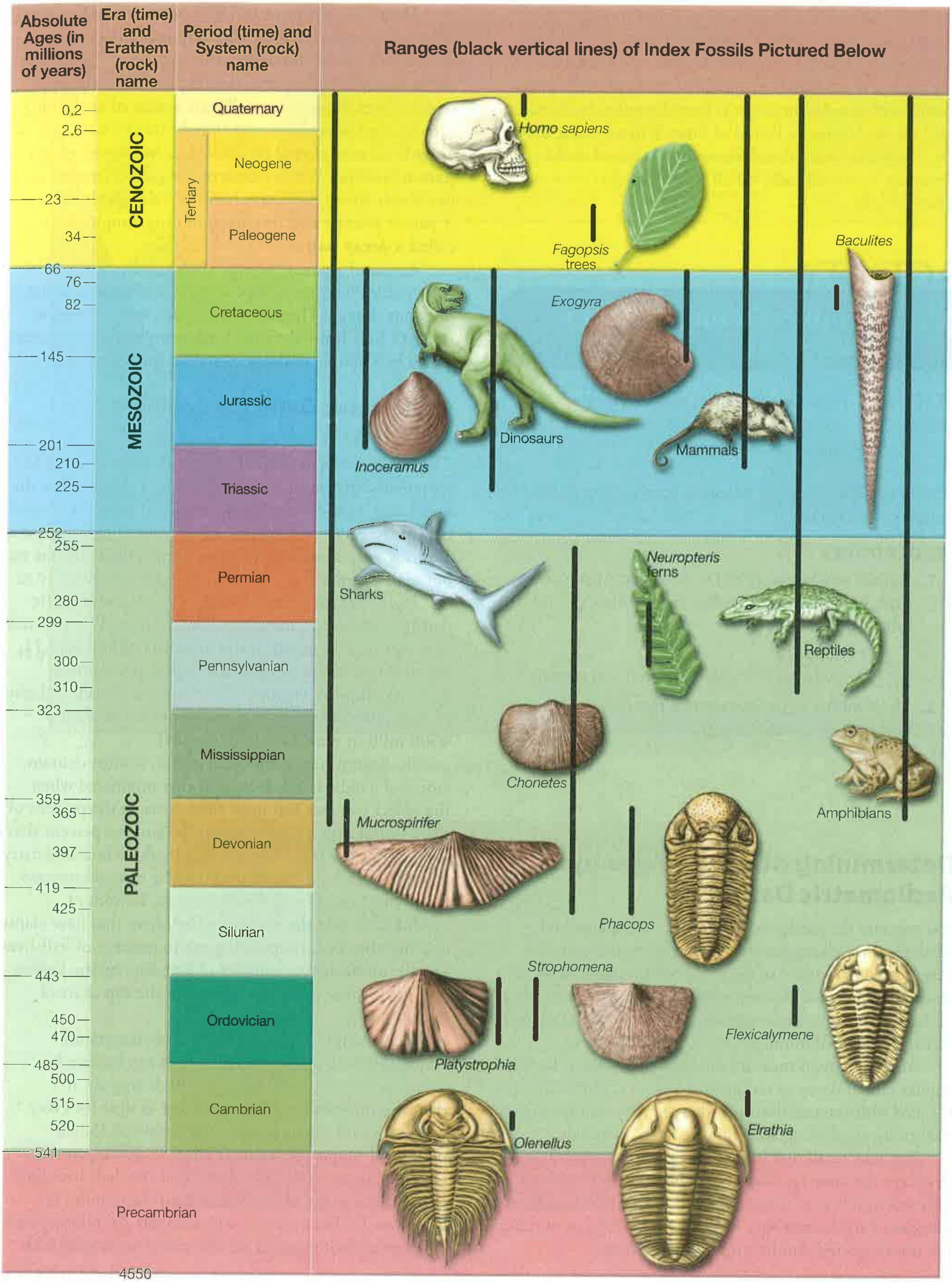


FIGURE 8.10 Range zones. Range zones (vertical bold black lines) of some well-known index fossils relative to named divisions of the geologic time scale.

There are times in this laboratory that you may be referring to a rock unit and other times when you may be referring to a time unit, so you will need to use the correct kind of unit for rock or time. For example, notice in FIGURE 8.10 that *Mucrospirifer* (a brachiopod) is an index fossil for the Devonian Period of time. When writing about this, you would write that *Mucrospirifer* is found in the Devonian System of rock, which represents the Devonian Period of time.

ACTIVITY

8.4 Absolute Dating of Rocks and Fossils

THINK About It **How do geologists determine the absolute age, in years, of Earth materials and events?**

OBJECTIVE Calculate absolute ages to date Earth materials and events.

PROCEDURES

1. **Before you begin**, read Determining Absolute Ages by Radiometric Dating below. Also, this is **what you will need:**
   ____ calculator
   ____ Activity 8.4 Worksheet (p. 222) and pencil
2. **Then follow your instructor's directions** for completing the worksheets.

Determining Absolute Ages by Radiometric Dating

You measure the passage of time based on the rates and rhythms at which regular changes occur around you. For example, you are aware of the rate at which hands move on a clock, the rhythm of day and night, and the regular sequence of the four seasons. These regular changes allow you to measure the passage of minutes, hours, days, and years.

Another way to measure the passage of time is by the regular rate of decay of radioactive isotopes. This technique is called **radiometric dating** and is one way that geologists determine absolute ages of some geologic materials.

You may recall that **isotopes** of an element are atoms that have the same number of protons and electrons but different numbers of neutrons. This means that the different isotopes of an element vary in atomic weight (mass number) but not in atomic number (number of protons).

About 350 different isotopes occur naturally. Some of these are *stable isotopes*, meaning that they are not radioactive and do not decay through time. The others are *radioactive isotopes* that decay spontaneously, at regular rates through time. When a mass of atoms of a radioactive isotope is incorporated into the structure of a newly formed crystal or seashell, it is referred to as a **parent isotope**. When atoms of the parent isotope decay to a stable form, they have become a **daughter isotope**. A parent isotope and its corresponding daughter are called a **decay pair**.

Atoms of a parent isotope always decay to atoms of their stable daughter isotope at an exponential rate that does not change. The rate of decay can be expressed in terms of **half-life**—the time it takes for half of the parent atoms in a sample to decay to stable daughter atoms.

Radiometric Dating of Geologic Materials

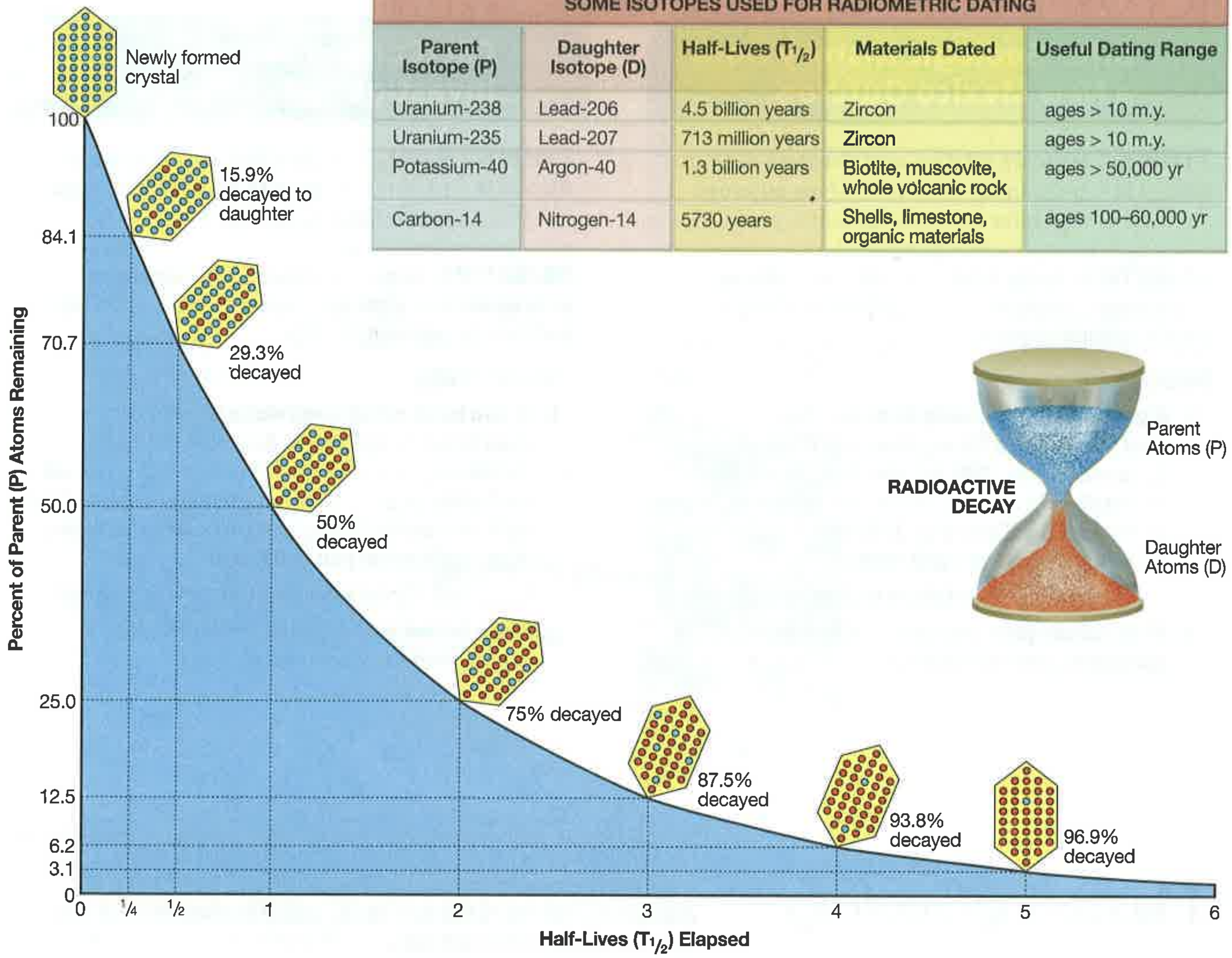
The decay parameters for all radioactive isotopes can be represented graphically as in FIGURE 8.11. Notice that the decay rate is exponential (not linear)—during the second half-life interval, only half of the remaining half of parent atoms will decay. All radioactive isotopes decay in this way, but each decay pair has its own value for half-life.

Half-lives for some isotopes used for radiometric dating have been experimentally determined by physicists and chemists, as noted in the top chart of FIGURE 8.11. For example, uranium-238 is a radioactive isotope (parent) found in crystals of the mineral zircon. It decays to lead-206 (daughter) and has a half-life of about 4500 million years (4.5 billion years).

To determine the age of an object, it must contain atoms of a radioactive decay pair that originated when the object formed. You must then measure the percent of those atoms that is parent atoms (**P**) and the percent that is daughter atoms (**D**). This is generally done in a chemistry laboratory with an instrument called a *mass spectrometer*. Based on **P** and **D** and the chart at the bottom of FIGURE 8.10, find the number of half-lives that have elapsed and the object's corresponding age in number of half-lives. Finally, multiply that number of half-lives by the known half-life for that decay pair (noted in the top chart of FIGURE 8.11).

For example, a sample of Precambrian granite contains biotite mineral crystals, so it can be dated using the potassium-40 to argon-40 decay pair. If there are three argon-40 atoms in the sample for every one potassium-40 atom, then the sample is 25.0% potassium-40 parent atoms (**P**) and 75.0% argon-40 daughter atoms (**D**). This means that two half-lives have elapsed, so the age of the biotite (and the granite) is 2.0 times 1.3 billion years, which equals 2.6 billion years. The useful dating ranges are also noted on FIGURE 8.11.

SOME ISOTOPES USED FOR RADIOMETRIC DATING				
Parent Isotope (P)	Daughter Isotope (D)	Half-Lives ($T_{1/2}$)	Materials Dated	Useful Dating Range
Uranium-238	Lead-206	4.5 billion years	Zircon	ages > 10 m.y.
Uranium-235	Lead-207	713 million years	Zircon	ages > 10 m.y.
Potassium-40	Argon-40	1.3 billion years	Biotite, muscovite, whole volcanic rock	ages > 50,000 yr
Carbon-14	Nitrogen-14	5730 years	Shells, limestone, organic materials	ages 100–60,000 yr



DECAY PARAMETERS FOR ALL RADIOACTIVE DECAY PAIRS			
Percent of Parent Atoms (P)	Percent of Daughter Atoms (D)	Half-Lives Elapsed	Age
100.0	0.0	0	0.000 x $T_{1/2}$
98.9	1.1	1/64	0.015 x $T_{1/2}$
97.9	2.1	1/32	0.031 x $T_{1/2}$
95.8	4.2	1/16	0.062 x $T_{1/2}$
91.7	8.3	1/8	0.125 x $T_{1/2}$
84.1	15.9	1/4	0.250 x $T_{1/2}$
70.7	29.3	1/2	0.500 x $T_{1/2}$
50.0	50.0	1	1.000 x $T_{1/2}$
35.4	64.6	1½	1.500 x $T_{1/2}$
25.0	75.0	2	2.000 x $T_{1/2}$
12.5	87.5	3	3.000 x $T_{1/2}$
6.2	93.8	4	4.000 x $T_{1/2}$
3.1	96.9	5	5.000 x $T_{1/2}$

FIGURE 8.11 Radiometric dating. Some isotopes useful for radiometric dating, their decay parameters, and their useful ranges for dating. The half-life of each decay pair is different (top chart), but the graph and decay parameters (bottom charts) are the same for all decay pairs.

ACTIVITY

8.5 Infer Geologic History from a New Mexico Outcrop

THINK About It | **How are relative and absolute dating techniques used to analyze outcrops and infer geologic history?**

OBJECTIVE Apply relative and absolute dating techniques to analyze an outcrop in New Mexico and infer its geologic history.

PROCEDURES

1. **If you have not already done so,** then read Relative Age Dating Based on Physical Relationships (p. 208), Relative Age Dating Based on Fossils (p. 212), and Determining Absolute Ages by Radiometric Dating (p. 214) before you begin. Also, this is **what you will need:**

   ____ Activity 8.5 Worksheet (p. 223) and pencil

2. **Then follow your instructor's directions** for completing the worksheets.

ACTIVITY

8.6 CSI (Canyon Scene Investigation) Arizona

THINK About It | **How are relative and absolute dating techniques used to analyze outcrops and infer geologic history?**

OBJECTIVE Apply relative and absolute dating techniques to analyze an outcrop in the Grand Canyon and infer its geologic history.

PROCEDURES

1. **If you have not already done so,** then read Relative Age Dating Based on Physical Relationships (p. 208), Relative Age Dating Based on Fossils (p. 212), and Determining Absolute Ages by Radiometric Dating (p. 214) before you begin. Also, this is **what you will need:**

   ____ Activity 8.6 Worksheet (p. 225) and pencil

2. **Then follow your instructor's directions** for completing the worksheets.

ACTIVITY 8.1 Geologic Inquiry for Relative Age Dating

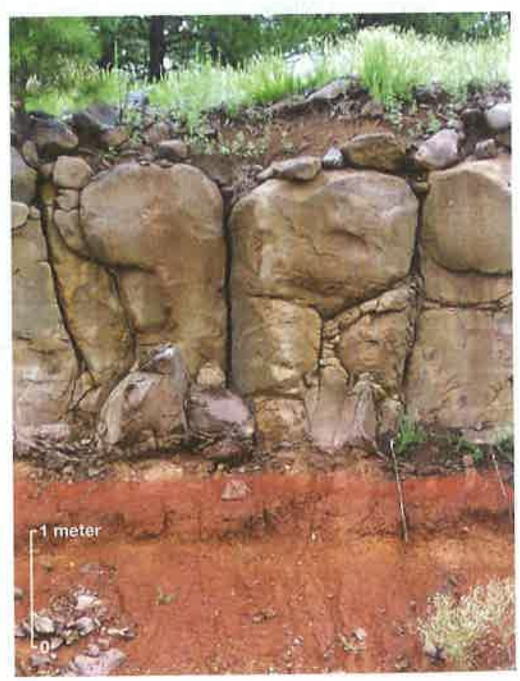
Name: ______________________ Course/Section: ______________ Date: ________

A. Analyze this block of layer cake. Each side of the block of cake is a vertical **cross section** of the layers. Also notice the surfaces between the layers, where two different layers touch each other. Geologists refer to surfaces between layers or other bodies of rock as **contacts**.

1. Think about the process used to construct the layer cake, from making and *depositing* (laying down) the first layer to making and depositing the last layer. On the left edge of the cake, number the layers to show the sequence of steps in which they were deposited to make the layer cake from 1 (first step) to n (the number of the last step).
2. Using a pen, draw lines on the layer cake to mark all of the contacts between layers. Then place arrows along the right edge of the cake that point to each contact. Label each arrow (contact) to show its relative age from 1 (the time when the first contact was created; the oldest contact) to "n" (the number corresponding to the last time a contact was created; the youngest contact).

B. The picture below is an outcrop about 5 meters thick near Sedona, Arizona. The red rock is an ancient body of soil. The brown layer in which grass is rooted is modern soil. The blocky brown-gray rock with wide fractures (cracks) is an ancient lava flow (basalt, a volcanic rock). This outcrop is a natural geologic cross section of rock layers, analogous to the cake.

1. Which layer is the oldest? How do you know?



2. Using a pen, draw a line on the picture that marks the exact position of:
   a. the contact between the red ancient soil and the lava flow.
   b. the exact contact between the top of the lava flow and the base of the darker brown modern soil in which grass is growing.
3. Notice the **fractures** (cracks) that cut across the lava flow layer. Are they older or younger than the lava flow? How do you know?
4. Notice that *clasts* (broken pieces) of the lava flow are included in the brown soil. Are they older or younger than the brown soil? How do you know?

C. Analyze this outcrop, photographed by geologist, Thomas McGuire. It is another natural geologic cross section with red sandstone layers on the bottom and a yellow conglomerate (gravel) rock layer on top. Notice that the red rock layers are not horizontal. They are bent up on the left and right, and down in the middle, as wave-like **folds** (like a crumpled rug).

1. Using a pen, trace two of the contacts between layers of the red sandstone as well as you can. Assuming that the red sandstone layers were originally horizontal, what may have caused them to be folded in this way?

2. On both sides of the picture, use an arrow to label the exact location of the contact between the red sandstone and the horizontal yellow conglomerate above it. This surface is an **unconformity**—a surface (contact) representing erosion of layers or a break in deposition of layers, like a place where pages are missing from a book. Something happened at the time represented by the surface, but no rock layer remains as a record of the event. What sequence of events may have happened to form the unconformity?

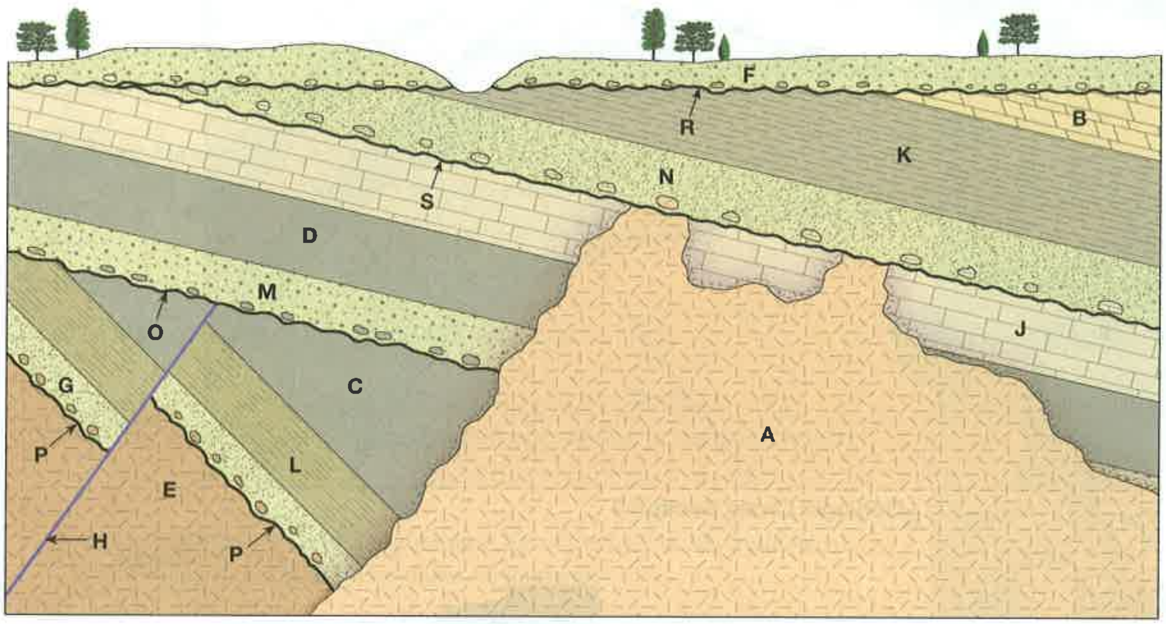
D. REFLECT & DISCUSS In all of your work above, you had to figure out the relative ages (from oldest to youngest) of rock layers, fractures, folds, and clasts included in soil. Based on your work, write down three rules that a geologist could follow to tell the relative ages of rock layers, fractures, clasts, and folds in geologic cross sections.

ACTIVITY **8.2**

Determining Sequence of Events in Geologic Cross Sections

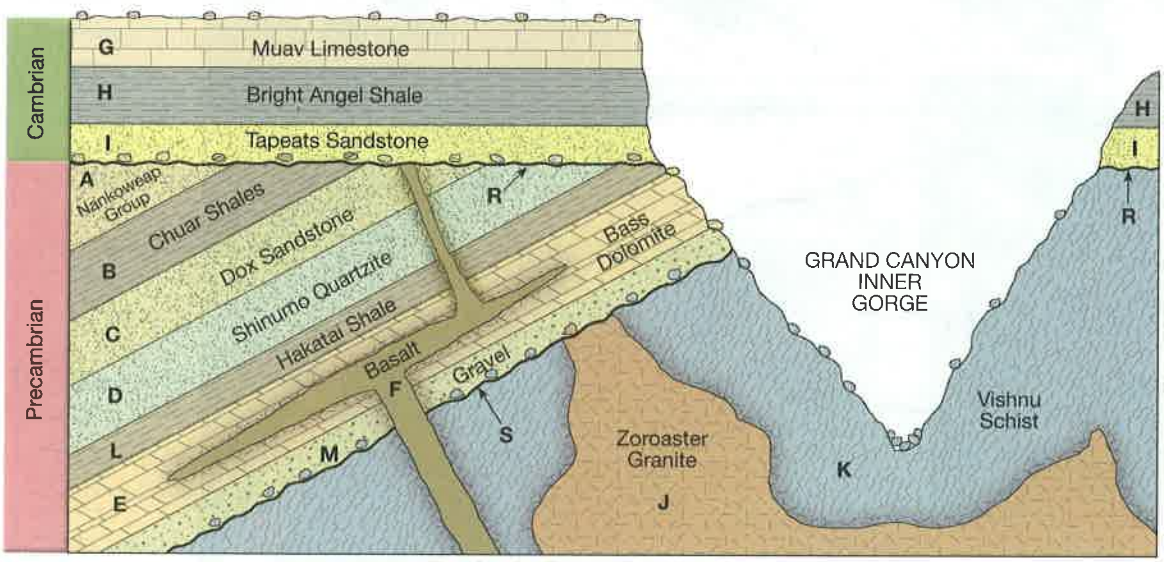
Name: ______________________ **Course/Section:** ______________ **Date:** ________

A. Review the legend of symbols at the bottom of the page. On the lines provided for each cross section, write letters to indicate the sequence of events from oldest (first in the sequence of events) to youngest (last in the sequence of events). Refer to FIGURES 8.1–8.9 and the laws of relative age dating (page 209 as needed).



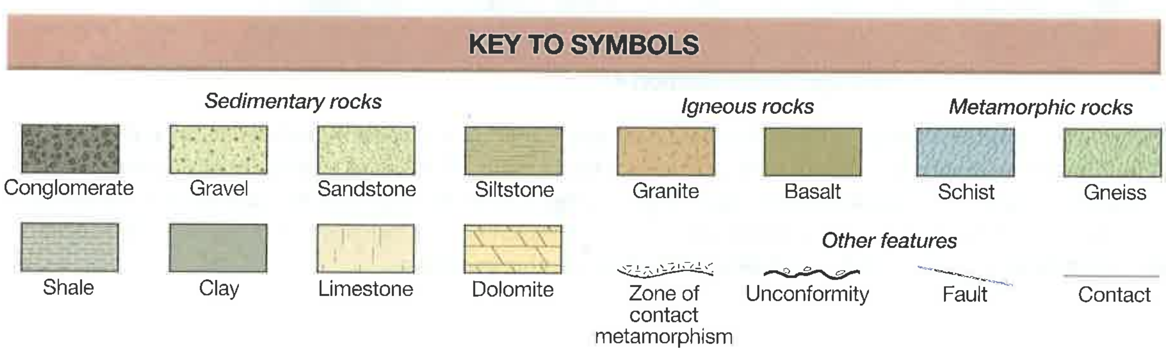
Geologic Cross Section 1

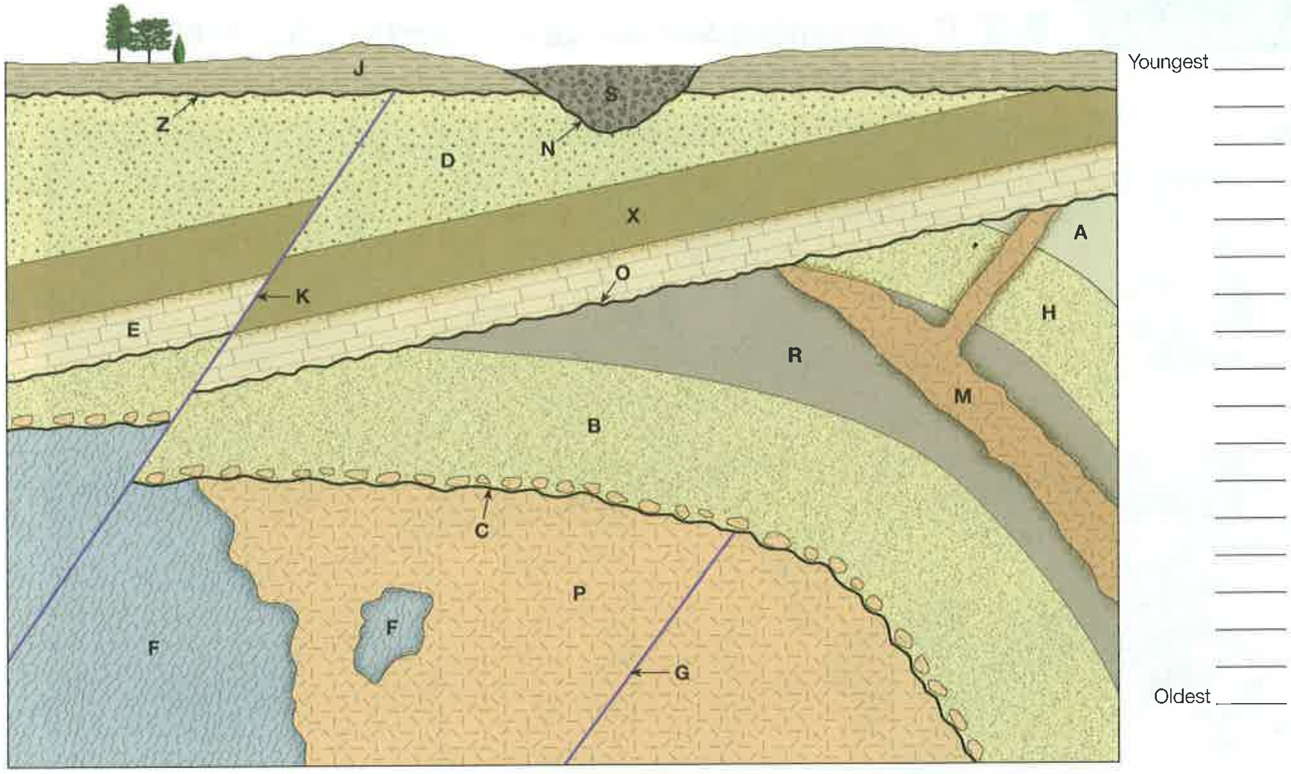
Youngest ______
______
______
______
______
______
______
______
______
______
______
______
______
______
______
______
Oldest ______



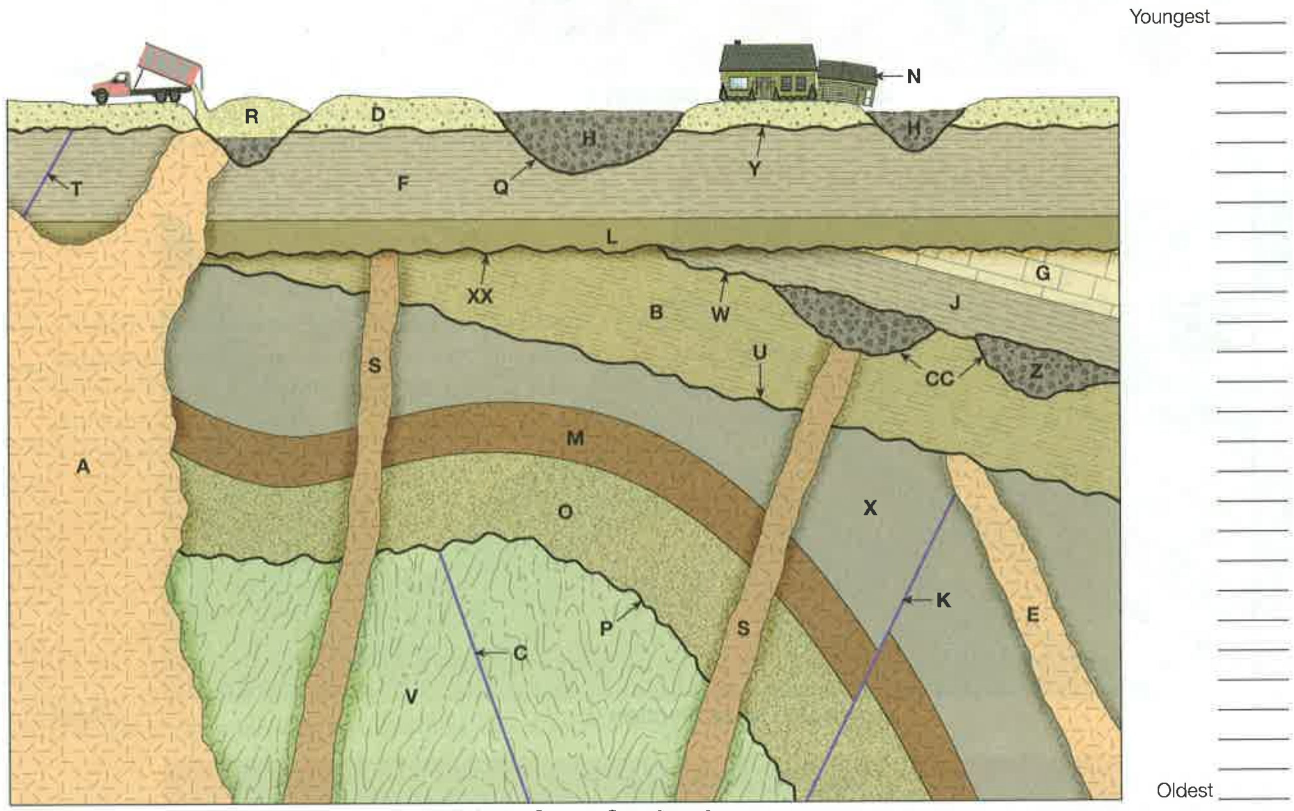
Geologic Cross Section 2

Youngest ______
______
______
______
______
______
______
______
______
______
______
______
______
______
Oldest ______





Geologic Cross Section 3



Geologic Cross Section 4

B. REFLECT & DISCUSS Return to geologic Cross Section 2, and notice how the Colorado River has cut down through the rocks to create the Grand Canyon Gorge. Discuss with a partner or small group, what law of relative age dating you would need to apply in order to draw in the rock layers of Grand Canyon Gorge that are missing from the cross section. As exactly as you can, apply the law and use dashed lines to draw in the contacts between named rock layers that were eroded away in Grand Canyon Gorge. Compare your completed drawing with those of other geologists.

ACTIVITY 8.3 Use Index Fossils to Date Rocks and Events

Name: ____________________ **Course/Section:** ____________________ **Date:** __________

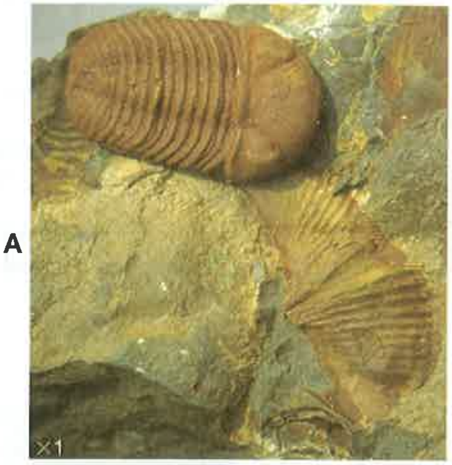
A. Analyze this fossiliferous rock from New York.

1. What index fossils from **FIGURE 8.10** are present?

2. Based on the overlap of range zones for these index fossils what is the relative age of the rock (expressed as the early, middle, or late part of one or more periods of time)?

3. Using **FIGURE 8.10**, what is the absolute age of the rock in Ma (millions of years old/ago), as a range from oldest to youngest?

A



B. Analyze this fossiliferous sand from Delaware.

1. What index fossils from **FIGURE 8.10** are present?

2. Based on the overlap of range zones for these index fossils what is the relative age of the rock (expressed as the early, middle, or late part of one or more periods of time)?

3. Using **FIGURE 8.10**, what is the absolute age of the rock in Ma (millions of years old/ago), as a range from oldest to youngest?

B

C. Analyze this fossiliferous rock from Ohio.

1. What index fossils from **FIGURE 8.10** are present?

2. Based on the overlap of range zones for these index fossils, what is the relative age of the rock (expressed as the early, middle, or late part of one or more periods of time)?

3. Using **FIGURE 8.10**, what is the absolute age of the rock in Ma (millions of years old/ago), as a range from oldest to youngest?

C

D. Using **FIGURE 8.10**, re-evaluate the geologic cross section in **FIGURE 8.2** based on its fossils.

1. Which one of the contacts (surfaces) between lettered layers is a disconformity?__________

2. A system is the rock/sediment deposited during a period of time. What system of rock is completely missing at the disconformity?

3. What amount of absolute time in m.y. (millions of years) is missing at the disconformity? __________ m.y.

E. **REFLECT & DISCUSS** What geologic event occurred during the Mesozoic Era in the region where **FIGURE 8.4** is located? Explain.

ACTIVITY 8.4 Absolute Dating of Rocks and Fossils

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. A solidified lava flow containing zircon mineral crystals is present in a sequence of rock layers that are exposed in a hillside. A mass spectrometer analysis was used to count the atoms of uranium-235 and lead-207 isotopes in zircon samples from the lava flow. The analysis revealed that 71% of the atoms were uranium-235, and 29% of the atoms were lead-207. Refer to **FIGURE 8.11** to help you answer the following questions.

1. About how many half-lives of the uranium-235 to lead-207 decay pair have elapsed in the zircon crystals? ____________

2. What is the absolute age of the lava flow based on its zircon crystals? Show your calculations.

3. What is the age of the rock layers above the lava flow? ____________

4. What is the age of the rock layers beneath the lava flow? ____________

B. Astronomers think that Earth probably formed at the same time as all of the other rocky materials in our solar system, including the oldest meteorites. The oldest meteorites ever found on Earth contain nearly equal amounts of both uranium-238 and lead-206. Based on **FIGURE 8.11**, what is Earth's age? Explain your reasoning.

C. If you assume that the global amount of radiocarbon (formed by cosmic-ray bombardment of atoms in the upper atmosphere and then dissolved in rain and seawater) is constant, then decaying carbon-14 is continuously replaced in organisms while they are alive. However, when an organism dies, the amount of its carbon-14 decreases as it decays to nitrogen-14.

1. The carbon in a buried peat bed has about 6% of the carbon-14 of modern shells. What is the age of the peat bed? Explain.

2. In sampling the peat bed, you must be careful to avoid any young plant roots or old limestone. Why?

D. Zircon ($ZrSiO_4$) forms in magma and lava as it cools into igneous rock. It is also useful for absolute age dating (**FIGURE 8.11**).

1. If you walk on a modern New Jersey beach, then you will walk on some zircon sand grains. Yet if you determine the absolute age of the zircons, it does not indicate a modern age (zero years) for the beach. Why?

2. Suggest a rule that geologists should follow when they date rocks based on the radiometric ages of crystals inside the rocks.

E. **REFLECT & DISCUSS** An "authentic dinosaur bone" is being offered for sale on the Internet. The seller claims that he had it analyzed by scientists who confirmed that it is a dinosaur bone and used carbon dating to determine that it is 400 million years old. Discuss the sellers claims with a partner or in a small group. Should you be suspicious of this bone's authenticity? Explain. (See **FIGURES 8.10**, **8.11**).

ACTIVITY 8.5 Infer Geologic History from a New Mexico Outcrop

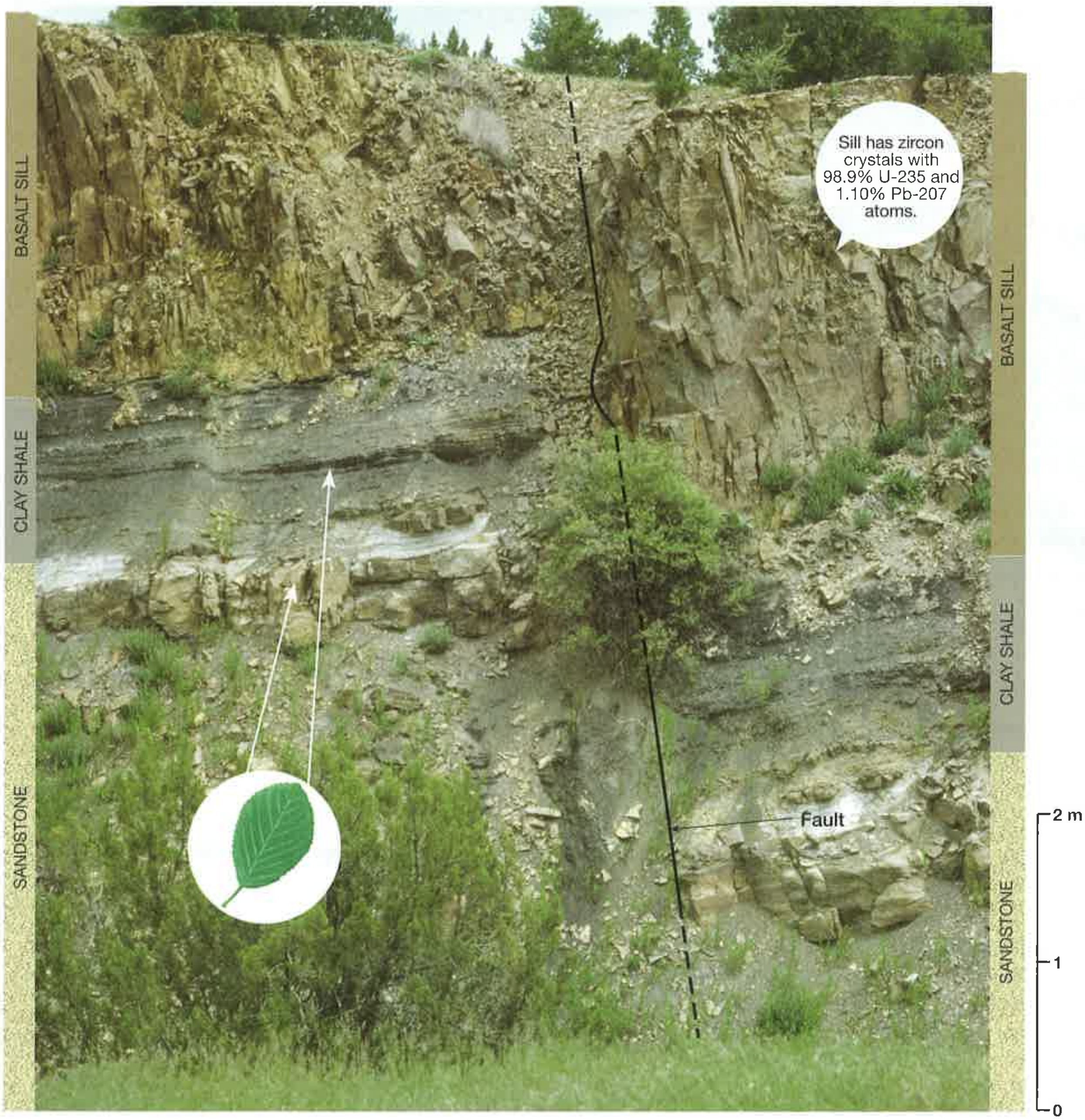
Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. Refer to the image below, an outcrop in a surface mine (coal strip mine) in northern New Mexico. Note the sill, sedimentary rocks, fault, places where a fossil leaf was found, and isotope data for zircon crystals in the sill.

1. What is the relative age of the sedimentary rocks in this rock exposure? Explain your reasoning.

2. What is the absolute age of the sill? Show how you calculated the answer.

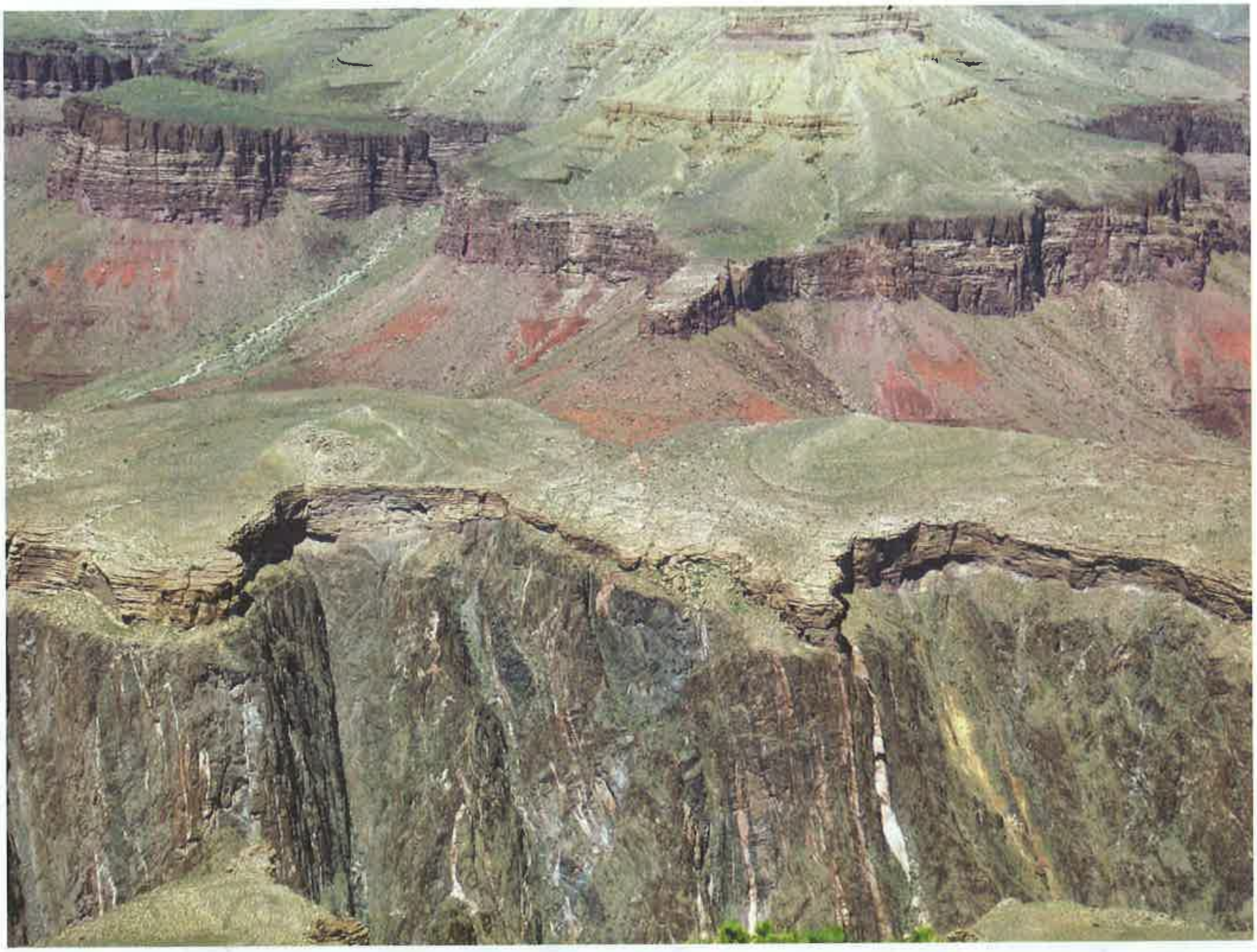
3. Locate the fault. How much displacement has occurred along this fault? ______________ meters



ACTIVITY 8.6 CSI (Canyon Scene Investigation) Arizona

Name: ______________________ **Course/Section:** ______________________ **Date:** ____________

A. This is a photograph of part of the bottom of the Grand Canyon, which runs east to west across northern Arizona. You are standing west of Grand Canyon Villiage, on the south rim of the Canyon, and looking at the north side of the bottom of the canyon.



Carefully analyze the photograph for rock layering. The very bottom rock layers in the foreground are folded Precambrian metamorphic rock called the "Vishnu Schist," which contains narrow bodies of granite (colored white). The Vishnu Schist is overlain here by relatively horizontal layers of sedimentary rock.

1. Using a pen, draw a line exactly along the contact (boundary) between the Vishnu Schist and the relatively horizontal sedimentary rocks above it.

2. Based on FIGURE 8.1, what specific kind of unconformity did you trace above?

3. **REFLECT & DISCUSS** The Vishnu Schist has an absolute age of about 1700 million years. The Lower Cambrian Tapeats Sandstone sits on top of the unconformity that you drew in Part A. If you assume that the Tapeats Sandstone includes strata (sedimentary layers) that were deposited at the very start of the Cambrian Period, then how much of a gap in time exists at the unconformity (where you traced it with a pen)?

B. This is another photograph of part of the bottom of the Grand Canyon. You are standing east of Grand Canyon Villiage, on the south rim of the Canyon, and looking at the north side of the canyon. All of the rocks in this scene are sedimentary rocks.

1. Analyze this canyon scene. Then, using a pen, draw a line on the photograph to show the exact position of an unconformity.

2. What kind of unconformity did you identify?

C. **REFLECT & DISCUSS** What evidence did you apply to justify drawing an unconformity where you did on the above photograph?