Name: ________________________

Lab 10: Geologic Time

Much of geology is focused on understanding Earth's history. The physical characteristics of rocks and minerals offer clues to the processes and conditions on and within Earth in the past. To understand the history of the planet more completely, however, one must be able to establish when the processes and conditions recorded in the rocks were active.

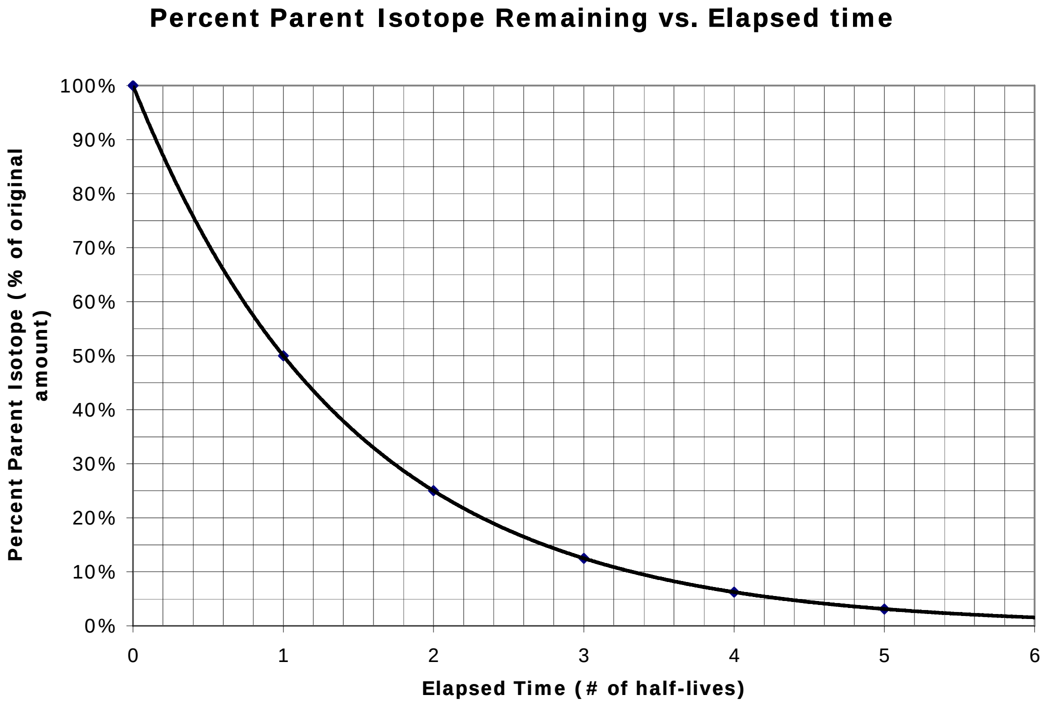
Geologic Events

Sequences of rock are often called part of the geologic record or rock record because they record the history of the planet. This record is composed of distinct events recognizable from the types of rocks present and their arrangement. There are three general types of events covered in this lab exercise: creative events, deformation events, and destructive events. Creative events are those that create new rocks and include deposition of sedimentary units and emplacement of igneous units by intrusion or eruption. Creative events are recognized simply by the presence of these rock units. Deformation events alter or deform existing rock units. These are often related to tectonics and include folding, faulting and metamorphism. Deformation events are recognized by the presence of metamorphosed rock and units that have been changed in shape (e.g. layers that are tilted, broken or bent rather than horizontal and flat). Destructive events are those that destroy rocks, such as erosion, and are therefore recognized in the rock record not by the presence of any feature or characteristic, but by the absence of certain features or characteristics. The removal of rock layers results in gaps in the geologic record. These gaps in the rock record represent *missing time* at that location and are called unconformities.

Absolute Age Dating

Once a geologic event has been recognized in the rock record, it is typically possible to determine when that event occurred. Various methods of absolute age dating will establish a numerical age in years. Most absolute age dating techniques are methods of radiometric dating, which is based on the recognition that some isotopes of certain elements decay over time to produce other isotopes at a predictable rate. The original isotopes are called parent isotopes and their decay products are daughter isotopes. The rate at which this decay occurs is expressed in three ways. The first is by the *half-life*: the time it takes one-half of the parent atoms to decay into daughter atoms. Second, the *characteristic time* is the time required for the number of parent atoms to decrease by 1/e ($e \cong 2.718$). The third is the fraction of parent isotopes that decay in one year, known as the *decay constant*. Some common parent isotopes, resultant daughter isotopes, and half-lives are shown in the table on the next page.

Radiometric dating is applicable when certain conditions have been met which permit one to infer the ratio of parent to daughter atoms at the time of the original event which is to be dated. For example, some daughter isotopes are noble gasses which will escape a magma but which will remain trapped in a solid rock, so in this case the clock "starts" at the time of magma solidification. Subsequent high-temperature metamorphism, however, may "reset" the clock if it permits the daughter atoms to escape. Care must be taken to consider which geologic processes have been active when such dating methods are applied and interpreted.



Some radioactive isotopes, their half-lives, and decay constants:

Parent Isotope	Daughter Isotope	Half-Life (years)	Decay constant (year^{-1})
^{14}C	^{14}N	5,730	1.21×10^{-4}
^{40}K	^{40}Ar	1.25×10^{9}	5.5×10^{-10}
^{87}Rb	^{87}Sr	49×10^{9}	1.42×10^{-11}
^{238}U	^{206}Pb	4.5×10^{9}	1.55×10^{-10}
^{235}U	^{207}Pb	0.7×10^{9}	9.8×10^{-10}

Radiometric dating indicates how long decay has been happening within a closed system and thereby dates the beginning of the accumulation of the daughter isotope. The dates determined in this way mean different things in different rock types. In igneous rocks, radiometric dating indicates how long ago the rock cooled. Metamorphism often recrystallizes minerals, effectively resetting their radiometric ages, so the date indicates the age of the metamorphism rather than the age of the rock's original formation. In sedimentary rocks, the date indicates the age of the particle rather than the age of the sediment. Therefore, radiometric dating provides information about the source rock that was weathered to create the sediment, but does not provide much direct information about the age of the sediment itself. Many sedimentary rocks are more effectively dated by their fossils rather than from radiometric techniques, or by their positions relative to adjacent igneous or metamorphic layers.

Calculating a Radiometric Age

By measuring the amounts of the parent isotope and daughter isotope present in a sample, one can determine the ratio of parent to daughter isotope, infer the percentage of parent isotope remaining, and relate that to the number of elapsed half-lives.

Relative abundance of parent and daughter isotopes during decay:

# of Half-Lives	% Parent Isotope	% Daughter Isotope	Ratio of Parent to Daughter
0	100.000%	0.000%	
1	50.000%	50.000%	1:1
2	25.000%	75.000%	1:3
3	12.500%	87.500%	1:7
4	6.250%	93.750%	1:15
5	3.125%	96.875%	1:31

The decay of parent isotopes can be expressed using a simple exponential equation. Given below is the relationship between isotope abundance and time:

$$N_P = N_0 e^{-\lambda t}$$

where N_0 is the original number of parent atoms, t is time elapsed (in years), and N_P is the number of parent atoms remaining after time t. Lambda (λ) is the decay constant (the fraction of atoms that will decay per year). This equation is used to solve for the number of atoms remaining from an initial amount after a particular length of time, or can be rearranged to solve for age (time), if one knows the starting and ending abundances of the parent isotope. One useful form of this relationship is the *age equation*, shown below, which indicates the age of a sample with respect to the number of parent (N_P) and daughter (N_D) atoms currently present.

$$t = \frac{1}{\lambda}\ln(1 + \frac{N_D}{N_P})$$

Relative Age Dating

Absolute age dating is not directly applicable to all rock types. It also requires the time, labor, and expense of laboratory analysis and is therefore not practical for all situations. Often it is sufficient instead to rely on methods of relative age dating to establish the chronological sequence of events recorded in the rock record. Relative age dating does not generally provide any numeric age for a unit or event, but establishes age relative to other units or events (younger than X or older than Y). Of course, if some parts of the sequence *can* be dated absolutely, this will provide absolute constraints on the possible ages of the other layers. Five stratigraphic principles are generally used to evaluate relative age relationships.

1. <u>Principle of original horizontality.</u> Sediments are deposited in flat-lying or nearly flat-lying layers, forming horizontal sedimentary rock strata.

2. Principle of superposition. In a sequence of undeformed sedimentary rock layers, the oldest are on the bottom and the youngest are on the top.

3. Principle of cross-cutting relations. Geologic features (intrusions, faults, etc.) are younger than the rocks that they cut.

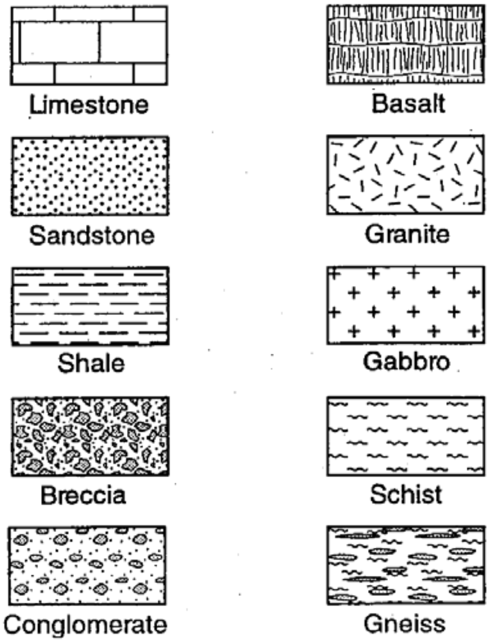
4. Principle of inclusion. A distinct physical fragment of a rock incorporated or included within another host rock is older than that host rock.

5. Principle of unconformities. Certain surfaces (unconformities) between layers indicate that a significant amount of time elapsed between the deposition of one layer and the next. Rocks from that intervening period are not preserved at that location, often because they were removed by erosion prior to the deposition of the younger layer. There are three types of unconformities:

    a. Angular unconformity. Strata below the unconformity are angled with respect to the unconformity. This indicates tilting and erosion of the older layers before the younger layers were deposited.

    b. Nonconformity. Sediments are in contact with older intrusive igneous or metamorphic rock, indicating that the older material was exposed at the surface via erosion before the younger sediments accumulated.

    c. Disconformity. A stratum of much older sediment is immediately under a much younger one, often separated by an erosional surface. This indicates either a lengthy hiatus in sedimentation or, more likely, the removal of some layers before sedimentation resumed.



Key to Lithographic Patterns

Relative and Absolute Dating with Fossils

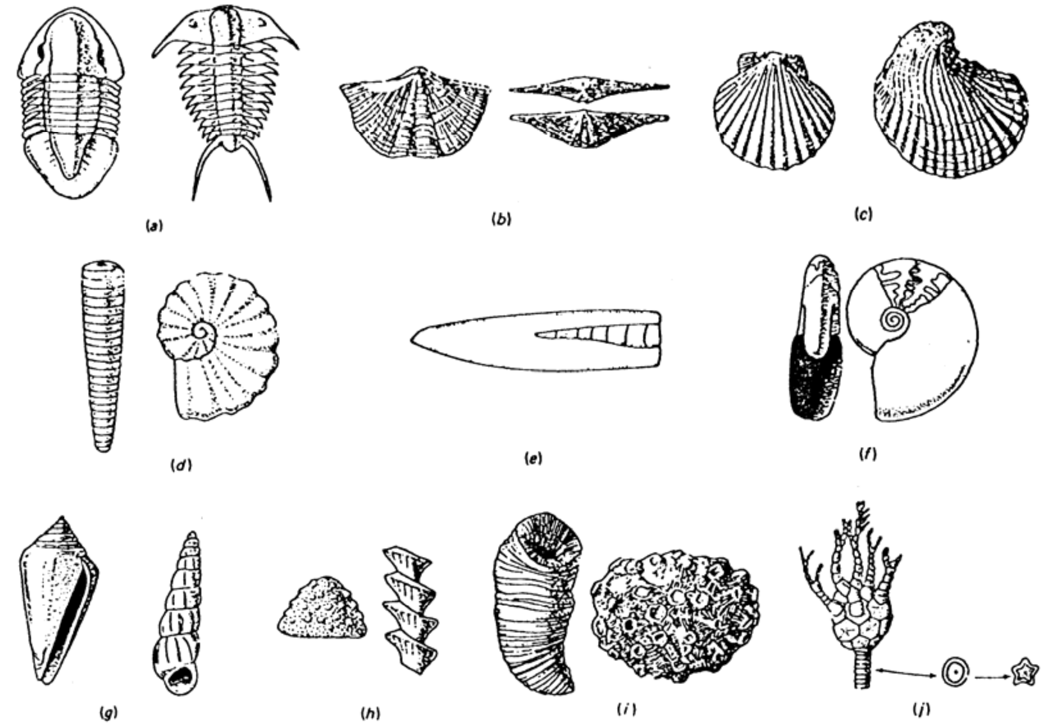
Fossils are immensely useful in dating sedimentary rocks. Geologists developed the Geologic Time Scale (the division of time into different eras and epochs) using relative dating and fossils, long before the discovery of radioactivity. Many of the major divisions in geologic time mark the point when either a large category of new life forms first appeared, or when large numbers of species disappeared (mass extinctions). Two examples of mass extinctions are the Permian-Triassic boundary (248 Ma), when nearly 90% of all species went extinct, and the Cretaceous-Tertiary boundary (65 Ma), when the dinosaurs and many other organisms disappeared.

The types and distributions of fossils are often specific to certain geologic time periods. Particularly useful are index fossils: fossils with wide geographic distribution, distinctive characteristics, and a short duration of existence as a species. Index fossils permit the relative ages of sediments to be correlated with other layers worldwide, by means of which a globally consistent sequence of ages was established in the mid-1800s. Since the early 1900s, radiometric dating has been used to assign absolute ages to the events of the Geologic Time Scale. Now that the fossil record has been calibrated in this fashion, it is possible to determine absolute ages of sedimentary rocks on the basis of fossils alone.

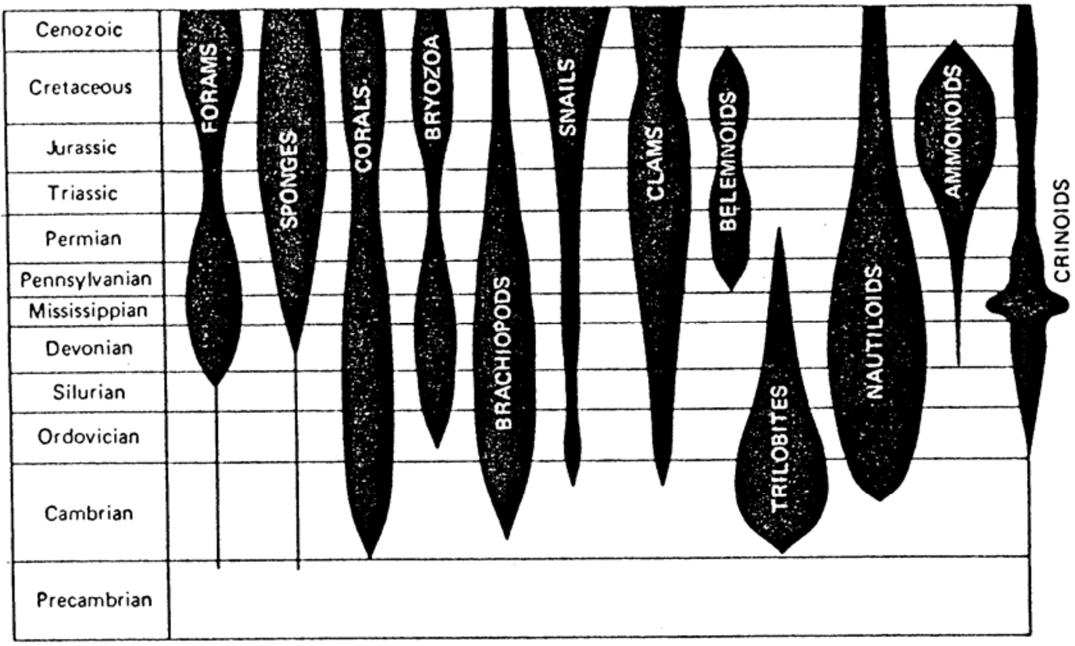
Although a detailed study of paleontology is outside the scope a course in physical geology (as opposed to historical geology), it is worthwhile to become familiar with the appearance of a few common fossils. The fossil content of a rock also provides evidence of depositional environment, though care must be taken to distinguish between the probable habitat and the probable resting place of a fossil. As one example, fossil wood is commonly found in shallow marine sediments. This does not indicate that trees used to live in the shallow ocean, but instead that dead wood is often transported to such a setting before it sinks and is buried.

Marine invertebrates (animals without backbones) are typically useful as index fossils, since they are widespread, readily recognized, and have distinctive preserved hard parts, such as shells. They often are found preserved in the sediments in which they lived, though post-mortem transport is still a possibility to consider. Many of these groups have persisted throughout most of the fossil record, but uniquely identifiable species within each group typically have had much briefer ranges and identifiably restricted habitats.

One final point of concern is the possibility that a fossil might itself be eroded, transported, and deposited in a new sediment of much younger age. Such reworked fossil material is quite unusual and is most often recognized easily by evidence of post-fossilization weathering of the specimen, which was simply another clast at that point in its history. Since many common fossils are made of carbonates, they typically would not be expected to have survived erosion and transport in the first place, which may account for their scarcity in reworked sediments.



Representative sketches of common groups of invertebrates: (a) trilobite, (b) brachiopod, (c) pelecypod (clam), (d) nautiloid, (e) belemnoid, (f) ammonoid, (g) gastropod (snail), (h) bryozoan, (i) coelenterata (coral), and (j) crinoid.



Generalized geologic ranges of the common invertebrate groups. Widths are proportional to fossil abundance (number of species in that group at that time).

The Geologic Time Scale

Era	Period		Epoch	Duration in Millions of years	Millions of years ago
Cenozoic	Quaternary	Neogene	Holocene	recent	
			Pleistocene	1.8	*1.8*
	Tertiary		Pliocene	3.5	*5.3*
			Miocene	18.5	*23.8*
		Paleogene	Oligocene	9.9	*33.7*
			Eocene	21.1	*54.8*
			Paleocene	10.2	*65.0*
Mesozoic	Cretaceous			79	*144*
	Jurassic			62	*206*
	Triassic			42	*248*
Paleozoic	Permian			42	*290*
	Carboniferous	Pennsylvanian		33	*323*
		Mississippian		31	*354*
	Devonian			63	*417*
	Silurian			26	*443*
	Ordovician			47	*490*
	Cambrian			53	*543*
Precambrian					

Part 1. Absolute Age Dating

1. What percentage of a parent isotope remains after 2.5 half-lives have elapsed?

2. If 35% of the parent isotope remains, how many half-lives have elapsed?

3. Analysis of a sample of potassium feldspar crystals shows 38 parts-per-million (ppm) ^{87}Rb and 2 ppm ^{87}Sr, the daughter isotope of ^{87}Rb.

    a. What percentage of the original ^{87}Rb remains?

    b. How many half-lives have elapsed since crystallization of the potassium feldspar?

    c. How old are the potassium feldspar crystals?

    d. If these crystals were collected from a granite pluton, what does the age of the feldspar imply about the pluton?

    e. If these crystals were collected from a gneiss (a high-pressure, high-temperature metamorphic rock), what does the age of the feldspar imply about that gneiss?

    f. If these crystals were collected from a sandstone, what does the age of the feldspar imply about that sandstone?

Part 2. Radiocarbon Dating

Radiocarbon, or ^{14}C, is a radioactive isotope of carbon. This isotope is continually forming in the upper atmosphere due to bombardment of ^{14}N atoms by cosmic rays. All living things take in ^{14}C (in the form of $^{14}CO_2$) through feeding and respiration and, while living, have the same ratio of ^{14}C to ^{12}C as the atmosphere (this ratio is approximately 1 ^{14}C atom per 1,000,000,000,000 ^{12}C atoms). After death, feeding and respiration stop, therefore the only change in ^{14}C content is its decrease by radioactive decay. The decrease in ^{14}C content of a sample dates the time of death of the sample material. The half-life of ^{14}C is about 5730 years. Radiometric dating methods are only useful for about six or seven half-lives because after that there is too little of the parent isotope to measure accurately; thus, radiocarbon dating is only useful for dating items less than about 40,000 years old. The best labs using the most pristine samples can give accurate ages up to about 70,000 years old. Though this is too limited a time period for dating most rocks, radiocarbon is incredibly useful as a tool for archeology and the dating of recent sedimentary deposits.

4. The decay constant of ^{14}C is 0.0001210 yr^{-1}. This is the fraction of ^{14}C atoms in a sample that will decay per year. If a sample contains 1,000,000 atoms of ^{14}C initially, how many atoms will decay during the first year? How many will be left? Show your work.

As a practical matter when measuring ^{14}C in a sample, often what is determined is the *activity* of ^{14}C, which is the number of individual decay events per minute of pure carbon extracted from the sample. The more activity, the more ^{14}C there is in the sample. By substituting activity into the age equation, one is left with:

$$t = -\frac{1}{\lambda}\ln\left(\frac{A}{A_0}\right)$$

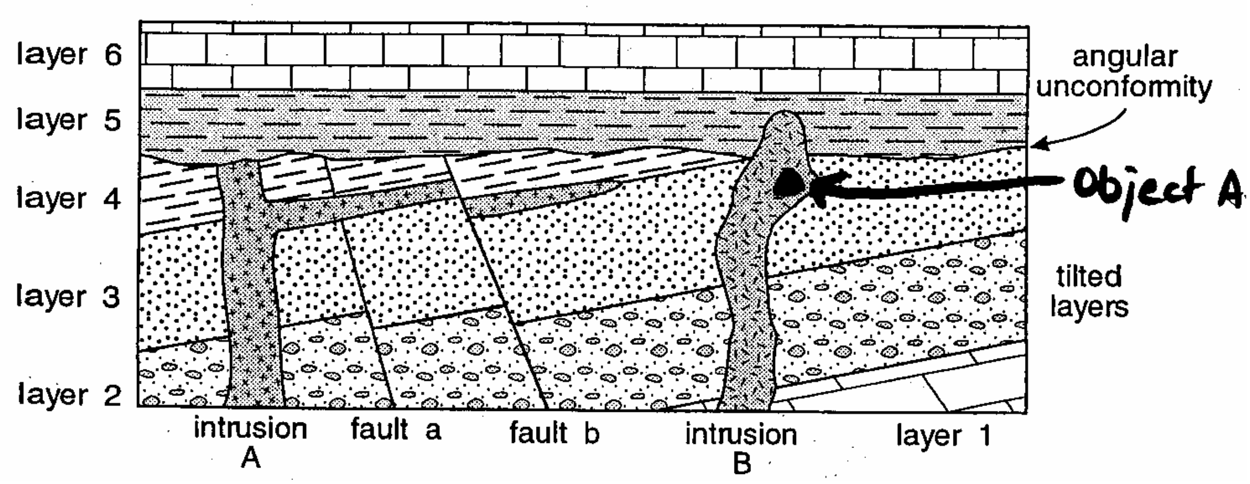
where A is the measured ^{14}C activity of the sample and A_0 is the initial ^{14}C activity. While it is true that the rate of atmospheric production of ^{14}C has not been constant (its history has been worked out in great detail), nevertheless sufficient accuracy often can be achieved by assuming A_0 has been constant.

5. The ^{14}C activity (A) of a sample taken from the Dead Sea Scrolls is 10.7 decays per minute (dpm). The ^{14}C activity of live wood (A_0) is 13.6 dpm. Using the equation above, calculate, in years, the radiocarbon age of the Scrolls. Assume the ^{14}C content of the atmosphere is the same now as it was when the plants were harvested to make the paper for the scrolls.

6. What is the expected activity of a 14,000 year-old sample?

Part 3. Relative Age Dating

7. Use the drawing below to answer the following questions. Use the key to the lithologic patterns.



   a. Which stratigraphic principle shows that a deformational event occurred after the deposition of layers 1-4?

   b. Which principle indicates that layer 2 is older than layer 3?

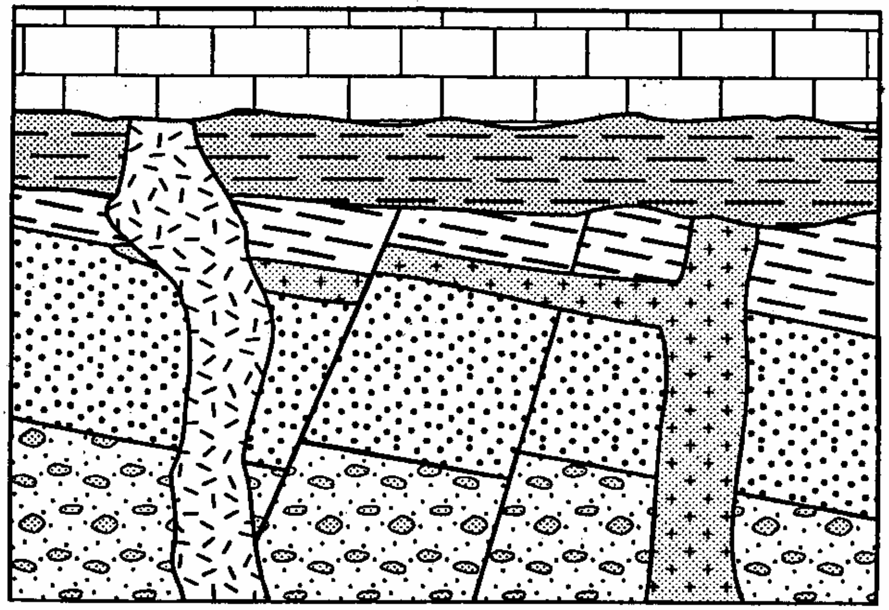
   c. Which principle indicates that intrusion A intruded before a major erosional event?

   d. Which two principles show that layers 5 and 6 were deposited after the erosion of the tilted layers?

   e. Which principle indicates that fault b occurred after fault a?

   f. Which principle indicates that object A is older than intrusion B?

8. Refer to the diagram below and the lithologic key for the following exercise:



   a. **Number** all the sedimentary layers from oldest to youngest.

   b. Label any intrusions with **capital letters** from oldest to youngest.

   c. Label any faults with **lower case letters** from oldest to youngest.

   d. Indicate any folded or tilted layers.

   e. Label all obvious unconformities by type.

   f. List all events (a-c) identified above in the order in which they occurred.

   g. Create a geologic history of this area in fewer than ten sentence using the order you just devised and *assuming*:
      i. Conglomerate is deposited close to mountains
      ii. Sandstone forms on the beach or in the ocean close to shore
      iii. Shale forms in the ocean farther from shore than sandstone
      iv. Limestone forms in the ocean far from the shore
      v. Sea level rising or falling changes the position of the shore

Part 4. Fossil Identification

9. For each specimen, identify the type of invertebrate, its mode of preservation (i.e. mold, cast, trace, or original material), and the relative and absolute ages during which this group existed. If it still exists, specify "through present." Finally, indicate the relative period(s) during which species of this type were most abundant.

	Invertebrate Type	**Preservation**	**Relative Range**	**Absolute Range**	**Most Abundant**
a					
b					
c					
d					
e					
f					
g					

10. If a stratum contains fossils of type d and e, what does this indicate about its absolute age? How would the additional presence of belemnoid fossils change this conclusion?

11. Refer back to the cross-section from Part 3, Question 7, above. If crinoids from the Mississippian Period are found in layer 4 and Jurassic ammonoids are found in layer 5, what can be said about the absolute ages of:

    Intrusion A:

    Intrusion B:

    Object A: