Lab 7: Geologic Time

Introduction

Geological processes have affected the Earth since its inception 4.6 billion (4,600,000,000) years ago. It is difficult for us to imagine the vastness of time which 4.6 billion years represents, or to perceive the amount of time required for many geological processes to occur (e.g., formation of ocean basins or mountain ranges).

The **geologic time scale** organizes the Earth's history into a series of chronologic subdivisions that are defined by important geologic events in the Earth's history (Figure 7-1). The largest of these time subdivision are **eons**, which define major developments in the Earth's evolutionary history (i.e., formation of the Earth, beginning of life). Eons are subdivided into **eras**, which define major life forms (i.e., age of the reptiles). Eras are subdivided into **periods**, which are defined by evolutionary changes in the fossil record. Periods are subdivided into **epochs**, which are defined by biological and nonbiological criteria.

1. (a) The first fossils of animals with hard parts appeared about 570 million years ago. What percentage of geologic time does the fossil record represent? **Show your calculations.**

   (b) Modern humans (*Homo sapiens sapiens*) appeared about 0.04 million years ago. What percentage of the geologic time scale includes the "human occupation of the Earth"? **Show your calculations.**

   (c) When the geologic time scale was first conceived, the Phanerozoic Eon was defined by the presence of fossils in the rock record. **What potential problems might arise from assigning numerical ages to geologic-time-scale boundaries as dating methods improve and/or the rock record is further studied?**

   (d) **Why do you think that Tertiary and Quaternary Periods have greater resolution in their subdivisions (epochs) than those periods comprising the Paleozoic Era?**

Dating Methods

Numerical dating provides a numerical age for a geologic feature or event. There are many methods of numerical dating that involve radioactive decay of naturally occurring elements. For example, the age of the Earth, approximately 4.6 billion years (or 4.6 Ga), has been determined using the decay of radioactive elements, such as uranium. We will not examine these methods in lab; however, you should read that section in your textbook.

Relative dating allows us to place events or rocks in chronological order, but can't tell us if a set of events or rocks is 1,000,000,000 years old or 1,000 years old. Today we will use **stratigraphic principles** and **biostratigraphy** to relatively date sedimentary and igneous rock units.

Eon		Era	Period		Epoch	Ma
Phanerozoic		Cenozoic	Quaternary (Q)		Holocene	0.0117
					Pleistocene	2.58
			Tertiary (T)	Neogene (N)	Pliocene	5.33
					Miocene	23.03
				Paleogene (Pg)	Oligocene	33.9
					Eocene	56.0
					Paleocene	**66.0**
		Mesozoic	Cretaceous (K)			145.0
			Jurassic (J)			201.3 ± 0.2
			Triassic (TR)			**252.17 ± 0.06**
		Paleozoic	Permian (P)			298.9 ± 0.15
			Pennsylvanian (Ᵽ)		Carboniferous (C)	323.2 ± 0.4
			Mississippian (M)			358.9 ± 0.4
			Devonian (D)			419.2 ± 3.2
			Silurian (S)			443.8 ±1.5
			Ordovician (O)			485.4 ± 1.9
			Cambrian (€)			**541.0 ± 1.0**
Precambrian (pC)	Proterozoic	Neo-P	Ediacaran			~635
			Cryogenian			~720
						1000
						2500 ± 200
	Archean					**4000**
	Hadean					**~4600**

Figure 1: Geologic time scale.

A. Determining Numerical Ages

Numerical dates are determined by examining radioactive elements and their products. The radioactive element, or the element that is said to decay, is the **parent isotope**. The element that is left behind after the parent decays is called the **daughter isotope**. Because getting an accurate radiometric date requires knowing the precise amounts of both the parent and daughter isotopes, the rock must have formed in a closed system. Specifically, all of the minerals in the rock must have formed at approximately the same time. This means that most radiometric dating can only be done on igneous and metamorphic rocks. Sedimentary rocks may be made of bits and pieces of rocks that formed at different times, and hence may have amounts of parent and daughter isotopes that are unrelated to the time that the sedimentary rock formed. Isotopes used for dating igneous and metamorphic rocks and minerals include Rb-Sr (rubidium-strontium), U-Pb (uranium-lead), U-Th (uranium-thorium), and K-Ar (potassium-argon). These isotope pairs can be used to date rocks that are generally older than 100,000 years.

Another important radiometric dating isotope pair is ^{14}C-^{14}N (carbon-14 – nitrogen-14). Carbon is an important component of life on planet earth, and so ^{14}C has become a very effective way to date some fossils. Both archeologists and geologists have found this method very useful to date plants and animals, which have been used to constrain the ages of some sedimentary rocks. This isotope pair has its limitations though, as the fossils must be between approximately 100 and 70,000 years old. This method of dating has played a key role in examining some of the earth's more recent climate changes (e.g. global warming and ice ages) and major geologic events (e.g. earthquakes, volcanic eruptions, and tsunamis). Some problems can arise while trying to radiometrically date a rock. For example, sedimentary rocks generally have 'inherited' ages, which come from being made up of older rocks. Heat and pressure can cause some of the daughter and/or parent isotopes to 'leak' from minerals, which can cause inaccurate dates for igneous and/or metamorphic rocks. Sometimes very little of the parent isotope remains, which causes difficulty in accurately calculating a radiometric date. In some instances, small amounts of datable material can also lead to difficulties in getting accurate radiometric dates. Despite these problems, numerical dates are still successfully used to solve significant problems in geology.

2. As an example of how radioactive decay works, the TA may lead a small demonstration. Each student will receive one penny and stand up. At this point all of the students are parent isotopes. Every student should then flip their penny. Students whose penny lands heads-up should sit down. These students who are now seated are now daughter isotopes. The remaining standing students should again flip their penny, and students whose penny lands heads-up should sit down to become daughter isotopes.
    (a) **How many students started out standing?**
    (b) **How many daughter isotopes were produced after the first flip of the pennies?**
    (c) **How many parent isotopes remained after the second flip of the pennies?**
    (d) **How well does each flip (or half-life) actually eliminate half of the remaining parent isotopes?**
    (e) **Would (d) be improved by making the sample population smaller or larger? Why?**

3. Sometimes numerical dates are referred to as 'absolute dates' because they give a quantifiable age to the rock. **Why might these numerical dates not always be absolute dates?**

4. In metamorphic rocks, minerals form at different temperatures and pressures. **What could this potentially do to radiometric dates from a metamorphic rock?**

B. Determining Relative Ages

Stratigraphic Principles

The **stratigraphy**, or layering, of rock units can tell us quite a lot about the relative ages of those units. There are several principles that help us date geologic rock units in a relative sense. It is important to understand these principles because they are very important to unraveling the history of the Earth, layer by layer. These principles are extremely straight forward, and they are used every day by geologists.

(1) The **Law of Original Horizontality** states that rock **strata** (layers) are originally deposited/formed as horizontal layers. Later geologic processes are responsible for tilting and/or folding those strata. This law applies primarily to sedimentary rocks, and most volcanic rocks.

(2) The **Law of Superposition** is based on the observation that each **stratum** (individual layer) is deposited on top of the previously deposited stratum. Therefore, unless the layers of rock have been overturned by subsequent processes, the oldest layers are at the bottom and the youngest layers at the top. Again, this law applies primarily to sedimentary rocks and most volcanic rocks.

(3) The **Law of Cross-Cutting Relations** states that a feature cutting across another feature is younger than the object it is cutting. For example, a crack in a concrete sidewalk is younger than the concrete it cuts, and an igneous intrusion is younger than the surrounding rock it intrudes.

(4) The **Principle of Inclusion** states that sedimentary clasts are older than the stratum that contains them. For example, the igneous clasts in a conglomerate formed before the conglomerate itself. Think about walnuts in fruitcake. The walnuts had to grow and be harvested before they could be suspended in the fruitcake.

Biostratigraphy

Fossils are the preserved remains or traces of animals, plants, and other organisms – for example, bones, leaves, and imprints (like footprints). They are frequently found in sedimentary rock, and are useful in assigning relative ages to strata. The order in which specific fossils appear in the geologic record is call the **fossil succession**, which is marked by the earliest (lowest) and latest (highest) appearance of a particular type of fossil. It forms the basis for the worldwide correlation of fossiliferous rocks with the geologic time scale.

Certain plants or animals lived only for brief periods of geologic time. Therefore, their fossil remains can be used as an index or guide to that time, and consequently are called **index fossils** (Figures 7-2 and 7-3). For example, a marine animal called a **trilobite** lived only during the Paleozoic Era. Rocks containing trilobite fossils can be inferred to have been deposited during the Paleozoic.

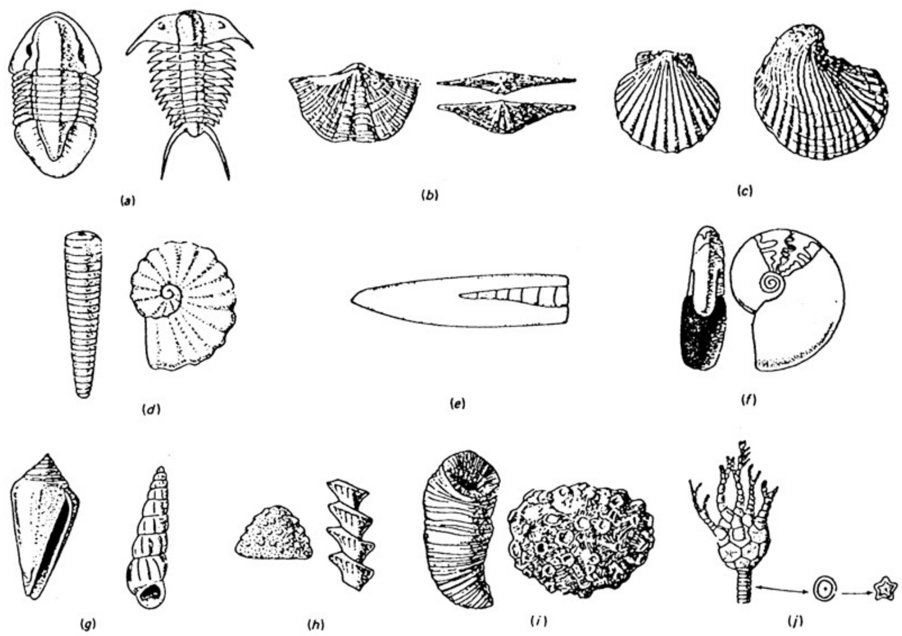


Figure 7-2: Representative sketches of the main groups of invertebrates. (a) trilobite; (b) brachiopod; (c) pelecypod (clam); (d) nautiloid; (e) belemnoid; (f) ammonoid (ammonite); (g) gastropod (snail); (h) bryozoan, (i) coelenterata (coral); and (j) crinoid.

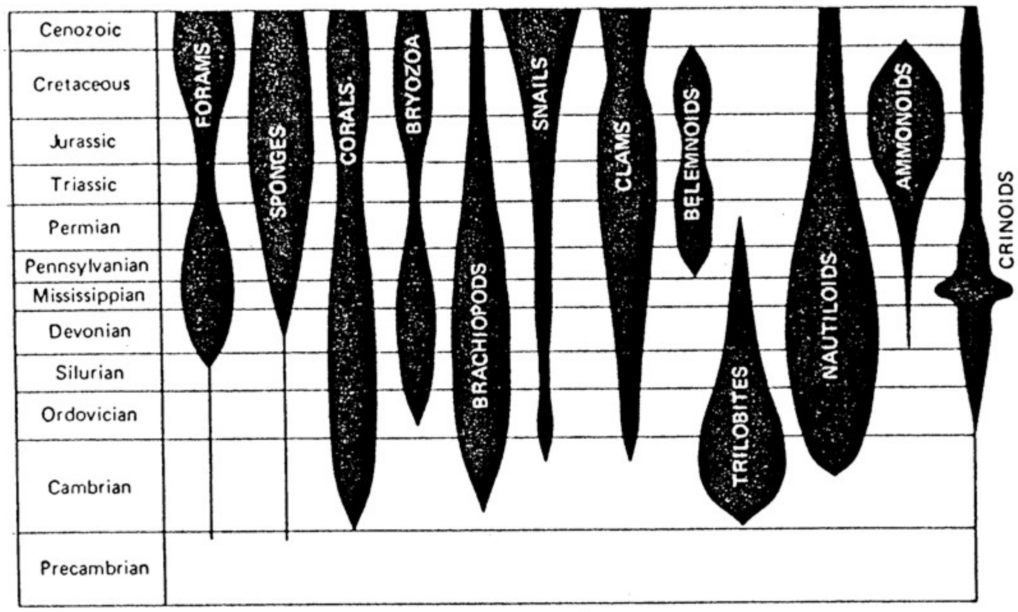


Figure 7-3: Generalized geologic ranges of the main invertebrate groups. The width of the lines indicates fossil abundance.

5. On the side table are three fossil samples. Using Figures 7-2 and 7-3, **identify the invertebrate group to which each fossil belongs, and indicate the range of geologic period(s) in which each lived.**

Specimen #	**Invertebrate Group**	**Range of Geologic Period(s)**
Fossil A		
Fossil B		
Fossil C		

Unconformities

When rocks get eroded, the geologic time that was represented by those rocks is erased. These gaps in the rock record are called **unconformities**, and they can be caused by erosion or non-deposition. There are three basic kinds of unconformities: nonconformities, disconformities, and angular unconformities. A nonconformity is where sedimentary rock rests on top of older plutonic or metamorphic rocks. A disconformity is where some geologic time is missing between two parallel layers of rock. An angular unconformity is where older parallel layers of rock that have been tilted intercept and are cut-off by a younger layer of rock that is deposited horizontally. Sometimes the fact that layers of rock are missing also reveals information about the geologic history. Figure 7-4 displays examples of these unconformities.

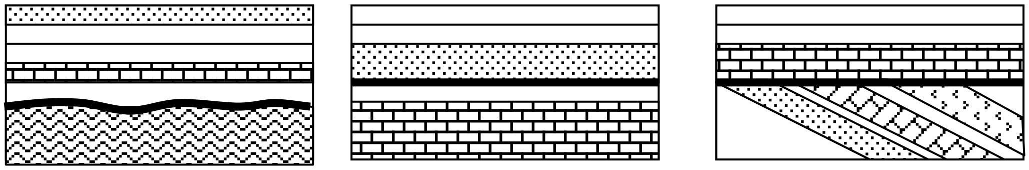
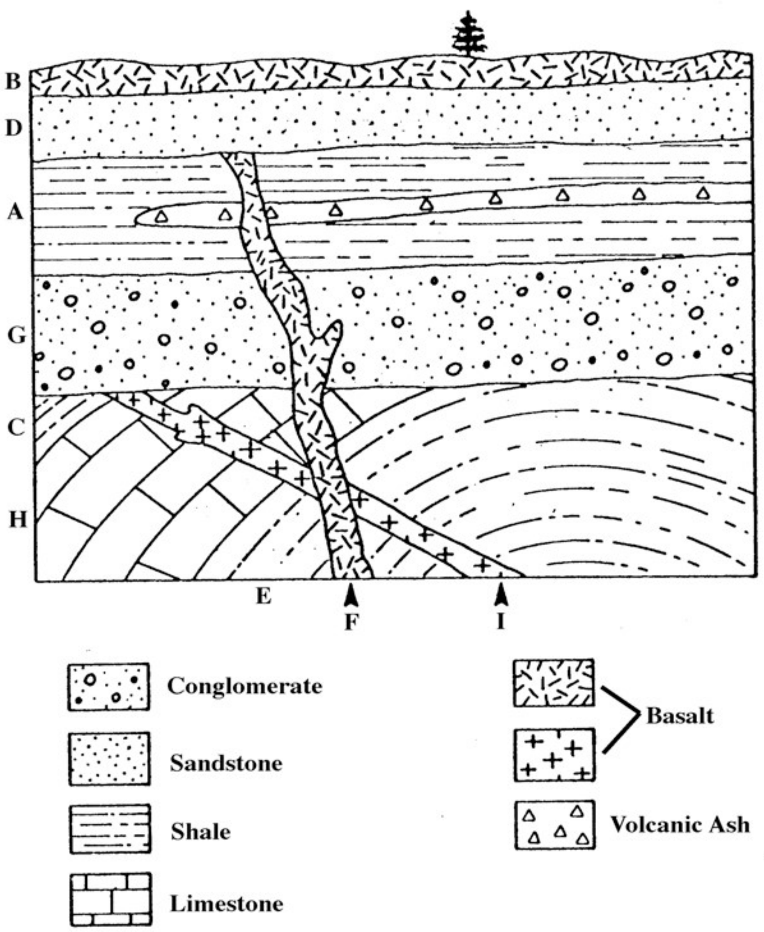


Figure 7-4: The 3 basic kinds of unconformities: a) nonconformity; b) disconformity; c) angular unconformity. These are cross-sectional views through rocks. The dark line represents the unconformity.

6. Examine the diagram below to answer the questions (a) through (h).
   (a) **List the relative ages of units A through I in order from oldest to youngest.**

   Oldest ____ ____ ____ ____ ____ ____ ____ ____ ____ Youngest



   (b) **Which stratigraphic principle did you use to determine the relationship between unit I and units C, E, and H?**

(c) **What kind of contact is between unit C and unit G? Discuss how this contact formed.**

(d) **Hypothesize as to the events that occurred between the deposition of these two units.**

(e) **How has the energy of the depositional environment changed between the deposition of unit G and unit A?**

(f) **Unit F has been numerically dated at 60 Myr (million years) and Unit I has been numerically dated at 220 Myr. Given this information, what can be said about the ages of units G and A relative to units F and I?**

(g) **Would you expect to find Fossil C, from question 5, in units G and A?**

(h) **If unit C contained belemnoids and trilobites, how old might these deposits be?**

7. Although it may seem strange, the storage of radioactive materials can be related to geologic time. It is believed that after approximately 10,000 years many of the nasty radioactive materials contained in this waste will have experienced one or more (the more the better!) half-life. This means that this waste needs to be stored in a 'facility' that will be safe from disturbances for at least 10,000 years.

(a) **How many generations of humans will come and go during this time? (Assume that the very optimistic life span of any one generation is 100 years.)**

(b) **What are some potential problems with the assumption that the waste would be untouched for 10,000 years?**

(c) **Assuming humans persist for tens of thousands of years into the future, what are some geologic problems to consider? Where might we store this waste (think on a tectonic plate scale)?**

(d) **What are some problems that future geologists may have if they tried to date rocks that were storage facilities for radioactive waste?**

Geologic Maps

Geologic maps show the **lithology** (rock or sediment type) exposed at the Earth's surface. These maps depict information such as rock type and age, orientation of rock layers, and geologic structures, such as folds and faults. This type of information is not only of academic interest, but it is also necessary for locating economic resources (petroleum, ores, water, etc.) and determining potential geologic hazards (earthquakes, landslides, etc.) of a given area.

Geologic maps typically show contour lines, so the geology can be interpreted in the context of the topographic landscape. Geologic cross-sections may also be provided to show details about subsurface geology. It is imperative to carefully read the legends, explanations, and other important information provided on the geologic map. Geologic maps also show chronologic information, which is important to infer the geologic history of the mapped area. Standard symbols for designating the age of rock or sediment units on geologic maps are shown below (Table 7-1). An updated, comprehensive geologic time scale is shown in Figure 1 (produced by the Geological Society of America, 2009).

Era	*Period*	*Symbol*
Cenozoic	Quaternary	Q
	Tertiary	T
Mesozoic	Cretaceous	K
	Jurassic	J
	Triassic	TR
Paleozoic	Permian	P
	Pennsylvanian	IP
	Mississippian	M
	Devonian	D
	Silurian	S
	Ordovician	O
	Cambrian	Ꞓ
Precambrian		pꞒ

Table 7-1: Standard symbols for designating chronologic units on geologic maps

Use the geologic map of Washington provided by your lab instructor to answer questions 8-10.

8. Most geologic map keys are arranged chronologically from youngest to oldest sediment/rock units; however, this one is not. **How is the legend of this map arranged?**

9. (a) **What lithologic unit (rock type) is represented by the darker brown color that covers much of eastern Washington forming the Columbia Plateau?**

   (b) **What lithologic (rock type) unit represents the summit region of Mt. Rainier?**

(c) **How does the age of volcanic rocks near the summit of Mount Rainier compare to the age of the Columbia Plateau volcanism?**

10. (a) **Where are the oldest lithologic units located in Washington State (northeast, northwest, southeast, or southwest part of the state)?**

(b) **How old are the lithologic units on south Whidbey Island, Washington?**