

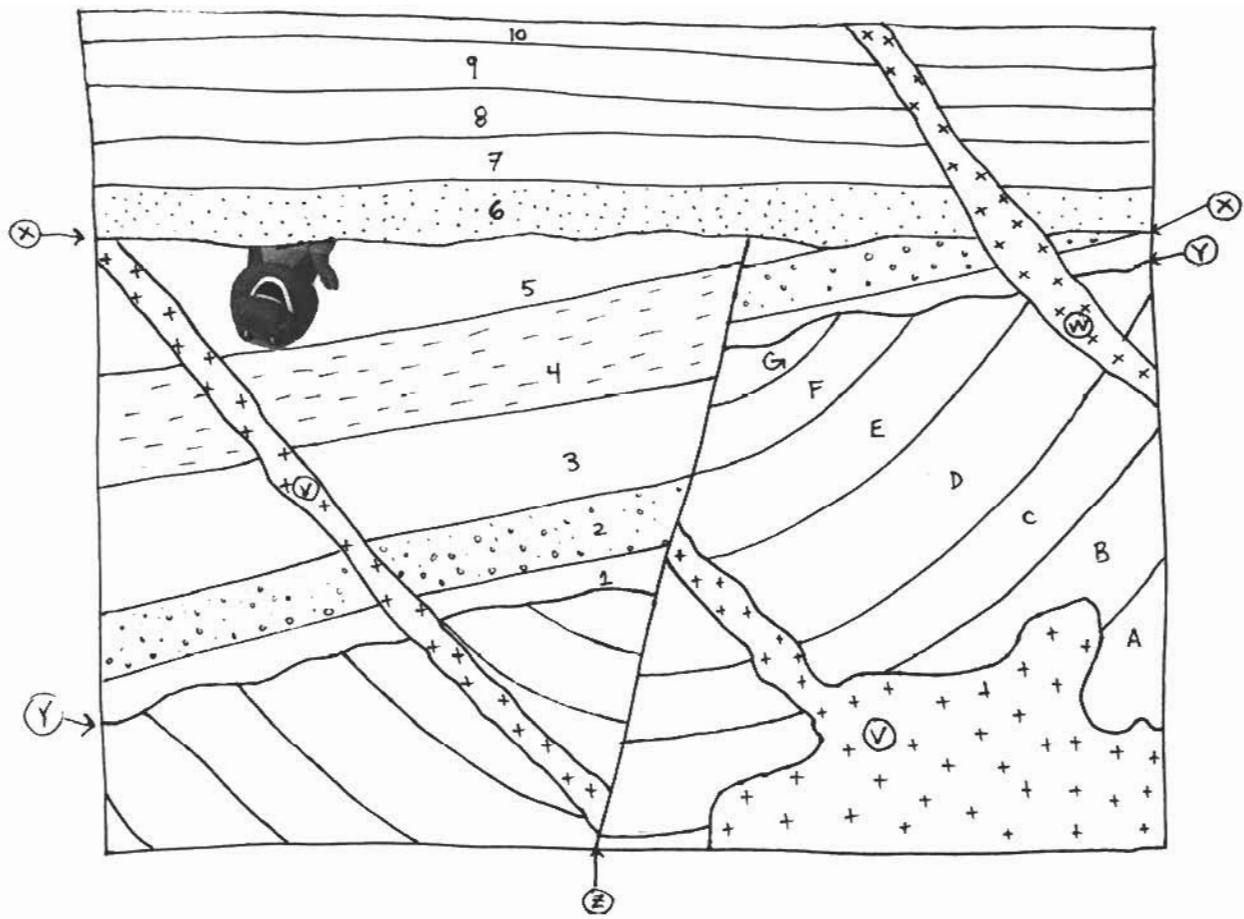
**12.102 Problem Set #2**  
**GEOLOGIC TIME & RATES OF GEOLOGIC PROCESSES**  
**Due Sept. 27, 2005**

**I. Read the articles on the webpage about Yucca Mtn. (in chronological order)**

**II. RELATIVE TIMING RELATIONSHIPS (Ch. 3 - MWM)**

The principles of Superposition and Cross-Cutting Relationships have been used to reconstruct the geologic history of the cross-section on the following page. A cross-section shows the distribution of rock units in a vertical slice through the earth, providing a view of the geology from the surface (top of the box) to some depth within the earth (bottom of the box). Note that the top left side of the box is in the north and the top right side of the box is in the south. This north-south cross-section would project as a line in a map view (looking down on the earth's surface) of the same area. To solve this geologic riddle you need to determine the relative ages of each rock unit and the processes that operated on them (faults, tilting, volcanism, intrusion of dikes, deposition of volcanic units, etc.). As a matter of both common sense and convention geologists start with the oldest rock units and events and work towards the youngest events with the oldest at the bottom and the youngest at the top. The order of events in this cross-section have been worked out in order to aid you with the following problem.

Some important points: It is not always possible to decipher the relative ages of certain events, and they must be clumped into groups (as is done on the next page with the tilting of sedimentary units 1-5, the intrusion of dike V and movement along fault Z.) It is often helpful to find markers of absolute time, as we see in layer 5. In this case, the untimely demise and fossilization of Barney marks a distinct point in time. Provided we know when that event occurred (hopefully soon), then we know when layer 5 was deposited and can begin to constrain the time of tilting, faulting and the intrusion of V. The fossil record is often key in placing absolute time on sedimentary rocks, because certain species are known to have existed during certain periods.



Youngest



Intrusion of W

Deposition of 6-10

Erosion along X

Movement on fault Z

Intrusion of V

Tilting of 1-5

Deposition of 1-5

Erosion of A-G on Y

Folding of A-G

Deposition of A-G

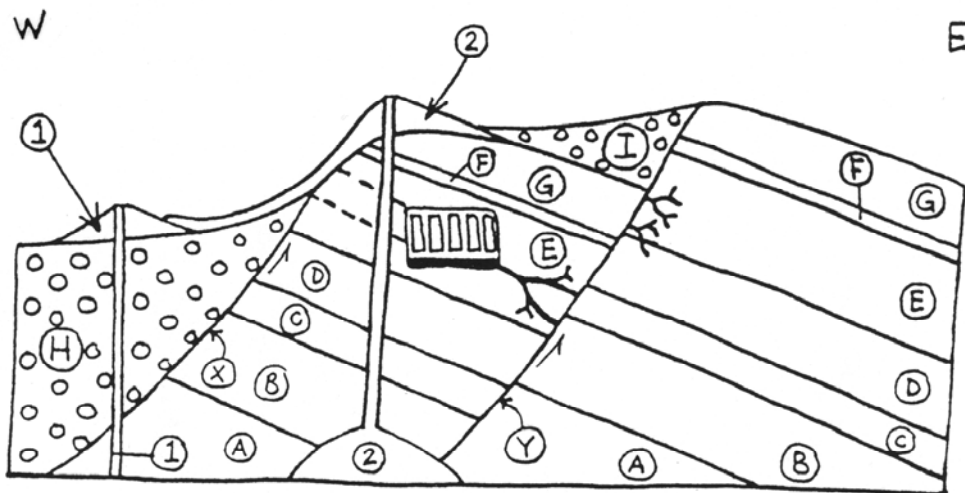
Cannot tell order

Oldest




1) Yucca Mountain, Nevada, located about 120 miles west of Las Vegas on the Nuclear Test Site, was chosen by the U.S. Congress as *the* storage site for all U.S. high level nuclear waste pending a suitability study. Congress mandated that the site must be deemed safe for 10,000 years. However, recent earthquake activity and pre-historic volcanic activity in the area around Yucca Mtn. represent potential problems for final approval of the site.

It's 5000 years from now. The Yucca Mtn. site was approved and waste was actually stored there early in the 21st century. The cross-section below shows the distribution of rocks layers and structures (faults, volcanoes, etc.) in the storage area assuming the government scientists guessed wrong about the geologic stability of the site. Suppose that all records from the early 21st century were lost long ago and you've been commissioned to reconstruct the sequence of events. Use the relative timing principles you have learned to determine the sequence of **all geologic events, installation of the waste storage facility, and leakage of waste from the storage facility**. Present your results using the format shown in the example on the previous page (30 pts.)

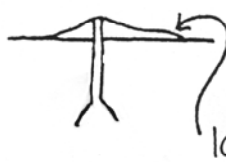



EXPLANATION

 conglomerate & breccia

 fault

 felsic volcanic rocks

 volcano & feeder dike  
lava flow

 waste storage facility  
access tunnel projected onto the plane of the cross-section  
pathway of waste that leaked

## II. ABSOLUTE TIME

### Dating rocks

We now venture back to the the 1980's, and research has begun to determine whether or not Yucca Mountain is a safe place to store nuclear waste. It turns out that you are a geochronologist, and have been called upon to date some of the volcanic rocks in the area to determine if the area is a volcanic hazard. The DOE has given you samples of felsic tuff (a type of volcanic rock you will learn about in the lab momentarily) which represent the rocks that the repository will be directly in (units D and E from problem 1). It is your job to date these rocks using the  $^{87}\text{Rb}/^{87}\text{Sr}$  method and tell the DOE whether they should put waste in them.

The Rb-Sr method is based on the following reformulation of the decay equation:

$$\left(\frac{^{87}\text{Sr}}{^{86}\text{Sr}}\right)_{\text{measured}} = \left(\frac{^{87}\text{Sr}}{^{86}\text{Sr}}\right)_{\text{initial}} + \left(\frac{^{87}\text{Rb}}{^{86}\text{Sr}}\right)_{\text{measured}}(e^{\lambda t} - 1)$$

where  $\left(\frac{^{87}\text{Sr}}{^{86}\text{Sr}}\right)_{\text{initial}}$  is the  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of Sr present before the radioactive clock began to tick and  $\lambda$  is the decay constant for  $^{87}\text{Rb}$ . Each isotope is divided by nonradiogenic  $^{86}\text{Sr}$  since the mass spectrometer (used to determine the isotopic composition) measures ratios, not absolute abundances.

Typically, the Rb and Sr isotopic compositions are measured for individual minerals in a rock sample, as well as a representative aliquot of the whole rock. You determine the ratios below in your mass spectrometer for phenocrysts from the porphyritic ash flow tuff in which the radioactive waste is to be stored.

	$\left(\frac{^{87}\text{Rb}}{^{86}\text{Sr}}\right)_{\text{measured}}$	$\left(\frac{^{87}\text{Sr}}{^{86}\text{Sr}}\right)_{\text{measured}}$
plagioclase	0.071	0.7012
alkali feldspar	12.720	0.7130
whole rock	24.352	0.7237
biotite #1	35.737	0.7347
biotite #2	56.852	0.7540

Determine the age of the rock (ie the time of eruption) using the following methods and using a half-life for  $^{87}\text{Rb}$  of  $4.88 \times 10^{10}$  years. PLEASE SHOW ALL OF YOUR WORK (15 pts each).

- 2) Assuming an initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of 0.7016, calculate the "model" age (an age based on an assumed initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio) for each mineral and the whole rock. Explain the results.

- 3) Note that the decay equation written above is a linear equation. Utilizing this fact, calculate the age of this rock without making assumptions about the initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio. How does this compare to the model ages?
- 4) Based on the geochronology *and* your expert geologic opinion, what will you report to the DOE? Will you recommend that this age proves the area is volcanically safe for the storage of nuclear waste, will you tell them the project is a bust, or neither?
- 5) What are the assumptions that go into the dates calculated above? To illustrate a point, let's take the U-Pb system, instead of the Rb-Sr system (it turns out the Rb-Sr system is rarely used for anything anymore). Using the half-lives for  $^{238}\text{U}$  and  $^{235}\text{U}$  listed in the following section, write a set of parametric equations for the dual decay of U to the two daughter products (don't remember what they are? Look them up). Then, plot a curve that represents equal time for the two decay schemes (the abscissa and ordinate axes should be the ratios of parent to daughter product)- this is called the concordia curve, and is one of the most useful tools in modern geochronology. What does it mean if you date a high-U mineral and it does not fall on this curve? Why is this useful to know when dating a mineral or rock? So why does no one use Rb-Sr anymore?

### Rates of Geologic Processes

- 5) A decay scheme is only useful as a geochronometer if there are enough atoms of both parent and daughter to measure (ie the age you are trying to determine is within reasonable range of the parent isotopes half-life). For the following radioactive nuclides, calculate the time required for both 10% and 90% of the original number of atoms to decay. This will be a reasonable proxy for a time range over which the decay scheme is useful as a geochronometer (15 pts). [ An easy way to do this is to use the decay equation given in class, and then use a spreadsheet or MATLAB to do the calculations]

<u>Parent</u>	<u><math>T_{1/2}</math> (years)</u>	<u>Parent</u>	<u><math>T_{1/2}</math> (years)</u>
$^{87}\text{Rb}$	$4.8 \times 10^{10}$	$^{230}\text{Th}$	$7.54 \times 10^4$
$^{238}\text{U}$	$4.47 \times 10^9$	$^{14}\text{C}$	$5.73 \times 10^3$
$^{235}\text{U}$	$7.04 \times 10^8$	$^{39}\text{Ar}$	$2.69 \times 10^2$
$^{10}\text{Be}$	$1.6 \times 10^6$	$^{210}\text{Pb}$	$2.23 \times 10^1$
$^{36}\text{Cl}$	$3.01 \times 10^5$	$^3\text{H}$	$1.23 \times 10^1$

- 6) There are many other geologically interesting (and potentially dangerous) events or processes that pertain the Yucca Mtn. project. Using insights gained from 5), list the radioactive nuclides appropriate (based on time alone) for determining the age or duration of the following processes, events or materials (5 pts each). Also, explain in one sentence why dating these may (or may not) be helpful to the Yucca Mtn. project.

Age of groundwater  
( $\approx 2 \times 10^5$  yrs)

Transport of nuclear waste in groundwater  
( $< 1 \times 10^2$  yrs)

Duration of the last glaciation 'event'  
( $\approx 1 \times 10^3 - 1 \times 10^4$  yrs)

The last notable meteorite impact in Nevada  
( $1.0 \times 10^8$  yrs ago)

The amount of time homo sapiens have been on earth

$(2.5 \times 10^6 \text{ yrs})$

Residence time of nuclear fallout in atmosphere  
 $(< 2 \times 10^{-2} \text{ yrs})$

7) What other factors describe whether or not an isotopic decay scheme is suitable for dating a certain event (10 pts.)

#### IV. POLITICS

- 8) An intelligent decision regarding the Yucca Mtn. Controversy will require an appreciation and fundamental understanding of geologic time and the rates of geologic processes in relation to rates of human activities. Use what you have learned in this problem set (keep in mind that the numbers and geologic cross-sections in parts I and II were invented for educational purposes, though the concepts are important), the reading given on the webpage, and any other sources you wish, to draft an ~2 page opinion-editorial piece on the Yucca Mountain project. Questions you may wish to address: Is Yucca Mtn. a safe place for our waste (ie, what does the science tell us)? What are the roles of science and politics in the decision-making? If not Yucca Mtn., where? (50 pts)