The Geology of Pacific Northwest Volcanoes, Mountains and Earthquakes

GEO142 Lab 4: Radioactive Decay and CRB Ages

Name: ____ Date: _______________

The Columbia River Flood Basalts (CRB) geologic province is a region of eastern Washington, eastern Oregon, the extreme northwest Nevada, and western Idaho where continental flood basalts erupted from fissure eruptions that eventually flowed westward toward the ocean via the ancient Columbia River Valley. The region through which they flowed is now called the Columbia River Gorge. These eruptions span from ~17 through ~5.5 million years.

There is a new brewery interested in developing a parcel that has access to a good supply of water. Interflow zones (top and bottom of CRB flows) and fault zones can form either barriers or pathways to subsurface water flow (read about hydrogeology). Your client needs to know the location of these basalts in order to better decide which land to purchase.

Your Geologic consulting company has been hired to do some drilling in search of a particular member of the CRB. Due to the local tectonics and faulting, the locations of different CRB members are poorly constrained in the region. You are tasked to determine which parcel has access to the Basalt of Lolo, part of the Priest Rapids member of the Wanapum Basalt. The drilling contractor has collected subsurface samples for you to analyze. Your coworker has already submitted the samples to the mass spectrometry lab and the results have been delivered to you electronically.

First we will review your knowledge of log scales and exponential functions. Then we will use the mass spectrometry results to determine the age of each sample. Finally, we will use these age estimates to determine which CRB member is accessed from each parcel. You will submit a report to your client listing the parcel(s) they should purchase.

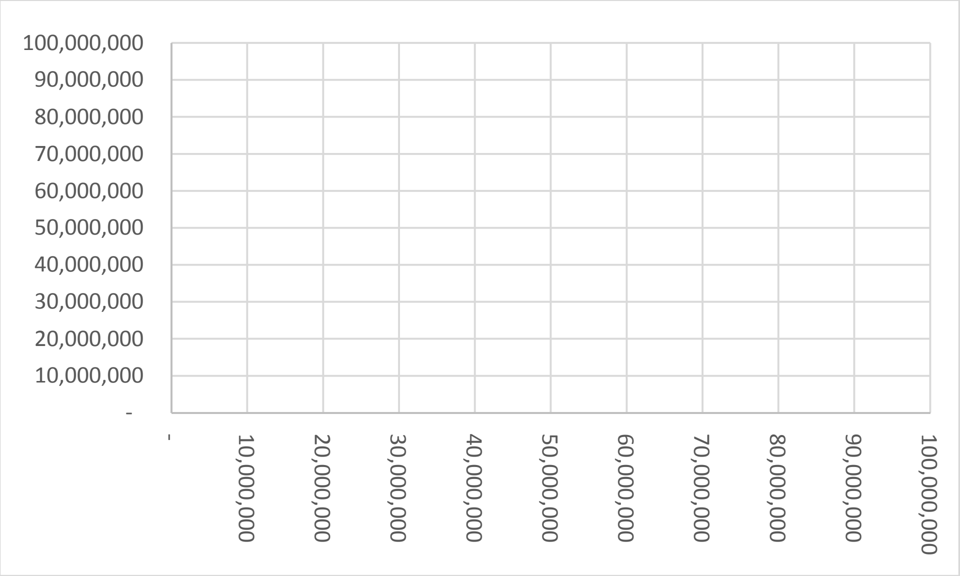
I. Log Scale and Exponential Functions

Exponentiation is a mathematical operation, written as **b^n**, involving two numbers, the **base b** and the **exponent (or power) n**. are ____. For example $10^2 = 10 X 10 = 100$ and $10^3 = 10 X 10 X 10 = 1,000$. Solve the following:

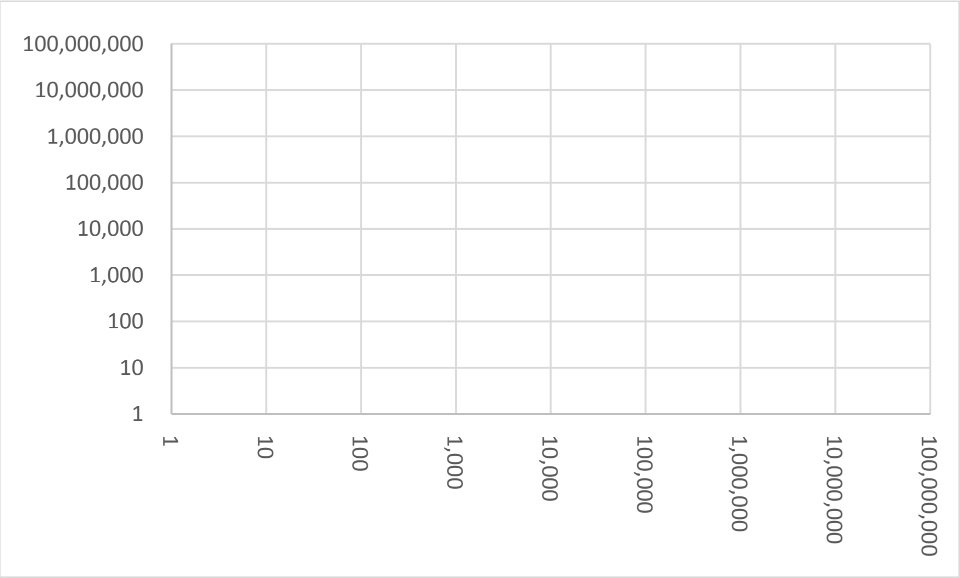
10^1 = _________ 10^2 = _________ 10^3 = _________ 10^4 = _________

10^5 = _________ 10^6 = _________ 10^7 = _________ 10^8 = _________

Plot on a Normal-Normal scaled grid sheet:



Plot of a Log-Log scaled grid sheet:



What is the benefit to plotting on a Log-Log scaled grid?

Exponents can be negative. In this case, they are placed in the denominator (the bottom of a fraction. For example $10^{-2} = 1 / 10^{2} = 1 / 100 = 0.01$ and $10^{-3} = 1 / 10^{3} = 1 / 1000 = 0.001$. Solve the following:

10^{-1} = __________ 10^{-2} = __________ 10^{-3} = __________ 10^{-4} = __________

10^{-5} = __________ 10^{-6} = __________ 10^{-7} = __________ 10^{-8} = __________

The **logarithm** (Log) of a number is the exponent to which another fixed value, the base, must be raised to produce that number. For example, the logarithm of 1,000 to base 10 is 3, because 10 to the power 3 is 1000. This is written like this: Log$_{10}$100 = 2. Solve the following:

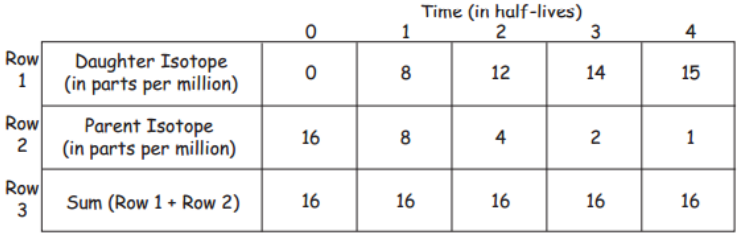
Log$_{10}$1,000 = __________
Log$_{10}$10,000 = __________
Log$_{10}$100,000 = __________

Log$_{10}$1,000,000 = __________
Log$_{10}$10,000,000 = __________
Log$_{10}$100,000,000 = __________

A special number used in science is “e.” e is an irrational and transcendental constant approximately equal to 2.718 281 828. Natural Logarithms use e as a base: ln = Log$_e$. Calculators and computer programs know how to solve calculations of natural logs.

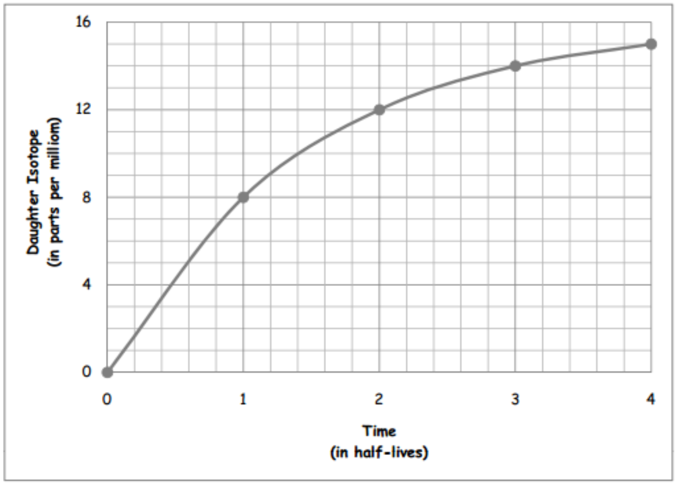
II. Radioactive Decay

Use the Data in the table at the right to fill the first three rows in the table below. Then follow the instructions for rows 4 – 6.

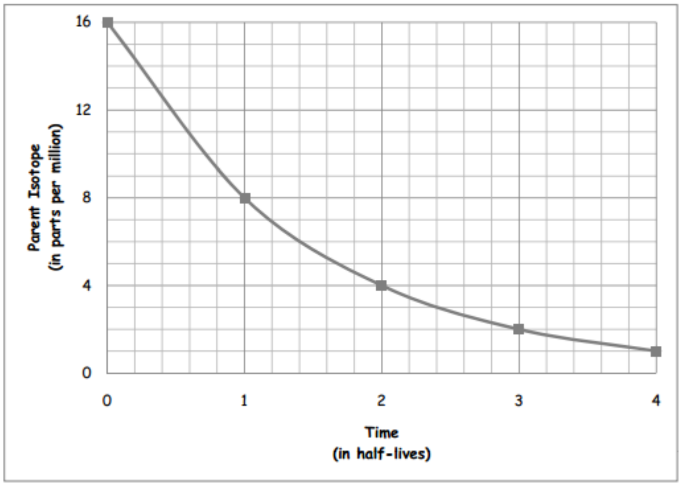


		Time (in half-lives)				
		0	1	2	3	4
Row 1	Daughter Isotope (in parts per million)	0	8	12	14	15
Row 2	Parent Isotope (in parts per million)	16	8	4	2	1
Row 3	Sum (Row 1 + Row 2)	16	16	16	16	16

Table 2—*Radiometric Dating Game* data table



Graph 1—*Radiometric Dating Game* daughter isotope abundance graph



Graph 2—*Radiometric Dating Game* parent isotope abundance graph

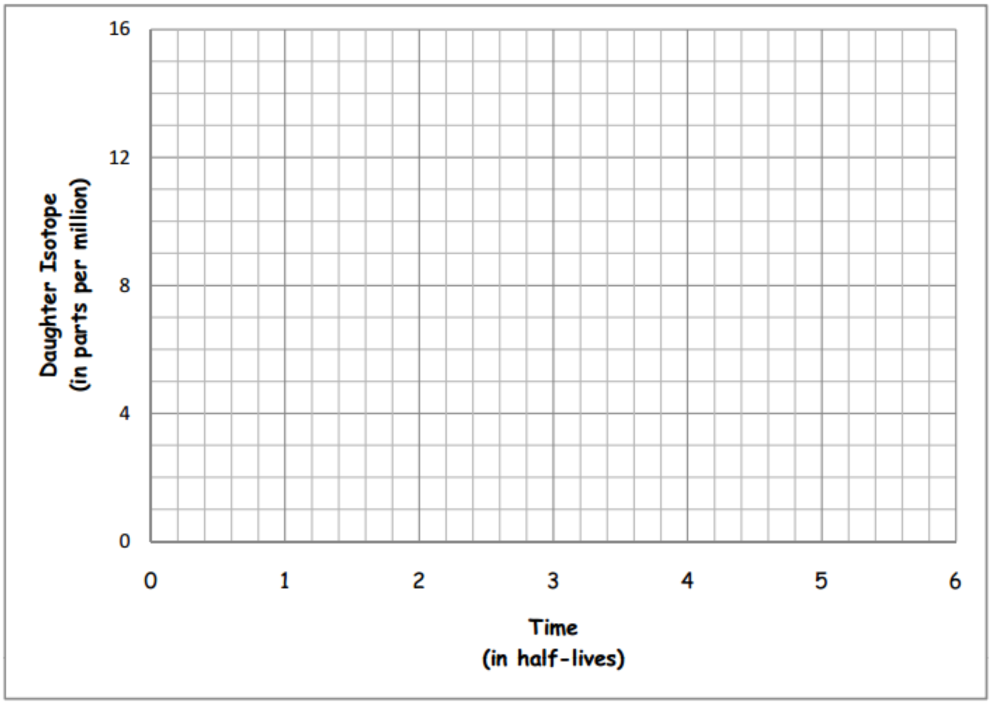
Row 4—determine the fraction of parent isotope remaining at time (in half-lives) =x, where x=0, 1, 2, 3, 4, 5, or 6 by placing the amount of the parent isotope (Row 2) at time=x in the numerator, and the sum of isotopes (Row 3) at time=x, which is equivalent to the initial abundance of the parent isotope, in the denominator. Simplify your fractions. Show your work.

Row 5—calculate the percentage of the parent isotope remaining at time (in half-lives) =x, where x=0, 1, 2, 3, 4, 5, or 6 by multiplying the value in Row 4 at time =x by 100 or by converting the fraction to a decimal and multiplying by 100. Show your work.

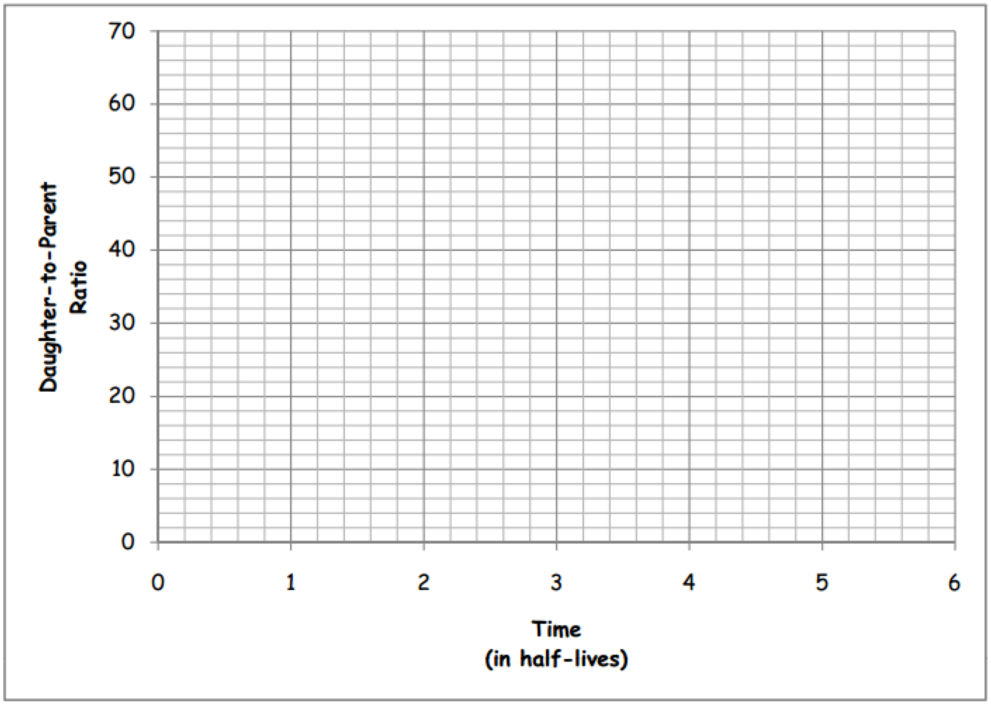
Row 6—determine the daughter-to-parent ratio at time (in half-lives)=x, where x=0, 1, 2, 3, 4, 5, or 6 by dividing Row 1 by Row 2 for time=x. Show your work.

		Time (in half-lives)						
		0	1	2	3	4	5	6
Row 1	Daughter Isotope (in parts per million)							
Row 2	Parent Isotope (in parts per million)							
Row 3	Sum of Isotopes (Row 1 + Row2)							
Row 4	Parent Isotope (fraction remaining)							
Row 5	Parent Isotope (percentage remaining)							
Row 6	Daughter-to-Parent Ratio							

Plot the information in Row 1 on the graph below to show the change in the abundance of the daughter isotope over time.



Plot the information in Row 6 on the graph below to show the change in the daughter-to-parent ratio over time.



Compare the graph of daughter isotope abundance in Problem 2 with the graph of daughter-to-parent ratio in Problem 3. Describe the shape of the curves and their trajectories. If both graphs contain information about the daughter isotope, then why do they behave so differently?

The initial abundance of the parent isotope at the formation of our sample was 16 parts per million (ppm). If modern mass spectrometers are capable of accurately measuring isotope abundance down to a level of 10 parts per billion (ppb), after how many half-lives will it no longer be possible to calculate an accurate age for the sample? [Hint: At time t=6, the remaining parent isotope equals ¼ ppm. There are 1000 ppb in 1 ppm. Calculate the amount of the parent isotope remaining in ppb for time t=x, where x=6, 7, 8, and so on until the quantity remaining is less than 10 ppb.] Show your work.

III. Columbia River Basalt

How old are they?

Using radioactive decay to determine the age of materials requires several geologically reasonable assumptions to be made. (1) The half-life has not changed through time. This is generally accepted. For example, tree rings have been counted back over 11,000 years to calibrate the radiocarbon curve. (2) The initial concentration of the parent isotope is known. This is also determinable for the various isotopes. (3) There was a closure time, when the radioactive clock began. There cannot be any contamination of “new” material to the system after this time (i.e. it is a “closed” system). This assumption is sometimes difficult to test and analyses may be cross checked with analyses with samples from different locations. (4) The sample was not contaminated and the measurement was taken with high precision.

Potassium–Argon dating, abbreviated K–Ar dating, is a radiometric dating method used in geochronology and archaeology. It is based on measurement of the product of the radioactive decay of an isotope of potassium (K) into argon (Ar). Potassium is a common element found in many materials, such as micas, clay minerals, tephra, and evaporites. In these materials, the decay product ^{40}Ar is able to escape the liquid (molten) rock, but starts to accumulate when the rock solidifies (recrystallizes). Time since recrystallization is calculated by measuring the ratio of the amount of ^{40}Ar accumulated to the amount of ^{40}K remaining. The long half-life of ^{40}K allows the method to be used to calculate the absolute age of samples older than a few thousand years.

To calculate the age of rocks in the ^{40}K-^{40}Ar system scientists use the following formula:

$$\mathbf{t = (1/\lambda)\ ln\ [(^{40}Ar/^{40}K)\ (correction\ factor)\ (\lambda/\lambda_e) + 1]}$$

Where t is the time since the radioactive clock started, λ is the decay constant of ^{40}K-^{40}Ca-^{40}Ar system (5.543×10^{-10}/yr and λe is the decay constant for the ^{40}K-^{40}Ar system (0.581×10^{-10}/yr). And ln is the natural log. The ratio of ^{40}Ar/^{40}K must be adjusted for the difference in atomic weight. The correction factor is 0.97838 (adjustment to handle the difference of masses for ^{40}Ar/^{40}K or: 39.0983/39.9623).

Table 1. Mass Spectrometry Results

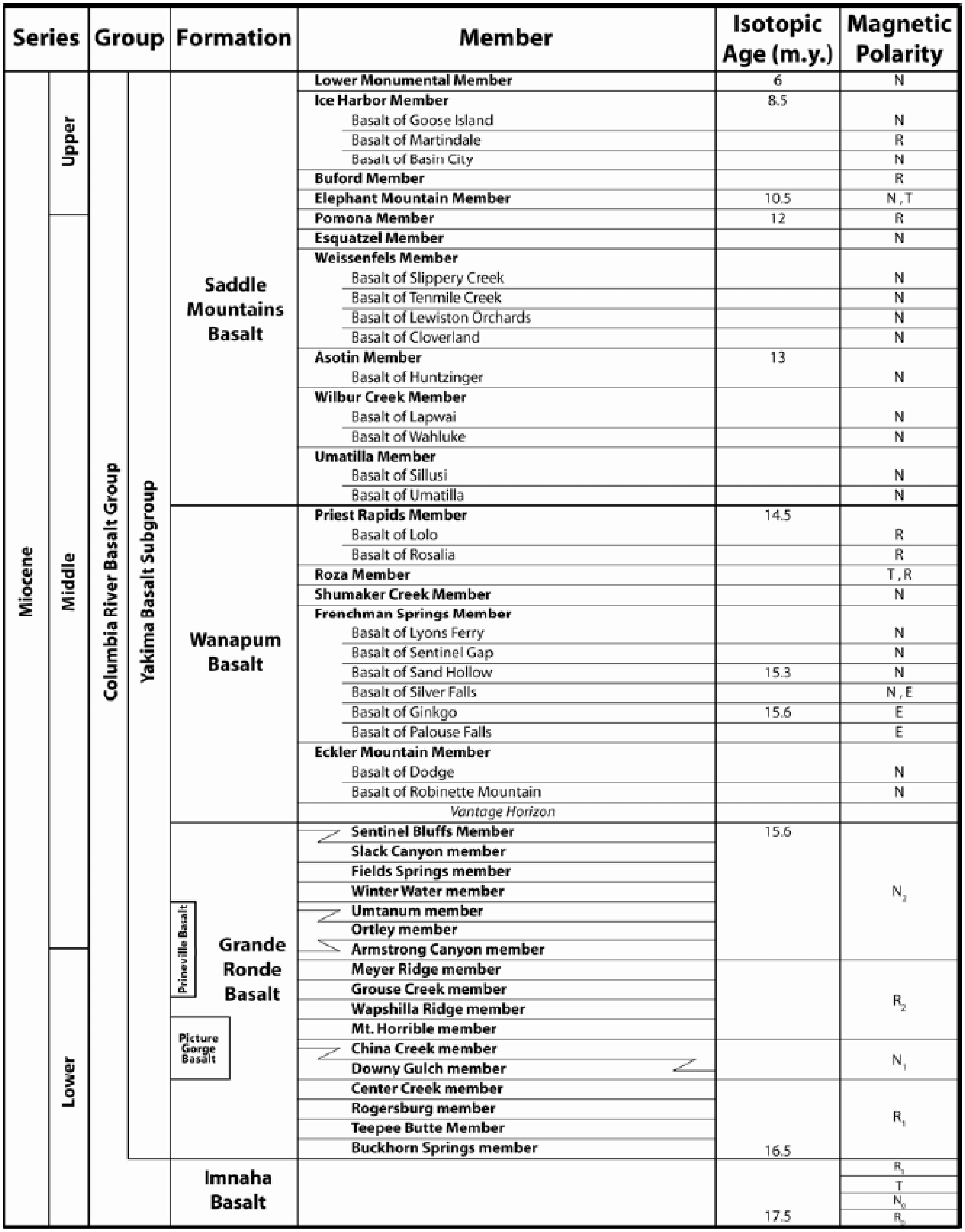
Parcel Number	Parent Concentration Time(t) (ppb)	Daughter Concentration Time(t) (ppb)	Decay Constant	Decay Constant Electron Capture
#	^{40}K	^{40}Ar	λ	λe
931-412-12	14,065	7.1	5.54E-10	5.81E-11
931-412-13	14,065	10.1	5.54E-10	5.81E-11
931-412-14	14,065	10.9	5.54E-10	5.81E-11
931-412-15	14,065	12.2	5.54E-10	5.81E-11
931-412-16	14,065	12.9	5.54E-10	5.81E-11
931-412-17	14,065	13.1	5.54E-10	5.81E-11
931-412-18	14,065	13.9	5.54E-10	5.81E-11

Calculate the ages for each of the seven samples. Show your work. Enter these ages in the table on the right. List the name of the Basalt that you interpret to be found in each parcel, based on your age determination and the table provided at the end of this packet. (From Reidel et al. (1989b) and Tolan et al. (1989).)

Parcel Number	Age	Basalt Name
#	(Ma)	Name
931-412-12		
931-412-13		
931-412-14		
931-412-15		
931-412-16		
931-412-17		
931-412-18		

Which parcel will work?

Write a paragraph explaining your age determinations. List the age determination you made for the Basalt of Lolo, part of the Priest Rapids member of the Wanapum Basalt. Finally list the parcel number that you recommend that they purchase for their development.



Series		Group		Formation	Member	Isotopic Age (m.y.)	Magnetic Polarity
Miocene	Upper	Columbia River Basalt Group	Yakima Basalt Subgroup	Saddle Mountains Basalt	**Lower Monumental Member**	6	N
					Ice Harbor Member	8.5	
					Basalt of Goose Island		N
					Basalt of Martindale		R
					Basalt of Basin City		N
					Buford Member		R
					Elephant Mountain Member	10.5	N, T
	Middle				**Pomona Member**	12	R
					Esquatzel Member		N
					Weissenfels Member		
					Basalt of Slippery Creek		N
					Basalt of Tenmile Creek		N
					Basalt of Lewiston Orchards		N
					Basalt of Cloverland		N
					Asotin Member	13	
					Basalt of Huntzinger		N
					Wilbur Creek Member		
					Basalt of Lapwai		N
					Basalt of Wahluke		N
					Umatilla Member		
					Basalt of Sillusi		N
					Basalt of Umatilla		N
				Wanapum Basalt	**Priest Rapids Member**	14.5	
					Basalt of Lolo		R
					Basalt of Rosalia		R
					Roza Member		T, R
					Shumaker Creek Member		N
					Frenchman Springs Member		
					Basalt of Lyons Ferry		N
					Basalt of Sentinel Gap		N
					Basalt of Sand Hollow	15.3	N
					Basalt of Silver Falls		N, E
					Basalt of Ginkgo	15.6	E
					Basalt of Palouse Falls		E
					Eckler Mountain Member		
					Basalt of Dodge		N
					Basalt of Robinette Mountain		N
					Vantage Horizon		
				Grande Ronde Basalt	**Sentinel Bluffs Member**	15.6	N_2
					Slack Canyon member		
					Fields Springs member		
					Winter Water member		
				Prineville Basalt	**Umtanum member**		
					Ortley member		
	Lower				**Armstrong Canyon member**		
					Meyer Ridge member		R_2
					Grouse Creek member		
					Wapshilla Ridge member		
				Picture Gorge Basalt	**Mt. Horrible member**		
					China Creek member		N_1
					Downy Gulch member		
					Center Creek member		R_1
					Rogersburg member		
					Teepee Butte Member		
					Buckhorn Springs member	16.5	
				Imnaha Basalt			R_3
							T
							N_0
						17.5	R_0

Stratigraphic nomenclature of the CRBG. From Reidel et al. (1989b) and Tolan et al. (1989).