Igneous Rocks: Fractional Crystallization of Magma Name___________________
GEOS 3010 Take Home Assignment #5

THE CANDY MAGMA CHAMBER

Objective

The objective of this exercise is to gain an understanding of magmatic differentiation by fractional crystallization using a magma chamber simulation. The activity was adapted from materials developed by Dr. Karl Wirth at Macalester College (http://www.macalester.edu/geology/wirth/CourseMaterials.html)

A Bit of History and Terminology

In this and other geology courses you learned about Bowen's reaction series and the importance of crystal-melt fractionation in generating the diversity of observed igneous rock compositions (e.g., basalt, andesite, dacite, rhyolite). *Magmatic differentiation* is the process by which diverse rock types are generated from a single magma. One way to accomplish differentiation is by *crystal-melt fractionation*, a two-stage process that involves: (1) the formation of crystals from a melt, and (2) mechanical separation of crystals and melt. In 1844 Charles Darwin described lava flows from the Galápagos Islands in which the lowest flows contained greater proportions of feldspar crystals. These observations led Darwin to propose that density differences between crystals and melt would result in mechanical separation of these two phases and the formation of different magma types. This process, known today as gravity settling, was the focus of detailed experimental studies by N.L. Bowen (as in Bowen's Reaction Series). Today, several additional mechanisms of crystal-melt fractionation are also recognized, including flow segregation and filter pressing.

Directions

1. Construct the magma chamber.

    a. In this exercise, each major cation in the magma (e.g., Si, Mg, Al) is represented by a different colored candy. To simplify the activity, we assume that the magma chamber contains enough oxygen anions to form all of the minerals that crystallize; so, we will make all calculations in cation atomic percent (rather than oxide weight percent, which is commonly reported for rocks). We also assume that there is no solid solution in minerals crystallizing from the magma.

    b. Before you begin, complete attached Table 1 (*Mineral Compositions*) by filling in each mineral formula and determining the proportions of cations in each mineral that will crystallize from the magma.

    c. Count out the candies by color and assign each color to a type of cation (for example, green for Si, yellow for Al, etc). The starting number of candies for each cation is listed in Table 2 (*No. Cations Remaining in Liquid*).

    d. Mix the candies together and place them at one end of the large sheet of paper (this will be the "liquid" end of your magma chamber – the other end will be the "solid" end).

e. Note the general proportions of the different colors in the magma chamber.

2. Begin fractional crystallization.

a. Remove the appropriate number of candies during each crystallization step in the table, below. As minerals crystallize, remove the candies from the “liquid” region and place them in sequential layers on the “solid” region of the magma chamber.

Mineral	**Crystallization Step**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Forsterite	2	3	4	3	2					
Fayalite			1	2	2	1				
Diopside				1	1	4	2	2	1	1
Anorthite		1	2	3	3	4	3	3	1	1
Albite						1	3	6	5	7
Orthoclase									2	2
Quartz									1	4

b. After each crystallization step, record the number of cations remaining in the liquid for each element (the number of each color of candy left in the “liquid”) in Table 2.

c. For each crystallization step, calculate the relative proportions of each element remaining in the magma as a percentage of the total number of elements remaining after that crystallization step [for example, if you remove 10 atoms of Mg and 5 atoms of Si in Step 1, %Mg = (30)/(355)]. Record this information in Table 3 (*Magma Composition*).

d. Also calculate the proportion of magma remaining (f) in each crystallization step by dividing the number of cations (candies) remaining in the liquid by the original total number of cations in the liquid [for example, if you remove 10 atoms of Mg and 5 atoms of Si in Step 1, f = (355/370)]. Record this information in Table 3.

3. Use the results of the fractional crystallization exercise to answer the questions, below.

Table 1. *Mineral Compositions*

	Candy Color	Forsterite	Fayalite	Diopside	Anorthite	Albite	Orthoclase	Quartz
Formula	-----							
Si								
Al								
Fe								
Mg								
Ca								
Na								
K								

Table 2. *No. Cations Remaining in Liquid*

Cation	**Start No.**	**Crystallization Step**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Si	184										
Al	71										
Fe	12										
Mg	40										
Ca	33										
Na	23										
K	7										
Total	370										

Table 3. *Magma Composition*

Cation	Start %	Crystallization Step									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Si	49.73										
Al	19.19										
Fe	3.24										
Mg	10.81										
Ca	8.92										
Na	6.22										
K	1.89										
Total	100.00										
Liquid Frac (f)	1.00										

Questions

1. Compare the types of minerals removed at the beginning of crystallization with those removed in the middle and end of crystallization (i.e., mafic versus felsic minerals). Does this exercise largely follow Bowen's reaction series? Why or why not?

2. Apply an igneous rock name to the mineral assemblages that were removed during the 2nd, 6th, and 10th crystallization steps:

<u>**Step**</u>	<u>**Minerals Removed**</u>	<u>**Rock Name**</u>
2nd	______________________________	______________________________
6th	______________________________	______________________________
10th	______________________________	______________________________

3. Use the data from Table 3 to graph the following (by hand on the graph paper, or print out graphs made with a spreadsheet program like Excel). As a general rule, create graphs that occupy the entire sheet of paper. Make sure your axes are labeled and put a title on each graph. Turn in your graphs and answer the next questions based on these graphs.

   a. On one graph, plot the liquid fraction remaining (f) on the y-axis, versus crystallization step on the x-axis.

   b. On a new graph, plot the % of each element below on the y-axis, versus crystallization step on the x-axis. Use a different color for each element:
      %Si
      %Mg
      %Al
      %K

   c. Describe the general trends you observe in each graph (i.e., increasing or decreasing element concentrations)

      Liquid fraction remaining:

      %Si:

      %Mg:

      %Al:

      %K:

   d. Which of these elements (Mg, Al, or K) is most compatible (easily incorporated into a crystalline structure)? Which is most incompatible (not easily incorporated)? How do you know?

e. Explain how the percentage of silica in magma increases during crystallization despite the fact that silicate minerals are being removed throughout the crystallization process.

4. Magmas are broadly classified by their silica composition according to the following:

Si%	40		54		70		85
	|	*Basalt*	|	*Andesite*	|	*Rhyolite*	

Using the above classification scheme, classify the magma at the following steps:

Step	**%Si (Table 3)**	**Magma Name**
Initial	____________	________________________________
2nd	____________	________________________________
6th	____________	________________________________
10th	____________	________________________________

5. Which aspects of this model magma chamber are realistic? Which are not? Suggest some ways to make the model more realistic.