USING AN M&M® MAGMA CHAMBER TO ILLUSTRATE MAGMATIC DIFFERENTIATION

MACALESTER COLLEGE

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Introduction

Students are introduced to the concept of magmatic differentiation in the introductory course. The details of this fundamental process are typically more fully developed in mineralogy and petrology courses. Many students, especially those at the introductory level, do not develop a usable understanding of differentiation processes. In particular, students often struggle to understand Bowen's reaction series and processes of fractional crystallization. The M&M® Magma Chamber model was developed to provide students with a hands-on activity that would result in a deeper understanding of fractionation processes. The activity also reinforces concepts in mineral stoichiometry, classification, solid-solution, and chemical variation diagrams.

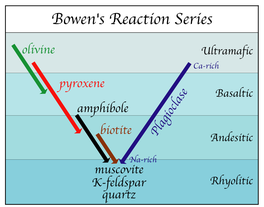


Figure 1. *Bowen's Reaction Series*

The Activity

The process of fractional crystallization by gravity settling can be illustrated using a model magma chamber consisting of M&M's®. In this model, each major cation (e.g., Si, Ti, Al, Fe, Mg, Ca, Na, K) is represented by a different color M&M®. Other kinds of differently colored or shaped pieces could also be used. Appropriate numbers of each color M&M® are combined to approximate the cation proportions of a basaltic magma; this is the "parental magma". The M&M's® are then placed in a group on a table top to form a magma chamber (Figures 2 & 3).

The M&M® magma chamber exercise can be conducted in the lecture or the laboratory setting. The activity requires 1-3 hours depending on the amount of preparation and post-activity analysis. The appropriate numbers of M&M®'s can be counted before class using a balance with a counting function (Figure 4).

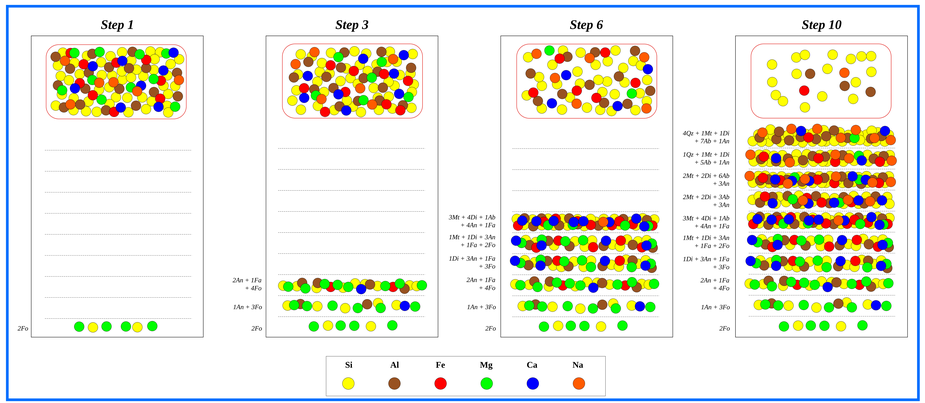
Figure 2. *Students conducting the activity during a lecture meeting of the introductory course.*

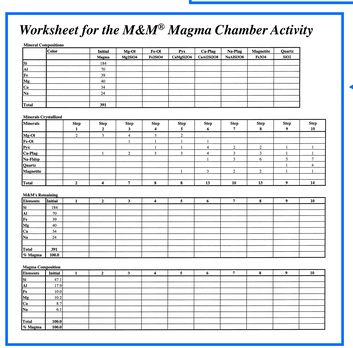
Figure 3. *Typically, 3-5 students work in each group to complete the magma chamber exercise.*

Figure 4. *Pre-counting the M&M®'s before the activity using a balance shortens the length of the in-class activity significantly.*

M&M® Magma Chamber

Figure 5. *Diagram illustrating the magma chamber after four crystallization steps. In each step, the black rectangle is the outline of the magma chamber and the red rectangle is the region of melt. Students fractionate the magma in ten crystallization steps. In each step the M&M's® are moved to the bottom of the magma chamber forming a series of cumulus layers. The M&M's® are removed in proportions that are identical to those of the stoichiometric proportions of cations in the crystallizing minerals (e.g., olivine, pyroxene, feldspars, quartz, magnetite). The fractionating assemblages are indicated along the left margins.*





Worksheet for the M&M® Magma Chamber Activity

Mineral Compositions

	Color	Initial Magma	Mg-Ol: Mg2SiO4	Fe-Ol: Fe2SiO4	Px: CaMgSiO6	Ca-Plag: CaAl2Si2O8	Na-Plag: NaAlSiO8	Magnetite: Fe3O4	Quartz: SiO2
Si		160							
Al		70							
Fe		39							
Mg		40							
Ca		34							
Na		24							
Total		391							

Mineral Crystallized

Minerals		Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9	Step 10
Mg-Ol		2	2	4	2	2					
Px-Ol			3	6	3	3	3				
Px							3	2	2	1	1
Ca-Plag			1	2	3	3	4	3	3	1	1
Na-Plag							4	3	3	1	1
Quartz										1	4
Magnetite						1	3	2	1	1	1
Total		2	4	7	8	8	13	10	12	9	14

M&M's Remaining

Elements	Initial	1	2	3	4	5	6	7	8	9	10
Si	160										
Al	70										
Fe	39										
Mg	40										
Ca	34										
Na	24										
Total	391										
% Magma	100.0										

Magma Composition

Elements	Initial	1	2	3	4	5	6	7	8	9	10
Si	47.1										
Al	17.9										
Fe	10.0										
Mg	10.2										
Ca	8.7										
Na	6.1										
Total	100.0										
% Magma	100.0										

Figure 6. *Worksheet for the M&M® Magma Chamber Activity. Students use this spreadsheet to determine the number of cations to remove in each crystallization step. The number of remaining cations and their normalized proportions are also calculated and recorded.*

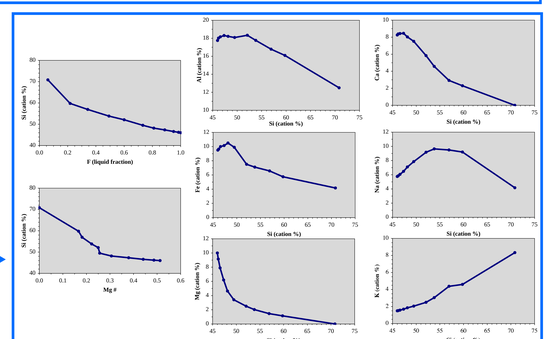
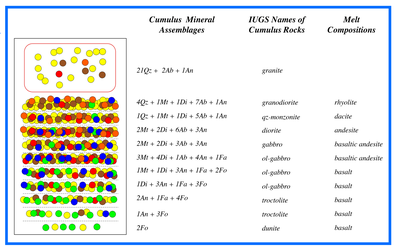


Figure 7. *After completing the activity with the M&M's® the students plot the changing compositions of the different cations in the melt. Plots can be generated by hand or using spreadsheet software.*

Analysis

After completing the exercise students are asked to analyze the results (e.g., Figure 8), including: (1) describing the behavior of different cations during crystallization (e.g., compatible versus incompatible), (2) changes in fractionating mineral assemblages, (3) the changing composition of the melt during crystallization, (4) the relation between melt volume and composition, and (5) an evaluation of the assumptions in the model (e.g., absence of important fractionating phases, no volatiles). More advanced students (e.g., petrology course) can classify the cumulates using IUGS classification guidelines. Students who have completed this exercise generally indicate a very positive experience and demonstrate increased understanding of Bowen's Reaction Series and fractionation processes. They also exhibit greater familiarity with mineral stoichiometry, classification, solid-solution in minerals, element behavior (e.g., incompatibility), and chemical variation diagrams.

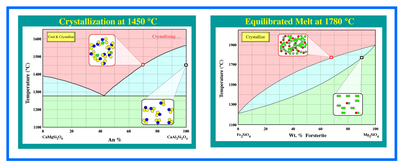
Figure 8. *Diagram illustrating the changing compositions of fractionating minerals, the cumulus rocks, and the resulting melt.*



Other Applications

M&M's®, or other colored pieces, can also be used to illustrate other difficult concepts (e.g., paths of equilibrium and fractional crystallization on phase diagrams) in upper level courses (e.g., mineralogy and petrology). These models could be used as either hands-on activities or as animated presentations in lecture (Figure 9).

Figure 9. *Clips from animated models of equilibrium and fractional crystallization processes on common phase diagrams (e.g., Anorthite-Diopside and Forterite-Fayalite). These models were constructed using Microsoft Powerpoint®.*



For Information and Course Materials
http://www.macalester.edu/geology/wirth/CourseMaterials.html

Paper No. 100-18