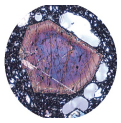


GEL4050 Igneous and Metamorphic Petrology

CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB

- GROUP LAB - (3 students max. per group)

Name:	Course section ID

Assignment Outline:

This is a GROUP assignment for maximal 3 students where you will simulate fractional crystallization of in a magma chamber using colored M&Ms as representations of mole oxides. Groups are SELF-Assignment (Sign-up in CANVAS under "People"). Everyone in the group will receive the SAME grade!

GROUP MEMBERS Maximal 3 group members - Everyone in the group will receive the SAME grade!
Log in to CANVAS and sign up for a group under "People" for this assignment.

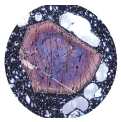
Group Member 1 Name: Contact Info:	Activity Description	Date	Hours (Hrs:min)
Job Summary:			
Should Group Member 1 receive Full Credit for the project?	Group Member 2	☐Yes ☐No ____ Initial	
	Group Member 3	☐Yes ☐No ____ Initial	

Group Member 2 Name: Contact Info:	Activity Description	Date	Hours (Hrs:min)
Job Summary:			
Should Group Member 2 receive Full Credit for the project?	Group Member 1	☐Yes ☐No ____ Initial	
	Group Member 3	☐Yes ☐No ____ Initial	

Group Member 3 Name: Contact Info:	Activity Description	Date	Hours (Hrs:min)
Job Summary:			
Should Group Member 3 receive Full Credit for the project?	Group Member 1	☐Yes ☐No ____ Initial	
	Group Member 2	☐Yes ☐No ____ Initial	

SUBMIT THIS COMPLETED SHEET WITH YOUR ASSIGNMENT

The group leader will submit the report for EVERYBODY in the group!



CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB

- GROUP LAB - (3 students max. per group)

ALL ANSWERS MUST BE TYPED USING A WORD PROCESSOR! This includes chemical formulas, equations, tables and special characters. Become intimately familiar with these functions in your preferred word processor. Be familiar with placing and sizing visuals into a written document.

GRADING

In general, for each fault in layout, grammar, spelling, content, concept, format, presentation, expression, design, citation, missing content, etc. I will deduct points. Multiple points can be deducted for larger infractions, such as missing content. Be aware that repeat mistakes will count MORE THAN ONCE !

RUBRIC:

/9 COMPOSITION & LAYOUT - one or multiple point deduction per infraction

The appearance is neat and orderly. A title page mentioning ALL group members and the completed page 1 of this assignment is included. The lab is typed and graphics and data are electronically prepared and analyzed. The lab is complete with all fields populated, if any. Graphics and data are placed in a coherent form. Proper formatted citations are included.

/15 WRITING & GRAMMAR - one point deduction per infraction

Spelling and grammar are correct. Word repetition and use of first person language is avoided. Statements are factually correct. Appropriate and complete language is used. Scientific notations / abbreviations as well as subscripts and superscripts are appropriately formatted.

/15 EXECUTION & DATA COLLECTION - one or multiple point deduction per infraction

Appropriate procedural execution of the lab is evident from the writing and data. Procedural detail is adequately mentioned. Explanations and inferences are logically drawn and supported by evidence.

/18 TABLES (6 Tables - 3 points ea.) - one or multiple point deduction per infraction

The spreadsheet includes 6 tables that need to be fully populated and presented. Each table has an appropriate header / caption. Tables are explained and tied together in the text..

/15 PHOTOS (5 photos - 3 points ea.)) - one or multiple point deduction per infraction

5 representative photos of the progression of the simulated magma chambers should be presented in a logical fashion. Photos are clear, sharp, and show good detail. If necessary, photos should be cropped. Every photo should have a FIGURE CAPTION describing the major points of each picture. Photos should have a "legend", if necessary.

/24 GRAPHS (8 graphs - 3 points ea.)) - one or multiple point deduction per infraction

There are 8 graphs within the Excel spreadsheet. These graphs should be added to the report and presented in a logical fashion. Graphs are clear, sharp, and show good detail with adequate lettering. Every graph should have a FIGURE CAPTION describing the major points. Graphs are explained and tied together in the text.

/4 CITATIONS (2 pts ea) - one or multiple point deduction per infraction

You must use a minimum of 2 properly formatted citations

GEL4050 Igneous and Metamorphic Petrology

CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB

- GROUP LAB - (3 students max. per group)

THE WRITE-UP

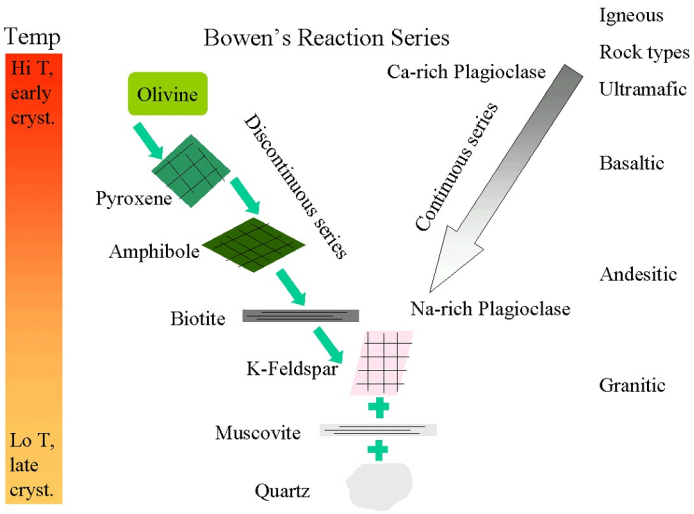
The write-up has a title page mentioning the title of the assignment, ALL group members the course and the date. The title page has NO page numbering.
The **completed** GROUP MEMBER PAGE found on page 1 of the assignment outline must be inserted after the title page and becomes PAGE 1 of this assignment. Your write-up work starts on page 2.
The group leader will submit the completed assignment as a PDF document by the DEADLINE or before through CANVAS!!! ***(Test your generated PDF to see if formatting and pictures exported correctly before submittal***).
Everyone in the group will receive the same grade, which includes any late penalties.

> The following assignment was modified from *Calculating of a CIPW norm from a bulk chemical analysis* (2013) Kurt Hollocher, Geology Department, Union College NY, and *Differentiation of Magmas By Fractional Crystallization* (2014), Cynthia Fadem, Earlham College.

Materials:

☐ Lots of M&Ms in multiple colors (about 450 total) ☐ Calculator ☐ Magma Chamber Tables
☐ Cell phone camera ☐ Poster Board ☐ Excel Spreadsheet for Magma Chamber Lab

Introduction:



You have learned about Bowen's reaction series and the importance of crystal-melt fractionation in generating the spectrum of observed igneous rock compositions (e.g., basalt, andesite, rhyolite). Magmatic differentiation is the process by which diverse rock types are generated from a single magma. Differentiation is accomplished by crystal-melt fractionation, a two-stage process that involves the formation and mechanical separation of compositionally distinct phases. In 1844 Charles Darwin described 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. Today, several additional mechanisms of crystal-melt fractionation are also recognized, including: flow segregation, filter pressing, and convective melt fractionation.

GEL4050 Igneous and Metamorphic Petrology

CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB

- GROUP LAB - (3 students max. per group)

Procedure:

Constructing the Magma Chamber

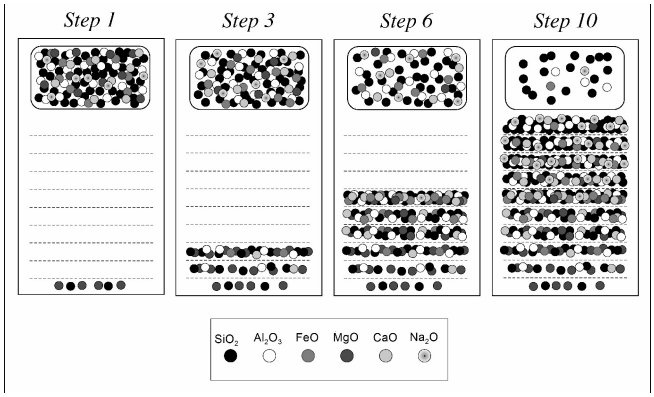
1. Each major oxide (e.g., Si, Ti, Al) will be represented by a different M&M color. Count out the appropriate number of M&M's for each oxide (refer to data sheet). Your magma chamber is represented by a drawing on a blank white piece of on the poster board. Mix the M&M's and pile them in your magma chamber.

Crystallization and Fractionation of the Magma

2. Before you begin, note the general proportions of the different oxides (colors) in the magma chamber. Determine the composition and stoichiometry of each of the minerals involved in the crystallization process using the first table.
3. Create your minerals from the oxides in the magma chamber according to the table given. Once a mineral is formed, remove it from the melt by settling it to the bottom of the magma chamber. For each oxide, record the number that remains in the magma chamber in the appropriate table.

NOTE: Take a picture (cell phone) of your model magma chamber **for each increment of crystallization** on your poster board. You can incorporate those into your lab write-up!

4. For each additional increment of crystallization, move the appropriate number of oxides (M&M's) from the melt to the floor of the chamber as they from minerals and fill in the table. (Note: it is helpful to group the oxides that were removed in each crystallization step in separate layers. In other words, move the M&M's that were crystallized during the first step the furthest away from the magma chamber; oxides from each additional crystallization step will be successively closer to the magma chamber. See illustration on right)



5. After each crystallization step, you should observe the proportions of the oxides (colored M&M's) in the remaining liquid and in the cumulus layers, recording this data in your tables as well.
6. Before your experiment is dismantled (or consumed), describe the general trends you observed during the fractional crystallization of the magma. Compiling your results into graphs to make your point will be helpful.

Analyzing the Results

7. Complete each data table and enter your data into a spreadsheet. A complete spreadsheet to analyze your results including generating of graphs can be downloaded here: http://college.earthscienceeducation.net/IMP/MM Excel.xls
8. Generate x-y plots of the following:
   a. % Al, Mg, Fe, Ca, Na, K, and Ti oxides remaining in the melt versus % SiO_2 remaining in the melt
   b. % SiO_2 and MgO remaining in the melt versus fraction of liquid remaining (% Magma)
9. Plot the various rocks formed in each step on the IUGS diagram. Which trend are you observing in the generation of plutonic rocks through fractional crystallization? What influences this trend?

GEL4050 Igneous and Metamorphic Petrology

CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB

- GROUP LAB - (3 students max. per group)

Building Blocks **- Enter Oxide Formula for each mineral species. Chose an M&M color for each oxide. Then list the number of oxides required to build these minerals (last!).**

Oxide	*Parent Melt*	*M&M color*	*Fractionating Minerals*								
			Forsterite Mg_2SiO_4	*Fayalite* Fe_2SiO_4	*Magnetite* Fe_3O_4	*Ilmenite* $FeTiO_3$	*Diopside* $CaMgSi_2O_6$	*Anorthite* $CaAl_2Si_2O_8$	*Albite* $NaAlSi_3O_8$	*Orthoclase* $KAlSi_3O_8$	*Quartz* SiO_2
Oxide Formula			$2MgO•SiO_2$								
SiO_2	270										
Al_2O_3	43										
MgO	36										
FeO	28										
Fe_2O_3	5										
CaO	25										
Na_2O	15										
K_2O	15										
TiO_2	3										
Total	440										

The Magma Chamber **- Use the M&Ms to crystallize your magma chamber according to the crystallization steps here. Calculate the totals for each mineral and each step. (The totals will help you with the calculations and questions later.)**

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

ALL TABLES AVAILABLE AS EXCEL SPREADSHEET DOWNLOAD http://college.earthscienceeducation.net/IMP/MM%20Excel.xls

GEL4050 Igneous and Metamorphic Petrology

CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB

- GROUP LAB - (3 students max. per group)

Rock Mineralogy **- Each crystallization step represents the formation of a new rock. For each rock, calculate the mineral percentages present. Then calculate total percent of the rock that is composed of mafic minerals and classify its chemistry. The first one is completed for you.**

Mineral	Crystallization Step									
	1	2	3	4	5	6	7	8	9	10
Forsterite	83.3%									
Fayalite	16.7%									
Magnetite	-									
Ilmenite	-									
Diopside	-									
Anorthite	-									
Albite	-									
Orthoclase	-									
Quartz	-									
% Mafic	100%									
Chemical Class	Ultramafic									

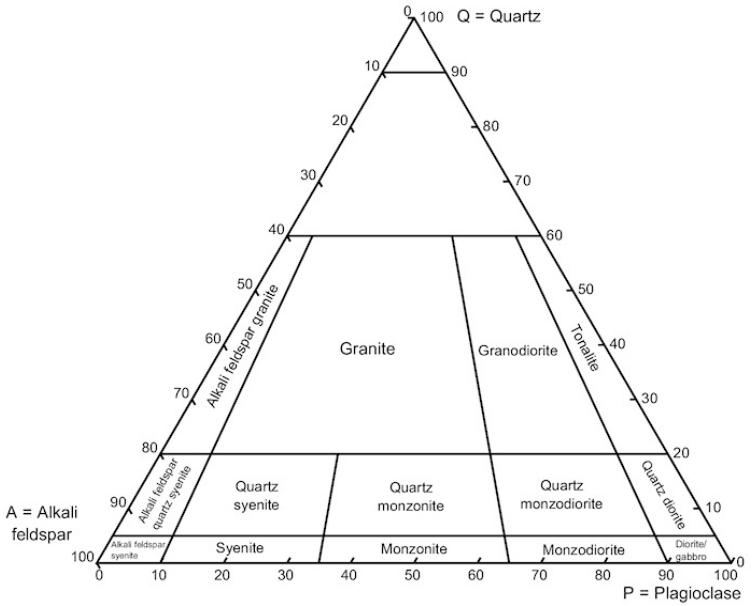
ALL TABLES AVAILABLE AS EXCEL SPREADSHEET DOWNLOAD http://college.earthscienceeducation.net/IMP/MM%20Excel.xls

GEL4050 Igneous and Metamorphic Petrology
CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB
- GROUP LAB - (3 students max. per group)

Rock Mineralogy (cont'd) **– Use the ternary classification keys to find names for your rocks. For some of them you will need to re-normalize to 100% using only the felsic minerals. The first two are completed for you.**

Chemistry	% Mafic Minerals
Ultramafic	≥90
Mafic	46-89
Intermediate	16-45
Felsic	≤15

Plot the rock types for each crystallization step on the QAP Diagram to the right.



ALL TABLES AVAILABLE AS EXCEL SPREADSHEET DOWNLOAD http://college.earthscienceeducation.net/IMP/MM%20Excel.xls

Components	Crystallization Step									
	1	2	3	4	5	6	7	8	9	10
Plagioclase (Anorth + Albite)	-	100%								
Alkaline Feldspar (Orthoclase)	-	-								
Quartz	-	-								
Aphanitic Rock Name	Komatiite	Basalt								
Phaneritic Rock Name	Dunite	Gabbro								

Magma Composition - *Left Behind* - Calculate the number of oxides remaining in the melt at each step.

GEL4050 Igneous and Metamorphic Petrology

CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB

- GROUP LAB - (3 students max. per group)

Oxides	Parent Melt	Crystallization Step									
		1	2	3	4	5	6	7	8	9	10
SiO_2	270	264									
Al_2O_3	43	43									
MgO	36	26									
FeO	28	26									
Fe_2O_3	5	5									
CaO	25	25									
Na_2O	15	15									
K_2O	15	15									
TiO_2	3	3									
Total	440	422									0
% Magma	100	95.9									0
% Minerals	0	4.1									100

The Evolving Magma **- Calculate the percentages of each oxide remaining in the melt at each step.**

Oxides	Parent Melt	Crystallization Step									
		1	2	3	4	5	6	7	8	9	10
SiO_2	61.4%	62.6%									
Al_2O_3	9.8%	10.2%									
MgO	8.2%	6.2%									
FeO	6.4%	6.2%									
Fe_2O_3	1.1%	1.2%									
CaO	5.7%	5.9%									
Na_2O	3.4%	3.6%									
K_2O	3.4%	3.6%									
TiO_2	0.7%	0.7%									
Total	100	100	100	100	100	100	100	100	100	100	100

ALL TABLES AVAILABLE AS EXCEL SPREADSHEET DOWNLOAD http://college.earthscienceeducation.net/IMP/MM%20Excel.xls

GEL4050 Igneous and Metamorphic Petrology
CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB
- GROUP LAB - (3 students max. per group)

Write-Up should contain the following:

☐	Title page
☐	Introduction to the Experiment
☐	Complete "tables" showing your results - *Your tables need title and table caption*
☐	The "evolution" of your magma chamber using **5 different representative pictures** showing the progression in crystallization. - *Your pictures need captions*
☐	Complete "graphs" showing Si vs selected other elements or magma - *Your graphs need captions*
☐	A description in your write-up of what happens during each of the pictured phases. Try to explain why this stoichiometric calculation works and roles "oxides" play.
☐	Show some sample calculation.
☐	ONLY **ONE** SUBMITTAL PER GROUP NEEDED, usually uploaded by the group leader.

GEL4050 Igneous and Metamorphic Petrology
CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB
- GROUP LAB - (3 students max. per group)
GRADING and NOTATIONS

ALL ANSWERS MUST BE TYPED USING A WORD PROCESSOR! This includes chemical formulas, equations, tables and special characters. Become intimately familiar with these functions in your preferred word processor. Where graphics are indicated insert the proper graphic or picture. Be familiar with placing and sizing visuals into a written document. Attach your completed document(s) to this sheet!

LAB PROCEDURE: This is a GROUP PROJECT. Everyone in the group will get the same grade. Be sure to log your hours and contributions to the project on "Page 1".

For ALL assignments use a citation's database:

ZOTERO citations database	ZOTERO is a citations database that incorporates itself into Word and your Browser.	Free open source software available at https://www.zotero.org/

Note: You may use a different citations database, if desired. But you MUST use a citations database!

NOTE: After downloading and installing ZOTERO, take an hour or two to become familiar with the operation of the software. One of your first tasks will be to set the citation style to the United States Geologics Survey (USGS) format in ZOTERO. The USGS citation system will be required for this course and your final product.

Loading the USGS citation format into ZOTERO: Once Zotero Standalone is installed, click on "Preferences" under the Edit tab. Once there click on "Cite" and go to the "Styles" tab. Click on the "Get additional styles..." below the Styles Manger Box. When the Zotero Styles Repository Window opens, click on the "geology" button within the "Fields" section. A list of geology journals should now appear. Scroll down to the U.S.Geological Survey and click on it. The U.S.G.S style will now be part of your Zotero system and you can set your citations to be formatted accordingly in Zotero.

General Writing Instruction Summary:

- Use professional language, which means AVOID first person expressions such as "I", "we", "our". Use normal prose, active voice and third party language. Do NOT use informal wording, contractions, jargon, slang terms, or superlatives. Exclude similes/metaphors (and humor!)
- Use present tense to report well accepted facts, e.g. 'Pyrite is a sulfide mineral'. Use past tense to describe specific results, e.g. 'When acid was applied, the specimen effervesced'
- Be quantitative wherever relevant (stats, numbers etc.).

Subscript & Superscript: Use appropriate subscript and superscript, especially when it comes to chemical formulas and mathematical units..
Acceptable examples: 2.9 g/cm^3, H_2O, PO_4^{3-}, a_g=9.8m/s^2
Unacceptable examples: 2.9 g/cm3, H2O, PO4 3-, ag=9.8m/s^2

- Use precise concrete language, no ambiguity e.g, 'correlated' ≠ 'related'. Use simple language – no unnecessary "frills" (distractions). Pay attention to sentence structure and grammar

COMPILING TABLES, FIGURES and EQUATIONS
GRAPHICS are the heart of any report. Nothing is more true than in science that a picture is worth a thousand words. Always compile graphics first and then write your text focusing on your graphic. In order to create good graphics and photographs, follow the instructions below.

GEL4050 Igneous and Metamorphic Petrology
CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB
- GROUP LAB - (3 students max. per group)

Cameras and Photos:

Cell phones with a 7.2MP camera are usually ok. When taking pictures, lighting and background is key. This means dark objects should be photographed with light or white backgrounds (sheet of paper) and visa versa for light objects. Having adequate lighting will also help to get sharp, crisp, in focus pictures. Blurry and out of focus pictures are not acceptable.

Graphics:

You should be able to modify, enhance, annotate or overlay graphics. Minimum resolution is 300dpi. Make sure graphics are crisp, clear and any label is easily readable. All graphics should have a caption stating the author and/or citation. Preferably use lossless graphic formats, such as .tif or .bmp. Unfortunately .jpg is NOT lossless and will degrade a little every time you open and save it again in order to manipulate picture contents.

Graphics Editor Software: You will need a graphics editor and learn how to use it. Windows comes with its default Windows Paint editor. It is found in the Windows Accessories Folder. For a more advanced option with many more professional features you may try GIMP: https://www.gimp.org/ This is a FREE, open source image editor working across all computing platforms (Windows, Apple, Linux, etc.). The software comes with ample documentation and examples on how to manipulate any picture or graphic.

Screen Capture Software: A screen capture or snipping software is advantageous in order to only grab the part of a graphic from the screen that is important or necessary. Windows 10 comes with a default snipping tools, such as "Snip & Sketch" found in its own folder or "Snipping Tool" found in the Windows Accessaries Folder. Note: When snapping a picture, make sure it is large enough on the screen to capture enough pixels to have adequate resolution for the final product.

NOTE: Compiling acceptable and good looking graphics and photographs is very involved and can not be rushed. These are often the heart of any report and should be compiled BEFORE writing. Last minute thrown together graphics will without doubt lower your grade on the client report significantly.

GEL4050 Igneous and Metamorphic Petrology
CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB
- GROUP LAB - (3 students max. per group)
COMPOSITION, LAYOUT, WRITING & GRAMMAR SUMMARY

Language

The following list is an example of common faults in language usage and attribution.

Errors / Mistakes / Faults	Examples with margin *Fault Counts & Codes*	
Spelling: incl. capitalization errors & spacing	| | hardness of four.	The mineral florite has a mohs
Grammar: incl. punctuation, superfluous words, transpositions	| the classical texts on science.	Nicolas Steno was trained in
Style: incl. paragraph, repetitive expressions / words erroneous expression / words, sub- or superscription, unprofessional style, word insertion	| isotropic Here light propagates at the same speed. | | many minerals mixed. |*Para.* sciences.¶Near the end of the 19th a new theory ... |||*rep* These light colored minerals are often light...	Isometric crystals are also Rocks are composed of many ... in the geologic ... is a light colored mineral.
Sentence: incl. grammar, run-on, strings of nouns	| sealing? of a limestone cave. |*sup* g/cm3. | | with my group. | incoherent precipitate. /\ | then? the density of silver. | structure, it is cubic. | | apparent in the sample.	Stalactites hang from the The density of quartz is 2.65 I was investigating the outcrop Sodium sulfate forms a chalky, *amorphous?* The density of gold is greater Pyrite has a symmetrical crystal Skarn mineral zonation? is

Content

Errors in content are spelled out. Severe infractions may count for multiple errors.

Errors / Mistakes / Faults	Examples with margin *Fault Counter & Codes*	
Unclear / erroneous statements	|*unclear, units?* in question is 16.5.	Mohs hardness of the mineral
False / nonsense	||*Nonsense* metamorphism of the region	~~Glaciation~~ cause severe

GEL4050 Igneous and Metamorphic Petrology
CRYSTALLIZATION OF AN M&M MAGMA CHAMBER LAB
- GROUP LAB - (3 students max. per group)
TABLES, FIGURES & EQUATIONS SUMMARY

Tables

Each table must be sufficiently complete that it could stand on its own, separate from text.

Only HORIZONTAL lines are allowed in tables. Do NOT use any VERTICAL lines.

DO consecutively number and caption tables and refer to them accordingly within your text. Captions go ABOVE the table.
DO provide a short description of your table within the caption.
DO place your tables appropriately, closest to their mention in the text.
DO make sure tables are legible and reproduce well. Print can be smaller than text, with an 8pt size minimum.
DO appropriately label columns. Do NOT forget units for numeric values.

AVOID splitting tables across pages.

Figures

Each figure must be sufficiently complete that it could stand on its own, separate from text.

DO number and caption figures consecutively and refer to them accordingly within your text. Captions go BELOW the figure.
DO provide a short description of your figure within the caption.
DO place your figures appropriately, closest to their mention in the text.
DO use appropriate citations for figures that are NOT your own. If you use a figure that has been modified by you, the phrase "modified after...." is most appropriate. Photos should show the name of the photographer.
DO make sure figures are legible and reproduce well. Print can be smaller than text, with an 8pt size minimum. Use a minimum resolution of 300dpi. This is a common publication standard.

AVOID cluttering of figures with too much detail. Simplify if necessary.
AVOID moire patterns in photos, a nuisance in copied or scanned pictures. Most scanners come with a moire pattern removal tool.

GRAPHS
Understand graphs: Bar graphs and/or line graphs are used when plotting nominal vs. ratio or interval data. Scatter plot graphs are used when plotting numeric vs. numeric data.
DO make sure that the graph axis are appropriately labeled and scaled. Axis should have titles as well as scalar units.
DO use electronic means to generated graphs. Hand drawn graphs are no longer acceptable.

Equations & Computations

☐ Equations should contain explanation of symbols used.
☐ A reader should be able to follow where your values or numbers come from. Indicate accordingly.
☐ WRITE DOWN UNITS!!!!
☐ Show equations used before indicating any computation

Acceptable Example: $F = m \times a = 0.034kg \times 9.8 {}^{m}/_{s^2} = 0.33 {}^{kgm}/_{s^2}$

where m is mass of the object in kg as determined with a triple beam balance and a is the gravitational acceleration. F indicates force expressed in kgm/s^2 or N (Newtons).

Unacceptable example: The answer is 0.33. This is obtained by multiplying gravity by 0.034.