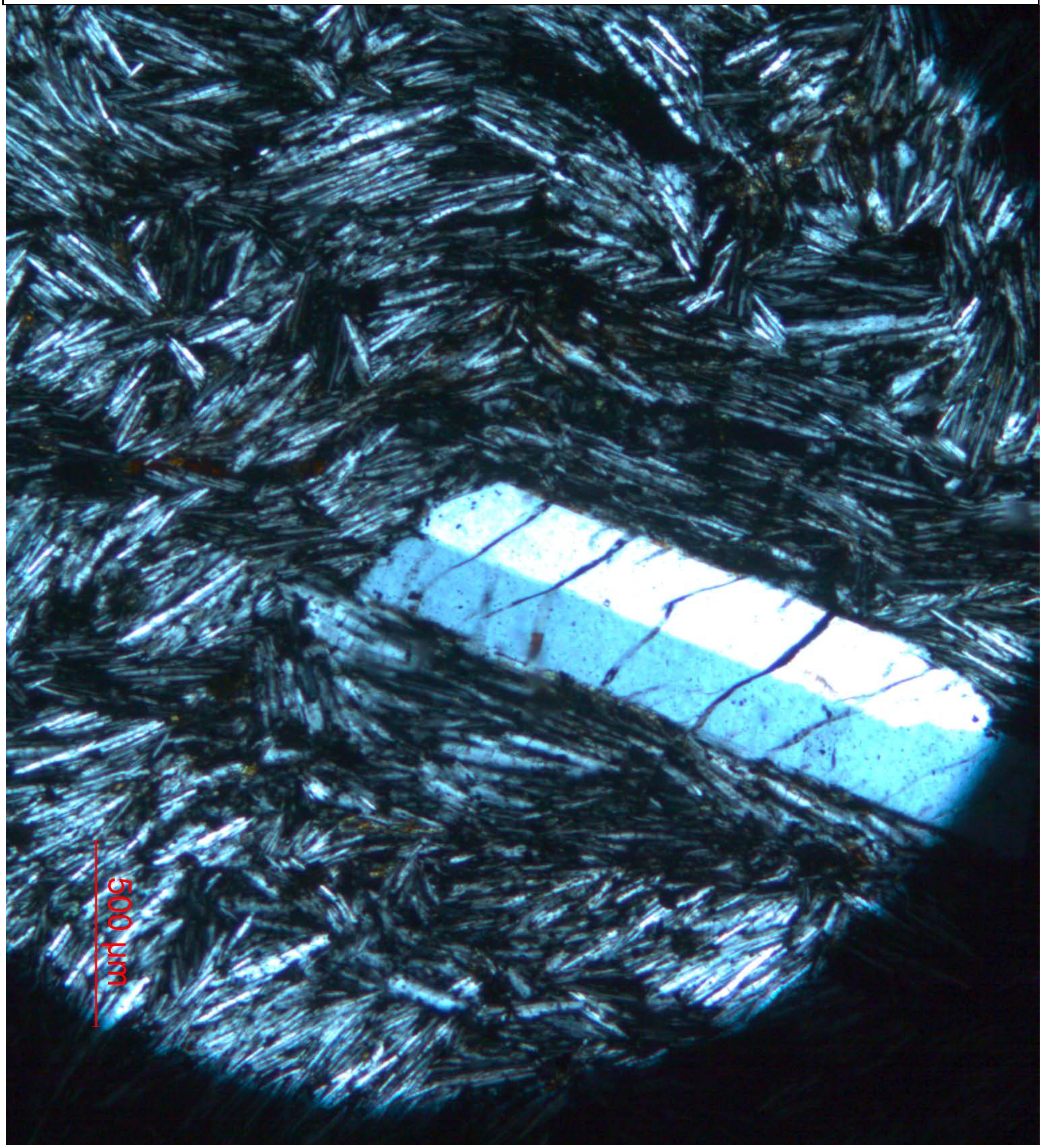
Student Name: **Scope Number:**

GEOL 242 2020 Lab Manual



Lab Completion Marks:

Lab	Complete?	Demonstrator:	Comments:
Lab 1			
Lab 2			
Lab 3			
Lab 4			
Lab 5			
Lab 6			

Lab 7			
Lab 8			
Lab 9			
Lab 10			
Lab 11			

Table of Contents

Lab Dates & Streams

Lab Demonstrators
Head demonstrator
J[redacted] G[redacted] [redacted]

Technical Staff
C[redacted] G[redacted] [redacted] [redacted]

Streams	Day	Time	Where
Stream 01	Thursday	12:00pm – 2:30pm	[redacted] 221
Stream 02	Friday	11:00pm - 1:30pm	[redacted] 221

Assessment

In Class Assignments/Lab Completion	10%
Week 6 Practice Lab Exam/Reflection	20%
Week 12 Final Lab Exam	30%
Final (Lecture) Exam	40%

Weekly Lab book Hand-in: Labwork should be completed by the following week's lab class when the Lecturer or Senior Demonstrator will come round and look at each students answers individually, discuss any issues and mark off completion. **Thus, you must complete your labwork before the following week's lab class.** Any difficulties completing the work in time, please speak to the lecturers or demonstrators ahead of the hand-in date.

After one week, answer keys will be posted online (Learn) for students to check their answers.

Very useful Lab Textbook: Optical Mineralogy David Shelly (available for purchase from Geology Dept., copies also available as reference in lab room).

Useful Lab Textbooks:
Winter, J.D. (2010) "Principles of Igneous and Metamorphic Petrology," Second Edition
Nesse, W.D. (2012) "Introduction to Optical Mineralogy" (Any editions)

Goal of the Course:
Prepare students for higher level igneous, metamorphic, and volcanological studies; advanced courses in economic and mining geology; and field geology classes.

Lecture and Laboratory Timetable:

Week #	Date week commences	Lectures	Lecturer	Laboratory	
		3 per week		Two streams	
1	17th Feb	Introduction to Mineralogy, Geochemistry, and Microscopes	BK	Intro to Microscopes	**Part I: Microscopes & Igneous Petrology**
2	24th Feb	Melting of the Mantle-Olivine, Pyroxenes, Oxides, and Plagioclase	BK	Solid Solutions and Mineral ID Techniques	
3	2nd March	Granites-Mica, Chlorite, Quartz, K-feldspar and Hornblende	BK	Phase Diagrams and Mineral ID Techniques	
4	9th March	Crystal Nucleation and Growth-Amphiboles, Glass and Bubbles	BK	Mineral and Rock Textures	
5	16th March	Rock Identification and Magma Differentiation	BK	Magma Generation versus Differentiation	
6	23rd March	Volcano Types and Banks Peninsula	BK	Volcanic Rocks; Practice Igneous Rocks Lab Exam	
7	30th March	Metamorphic Introduction and Classification	AN	Metamorphic Minerals and Foliated Metamorphic Rocks	**Part II**
	BREAK	Monday 6th April to Friday 26th April Glens of Tekoa Fieldtrips (GEOL 240)			
8	29th April	Metamorphic Textures	AN	Contact and other Non-foliated Metamorphic Rocks	**Part II: Metamorphic Petrology**
9	6th May	Metamorphic Processes	AN	Metamorphic Textures	
10	13th May	Metasomatism	AN	Dynamic and Contact Metamorphic Rocks	
11	20th May	Metamorphic Rocks in New Zealand	AN	High-Grade Metamorphic Rocks	
12	27th May	Ores and Igneous and Metamorphic Ore-Forming Processes; Review	AN	*Lab Exam: Igneous and Metamorphic Rocks in Thin Section*	

Lecturers:

B[redacted] K[redacted] ([redacted] Room 213, [redacted])
e-mail: [redacted]

A[redacted] N[redacted] ([redacted] Room 214, [redacted])
e-mail: [redacted]

Lab Philosophy

Goals:
After reading this you should...
- Be able to explain the layout, structure and reasoning behind GEOL242 Labs
- Appreciate why you should come to every lab.

The Basics:
Mineral identification and microscope work is all about **PRACTICE**. The more time you spend working and looking at new minerals and rocks – the better you will become. You should come with the expectation of staying the entire lab period. The demonstrators are there to answer your questions and guide your progress. Collect your Lab Manual and **bring this to every lab!** You will need to refer to old labs in order to understand the new material.

Typical Lab Structure:

Pre-lab: Lab Introduction FEEDBACK + QUESTIONS
Section 1: Brief theory question(s) relating the day's activities to lecture. THEORY
Section 2: Mineral Identification OBSERVATIONS
Section 3: Activities related to the day's rock, thin section work! OBSERVATIONS
Section 4: Practice exam questions which link theory, observations. INTERPRETATION

Lab Goal Example:
Describe and **Illustrate** the textures of a Gabbro (rock).

Note: The verbs are highlighted to explicitly help you know what to do.

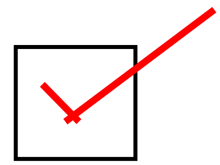
Verbs: List, Describe, Illustrate, Explain are all verbs that you will see in the Labs.

What are Lab Goals?
The labs are going to be very goal-oriented; you will be presented with goals at the beginning of each lab complete with questions that are specific to these goals. Goals are used to communicate to you what the lecturers want you to be able to **UNDERSTAND** and **ACCOMPLISH** during the lab. These goals should help guide your studying.

General Lab Etiquette

Lab completion marks are used to check that you have completed and understood all of the material in the lab. This system is designed so that the lecturers and demonstrators know that everyone in the class understands and that no one is being left behind. Therefore, for you to get a full marks **you have to come to all the labs and complete the designated tasks.** We encourage people to work together to figure the answers out, the best way to show that you have mastered a concept or idea is to try and ***teach someone else.*** You'll find that you'll remember the day's lesson a lot easier if you argue with one of your mates about how something actually works.

Lab Completion Marks: You complete all the material in that week's lab. The following week the lecturer or demonstrator will look over and discuss with you what you have done. If they are satisfied with your response you will receive a 'tick,'. If you have not completed the work in the lab to a satisfactory level, you will receive partial or no credit for that lab.



General Lab Etiquette:
Lab time is the time to ask questions, receive feedback, and work through the academic tasks. **It is common for students to require more time to complete labs (up to 3 or 4 hours).** This is the responsibility of the student to do so. The lab space is typically open to students most days (8AM to 6PM), and if it is locked, you can see staff on Level 3 of West in order to obtain access.

If you cannot make it to a lab: EMAIL the head demonstrator (Elodie) to let them know right away. We will accommodate you if you are sick, or have a legitimate reason for missing the lab. The lecturers are the people to discuss larger issues (long term illness, death in the family, etc.). Please review Canterbury's policy on **Aegrotats**, before going to the lecturers.

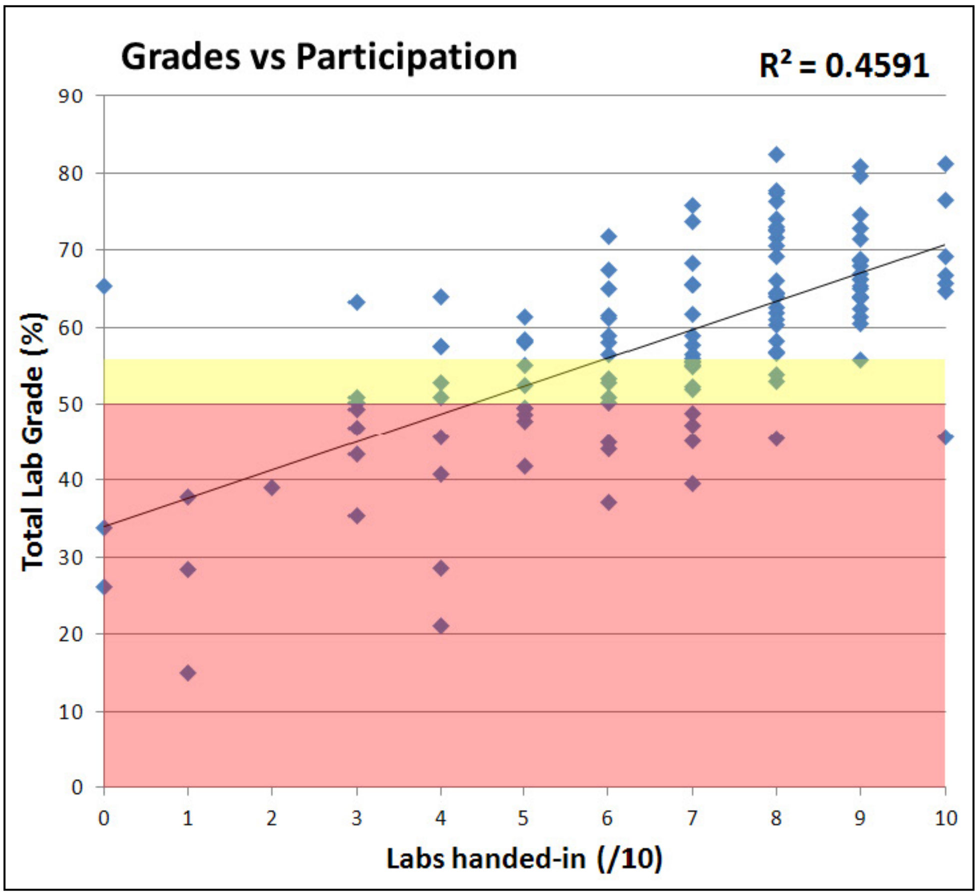
Demonstrators and peers are to be treated with **respect** at all times. **Plagiarism** is not tolerated and will result in major consequences to the student. Any behavioural problems will be dealt with in accordance to University of Canterbury policies.

A reason to <u>come</u> to labs, and <u>complete</u> them:

Research carried out here at UC, and internationally shows that students' grades are directly (and proportionally) connected to the effort that they put in (**Figure 1** below).

In the past three years, we have shown that students who hand-in their labs and complete them to the best of their ability – generally **score much higher**, and **pass the course**.

Figure 1: Total lab grade (in %) versus **Lab participation** for 2011 students in GEOL242. Students who completed 5 labs, generally passed the lab component. Students who completed 8/10 of the labs generally scored >65%.



Mineral Identification & Texture Booklet

This year you will be constructing your very own Mineral Identification & Textures 'Booklet'. Each lab you will be given a certain amount of time to work on given mineral descriptions, and you put these together to make a booklet. At the end of the term you should have a comprehensive resource containing all the minerals and textures you have observed. ***The ID booklet will not be graded, but will be one of the only resources that you will be allowed to take in with you for the laboratory exams.*** The goal is for you to create a resource that you continue to use during your undergraduate career and possibly beyond.

To aid you in the identification of minerals and textures in thin section during the labs you are going construct a mineral identification booklet for your own use. This booklet will not be graded per se, but will be completed during each lab to ensure that you are making progress. This will contribute to your overall participation mark for the course (10%). **This booklet will be allowed to take into the laboratory exams – therefore they are your 'cheatsheet' to success.** Practicing drawing the minerals is valuable, since the lab exams will require you to make detailed sketches of the thin sections and relate any interpretations you have made to your drawings. ***Lab theory, rock names, or classification is not to be included in your Booklet – just the mineral properties and textures.***

MINERAL IDENTIFICATION SHEET (***EXAMPLE***)

Chlorite

Chemical Formula: $(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2 \cdot (Mg,Fe)_3(OH)$

Mineral *Class*: Silicates

Mineral *Subclass*: Phyllosilicates

Mineral *Group*: Chlorite Group

Picture (CPL & **PPL**)

Colour Range: Green, white, yellow, pink, red and **browns**

Birefringence: low – med, **Anomalous purple-blue**

Pleochroism: weak – **moderate**; pleochroic **green**

Relief: moderate

Crystal Habit: euhedral-subhedral, **platy**, tabular to acicular, can be radiating and wispy as well.

Cleavage: 1 good direction

Twinning: Uncommon

Other Features: Alteration from biotite to chlorite is common.

Occurrence: Abundant mineral in low to medium grade metamorphic rocks and as a secondary mineral in igneous (mafic) rocks. **Often found with other phyllosilicates** (e.g. muscovite and biotite). Chlorite is also often found with other green coloured minerals such as epidote, and amphibole.

****Bolded*** *terms are used to note the Distinguishing (or Diagnostic) features.*

Lab 1: Introduction to Microscopy

Goals:

1. Use basic mineral chemistry and chemical formulas to identify the cation and anion in a mineral's chemical formula(e)
   Section 1 → Basic Mineral Chemistry
2. Use mineral chemistry to explain substitution, and binary systems
   Section 2 → Binary Plots
3. Describe minerals in thin section, and describe **olivine** in thin section
   Section 3 → Introduction to Microscopy
4. Explain why olivine is so important to geologists, and to practice writing essay style questions.
   Section 4 → Essay questions
5. Over the next week, do Homework and use the virtual microscope to describe unknown minerals from one another
   Homework → Virtual Microscope

Section 1: Basic Mineral Chemistry

Instructions: Read the Lab 1 Readings to review chemistry concepts, the definition of a mineral, and learn about the Dana mineral classification system. Complete the questions below.

Question 1: List the proper classification for the minerals below:

Graphite
Class:
Mineral Formula:

Diamond
Class:
Mineral Formula:

Calcite
Class:
Mineral Formula:

Biotite
Class:
Subclass:
Mineral Formula:

Question 2: Using the full definition of a 'Mineral', explain WHY Volcanic Glass is NOT a mineral:

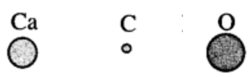
Question 3: Look at the chemical formulas listed below (A-C) and:

i. Identify (label) the cation and anion;
ii. Represent each element's ionic radii with a circle of appropriate size and charge
iii. Demonstrate that these are balanced
iv. Label the parts of the chemical formulae that indicate what Mineral Class these minerals belong to. Use example below to help you, as well as any other resources available in the lab.

E.g: Calcite: Ca CO_3

I. Cation Anion **IV.** Carbonate class (CO_3^{2-})

II.



Ca^{2+} C^{4+} O^{2-}

III.

$$\boxed{\begin{array}{cc} (Ca^{2+}) = +2 & (C^{4+})[(O^{2-})*3] = -2 \\ \text{Cation} & \text{Anion} \end{array}}$$

A. Halite NaCl

B. Forsterite Mg_2SiO_4

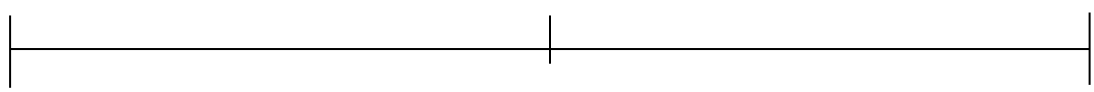
C. Hematite Fe_2O_3

Section 2: Binary Plots

Question 4: In the Olivine Group there are two minerals that are in solid solution with one another: Forsterite (Mg_2SiO_4) and Fayalite (Fe_2SiO_4). Minerals in this solid solution are represented as a "Fo" (Forsterite) [value 100% Mg = Fo_{100}].

I) Label the binary plot below with the end-member names and the dominant cation.
II) Why can Mg and Fe substitute for one another in olivine and what charge is the Fe?

III) Plot and label the olivines with the following composition: (1) Fo_{25} (2) Fo_{60} (3) Fo_{90}.



Section 3: Introduction to Microscopy

Instructions: Now that you all have your microscopes, we are going to have a look at the first thin section. Without going through any identification tips, tricks, and procedures, you are going to describe the minerals in your own words. This is very important!!!

Developing your own strategies for mineral identification is far superior then relying on a textbook. You should identify the different minerals present by comparing them with one another and highlighting their perceived differences.

Example: Crystal A is green and circular; Crystal B is black and squarish and so forth.

Try putting the analyzer in and out, rotating the stage, to distinguish between minerals for a start. Supplied below is table that will allow you to logically distinguish between the differing minerals by using observed features under the microscope. Four of the columns have been left blank, use the features you have noticed in thin section to systematically separate them.

Question 5: Identify the minerals present in thin section **4929** on your own terms.

Crystal A	Colour					Drawing
Crystal B						
Crystal C						
Crystal D						
Crystal E						

Question 6: Olivine; Today you will make your first entry into your mineral identification booklet with olivine. A mineral identification sheet template is provided. Do your best at filling out the properties of Olivine. We will continue this next week, but we want you to start using Shelley, and other resources to become familiar with the terms we use to describe features of minerals.

Section 4: Practice Essay Questions

Question 7: I) How do the olivine crystals relate to the other crystals in the rock? (Are they phenocrysts? What proportions are they in? Are they filling in spaces between other crystals?) (7 marks)

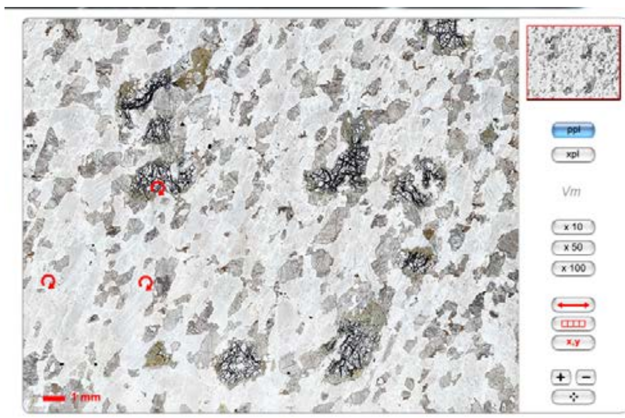
II) What kind of environment do you think the rock comes from? (Intrusive/extrusive/ metamorphic/sedimentary) Why? (7 marks)

Homework: Virtual Microscope

Read the readings in Section 4 (at the back of this packet). Then, use the website provided to explore the appearances of minerals under a 'Virtual Microscope' online, at home:

http://www.virtualmicroscope.org/content/olivine-gabbro-huntly

Instructions: Click on the Gabbro thin section. Click on the **ppl** and the **xpl** buttons, to observe the differences in the thin section.



ppl

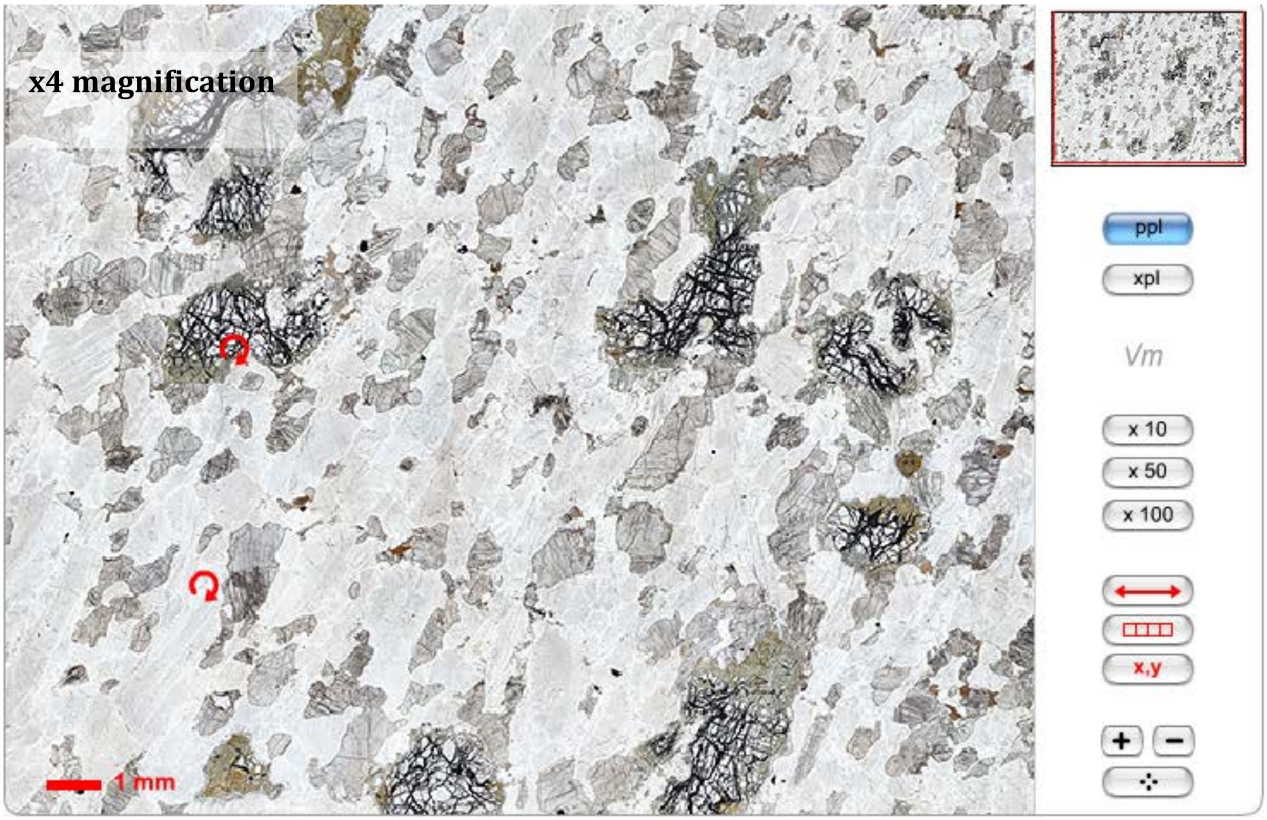
xpl

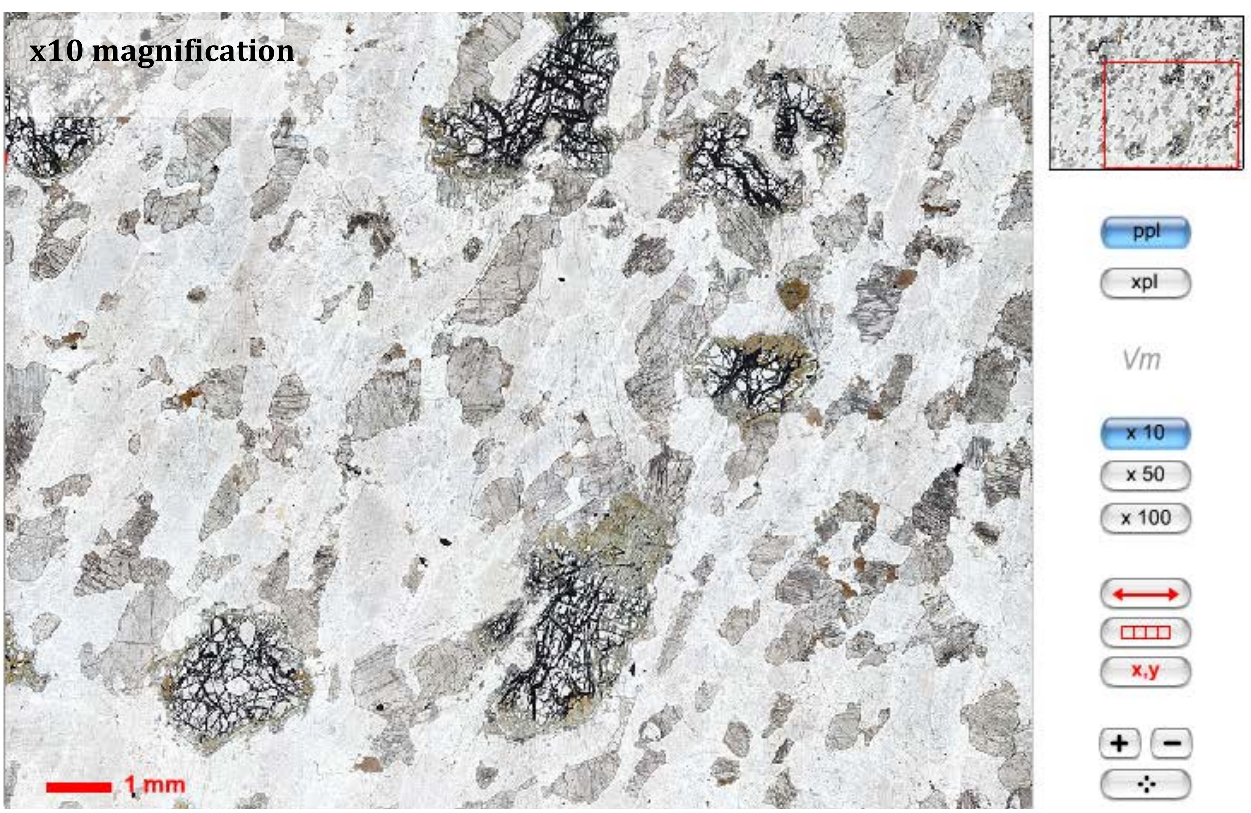
Question 1: A. Based on the supplementary material, and your lecture theory so far - Explain what the **plain-polarized light** (ppl) setting is on your microscope (in your own words).

B. Explain what the **cross-polarized light** (xpl OR cpl) setting is on your microscope (in your own words).

C. In the ppl setting, i. List the number of different minerals you believe to be present. ii. Fill out the properties (in your own words) (E.g. Colour) in the chart that aided in your differentiation; and iii. Draw and label a representative crystal grain of each mineral. (*Use the red box in the top right corner of each image, to help you see the level of magnification you are seeing)*

Crystal A	Colour					Drawing
Crystal B						
Crystal C						
Crystal D						
Crystal E						


x4 magnification
1 mm
ppl
xpl
Vm
x 10
x 50
x 100
x,y


x10 magnification
1 mm
ppl
xpl
Vm
x 10
x 50
x 100
x,y


1 mm
ppl
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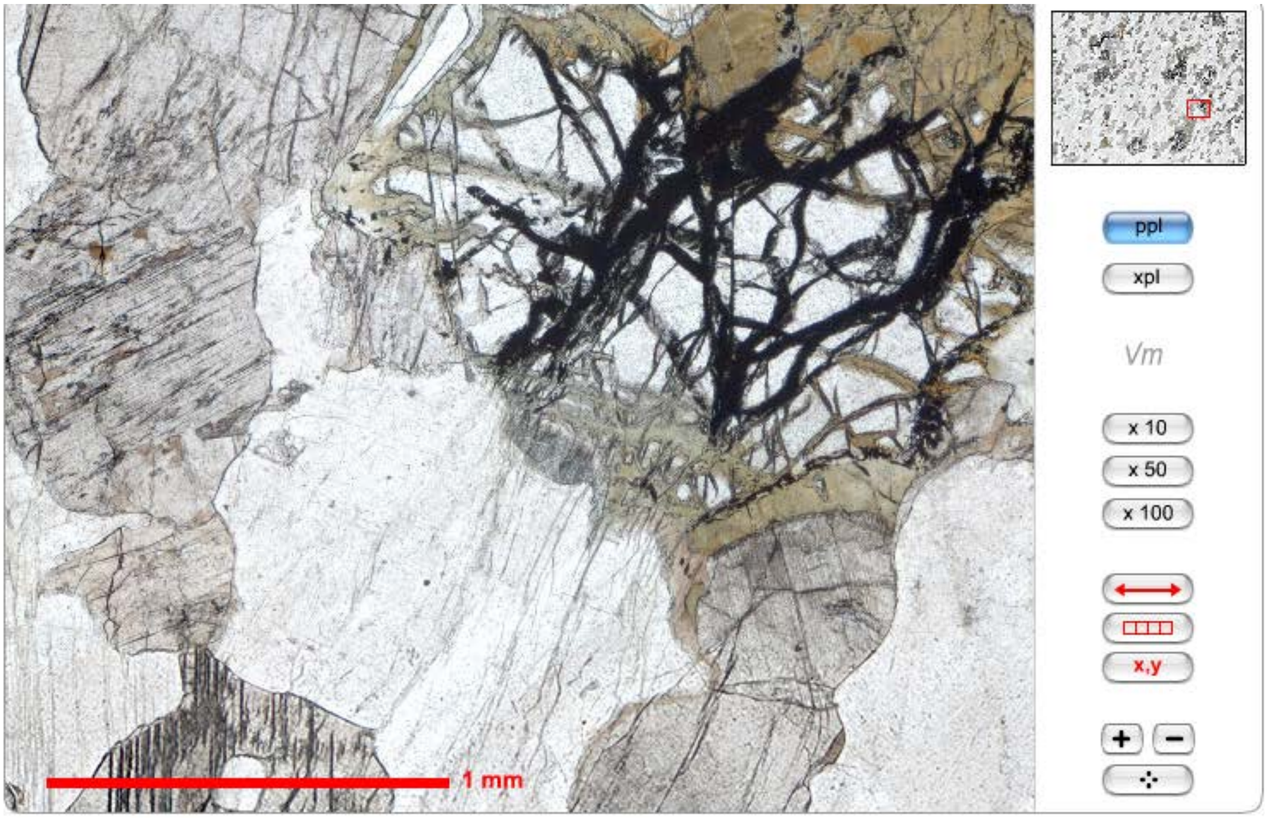
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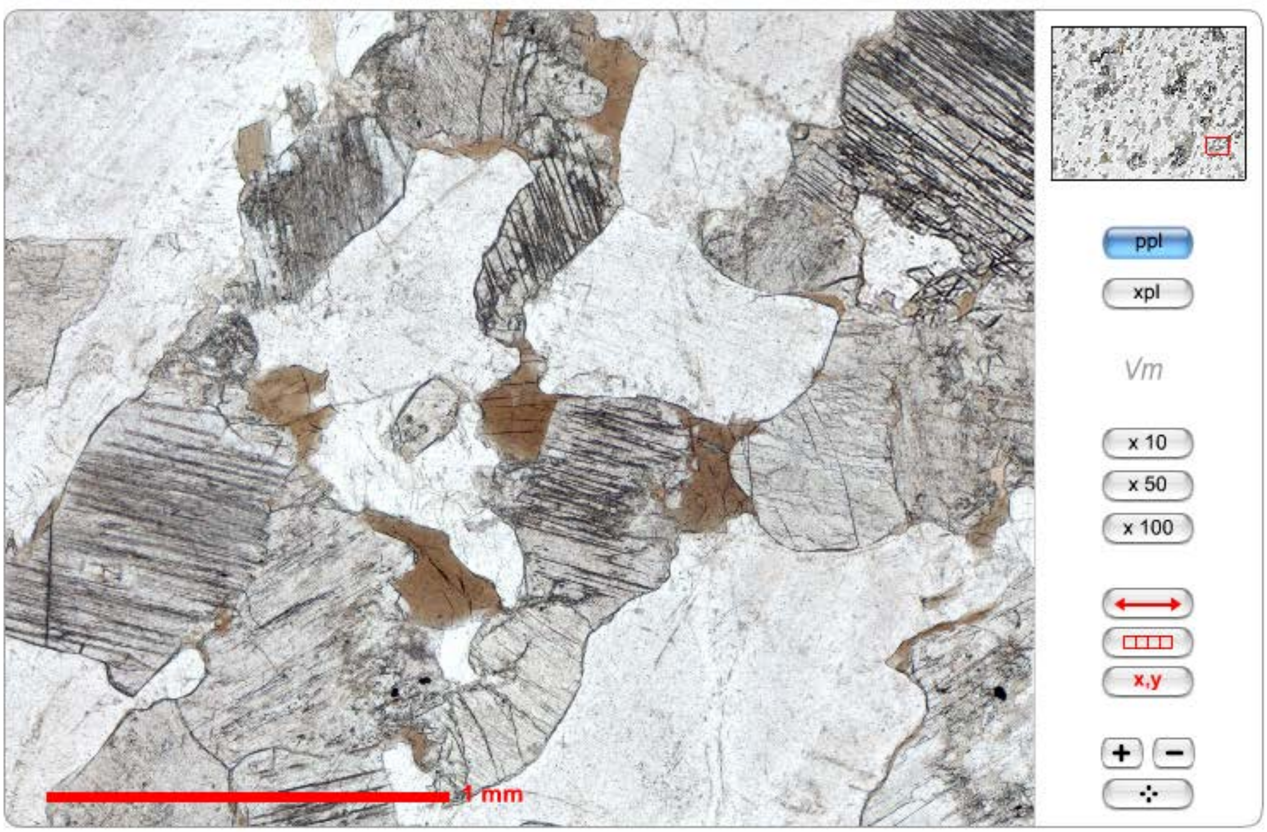

1 mm
ppl
xpl
Vm
x 10
x 50
x 100
x,y

Lab 1 Readings:

Section 1: Basic Mineral Chemistry

Goal: Use the chemical properties shown in the periodic table (i.e. atomic radii, charges) to:

A) Identify different parts of a mineral formula (e.g. Cation and Anion);
B) Identify the difference in the size of ions;
C) Balance a chemical formula of a mineral; and
D) To label parts of the chemical formula that allow mineral to be classified

Definitions:

An **ion** is an atom or molecule which has lost or gained one or more valence electrons, making it positively or negatively charged.

A negatively charged ion is known as an **anion**.

A positively charged ion, which has fewer electrons than protons, is known as a **cation.**

The **ionic radius**, is a measure of the size of an ion in a crystal lattice.

Cations and anions can be simple (made up of one atom) or polyatomic (made up of many atoms).

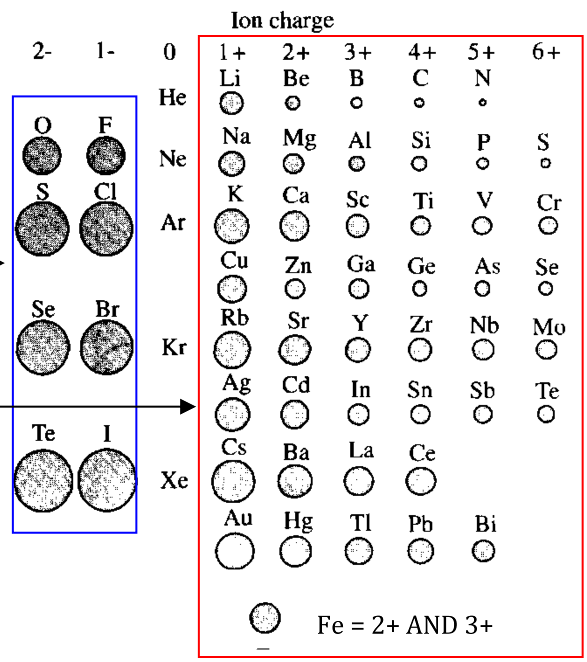
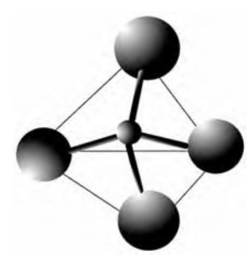


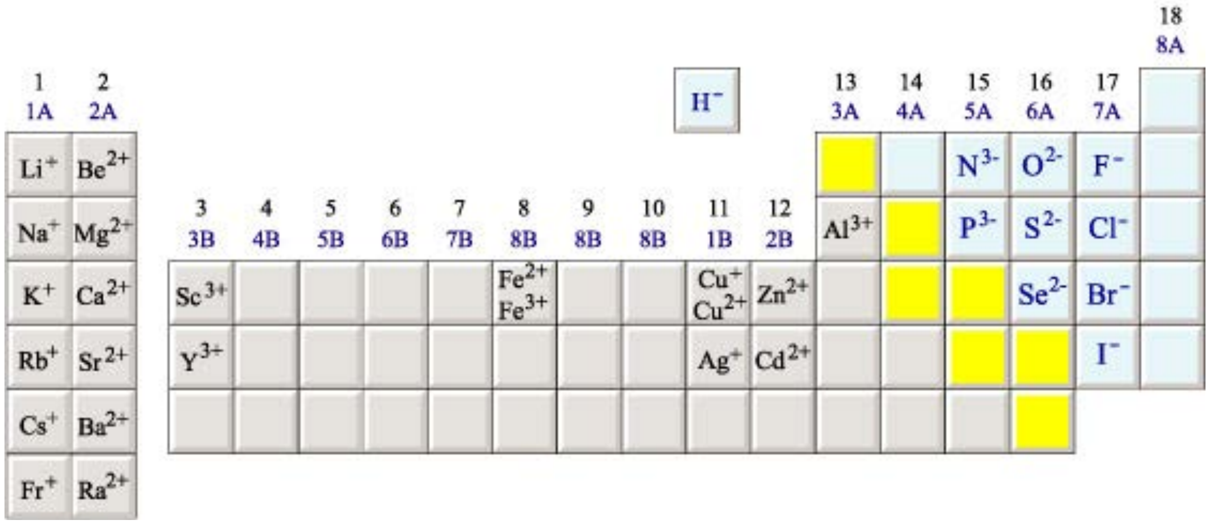
Figure 1.1: Relative sizes (ionic radius) of some ions with the same electron configuration.

What is a mineral?

- naturally occurring (inorganic)
- solid, crystalline substance
- unique crystal structure
- fixed chemical composition
- distinguished by set of unique physical properties



Common Cations:



Common Anions			
Carbonate	CO_3^{2-}	Phosphate	PO_4^{3-}
Chloride	Cl^-	Fluoride	F^-
Oxide	O^{2-}	Silicate	SiO_4^{4-}
Sulfate	SO_4^{2-}	Sulfide	S^{2-}
Sulfite	SO_3^{2-}	Hydroxide	OH^-

What are mineral classes and mineral groups?
Minerals can be classified primarily on the crystal structure of the mineral. Mineral **classes** are based on the main **anion** (O^{2-}, S^{2-} etc.), **anionic complex** (OH^{1-}, SO_4^{2-}, CO_3^{3-}, PO_4^{3-}, $B_xO_y^{Z-}$, $Si_xO_y^{Z-}$ etc.) or lack of an anion (native elements). An example of a mineral class is: **silicates** ($Si_xO_y^{Z-}$).

Minerals can also be further classified in terms of mineral groups. A mineral group consists of two or more minerals with the same or essentially the same structure, and composed of chemically similar elements. An example of a mineral group is the **calcite group**, which contains the minerals: calcite, magnesite, smithsonite, siderite, rhodochrosite and otavite.

We will focus on mineral properties and using the microscopes. For more information on the classification and crystal structure of minerals see:
http://www.mindat.org or http://www.webmineral.com

Basic Dana Mineral Classification System:

Non-silicates	**Minerals:**
Native Elements**	Copper, Graphite
Sulphides**	Bornite, Galena, Sphalerite, Chalcopyrite, Pyrrhotite, Pyrite, Molybdenite
Oxides and Hydroxides**	Hematite, Ilmenite, Magnetite, Rutile
Halides	Fluorite, Halite
Carbonates*, Nitrates, Borates	**Calcite,** Aragonite, Dolomite, Malachite, Azurite
Sulfates, Chromates, Selenates	Gypsum, Barite
Phosphates, Arsenates, Vanadates	Apatite

Class: Silicates

Subclass: **Nesosilicates**	**Olivine, Garnet**, Andalusite, Sillimanite, Kyanite, Staurolite
Sorosilicates	Epidote
Cyclosilicates	Tourmaline, Beryl
Inosilicates or Chain silicates	**Pyroxene Group: Orthopyroxene** (e.g. Enstatite), **Clinopyroxene** (e.g. Augite), Tremolite, Actinolite, **Amphibole Group** (e.g. Hornblende)
Phyllosilicates or Sheet-silicates	**Micas: Muscovite, Biotite,** Chlorite, **Clays:** Kaolinite
Tectosilicates	**Quartz, Feldspar Groups: Alkali Feldspar** (e.g. Microcline) and **Plagioclase** (e.g. Albite)

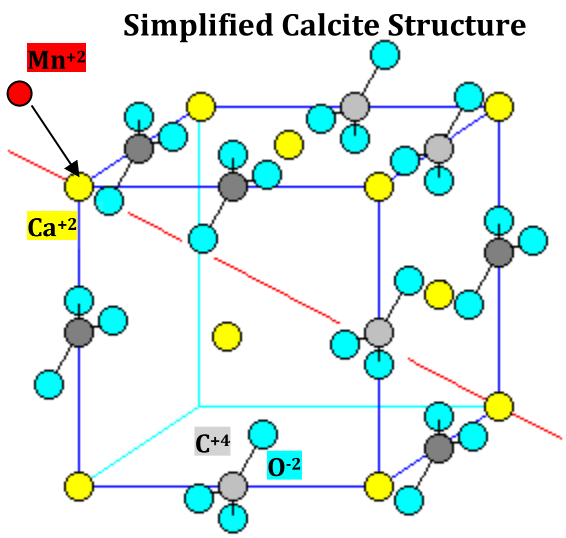
*****_Bolded Classes and Minerals are the most common. NB: Don't worry about memorising this table._

** These minerals appear as 'Opaque's in thin section.

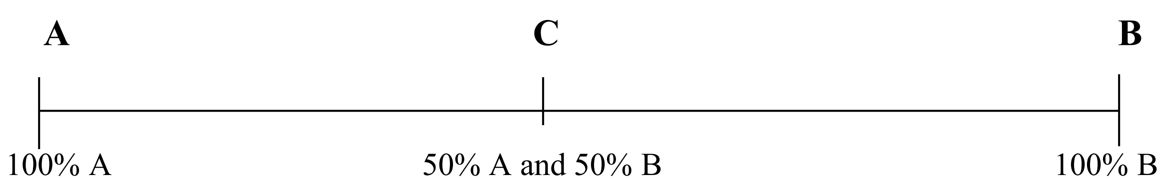
Section 2: Binary Plots:

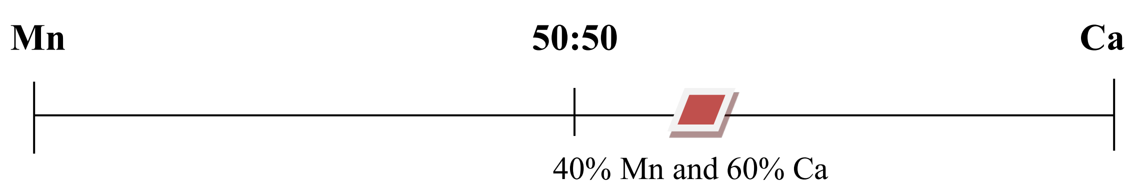
Using diagrams to represent complex data is really important in Mineralogy. **Solid Solutions** occur when one element is substituting in the crystal structure to create a mineral with a different composition but retaining the same structure. **Substitution** is the placement of an **ion** (or group of atoms), in a mineral structure with another. Substitution occurs when the charge of the ion is the same, and the ionic size is within 15% difference.

Calcite and rhodochrosite are in the calcite group. Their **cations** are Ca^{2+} and Mn^{2+} and are relatively the same size. The **anion** for both is CO_3.
The Mn ↔ Ca substitution depends on availability of the elements during crystallization and the conditions that the mineral forms under. We can plot the Mn ↔ Ca substitution on a **binary plot** which will tell us which of the two compositions the mineral is closest too.



A **BINARY** solid solution between **two** minerals is illustrated below:
Pure Mineral A is at one end, called an **endmember**, and pure Mineral B is at the other end. Any compositions between them are a percentage of both (i.e. C = 50% of A and 50% of B).





For example, if our carbonate mineral shown above, is 40% Mn (rhodochrosite) and 60% Ca (calcite) it would plot like above.

The Periodic Table of the Elements

1 **H** Hydrogen 1.00794																	2 **He** Helium 4.003
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012182											5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.00674	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.9984032	10 **Ne** Neon 20.1797
11 **Na** Sodium 22.989770	12 **Mg** Magnesium 24.3050											13 **Al** Aluminum 26.981538	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.973761	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.4527	18 **Ar** Argon 39.948
19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.955910	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.938049	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933200	28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.92160	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.80
37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.90585	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.90638	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium (98)	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.90550	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90447	54 **Xe** Xenon 131.29
55 **Cs** Cesium 132.90545	56 **Ba** Barium 137.327	57 **La** Lanthanum 138.9055	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.9479	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.078	79 **Au** Gold 196.96655	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98038	84 **Po** Polonium (209)	85 **At** Astatine (210)	86 **Rn** Radon (222)
87 **Fr** Francium (223)	88 **Ra** Radium (226)	89 **Ac** Actinium (227)	104 **Rf** Rutherfordium (261)	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (263)	107 **Bh** Bohrium (262)	108 **Hs** Hassium (265)	109 **Mt** Meitnerium (266)	110 (269)	111 (272)	112 (277)	113	114				

58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.90765	60 **Nd** Neodymium 144.24	61 **Pm** Promethium (145)	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.92534	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93032	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93421	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967
90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.03588	92 **U** Uranium 238.0289	93 **Np** Neptunium (237)	94 **Pu** Plutonium (244)	95 **Am** Americium (243)	96 **Cm** Curium (247)	97 **Bk** Berkelium (247)	98 **Cf** Californium (251)	99 **Es** Einsteinium (252)	100 **Fm** Fermium (257)	101 **Md** Mendelevium (258)	102 **No** Nobelium (259)	103 **Lr** Lawrencium (262)

Section 3 & Homework: Introduction to Microscopy

Microscope Care and Maintenance

This portion of the lab serves as an introduction to the Polarizing Microscope, which will be used in all subsequent labs (except one) and in related 3rd and 4th year courses. The replacement cost of the microscopes you will be using is ~$7-10,000, and with proper care the current microscopes will last another 30 years. Please be careful with the microscopes. We'll first allocate microscopes, then discuss their care and introduce the different parts of the microscope.   This stage 2 lab is yours for the year- treat it as a base- study in here when you like- (open approx. 8.30-5.30 Mon-Fri). Just be considerate of other users and don't consume food or drink in the lab.

General care of the microscope:

1. Always carry the microscope with two hands, one under the neck and one supporting the base.
3. Keep the microscope in its locker at all times when not in use.
4. Microscopes are to be used in the second year lab only. If this room is occupied then move into the third year lab. Microscopes are not to be removed from the Second Floor.
6. DO NOT ATTEMPT ANY REPAIRS YOURSELF!! If you have problems with the microscope, use the 'microscope problem' sheet pinned on the back of the lab door. We need to know the date, who notified the problem, the instrument number and most importantly...a precise description of what the problem is - comments like microscope doesn't work are not helpful!
7. Turn the objectives by holding the bevelled ring on the nosepiece, not the objectives themselves
8. DO NOT ATTEMPT TO CLEAN THEM YOURSELF, we have special tissues and cleaners to do the job! contact [redacted] [redacted] in room 219
9. Take care not to damage the high power objective due to small working distance.
10. **DO NOT DRAW OR WRITE ON THE MICROSCOPE**

Putting your microscope away:

1. Rotate the objective to the lowest power before storing, so when you take out and put in new slides they don't get scratched.
2. Turn down and switch off the microscope light source before switching off the power source and unplugging. Otherwise the next person who plugs the microscope in will give the cold bulb a big voltage surge and reduce the bulb life considerably. When unplugging the microscope power cord pull on the plug not the cord.
3. Allow the microscope to cool down before you put it away.
4. Secure the tint plate under the stage clips making sure the small screw is facing upward and not scratching the stage surface.
5. The microscope number is located at the base of the microscope. Place your microscope in the cupboard of the same number, with the back of the microscope facing outward to allow easy removal when next used.

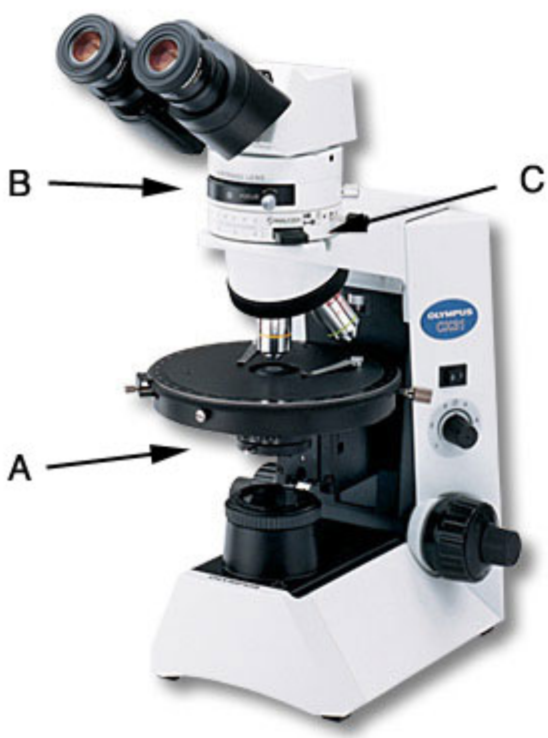
Because the microscopes are used by 3 streams, it is important to get into the routine of tuning the microscope each time you begin a session. First and foremost always adjust the focus of the eyepiece for your eyes.

<u>Nature of Science and 'Observations':</u>

The scientific method requires observations of nature to formulate and test hypotheses. It consists of these steps:

1. Asking a question about a natural phenomenon
2. Making **observations** of the phenomenon
3. Hypothesizing an explanation for the phenomenon
4. Predicting a logical consequence of the hypothesis
5. Testing the hypothesis by an experiment, an observational study, or a field study
6. Creating a conclusion with data gathered in the experiment

In mineralogy we use microscopes to observe rocks: their **minerals** (what they are made of), and their **textures** (how they look). Optical Mineralogy is the scholarly and scientific method of recording the identification, classification, and categorization of minerals, their properties, and their uses. By observing the minerals, we can say something about the composition and origin of the rock. By knowing the textures we can say something about the history of its formation.



Optical Microscopy:
The compound optical microscope is a modern microscope which uses **visible light** and a system of lenses to magnify images of small **'thin sections'** of rock samples. A lens magnifies, by bending the light. Typically, on a standard compound optical microscope, there are three objective **lenses (C)**: a scanning lens (4×), low power lens (10×), and high power lens (40×).

Filters otherwise known as **polarizers (A, and B)** are used to filter out some light waves vibrating in different directions. This is used because each mineral (with its respective chemistry and structure) has unique properties and will change properties based on the 'settings' of the microscope. The two 'settings' are with only one polarizer (plain-polarized light), and with both polarizers 'crossed' (cross-polarized light) (at 90 degrees to one another). These two different settings allow us to identify respective minerals within rocks → leading to their identification and classification.

Mineral Properties and Techniques:
Every mineral looks different in the microscope due to its **unique** chemistry and crystal (or atomic) structure. Based on several properties, we can observe, and name minerals based on its appearance. A **diagnostic property** is a special property of a mineral (when looking down the microscope, or holding it in the field) that is special, and allows for quick determination of what it is. This is similar to a medical diagnosis: the special symptoms of a patient allows a doctor to diagnose the illness. We use diagnostic properties to eliminate other possible minerals, and come to a correct identification. However, be sure to be thorough and record all the observations that you can, as this is a good scientific technique.

How does the microscope work?
The microscope allows for the examination of thin sections (thin slices of rock through which light passes).
Light is passed upward through the specimen from a lower light source, and is affected by the specimen. The light travels up from the specimen through the eyepiece and we see the image. That's all. There are several different viewing modes in terms of the type of light that we observe. The different viewing modes allow us to check different optical properties of a mineral that help us to identify it.

Basic Start-up of the Microscope:

1. Place the thin section on the stage, the right way up, with the cover slide up.

2. Turn on the microscope and obtain a well illuminated image (not too bright- about same intensity as ambient light).

3. Focus the image. CHECK with neighbours and demonstrators that you have a good image.

4. Rotate the stage, and insert the analyser, rotate further.

Parts of the microscope (Images following):

Rotating stage
Marked in degrees to allow measurement of angles, and with a clamp to fix the stage in position

Focus
Coarse and fine focus

Objectives
Lenses used to magnify the specimen. Range from low to high power- don't hold onto objectives themselves when changing magnification, hold rotating nosepiece.

Polarizer
Sheets of Polaroid to polarise light to vibrate in certain direction. The polariser is fixed in position located below the slide (polariser-EW vibration direction)

Analyser
A polaroid sheet above the light (analyser-NS). The analyser can be swung in and out of position, these allow extinction in the correct orientation parallel to the cross hairs.

Eyepiece
Is a lens fitted at the top of the microscope tube to magnify and focus the image produced by the objective lens. Contains cross-hairs (NS and EW), which can be focussed by raising or lowering eyepiece. Total magnification = objective x eyepiece.

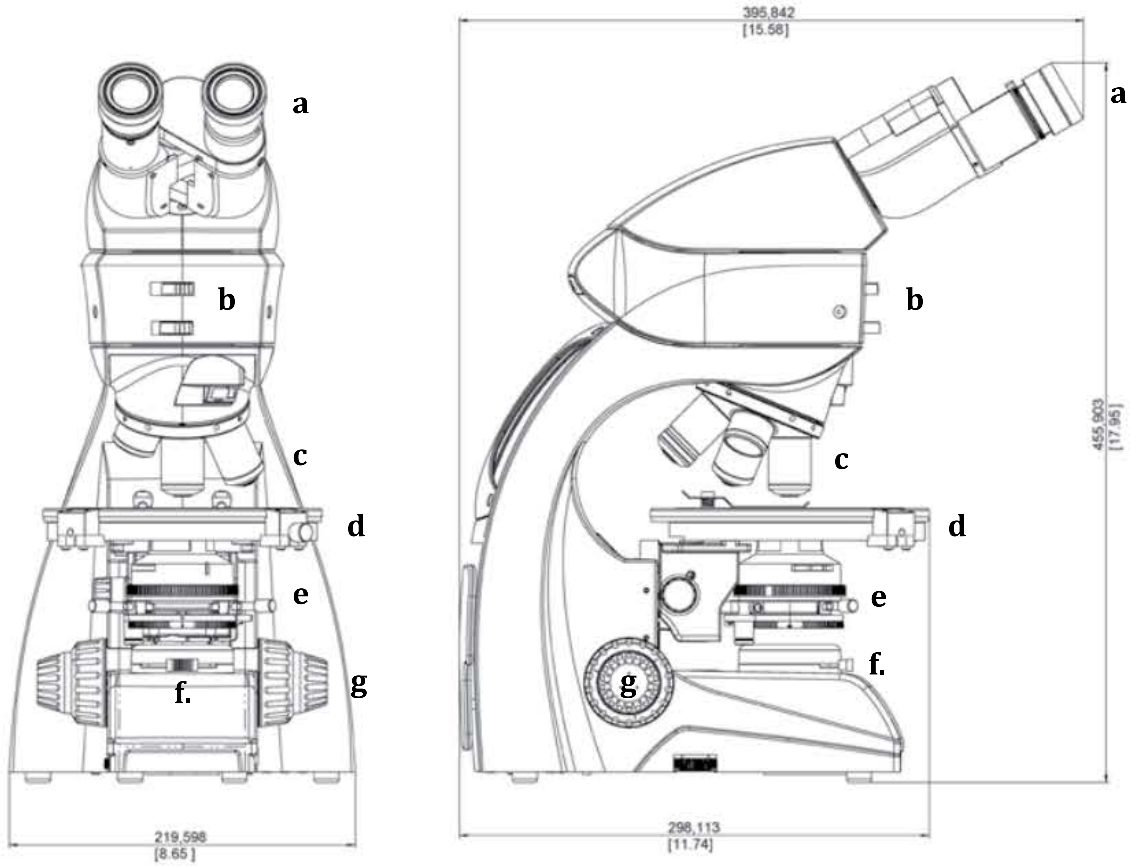
Condenser system
Lenses below the stage that vary the path of light onto the specimen (described later).

Substage diaphragm
An iris diaphragm that can be partly closed during some viewing modes (discussed later).

Illumination (light and mirror)

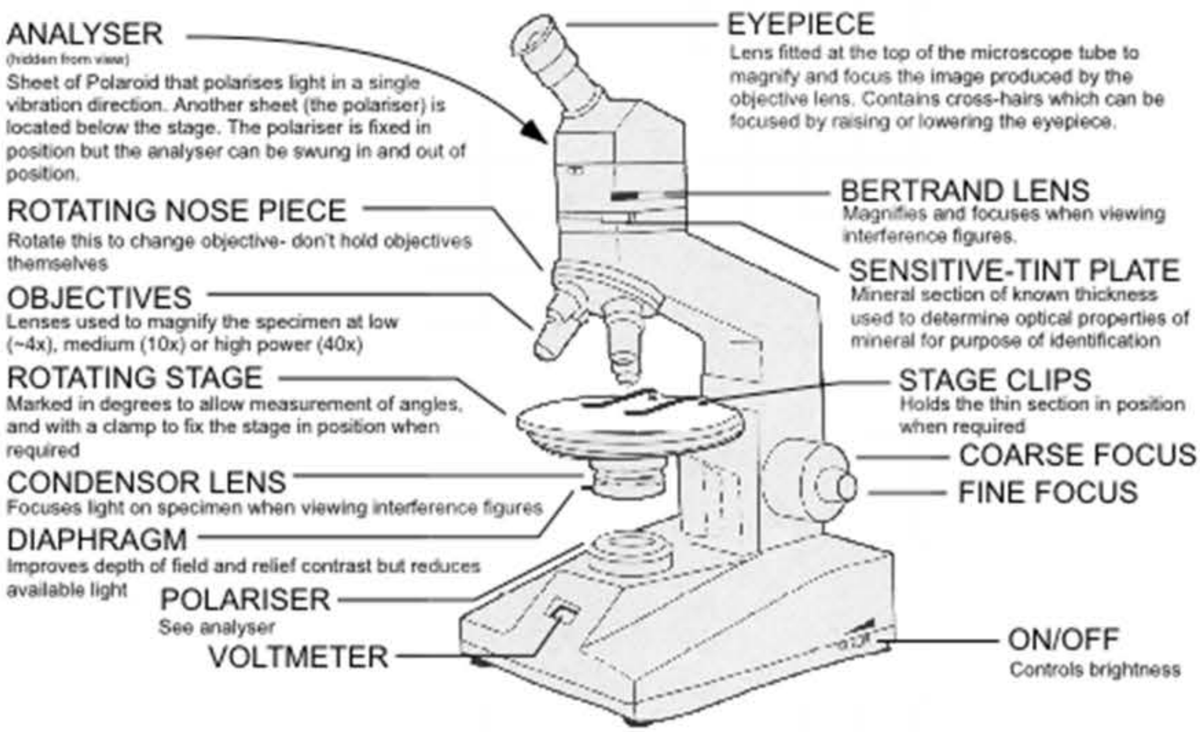
Tint plate
Mineral section of known thickness used to determine optical properties of mineral for purpose of identification.

Leica Microscope:



a. **Eyepieces**
b. **Upper analyser (polariser) + Bertrand lens**
c. **Objectives (lenses)**
d. **Stage**
e. **Lower polarizer**
f. **Light source**
g. **Focus knobs**

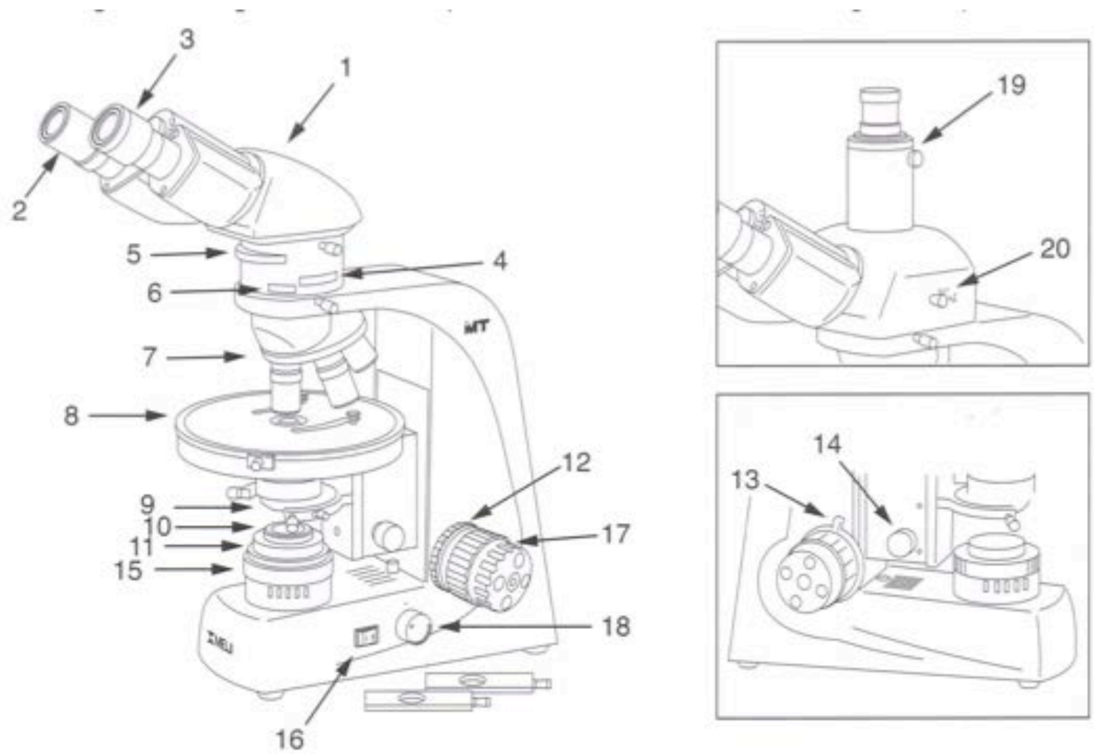
Swift Microscope:



Putting your Microscope Away:

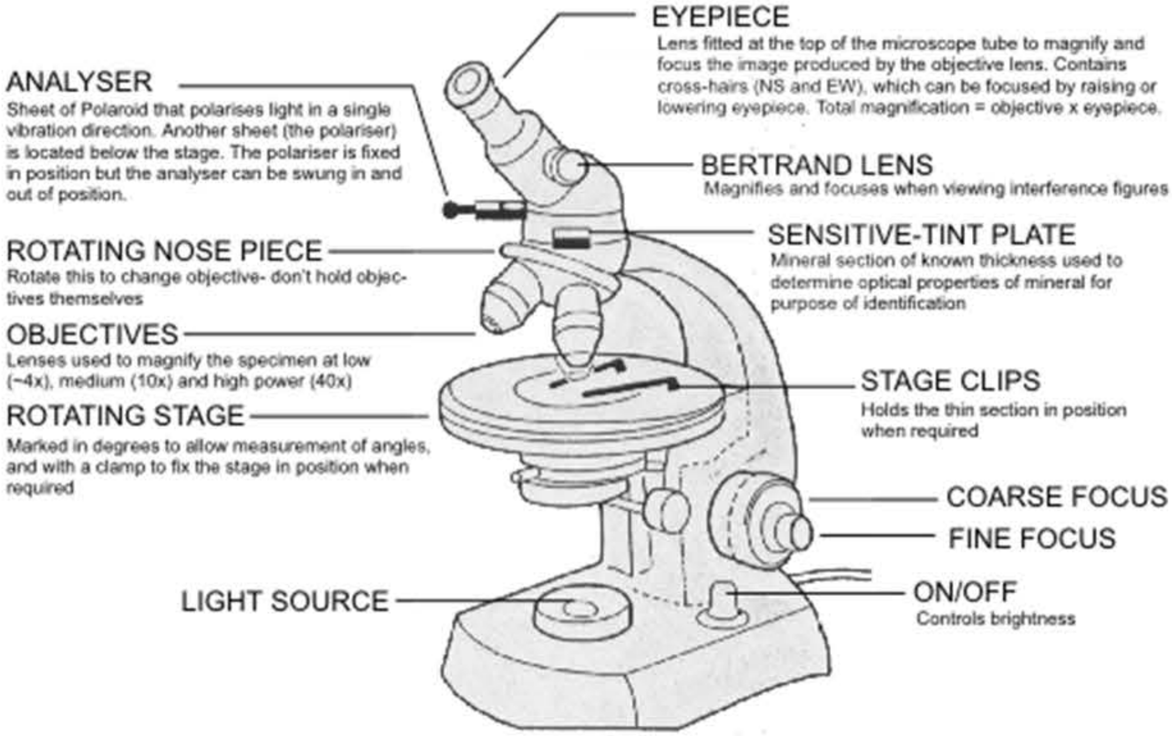
1. Switch off the microscope before switching off the power source and unplugging.
2. Allow the microscope to cool down before you put it away.
3. Secure the tint plate under the stage clips making sure the small screw is facing upward and not scratching the stage surface.
4. The microscope number is located at the base of the microscope. Place your microscope in the cupboard of the same number, with the back of the microscope facing outward to allow easy removal when next used.

Meiji Microscope



1. Siedentopf Binocular Head
2. Eyepiece KHW10X, F.N.20
3. Eyepiece KHW10X-F with cross-line and guide pin
4. Analizer in slider mount
5. Rotatable Bertrand Lens (fixed)
6. Compensator Slot
7. Ergonomic reversed centerable nosepiece
8. Ceramic coated rotatable stage
9. Strain free Abbe 1.25 condenser with built-in Iris diaphragm
10. Rotatable swing-out polarizer
11. Filter tray for 29.8mm blue filter, swing out the polarizer to open filter slot
12. Focus tension adjustment, turn the knurled ring counter-clockwise to tighten the tension
13. Adjustable safety knob, turn lever clockwise to lock the stage height
14. Condenser rack height adjustment knob
15. Field Iris
16. Power switch
17. Low positioned ergonomic coaxial coarse and fine focusing control
18. Low positioned variable brightness control
19. Trinocular head with integrated male C mount
20. Beam splitter for camera port

Zeiss Microscope:



Putting your Microscope Away:

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4. The microscope number is located at the base of the microscope. Place your microscope in the cupboard of the same number, with the back of the microscope facing outward to allow easy removal when next used.

Notes from Lab 1:

Lab 2: Solid Solution and Mineral ID

Goals:

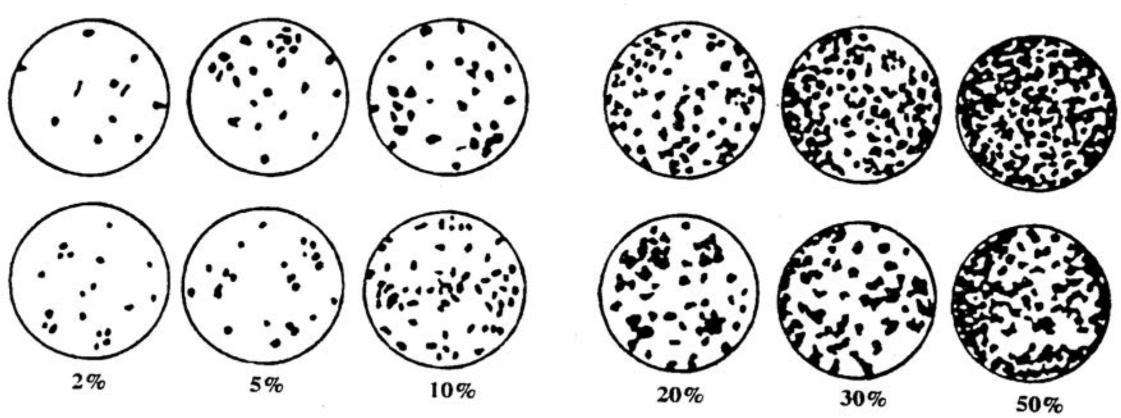
1. Estimate mineral proportions (or percentages) from a thin section, based on diagnostic properties using the Virtual Microscope
    Section 1: Estimate Mineral Percentages
2. Use ternary plots to visualise mineral compositions and to name minerals
    Section 2: Ternary plots
3. Classify the rock using ternary diagrams and mineral percentages
    Section 3: Classify the rock
4. Describe and identify clinopyroxene, plagioclase, & an 'opaque' mineral in thin section.
    Section 4: Mineral Identification Sheets
5. Relate the rock and minerals to igneous processes
    Section 5: Practice Exam Questions

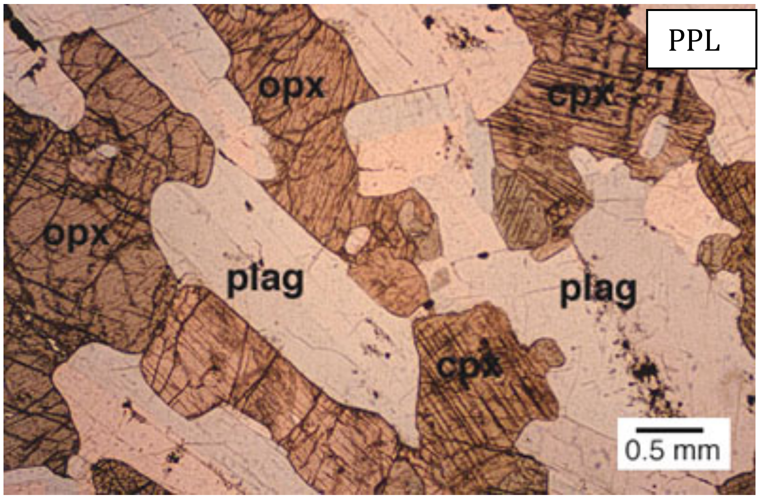
Section 1: Estimate Mineral Percentages

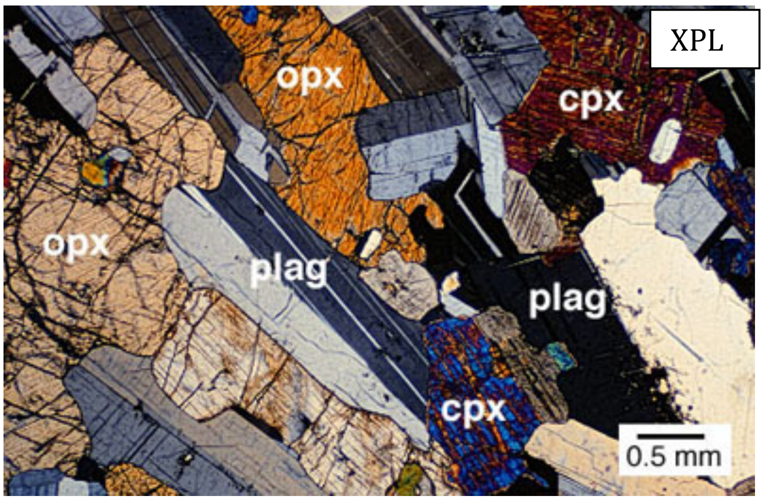
Instructions: Using the chart below, we estimate the **% of minerals** in any given thin section. This allows us to USE NUMBERS to describe the rock, and its composition. **Read the Appendix, for the mineralogy terms we use to describe the features you see.**

In each rock, there are likely to be **mafic** (or dark-coloured) minerals and **felsic** (or light-coloured) minerals. It is good to begin with splitting these up, and estimating their proportion (e.g. 20% mafic and 80% felsic).

You finish by splitting up the felsic and mafic parts into recognizable minerals (e.g. Felsic minerals 10% Quartz[**qtz**], 30% Plagioclase[**plag**], and 40% Alkali Feldspar[**kspar**])







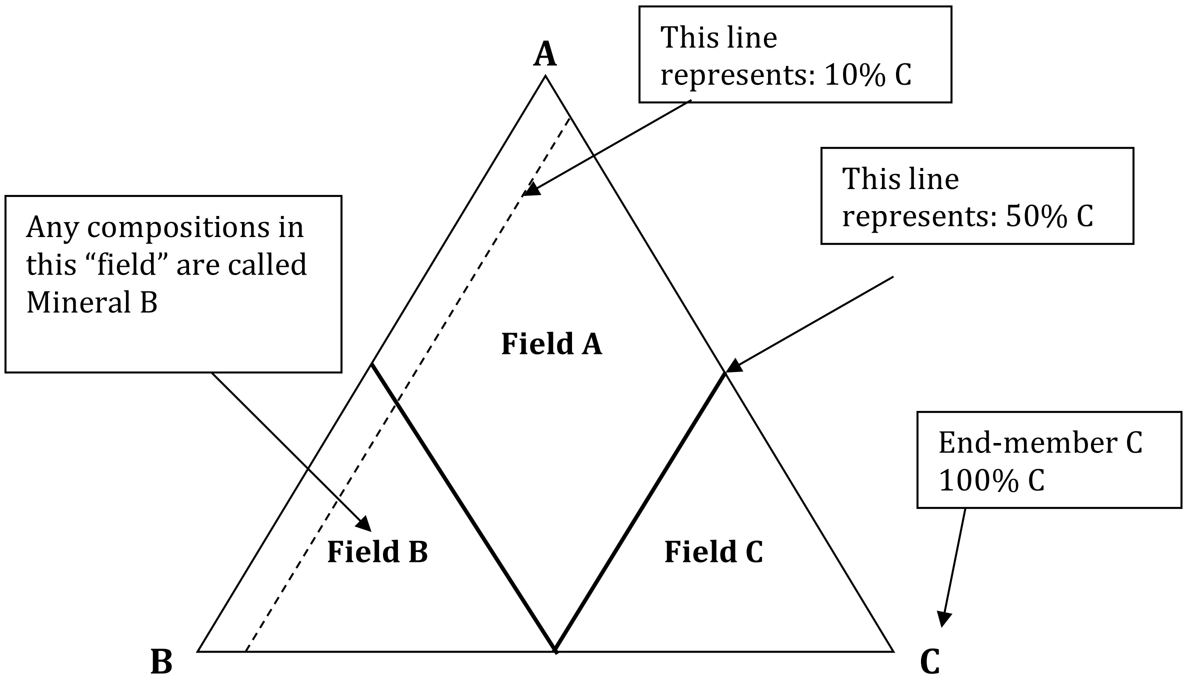
Question 1. Fill-out the table below with the mineral percentages in this thin section (above) and a short description of what they look like (how you can tell them apart). Hint: There are 4 minerals in this thin section.

Mineral	**%**	**Description**

NB: Check out this website for other thin sections of igneous rocks:
http://www.geolab.unc.edu/Petunia/IgMetAtlas/plutonic-micro%7F/plutonicmicro.html

Section 2: Ternary Plots

When three minerals from the **same group** form solid solution series with each other, we can plot them on a **TERNARY** diagram. The ternary diagram can be considered as three **binary** plots put together. There are three end members in ternary diagrams A, B and C, with fields that represent each of these three minerals. Field A for instance, has more A, than it does B or C. Thus, if we have a mineral which when analysed falls within Field A, we will be able to give it the name of the end member. Values of A, B and C cannot be plotted unless "NORMALISED" to 100%.

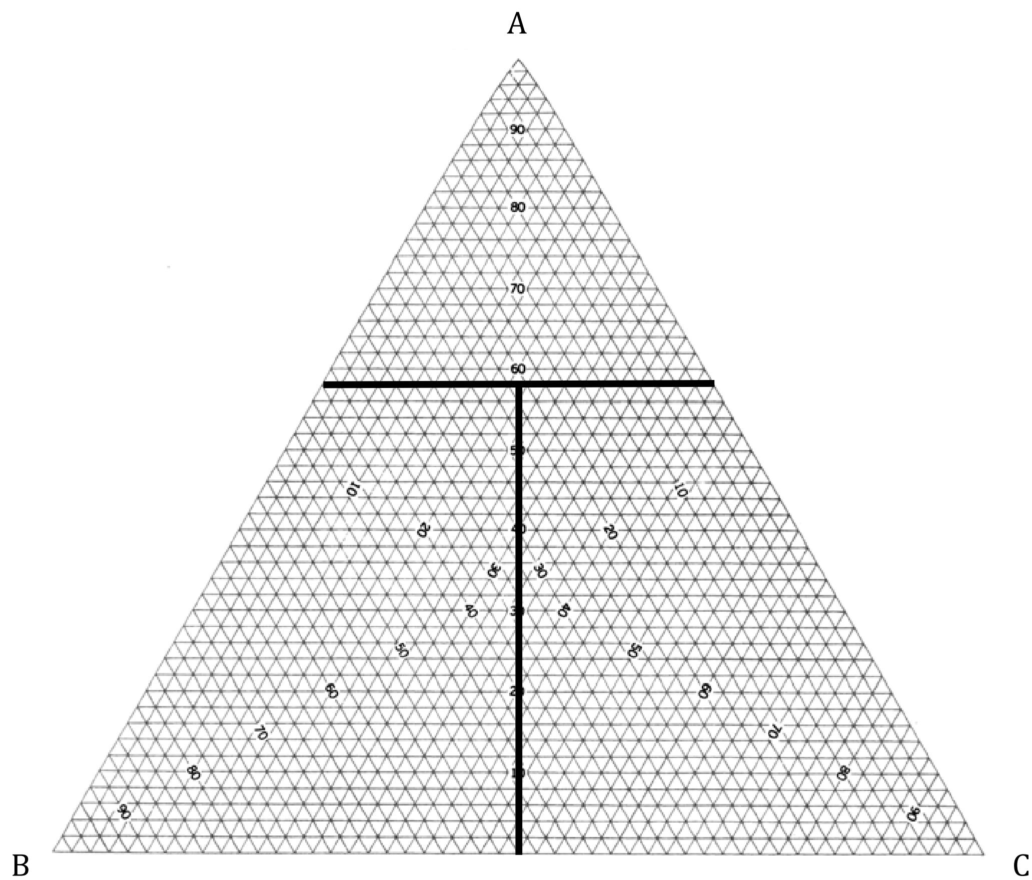


Question 2: Normalizing: Given the analyses below (1, 2, & 3):

I. NORMALIZE values to 100% (where necessary).

	Observed %			Normalised %		
	A	B	C	A	B	C
Analysis 1	10%	40%	50%			
Analysis 2	10%	20%	30%			
Analysis 3	5%	25%	55%			

II) Plot the analyses (1, 2, 3) from Part I. Which mineral is this?_________________________



Section 3: Mineral Identification

You will be required to identify and complete the remaining minerals in your thin section: Plagioclase feldspar, Clinopyroxene, and opaques. There is also **biotite** in the rock. Use the example (previously given to you) of Chlorite, to help guide your progress.

Question 3: Finish identifying & describing olivine. Identify, describe and catalogue Plagioclase, Clinopyroxene, and Opaques.

Section 4: Classify the Rock

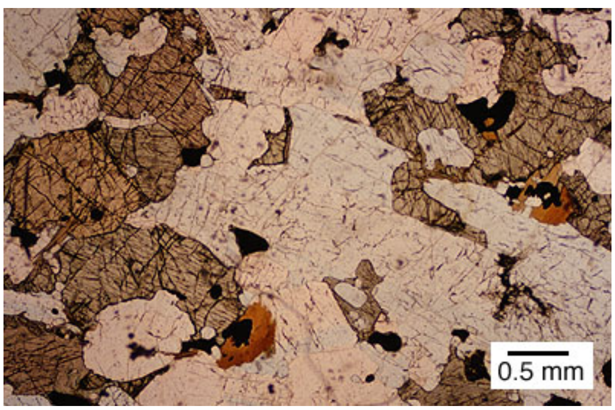
Instructions: Classify some example compositions, and then the thin section you have been using today. You will use the IUGS rock classification scheme (***Figure 1***).

Example A: Here is an example that has been plotted on Figure 1. The % of minerals did not equal 100%; the values have been normalized. Example A has been plotted as a **Gabbro**.
(*Note: Pyroxenes have two types: Ortho- and Clino-; these can be combined on this diagram*)

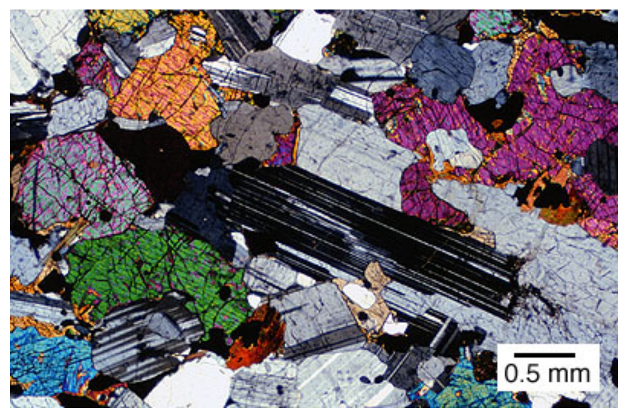
This mineral is not present, but is included here to make the example easier to understand.

Mineral	%	Normalized %
Olivine	*0*	*0*
Plagioclase	65	72
Orthopyroxene	25	27
Biotite	5	-
Opaques	5	-

PPL



CPL

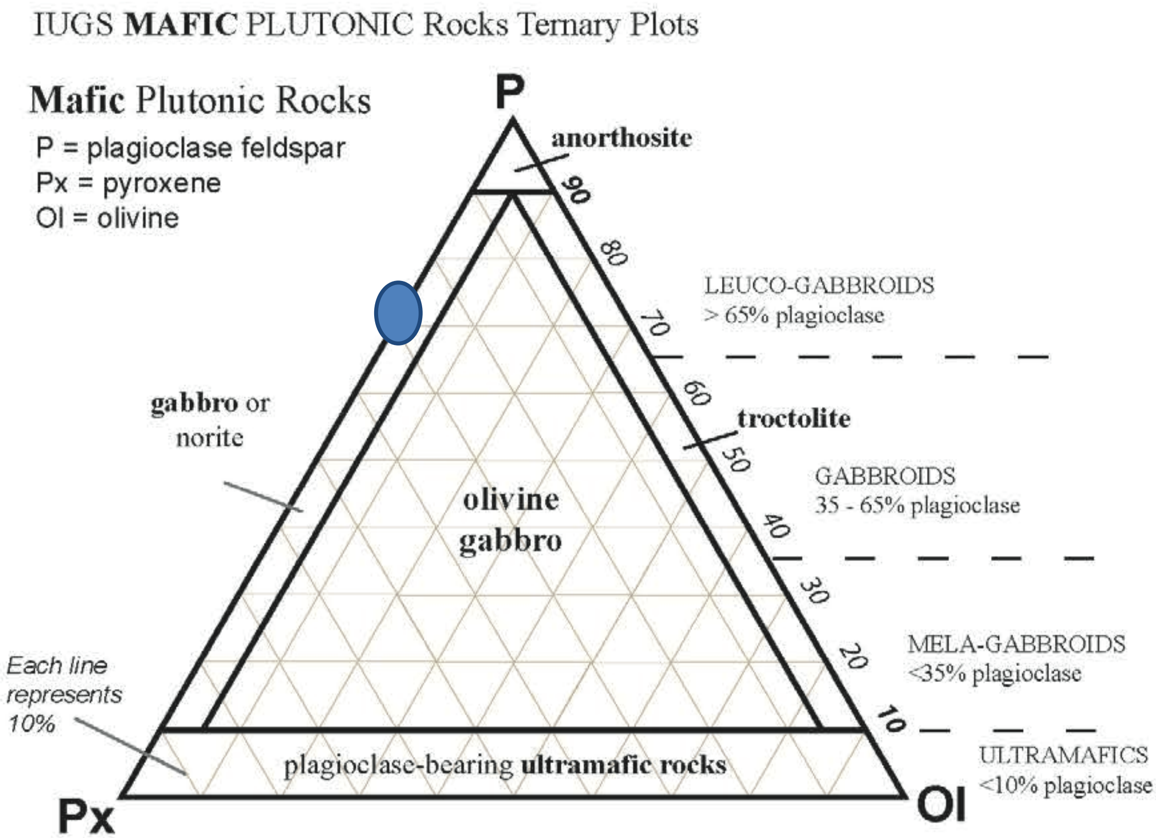


Question 4: To make sure that you understand, **label** on the thin section photos, all the minerals in Example A (Plagioclase, Orthopyroxene, Biotite, and Opaques) using the percentages to guide you.

Figure 1. ***IUGS Classification Scheme for Mafic Plutonic Rocks***

This diagram is used when classifying igneous plutonic rocks.

Question 5:
The three end-members are ________________, _____________, and ____________



Question 6: Example! Plot these rock compositions (1 & 2) on the ternary diagram (attached). Normalise the values where necessary.

Rock 1

Mineral	%	Normalized %
Biotite	10	
Orthopyroxene	0	
Olivine	5	
Plagioclase	20	
Clinopyroxene	65	
Opaques	0	

Rock 2

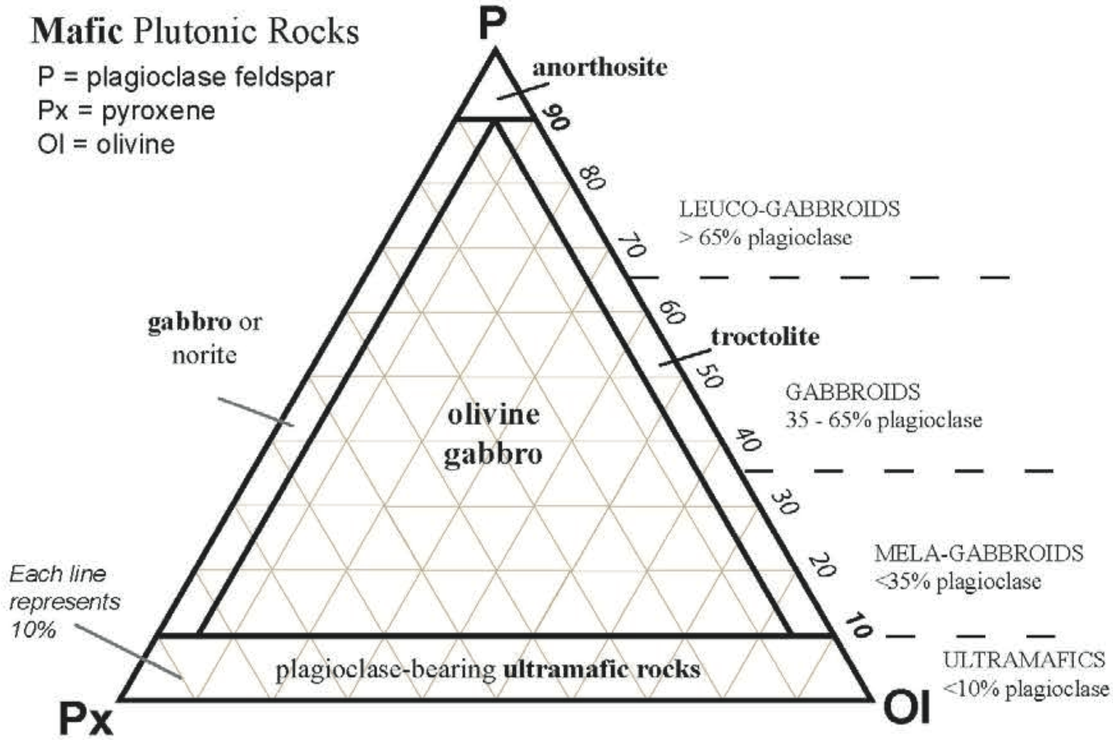
Mineral	%	Normalized %
Biotite	0	
Orthopyroxene	10	
Olivine	15	
Plagioclase	65	
Clinopyroxene	10	
Opaques	0	

Question 7: Classify your thin section. Now that you have had lots of practice, it is time to figure out what kind of rock you have been looking at. You will be doing lots of this in the future. Use different objectives (or 'zooms') on your microscope to help estimate the correct percentages, and in order to be statistically correct - take your estimations over 4-6 different areas of the slide.

I) Fill in the table for your thin section.
II) Normalise,
III) Plot and label your composition on the ternary (page, over).

Mineral	%	Normalized %
Biotite		
Orthopyroxene		
Olivine		
Plagioclase		
Clinopyroxene		
Opaques		

Figure 1. ***IUGS Classification Ternary Plot for Mafic Plutonic Rocks***



IV. What is the name of your rock sample? ________________________________

Section 5: Practice Exam Questions

Question 8: I) Why do we see this combination of minerals in Sample 4929? (2 marks)

II) Theoretically which minerals do you expect to see first (because they crystallised first)? (3marks)

III) From the thin section is there any evidence to support this? (3marks)

IV) What type of feldspar would you expect to see in this rock? (2 marks) Which cations would you expect this rock to be rich in and why? (4 marks)

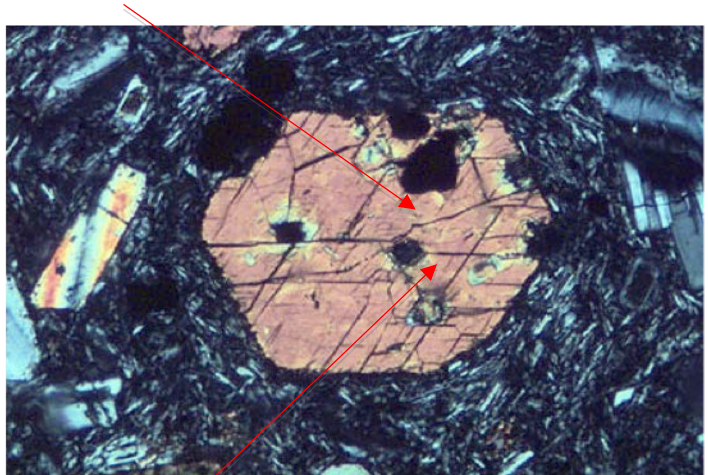
V) List the most likely tectonic setting that produced the magma that eventually became the rock you are observing in thin section? Explain why it is this tectonic setting, and not another (6 marks)

Appendix 1: Mineral Identification Properties & Techniques

Mineral Identification Terms

Cleavage: Many crystals break along smooth planes, which are parallel to possible crystal faces, usually simple index ones, and across which the interatomic bonding is relatively weak. These planes are termed cleavage planes and appear as planar striations through the crystal. Cleavages are repeated by the symmetry of a crystal in exactly the same way as faces. Cleavages may be referred to as perfect, good, distinct, imperfect or poor depending on its ease of development. (Shelly, 10)

Uneven fracture



Perfect $120^0/60^0$ cleavage of hornblende (CPL)

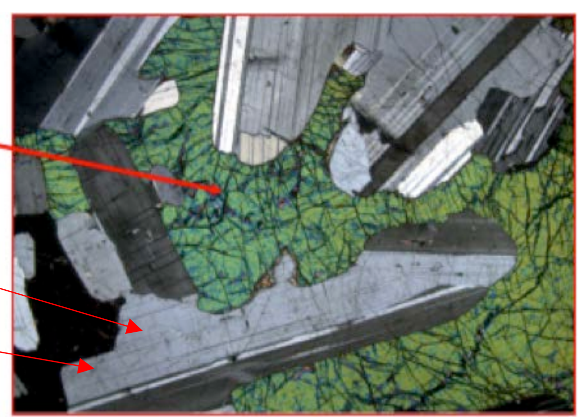
Fracture: Refers to the shape of surfaces formed by breaking a crystal along directions other than cleavages. If a crystal has a number of perfect cleavages, it may be difficult to observe. Fracture can be conchoidal (shell-like surfaces), even (sub-planar), uneven, or hackly (jagged). Take a look at the above Hornblende crystal again; there is an uneven fracture that runs the length of the crystal. Notice how the fracture runs through any apparent cleavage planes. (Shelly, 10)

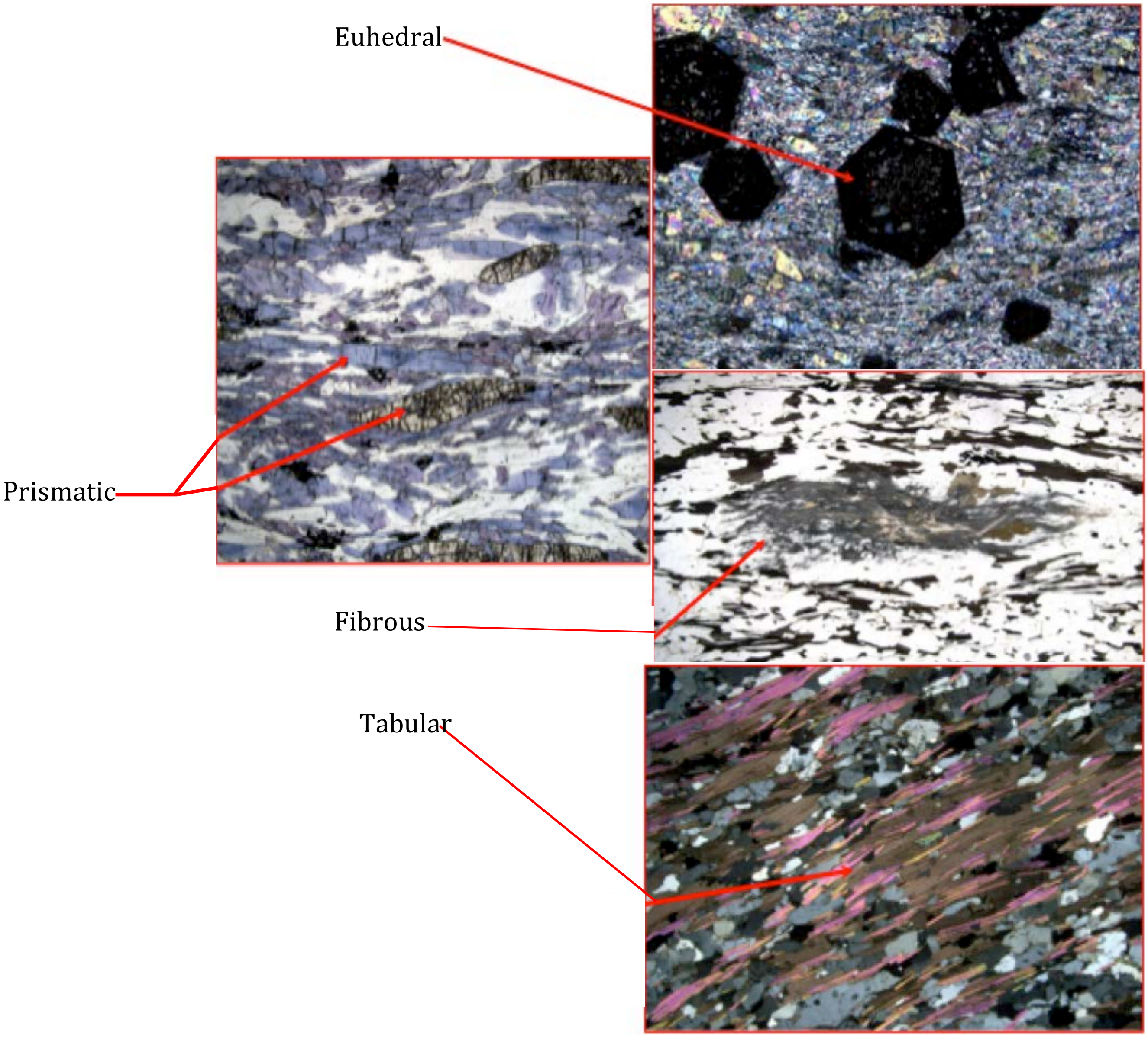
Crystal Habit: Crystals, even of one species, vary considerably in shape, depending on rates of growths, impurities present during growth, and a host of other factors. Nevertheless, certain shapes called crystal habits characterise particular species. Well-known terms that are self-explanatory are fibrous, acicular (needle-like), columnar, tabular, scaly, micaceous. In addition crystal form names are used if a particular form is well developed, hence cubic, prismatic, pyramidal, etc. The above hornblende crystal displays a subhedral hexagonal shape. (Shelly, 10)

Anhedral/irregular

Blocky

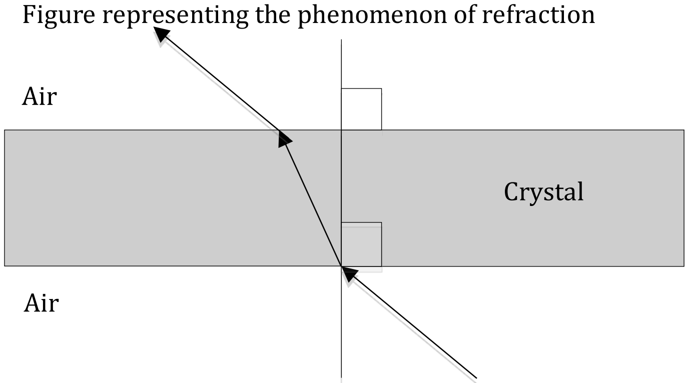
Elongate





Refractive Index and Relief: A ray of light is usually bent when passing from one substance to another, a phenomenon known as refraction. The Refractive Index (RI) is given by a ratio of the sines of the angles of incidence and refraction of light passing from air into the substance (the RI of air is taken to be 1). Light travels most quickly in a vacuum and is slowed when passing through any substance. The denser the substance, the slower the light travels through it. It can be shown simply that the RI of a crystal is equal to the ratio of the velocities of light in air and in the crystal: (Shelly, 26-29)

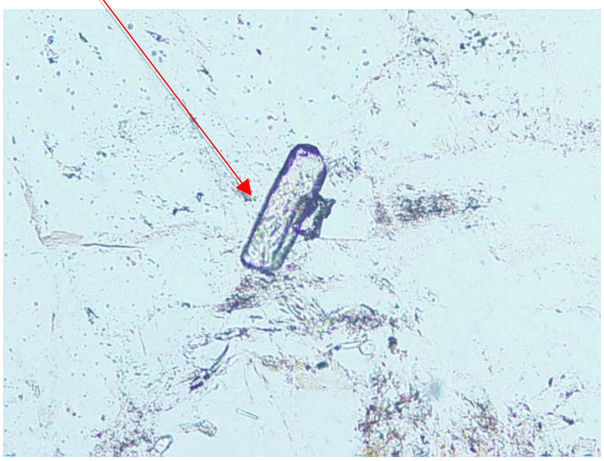
Figure representing the phenomenon of refraction



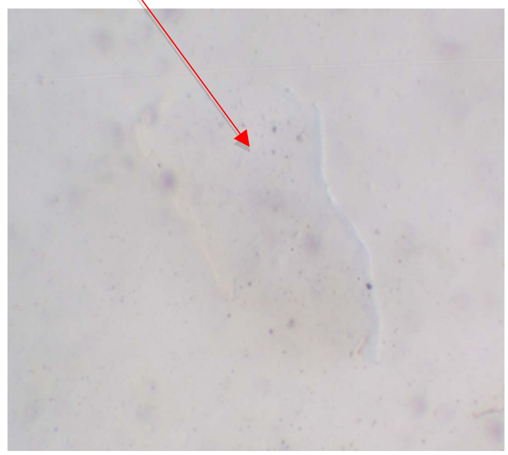
$$RI = \frac{\text{Velocity of light in air}}{\text{Velocity of light in crystal}}$$

Relief: If there is a difference in RI between the mineral and the cement, the light is scattered by reflection and refraction. The effect is to give an impression of three-dimensional relief. If the difference in RI is small the irregularities will be barely visible and the mineral has *low* relief. A large difference results in *high* relief.(Shelly,56-57)

Zircon crystal with high relief, the groundmass has low relief

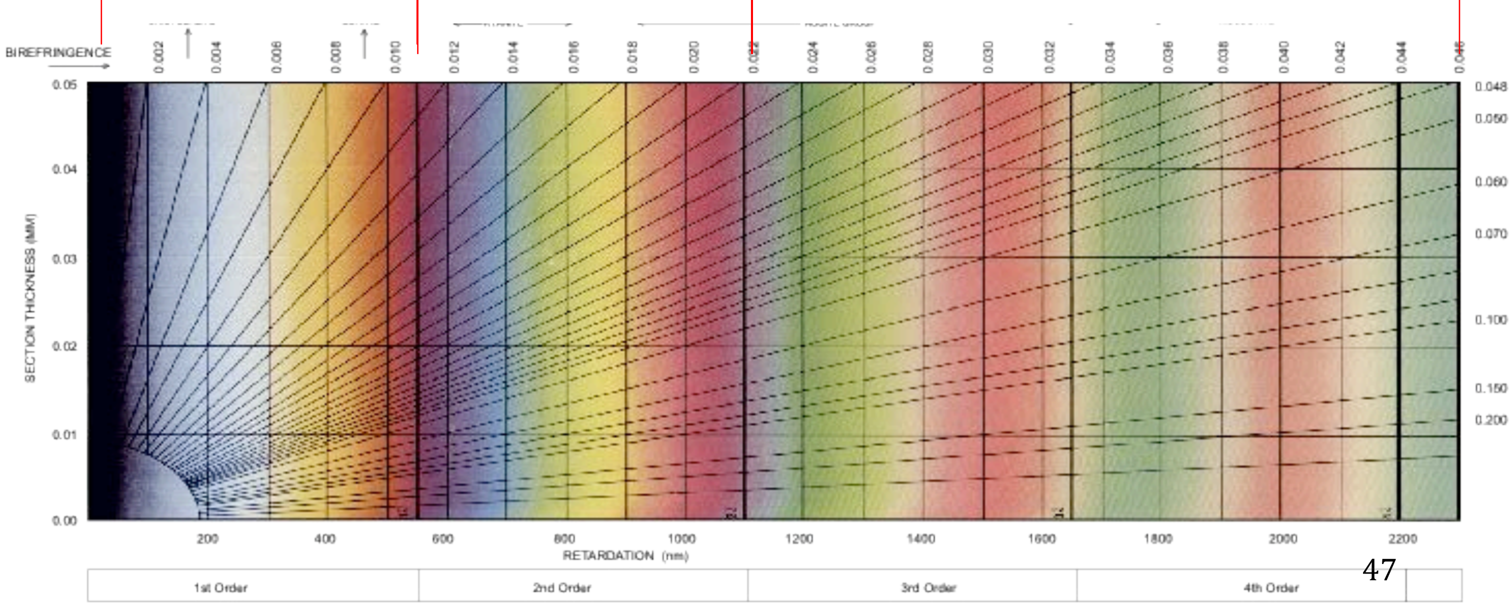


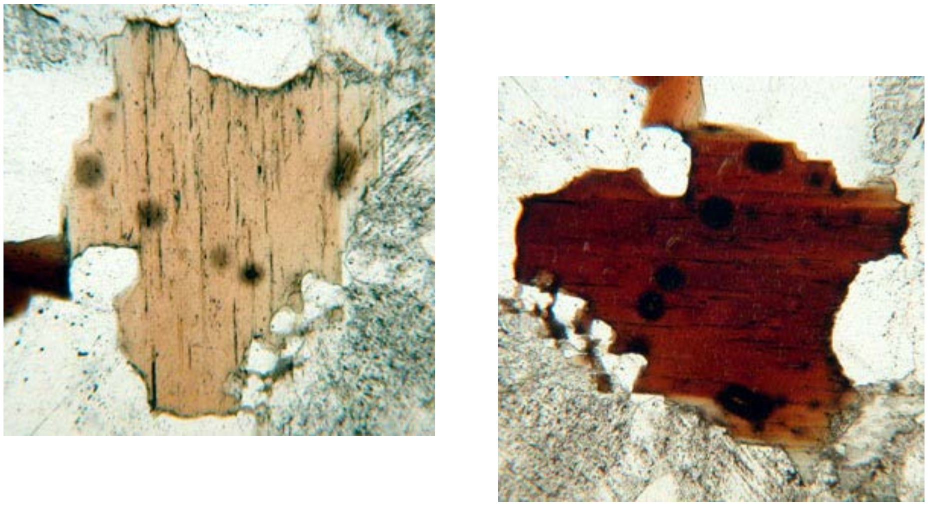
Quartz crystal with low relief



Birefringence: Is the range of retardation of light as it passes through a crystal (CPL). This is determined using interference colors. When you insert the analyser each crystal will have an interference color. For this portion of the course we are not going to get too technical, interference colors will only be referred to as low, medium and high. These zones are shown below on a Michelle-levy interference color chart. Quartz is a classic example of a mineral with a low interference color and will appear white to mottled grey. (Shelly, 29-35)

Low	**Medium**	**High**
1st Order	2nd Order	3rd – 4th Order



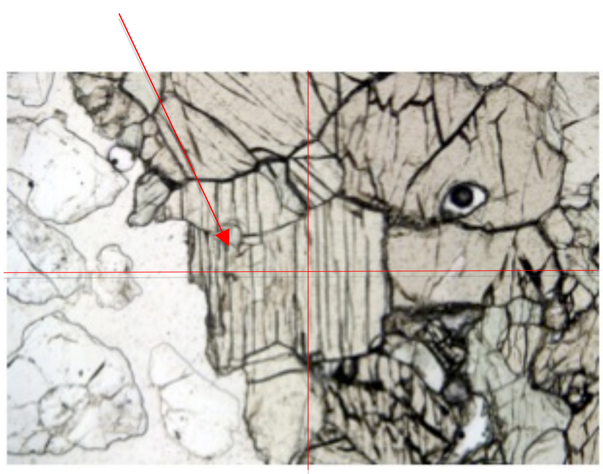


A biotite crystal shows brown pleochroic behaviour as the stage is rotated.

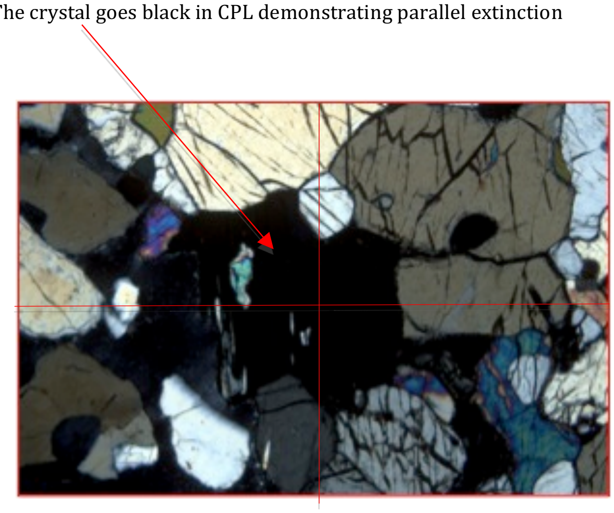
Pleochroism: The preferential absorption of light along differing crystal axes. In English: the color of the crystal will darken as you rotate the stage in PPL. (Shelly, 52)

Extinction angle: If the crystal is orientated along its vibration direction it will go extinct (turn black in CPL). This will be either parallel to the crosshairs on the microscope (straight extinction) or at some angle (inclined extinction) (Shelly, 82). The angle between a vibration direction and a cleavage or prominent crystal face is called extinction.

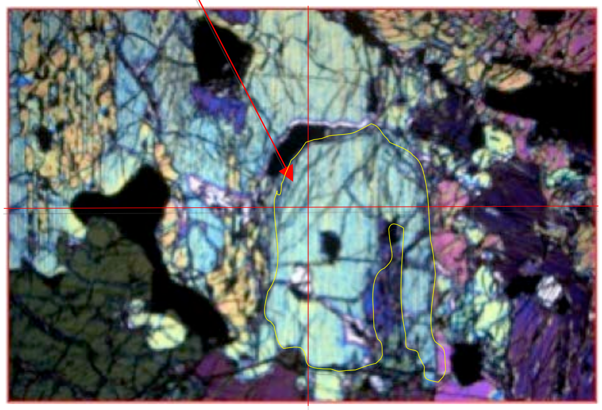
Notice cleavage direction is parallel to crosshairs in PPL



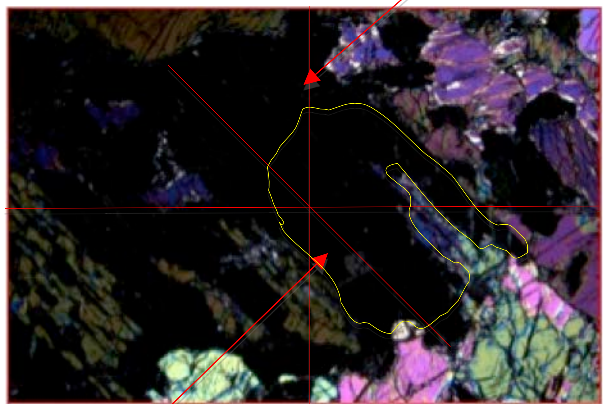
The crystal goes black in CPL demonstrating parallel extinction



Clinopyroxene (CPL) parallel to crosshairs

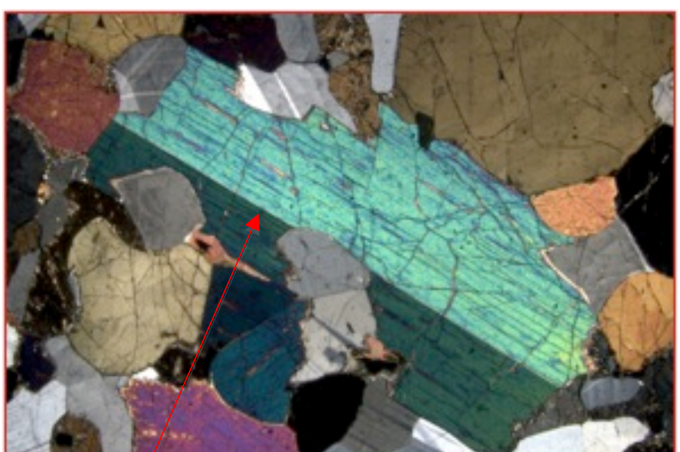


Extinction Angle



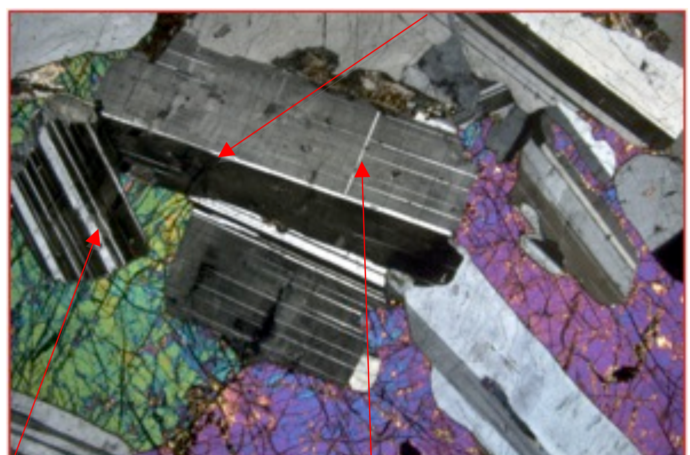
Clinopyroxene at an angle to the crosshairs and extinct (Inclined extinction)

Twinning: is formed of two or more individuals of the same species, joined together according to a definite law. They must be joined together as contact twins, simply united by a common plane (Simple, Polysynthetic), or as penetration twins (Carlsbad), where they appear to cross each other in a complex, but symmetrical way. Simple twins consist of just two individuals; polysynthetic twins consist of several individuals, often in lamellar form. (Shelly, 10)



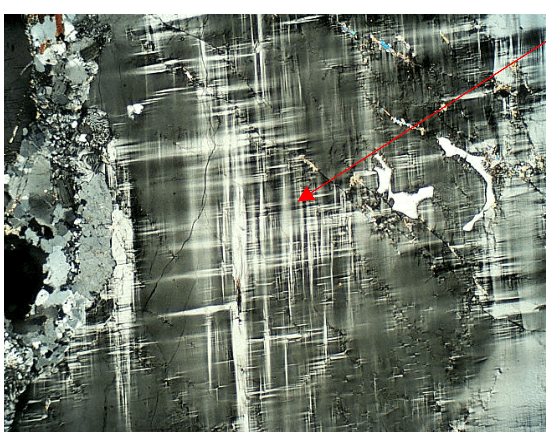
Simple Twin in Clinopyroxene

Simple Twin in Plagioclase



Polysynthetic (Albite) twinning in Plagioclase

Pericline twin, perpendicular to the long axis of the crystal



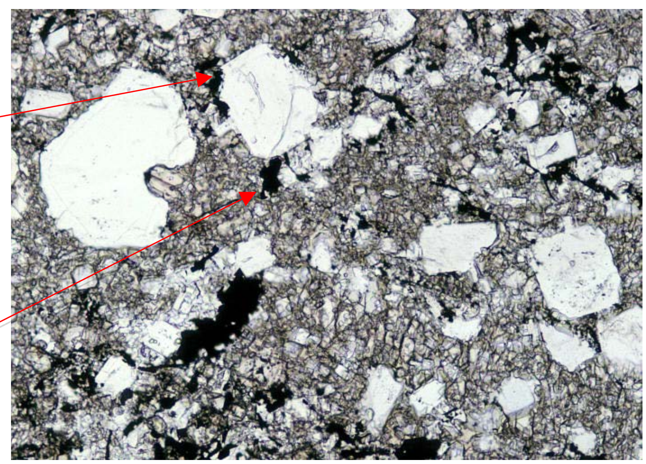
Microcline (Cross-hatched) twinning in alkaline feldspar

Carlsbad twin, note irregular boundary

*A note on feldspar twinning: Some very common terms used when classifying feldspar twins can seem a bit confusing in Shelly. Here is a simplification of these and what they will look like under the microscope. (Shelly, 249-250)

Twin Name	Corresponding microscopic feature
Albite	Polysynthetic.
Carlsbad	Simple twin with irregular boundary.
Pericline	Twin's perpendicular to long axis of crystal, can be polysynthetic.
Microcline/Transformation	Cross hatched twinning

Opaques: Minerals incapable of letting light transmit through them. These minerals appear black at all times in CPL and PPL. They can be distinguished from each other by their crystal shape. Later on in the year you will use reflected light microscopy to further examine these minerals.



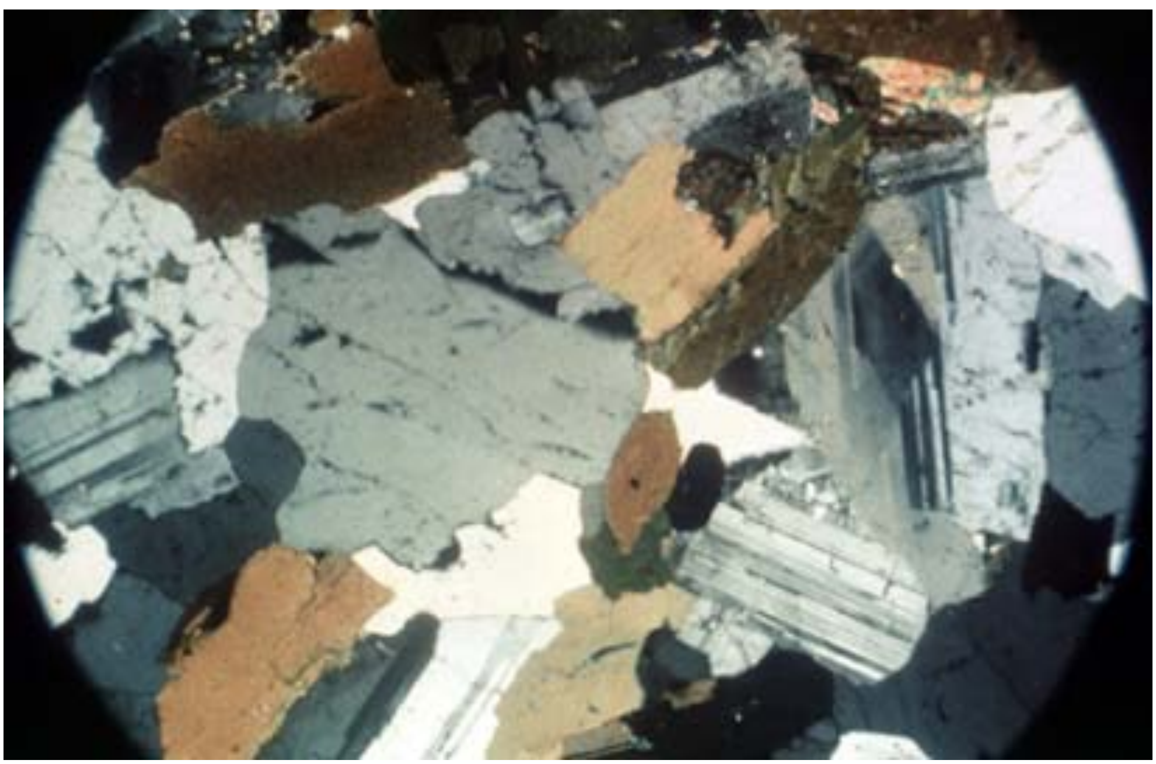
For more help with mineral id properties, check out:
http://www.uwsp.edu/geo/projects/geoweb/participants/dutch/petrolgy/Tsecplp.htm

Notes from Lab 2:

<u>Lab 3: Mineral Identification and Phase Diagrams</u>

Lab Goals:

1. Get introduced to the concept of 'Relief'. Use refractive indices to compare which minerals must have higher or lesser relief.
   Section 1: Relief & RI
2. Identify and describe the minerals; **biotite**, **chlorite**, **alkali feldspar**, and **quartz** and use the minerals present to give that rock a name under the IUGS classification system
   Section 2: Identify new minerals
   - Classify the Cathedral A thin section
   - Illustrate different types of twinning
3. Show how an alkaline feldspar crystal develops from a melt and how the development is affected by melt composition.
   Section 3: Alkali Feldspar Phase Diagrams
4. Explain the relationship between the mineralogy, textures of Granites
   Section 4: Practice Exam Questions



Section 1: Relief

Instructions: Use thin sections: **4929** and **Cathedral A** to help you do this. 1) Look up (in Shelley) the refractive indexes (RI) of each mineral listed below. 2) Look down the scope at each mineral and describe whether the minerals have ***high***, ***med***, or ***low*** relief. 3) Then compare the minerals to one another and insert the appropriate sign below (>, <, or =).

What is Relief?

Mineral 'relief' is the extent that one mineral stands out in PPL from another. High relief minerals appear as if they have a dark border that goes all the way around. If high relief minerals have cracks, or cleavage, this will also show up easily to your eyes. Low relief minerals appear very faint in PPL. The borders of the individual crystals will not be easily seen.

Minerals:	**RI (range):**	**Description (in PPL):**
Olivine		
Clinopyroxene		
Plagioclase		
Alkali F		
Quartz		

Which is higher? Or are they Equal?

Clinopyroxene ____ Plagioclase

Olivine ___ Clinopyroxene

Alkali Feldspar ___ Plagioclase

Plagioclase ___ Quartz

Alkaline Feldspar ___ Quartz

Section 2: Cathedral Square A

Today you will be looking at the thin section Cathedral Sq. (A). The slide contains the new minerals: **alkali feldspar**, plagioclase feldspar, **biotite** with some **chlorite** replacement, and **quartz**. Fill-in Mineral ID Booklet papers for each new mineral (provided).

Question 2. Use the Figure 2 ternary diagrams to plot, and determine rock names. For the samples below, normalise the results if necessary, determine the correct IUGS triangle, plot the results and give the rock its correct name.

Sample: Rock 1

Mineral		%	Normalized %
Q		5	
A		0	
P		3	
Mafics	Olivine	27	
	Clinopx Orthopx	15 25	
	Opaques	25	

Which Diagram did you use?_________
Rock 1 Name:

Sample: Rock 2

Mineral		%	Normalized %
Q		28	
A		26	
P		36	
Mafics	Olivine	0	
	Clinopx Orthopx	5 0	
	Opaques	5	

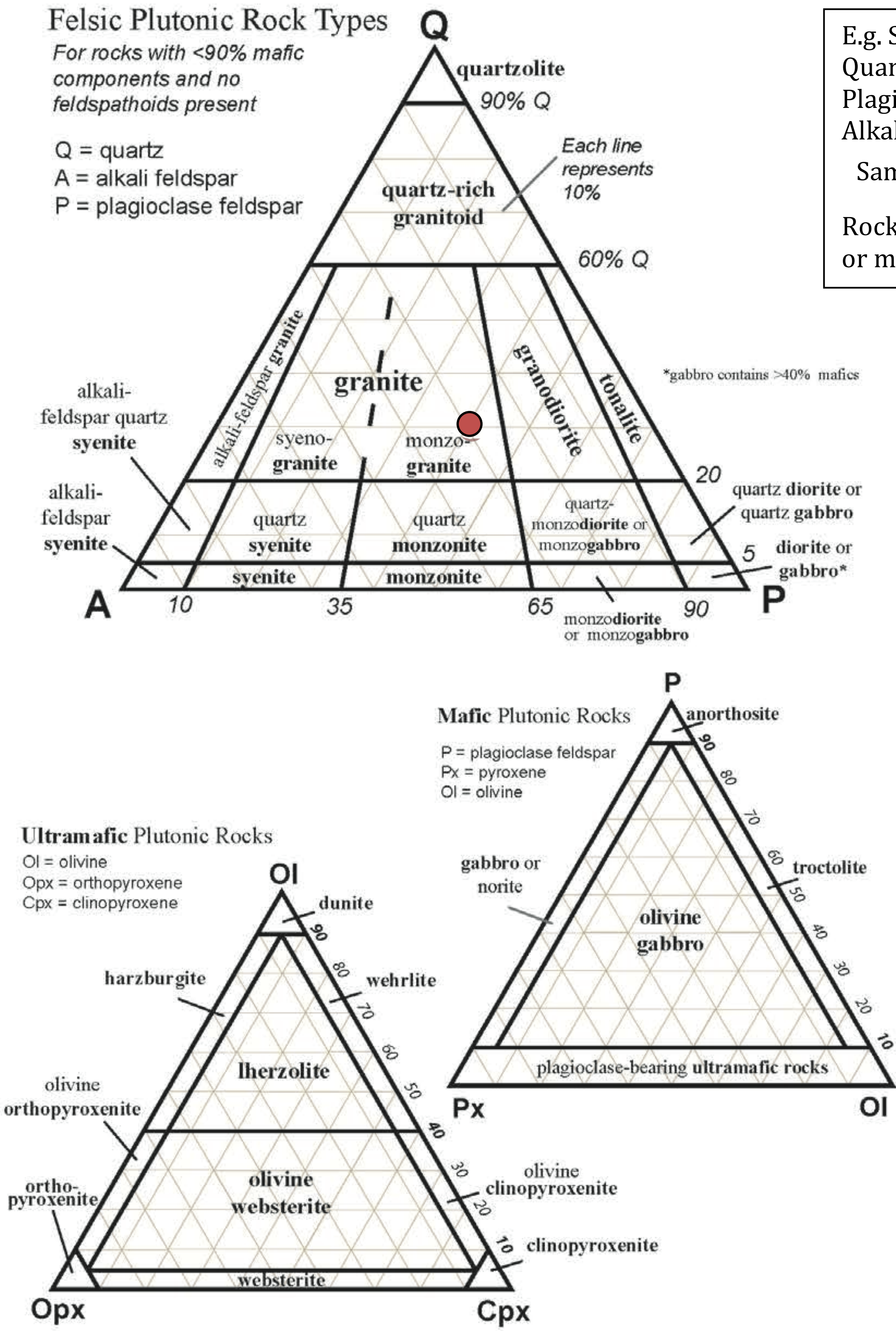
Which Diagram did you use?_________
Rock 2 Name:

Question 3: Determine the modal mineral percentage for the sample **Cathedral Sq. (A)** and give the rock a name based on the appropriate ternary diagram.

Diagram:
Rock Name:

Mineral	%	Normalised

Figure 2: IUGS Classification for all Plutonic Rocks



E.g. Sample A
Quartz – 30%
Plagioclase – 40%
Alkali Feldspar – 30%

Sample A

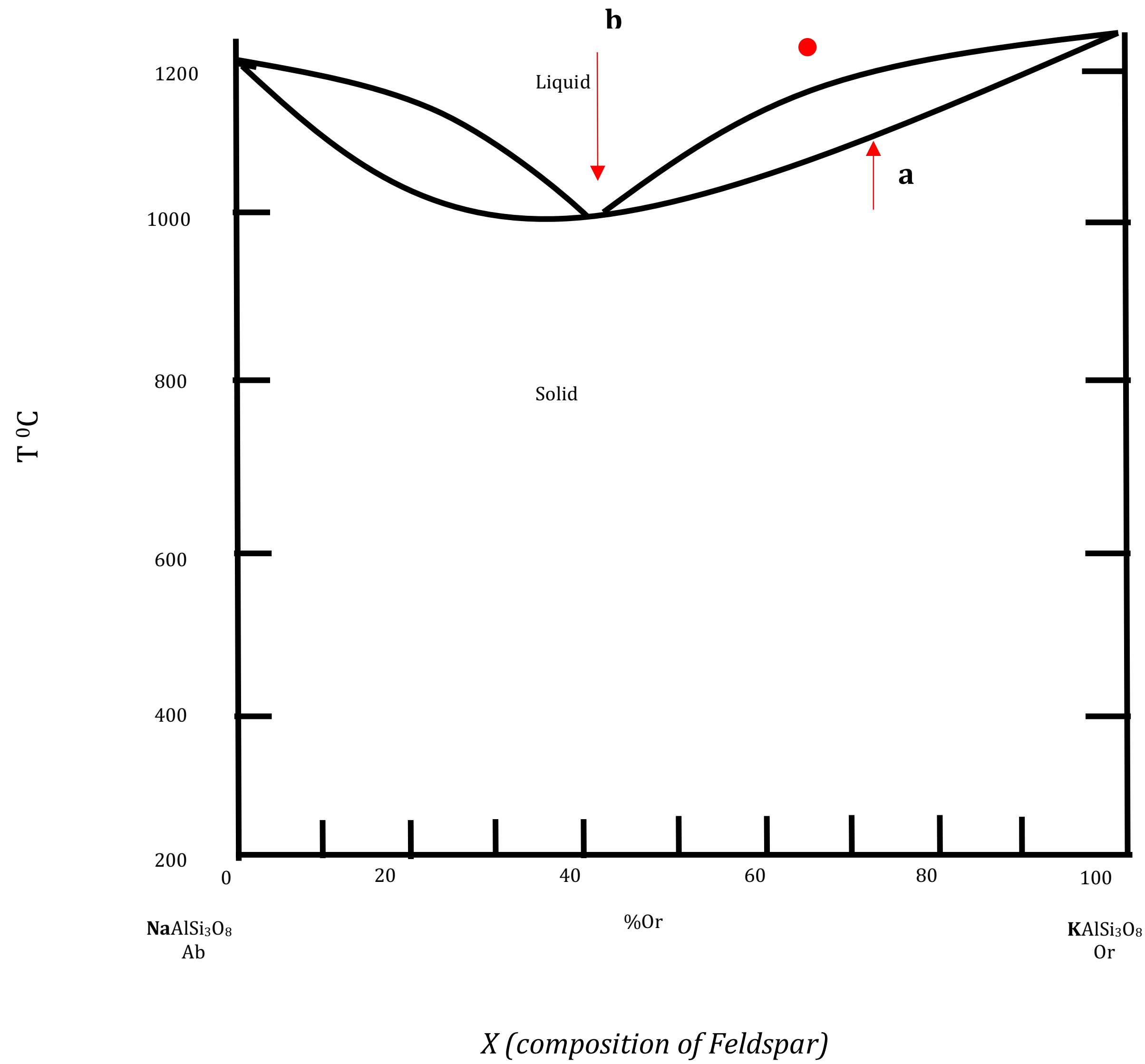
Rock Name: "granite" or monzogranite

Question 4: Illustrate the four-major types of twinning found in Feldspars and other minerals. Use Shelley to assist this. ***Note, which type of twinning is common or rare in Alkali Feldspar, Plagioclase, Amphiboles, and Pyroxenes***

See: http://www.tulane.edu/~sanelson/eens211/twinning.htm for some theory behind this.

Twin Name	Corresponding microscopic feature	Drawing/Sketch	Minerals with this twinning
Albite	Polysynthetic.		
Simple (e.g. Carlsbad)	2 distinct zones within a crystal (Carlsbad has an irregular boundary)		
Pericline	Twin's perpendicular to long axis of crystal, can be within polysynthetic twins		
Microcline/Transformation	Cross hatched twinning, Tartan twinning		

Section 3: Alkali-Feldspar Phase Diagram (T vs. X)



Instructions: Use the Temperature-Composition(X) Diagram above to answer the following questions. The solid solution phase diagram explains the behaviour of chemical solid solution series for a varying composition (Albite (Na-rich) to Orthoclase (K-rich) feldspar) and varying temperatures (high and low). For this question assume equilibrium crystallization and that it is a closed system.

NB: For more examples of T-X phase diagrams see:
http://csmres.jmu.edu/geollab/fichter/IgnRx/SolidSol.html

Question 5: I) A blob of melt, represented by the circle begins to cool. Draw the complete path of crystallisation and melt evolution, using arrows to show how the melt interacts with the phase diagram***. Don't forget to LABEL the lines on the diagram!***

II) At what temperature does the first crystal form and what is it's composition?

III) Will the crystallisation path intersect point **a** on the solidus? If so, what composition will be crystallised at that point?

IV) Will the 'melt' composition path intersect point **b** on the liquidus? If so, what composition is the melt at that point?

V) What is the composition of the last drop of melt?

VI) What is the end composition of the last crystal that crystallises? (Assume that the melt has undergone even cooling)

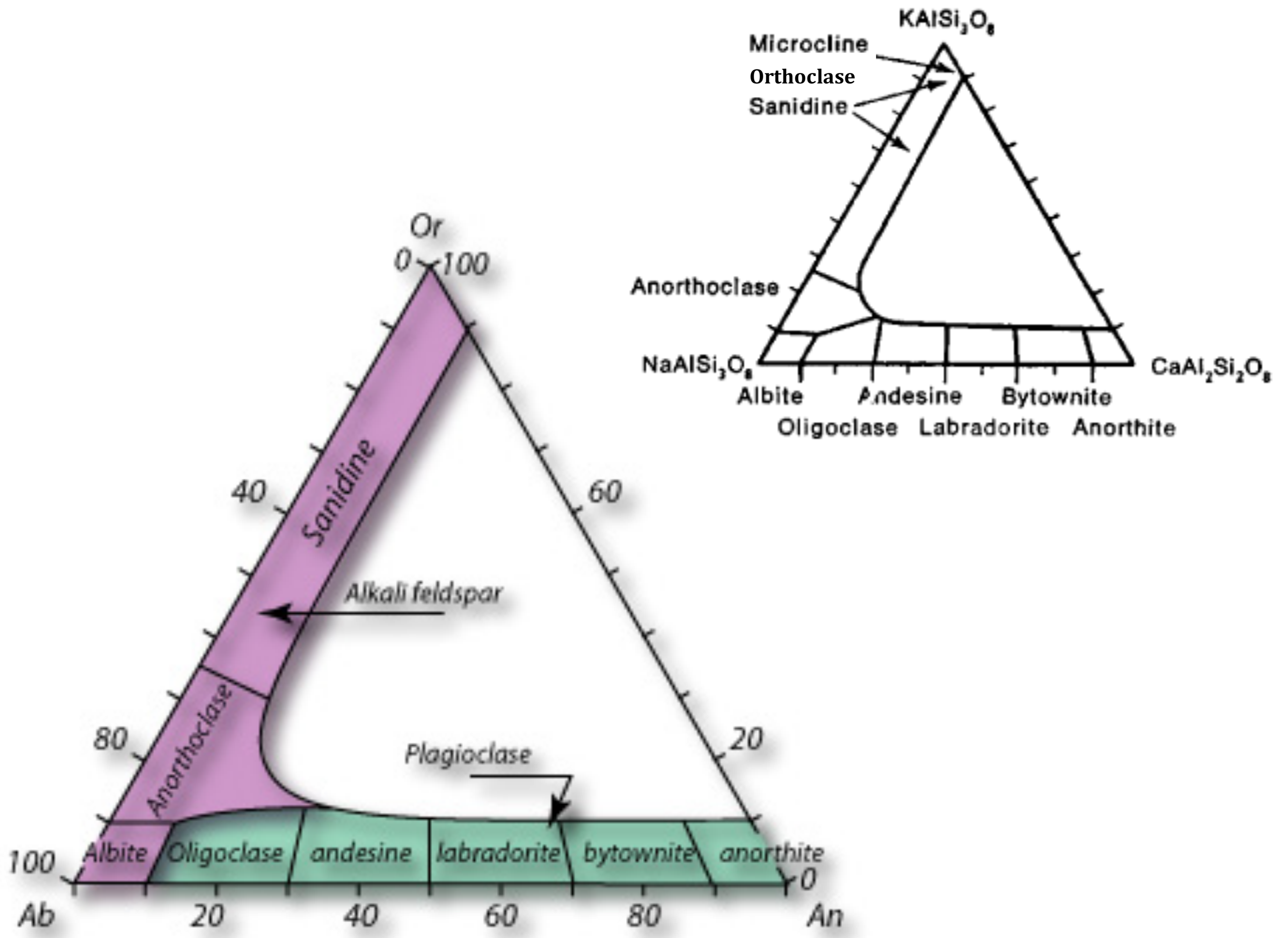
Section 4: Granite Essay Questions

Question 5. I) List the minerals in a Granodiorite, their respective mineral formulas, and their major cations (2 Marks)

II) Is a Diorite, a mafic or felsic igneous rock? Explain how you know this. (4 Marks)

III) Use this information to discuss the magmatic conditions and tectonic environments True-Granites form in. (6 Marks)

Figure 3. Feldspar Compositional Ternary Diagram
(helpful for understanding Shelley...)



Felspars are composed of a network of SiO_4 tetrahedron in which some of the Si^{4+} are replaced by Al^{3+}. The building blocks of feldspar are either $(AlSi_3O_8)^-$ or $(Al_2Si_2O_8)^{2-}$.

The electrical balance is restored by ions such as Na+, K+, and Ca2+. Therefore the composition of most feldspar can be represented on a ternary diagram with $KAlSi_3O_8$ (Alkali feldspar, Orthoclase, Or), $NaAlSi_3O_8$ (Albite, Ab), and $CaAl_2Si_2O_8$ (Anorthite, An).

Feldspar with compositions ranging from Or to Ab are called Alkali Feldspar.

Feldspar with compositions ranging between Ab and An are called Plagioclase.

Notes from Lab 3:

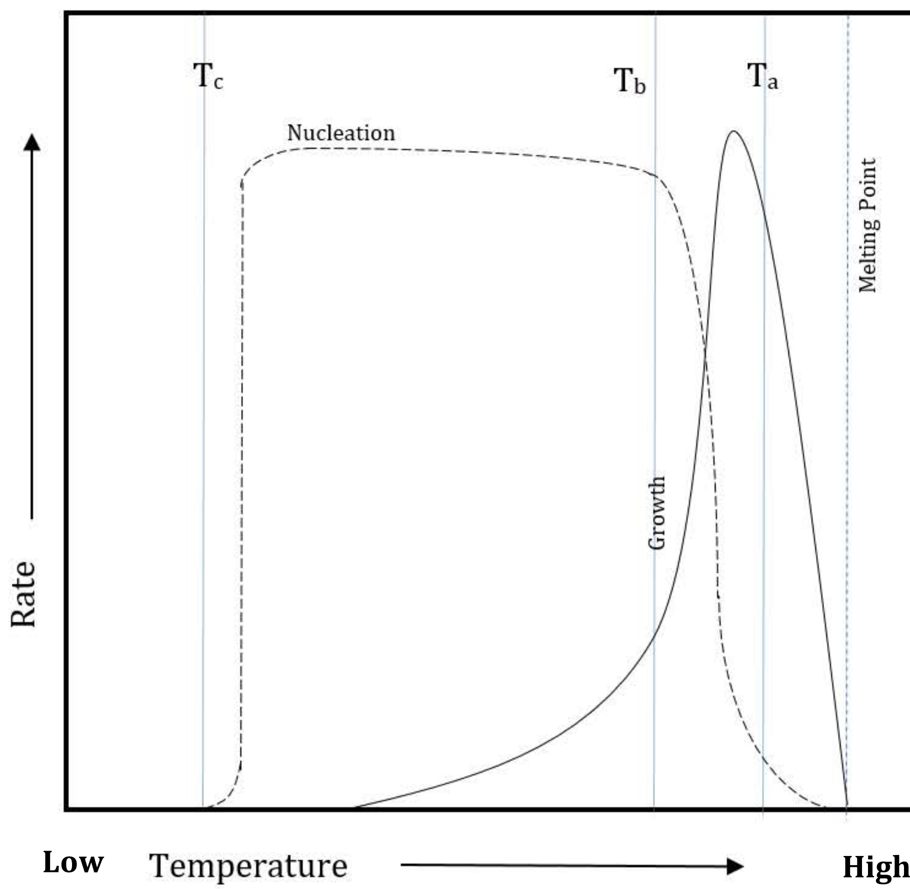
Lab 4: Igneous Textures

Lab Goals

1. Describe the relationship between undercooling, nucleation and crystal growth
    - Section 1: Undercooling
2. Describe the minerals **Orthopyroxene** and **Amphibole**
    - Section 2: Mineral ID Book
3. Identify different intrusive and extrusive textures shown in thin section
    - Section 3: Textures
    - Read Appendix 1 - Textures
    - ***Fill out new Texture Templates***
4. Explain the formation history of the rock provided using texture analysis;
    - Section 4: Sample Essay question

Section 1: Undercooling, Crystal Growth & Nucleation

Thoroughly read Section 1 in the reading section at the back of the Lab. Answer the questions on the following page using **the graph provided below**.



Question 1: I) Draw the expected crystal texture in a rock that was undercooled to **Ta**. Explain in terms of the position of the graph. (For example, a large crystal forms during minor undercooling following the growth curve in the graph)

II) The expected crystal texture in a rock that was undercooled to **Tb**. Explain in terms of the position of the graph.

III) Would you expect a change in crystal size and number of crystals if rock was undercooled to **Tb** compared to **Tc**?

IV) Draw the expected crystal texture in a rock that was undercooled to **Ta** then underwent further undercooling to **Tb** and was then was undercooled to **Tc**. Explain in terms of the positions on the graph.

Section 2: Mineral ID Book

Use Sample **KB22** to correctly identify Amphibole, use Sample **2** to correctly identify orthopyroxene.

Question 2: Enter **Amphibole** and **Orthopyroxene** into your Mineral ID booklet.

Section 3: Textures

Read Section 3 in your supplementary material for information on some of the textures you will see in the thin sections **KB22** and **2**.

Question 3: I) Practice drawing thin section (**KB22**) in the space provided and **label** the **minerals** and **textures** you can identify. (Remember to include a scale!). Once you have completed your first sketch – ***ask a demonstrator for some feedback***.

II) Fill out the **texture templates** for each texture you have identified within this sample, describing the **features** and the **history of formation**.

III) **Observe** the different grain sizes of the crystals and their relationship in **KB22** to one another in the slide. **Describe** and **explain** the **order** of crystallization (4 Marks)

Section 4: Sample Essay Questions

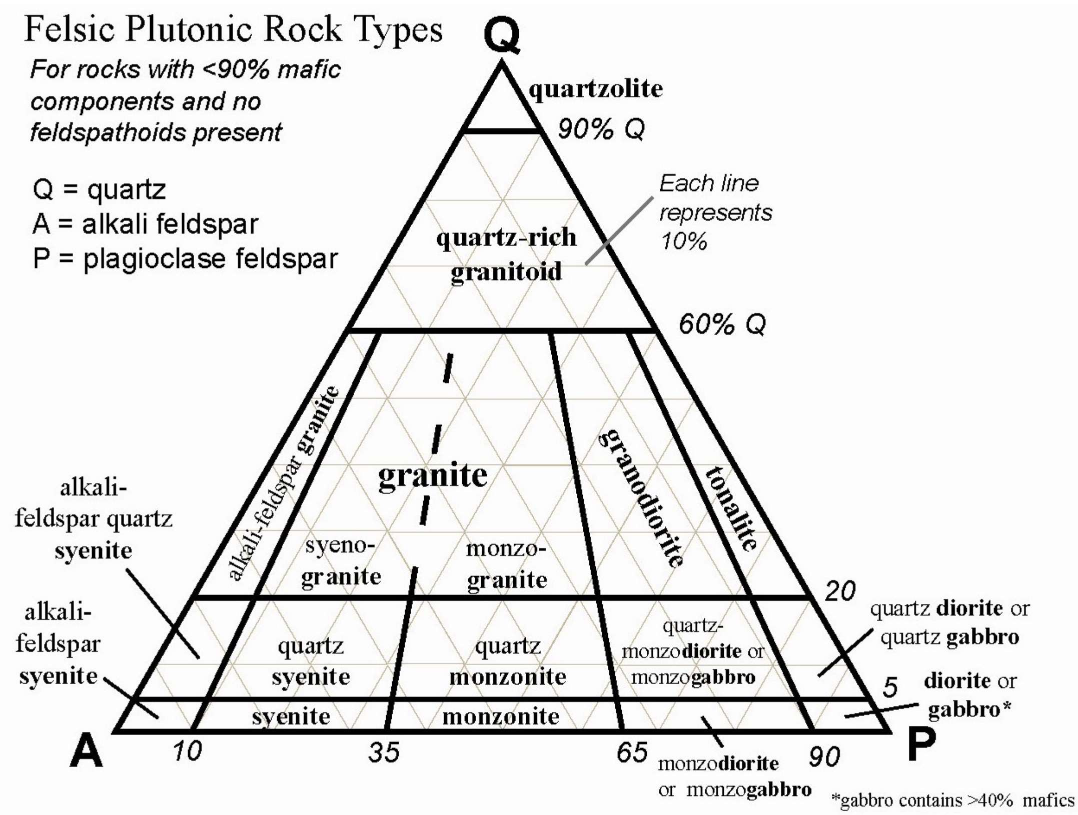
Question 4: Using Sample 2:
I. Name the rock using the IUGS ternary diagram (Include your whole rock modal %'s, normalized %, and a sketch of the diagram you used to do this.) (3 Marks)

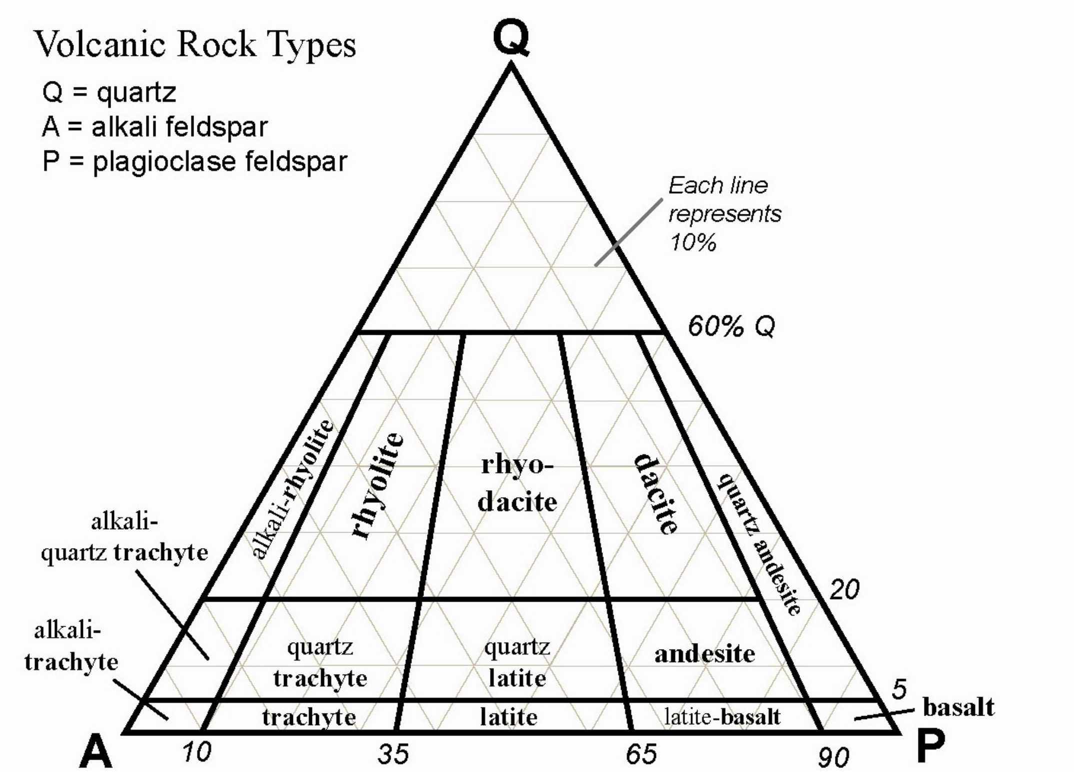
II. **List** and **define** two types of secondary textures observed in these thin sections (2 Marks)

III. **Explain** the crystallisation history in terms of the textures and different minerals observed in thin section. (Refer to the undercooling graph to help you explain) (4 Marks)

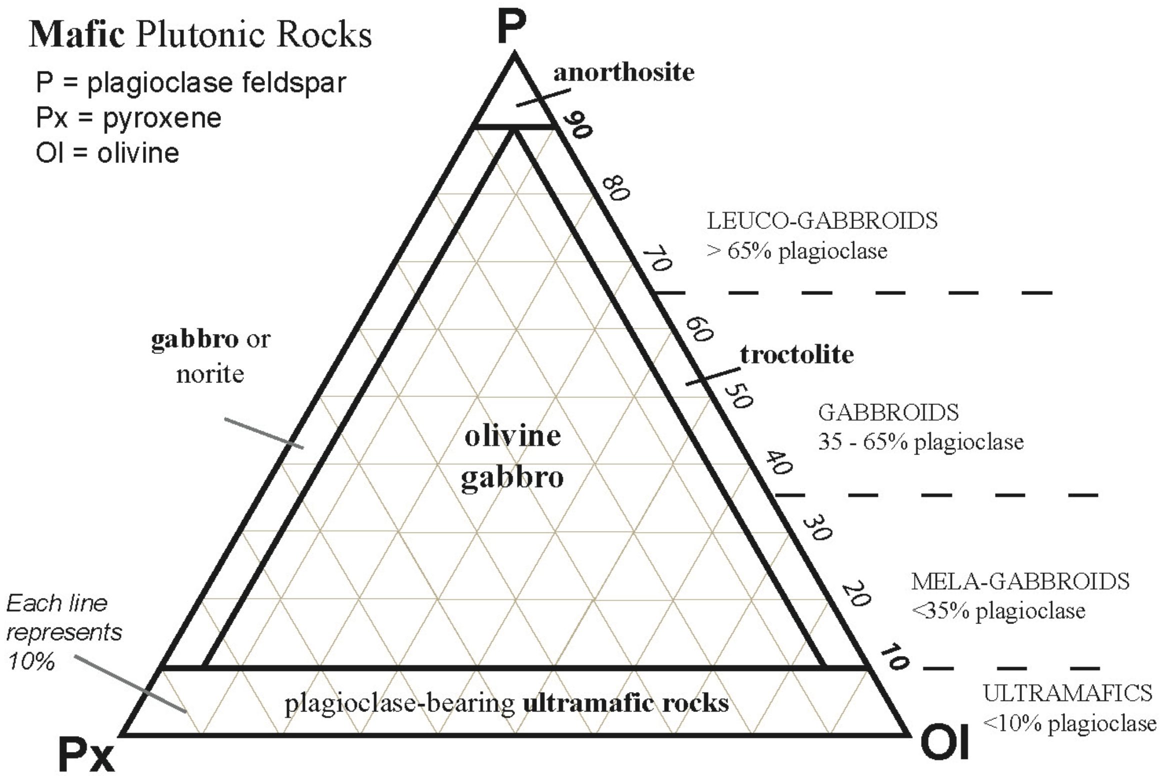
IV. **Explain** the textural differences between thin section 2 versus the thin section KB22. **Draw** and **label** pictures to help you explain. (8 Marks)

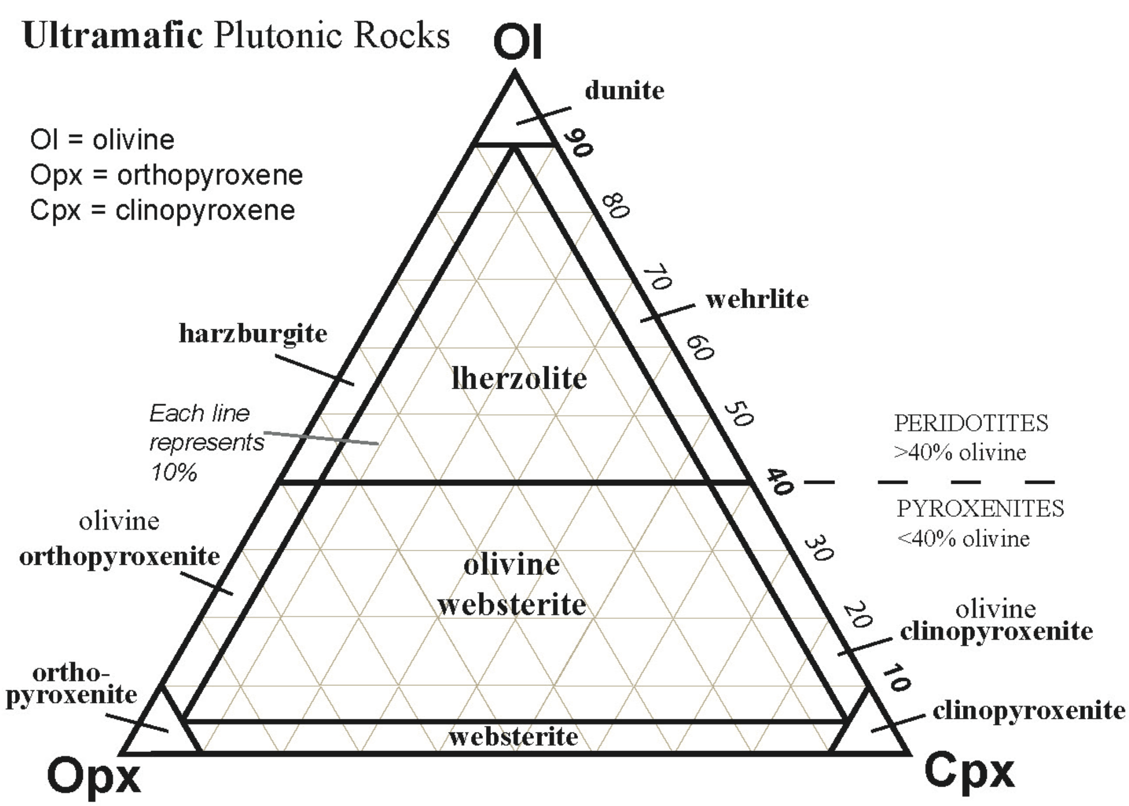
IUGS Ternary Plots: Plutonic and Volcanic Rocks





IUGS **MAFIC** PLUTONIC Rocks Ternary Plots





Lab 4 Readings

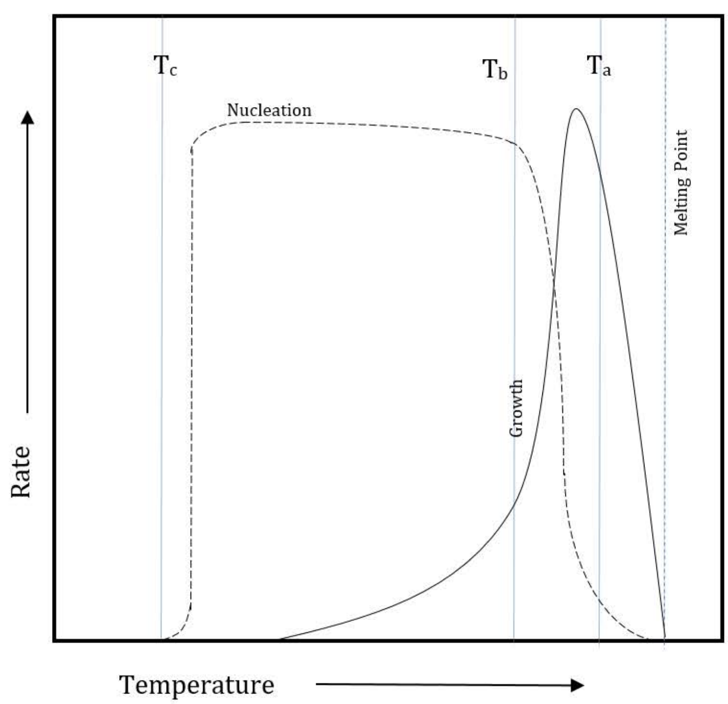
Section 1 – Undercooling, nucleation and growth of crystals

A major factor determining the texture of an igneous rock is the ***cooling rate*** (dT/dt). The other factors involved are; the diffusion rate, the rate of nucleation and the growth rate of crystals.

Diffusion Rate is the rate at which atoms or molecules can move (diffuse) through the liquid.
Rate of Nucleation of new crystals is the rate at which enough of the chemical constituents of a crystal can come together in one place without dissolving to form a juvenile crystal.
Growth Rate of crystals is the rate at which new constituents arrive at the surface of the growing crystal; this depends largely on the diffusion rate of the molecules.

The temperature of the system strongly influences these rates of growth and nucleation. For nucleation and growth to occur the temperature must be below the temperature at which equilibrium crystallization occurs.

Undercooling is defined as the state whereby a liquid must be cooled to well below its solidus temperature before nucleation and crystallization are initiated. The different degrees of ***undercooling*** influence nucleation versus crystal growth and thus the texture that a rock will have.

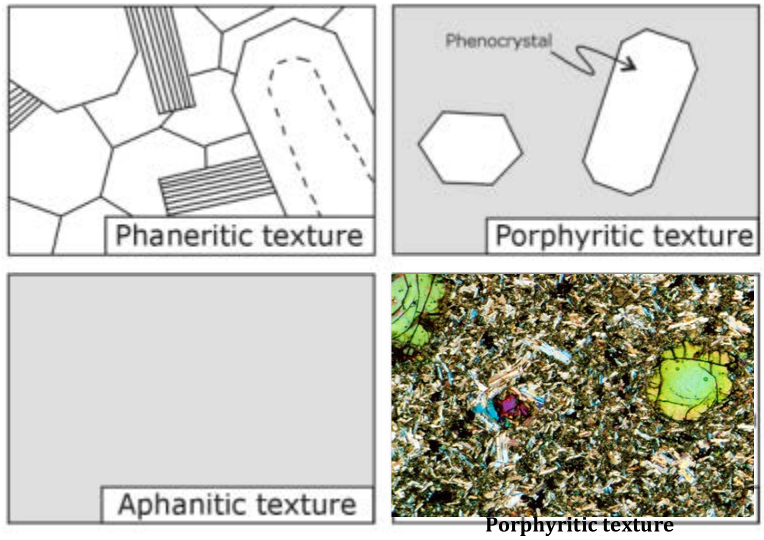


A crystal forms when its free energy becomes less than the free energy of the melt, which occurs due to changes in T, P or the concentration of a component. The chemical constituents that make up the crystal must be at the same place at the same time to form a crystal ***nucleus (nucleation).*** Once the ***nucleus*** has formed the chemical constituents must continue to diffuse through the liquid to the crystal growing surface for ***growth*** to occur. If the chemical constituents are unable to diffuse to the growing surface of the crystal the juvenile crystal will not grow.

This graph displays idealised rates of crystal nucleation and growth as a function of temperature below the melting point. Slow cooling results in only minor undercooling (T_a), so that rapid growth and slow nucleation produce fewer coarse-grained crystals. Rapid cooling permits more undercooling (T_b), so that slower growth and rapid nucleation produce many fine-grained crystals. Very rapid cooling involves little if any nucleation or growth (T_c) producing a glass.

Appendix 1: Textures

BASIC IGNEOUS TEXTURES

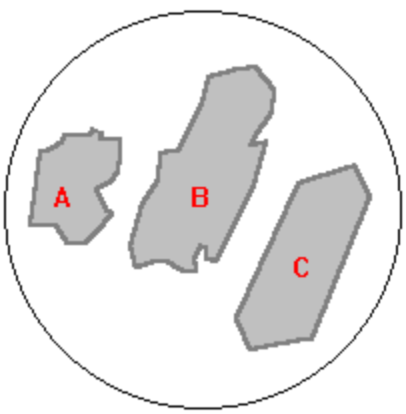


Igneous rocks are described with three major textures:

Phaneritic texture is the result of crystals of similar size in an interlocking mosaic.

If the size of the grains are so small that the crystals cannot be seen with the 'naked eye', it is called **aphanitic**.

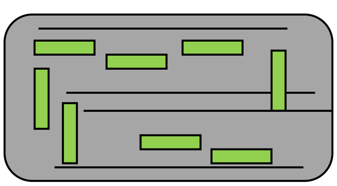
If there are two distinct stages of cooling (e.g. slow cooling making big crystals, and then fast cooling, leaving smaller crystals) we call this **Porphyritic**. The bigger crystals are called phenocrysts and the small ones – the Groundmass.



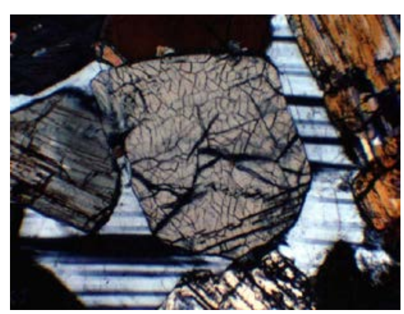
Crystal shapes:
Grains that show no recognizable crystal form are said to be *anhedral* (A). Grains that show imperfect but recognizable crystal form are said to be *subhedral* (B). Grains that show sharp and clear crystal form are said to be *euhedral* (C).

PLUTONIC TEXTURES

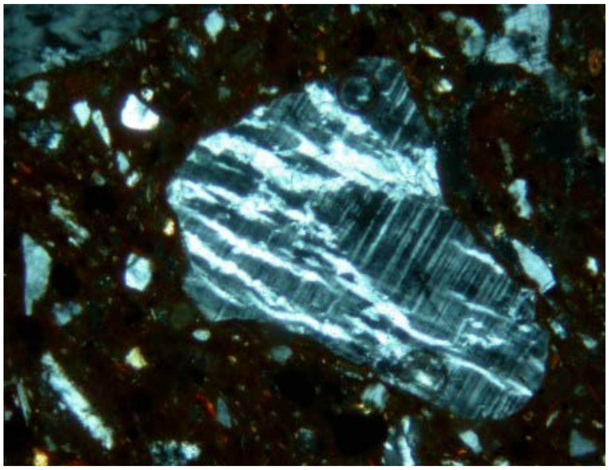
Plutonic rocks have a generally '**interlocking crystal**' texture. If all the crystals are the same size we say: it is **equigranular**. If the crystals are not the same size we say: it is **in-equigranular**.



Poikilitic is a term used in igneous rocks, for the **inclusion** (green crystals) of smaller crystals, within another larger crystal (grey crystal)



This slide (right) shows **euhedral** orthopyroxene with **interstitial (or 'filling in the spaces')** plagioclase. Plagioclase is the last crystal to form, that is why it fills in the gaps of in between the larger well-formed crystals.



Perthite texture in alkali feldspar

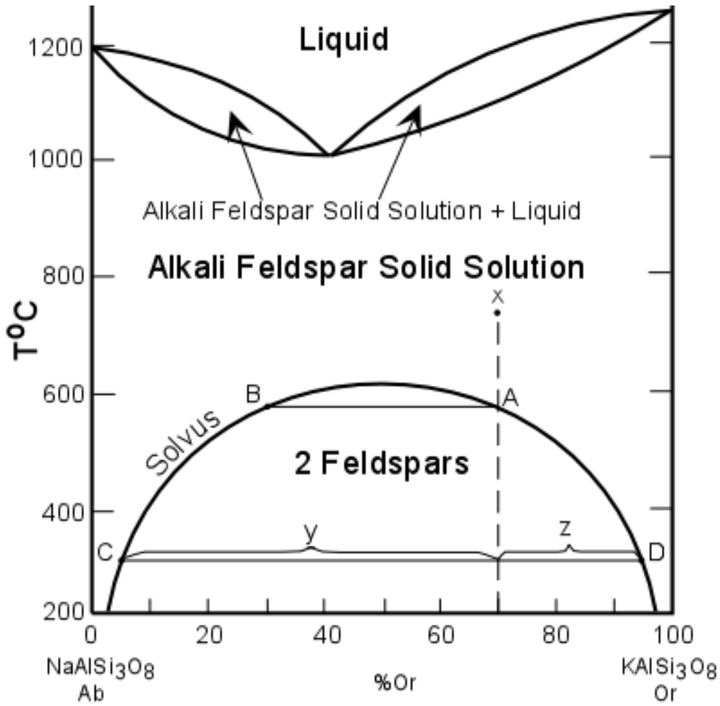
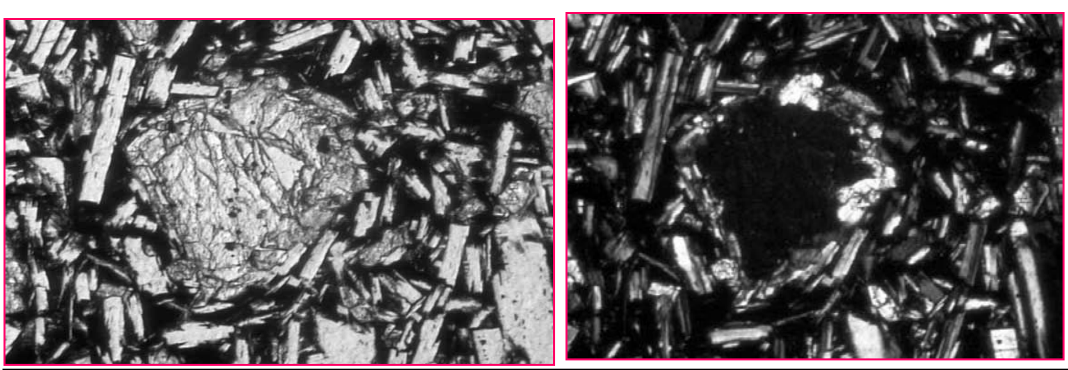


Figure 4

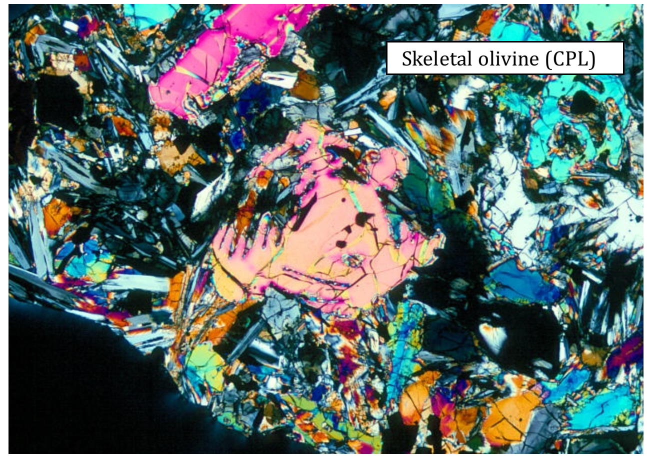
As a composition of alkali feldspars cools, x, it intersects the solvus at ~600^{o}c (Figure 4). At this point the single feldspar that had crystallised earlier will separate into two feldspars of composition A and B respectively. The mobility of ions within the solid structure is rather limited, and as a result the separating species rarely form separate crystals. Rather, the less abundant phase will typically form irregular, planar bands or **exsolution** lamellae in the more abundant host. When Na rich crystals form in a K rich host, the texture is called **perthite**. When K rich crystals form in a Na rich host the texture is called **antiperthite**.

When multiple-grain clusters of phenocrysts adhere together, the texture is called **cumulophyric** texture. If the clusters are essentially of a single mineral, it is called **glomerophyritic**.



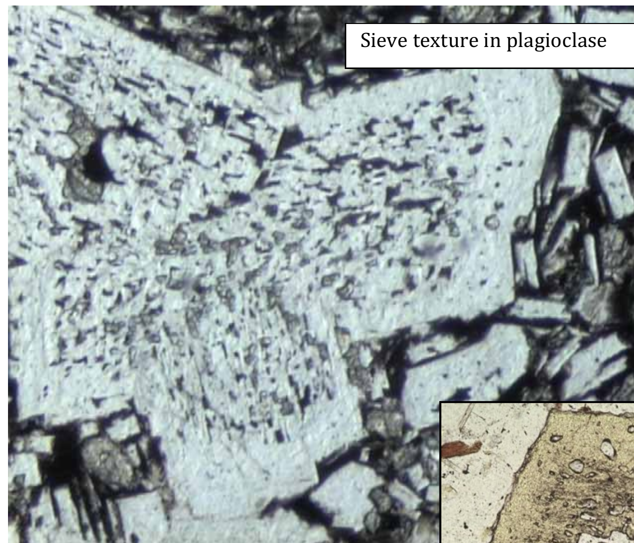
An olivine crystal is surrounded by pyroxene, the pyroxene is better observed in CPL (**right**)

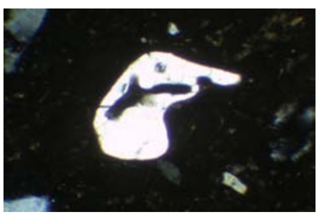
VOLCANIC TEXTURES

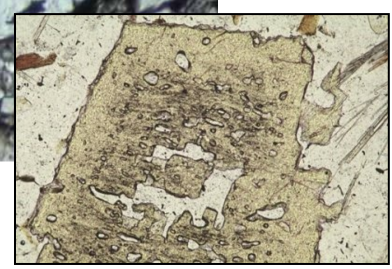

Skeletal olivine (CPL)

Skeletal Crystals – Crystals corners and edges have a larger volume of nearby liquid to tap for components (or to dissipate the heat of crystallization) than do the crystal faces. Corners and edges have a higher proportion of unsatisfied bonds. Thus we might expect the corners and edges to grow more rapidly than the faces in quench situations.

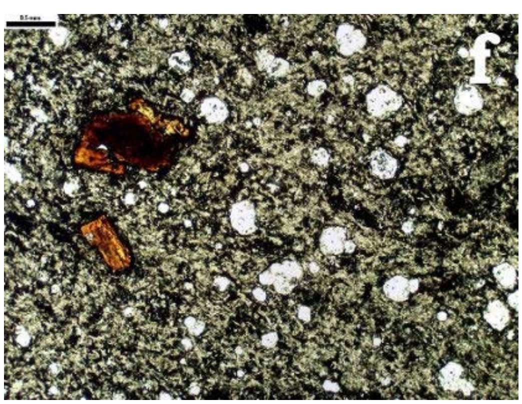
Reabsorption: term applied to re-fusion or dissolution of material back into a melt or solution from which it formed. Reabsorbed crystals commonly have rounded corners or are embayed. Some may have a **sieve texture**, which is a series of deep and irregular **embayments** within the crystal. Advanced reabsorption can produce large embayments within a crystal and round the outer edges of the crystal .

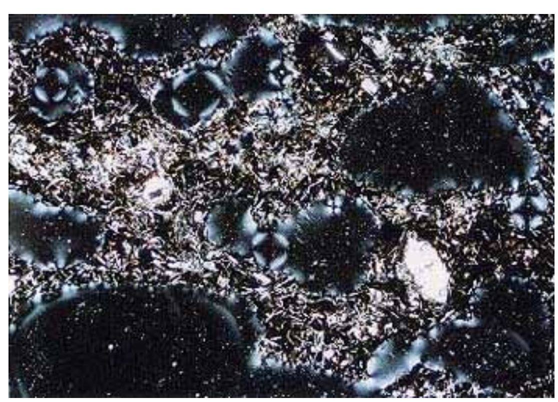

Sieve texture in plagioclase


Rounded reabsorbed edges in olivine crystal (CPL)


Embayed garnet (PPL)

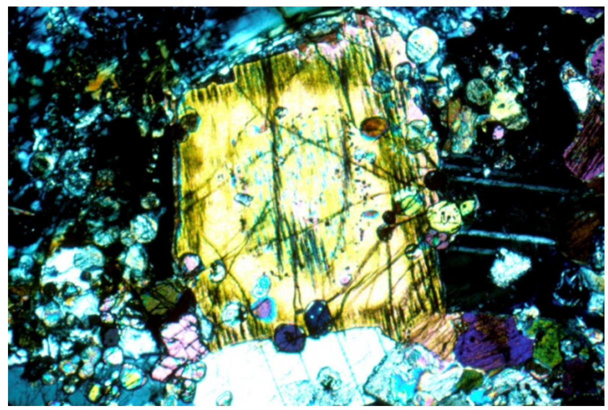
Vesicular Texture - Vesicles: spherical, ellipsoidal, or more irregular colourless holes in volcanic rocks (**PPL below, left**) formed by the collection of volatiles exsolved from magma during cooling or decompression. They go black under **CPL** (**below, right**).
When the vesicles are filled with secondary crystal growth they are called **amygdales**.





Compositional Zoning – Common and occurs when a mineral changes composition as it grows during cooling. Zoning occurs when equilibrium is not maintained and a rim of the new composition is added around the old. The expected zonation in cooling igneous plagioclase would be from an anorthite-rich core toward a more albite-rich rim (remember BRS, CA→ Na). This is called normal zoning. Reverse zoning is the opposite with more sodic inner and calcic outer zones. It is common in metamorphic rocks where growth is accompanied by a temperature rise. Oscillatory zoning (as seen below) requires abrupt changes in the conditions of the magma chamber. Most petrologists believe that the injection of hotter, more juvenile magma into a cooling and crystallizing chamber effects this change.

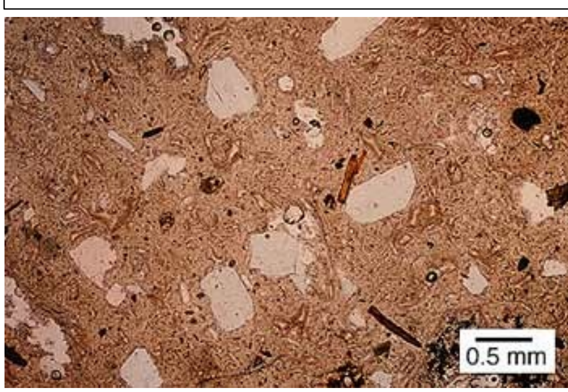
Oscillatory Zoning in a plagioclase crystal, notice the concentric change in color of the rims and the simple twins that occur underneath.

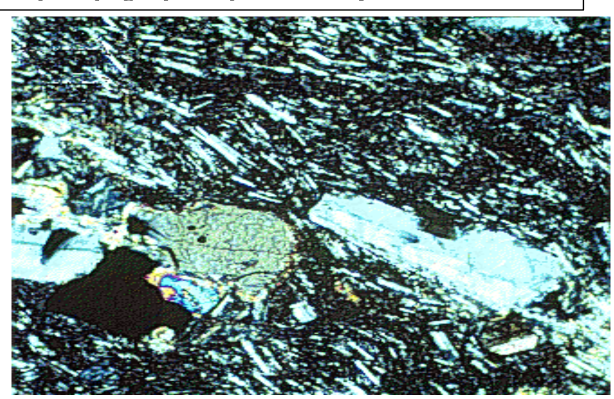


(Above: Less obvious zoning in a pyroxene)

Volcanic glass will appear as tan to brown in PPL (**left**) in thin section but will be isotropic and appear black in CPL (Black background, **right**).

Left (**PPL**): Brown glass (groundmass/background) with Quartz (clear) and biotite (dark brown);
Right (**CPL**): Opaque glass groundmass with phenocrysts (big crystals) and **trachytic** microlites





Trachytic Texture – When lath-shaped feldspar (both kspar and plag) **microlites** in a volcanic rock are strongly aligned (commonly flowing around phenocrysts; **right**).

Lab 5: Intrusive and Extrusive Rock Classification

Lab Goals

1. Distinguish between intrusive and extrusive igneous rocks
   Section 1: Intrusive or extrusive
2. Identify the given rocks using IUGS standards
   Section 2: Classification
3. Recognize geochemical differences between samples and determine the relationship between the samples
   Section 3: Textures
4. Illustrate a thin section in a thorough descriptive sketch, with labels
   Section 4: Sketches
5. Identify the link between mineral assemblages and melt generation
   Section 5: Magma Generation

Section 1: Intrusive or Extrusive

Question 1: I) Draw an ideal example of an intrusive and extrusive igneous rock, as it would look in thin section. **Draw and label** at least three textures that you would expect to see in each and briefly explain why you would see them.

Textures: Explanation:

Textures: Explanation:

Section 2: Classification

Question 2: I) Determine the minerals present in each of the rocks provided (sample **XY** and sample **CR-**), and their modal percentage.
II) Classify the rocks using the correct triangle provided. Check the reading on how to correctly classify volcanic rocks.
III) Classify the bulk chemical analysis of both rocks (using the TAS diagram).

SAMPLE CR:

Mineral	Modal %	Normalized %

SAMPLE XY:

Mineral	Modal %	Normalized %

Bulk Composition of samples:

Major Oxide	Sample CR- (Weight (%))	Sample XY-
SiO_2	54.6	42.8
TiO_2	1.75	4.14
Al_2O_3	19.5	14.3
Fe_2O_3	2.83	5.89
FeO	2.87	8.55
MnO	0.18	0.17
MgO	1.5	6.76
CaO	5.65	12
Na_2O	5.82	2.79
K_2O	4.85	2.06
P_2O_5	0.51	0.58
Total	100.06	100.04

Rock Name (Sample CR-)
By mineralogy:
By chemistry:

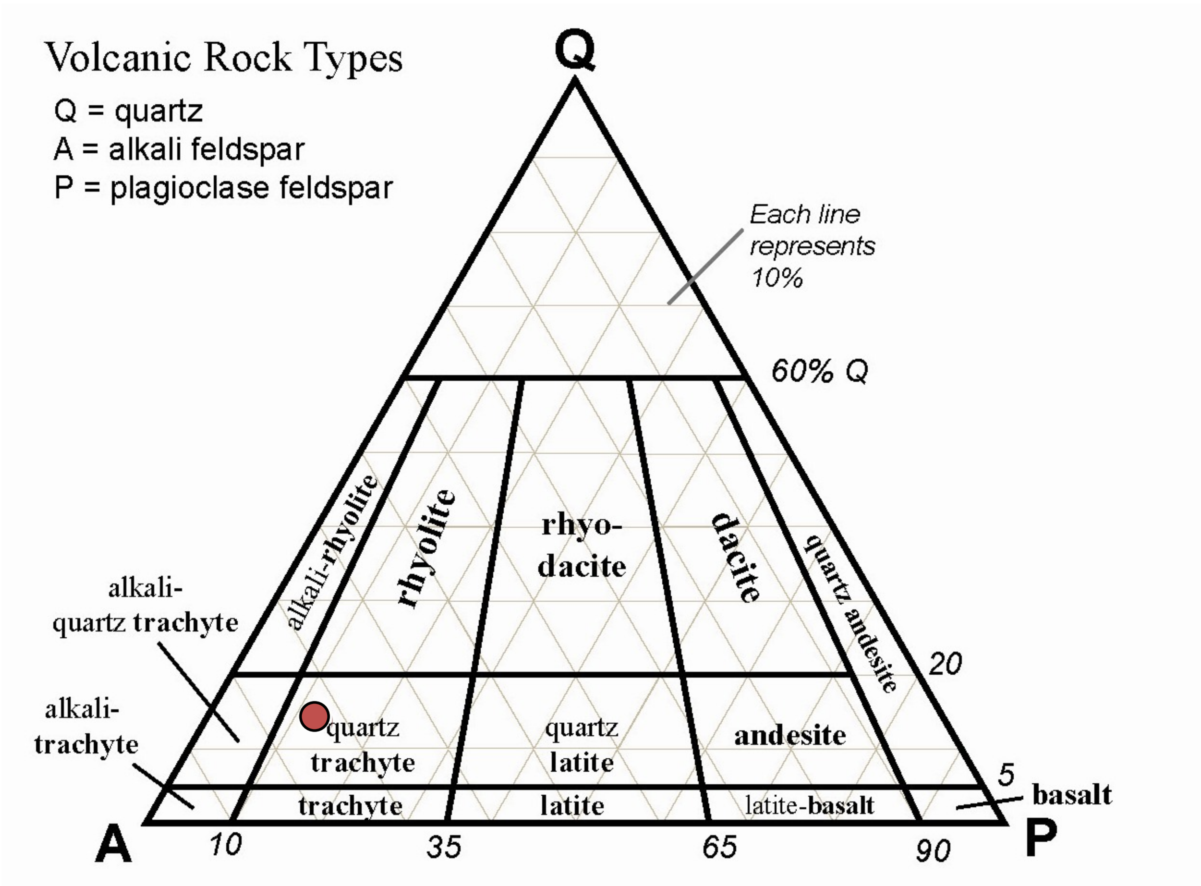
Rock Name (Sample XY)
By mineralogy:
By chemistry:

IV) Is there a difference between the TAS diagram and the IUGS classification for the volcanic rock? Discuss why there might be a difference between the two classification systems. (3 Marks)

V) What are the differences between the two thin sections, if any? Could they have come from the same volcanic system? Explain using evidence-based writing. (6 Marks)

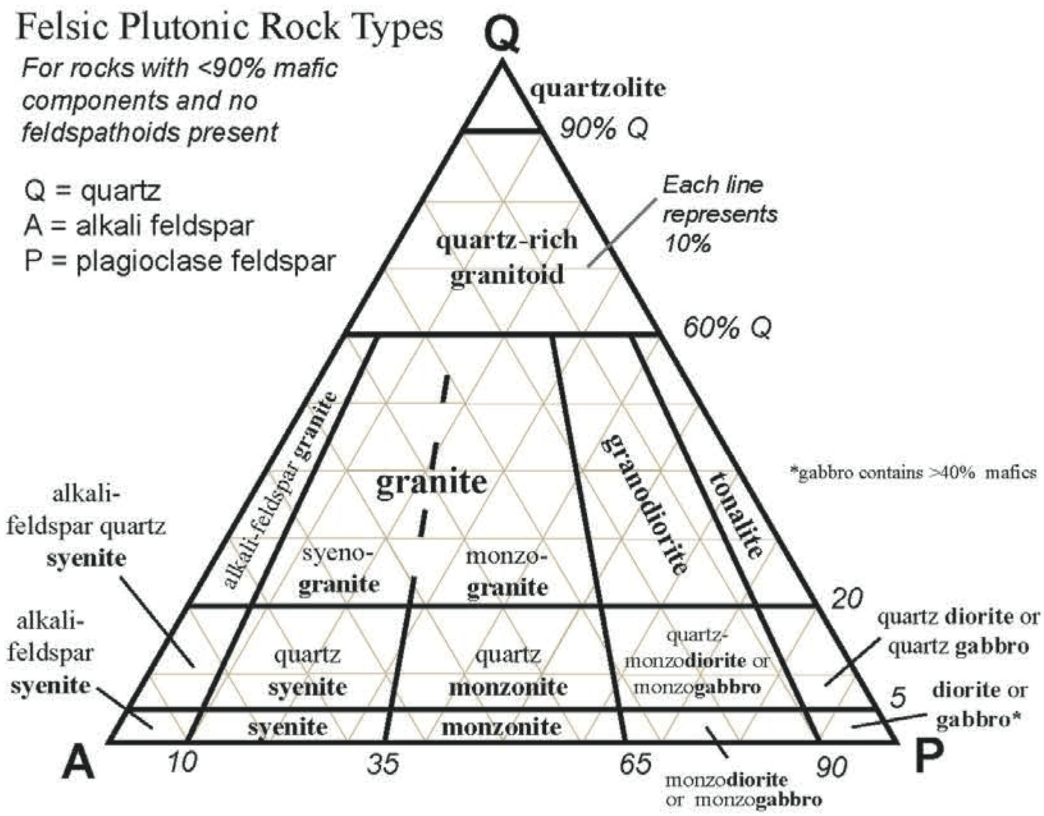
VI) Sample A and C lavas (See the TAS diagram) erupted from the same volcano. How would the chemistry change within the volcano from A to C? Use the TAS diagram to help you explain. (4 Marks)

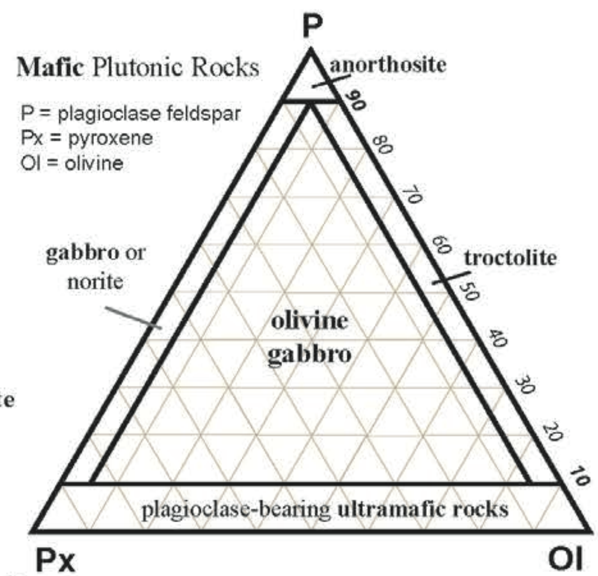
Figure 4A: IUGS Volcanic Rock Classification Diagram (using phenocrysts)



Sample D – red circle

Figures 4B: IUGS Plutonic Rocks





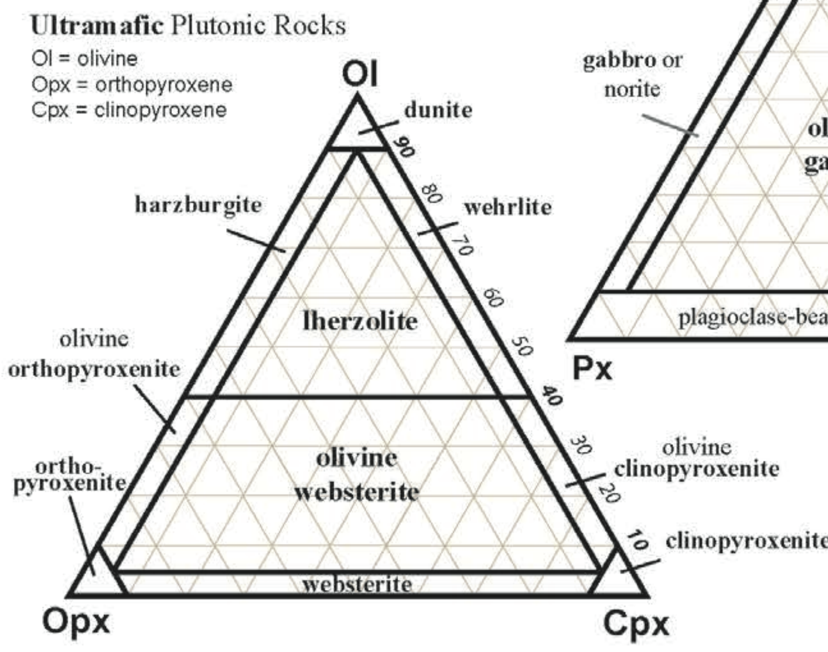
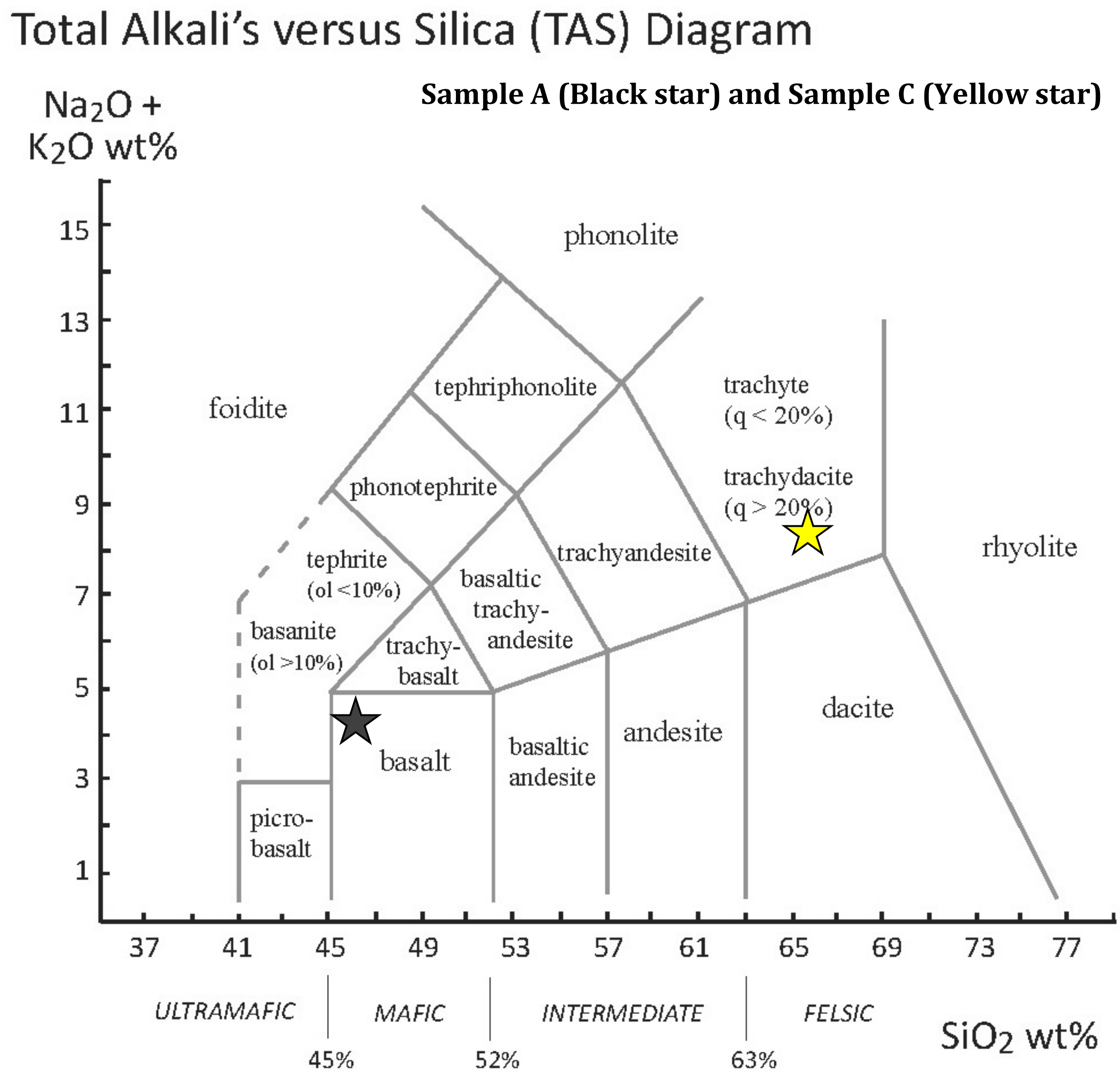


Figure 5: TAS Geochemical Diagram for Volcanic Rocks



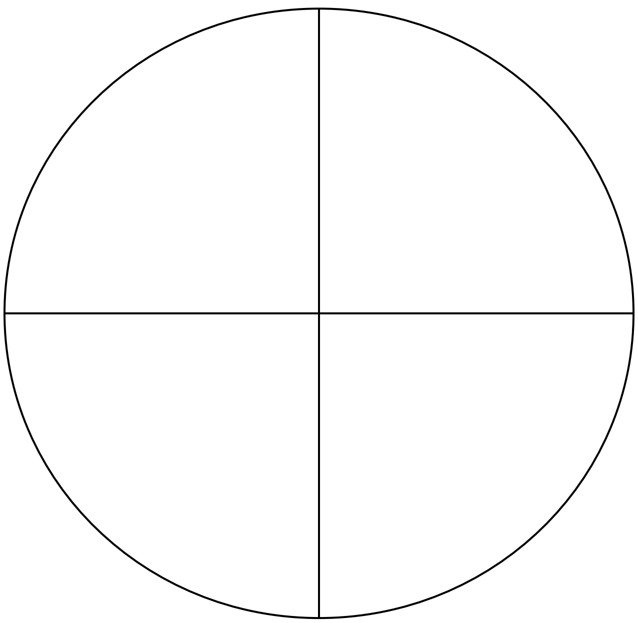
Section 3: Textures

Question 3: I) For both rocks (XY and CR) fill out the texture templates with the textures seen and explain how these textures have formed.

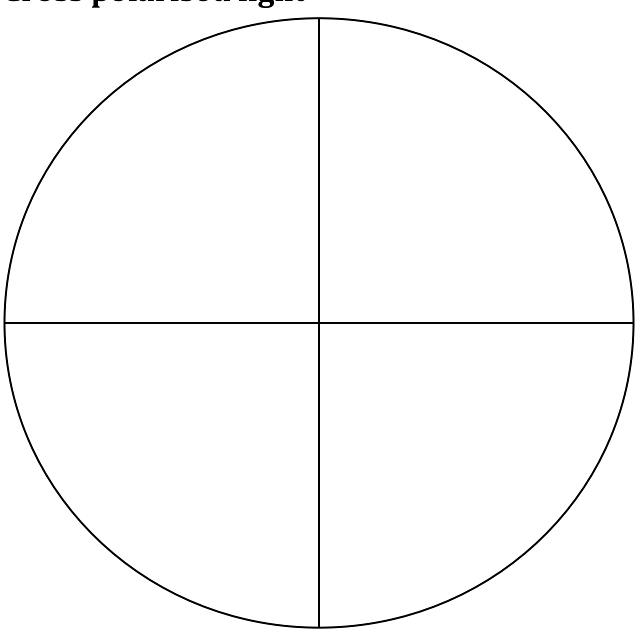
Section 4: Sketch

Question 4: Draw two labelled sketches of the thin section **CR-** (ppl and cpl). Indicate on the sketch the different mineral species and textural features that aided identification and that are important for understanding the rock's history (e.g. twins, cleavage)

Plain polarised light



Cross polarised light



Section 5: Interpretation + Magma Generation

Question 4: I) What major textures tell you which rock is extrusive and why? Draw examples of the textures to help you explain (4 Marks)

II) Explain what magma composition these rocks formed from? Provide evidence (3 Marks).

III) What type of tectonic environment were these rocks formed in? Explain. (5 Marks)

IV) Both these rocks are slightly ‘altered’. How do you know this? (3 Marks)

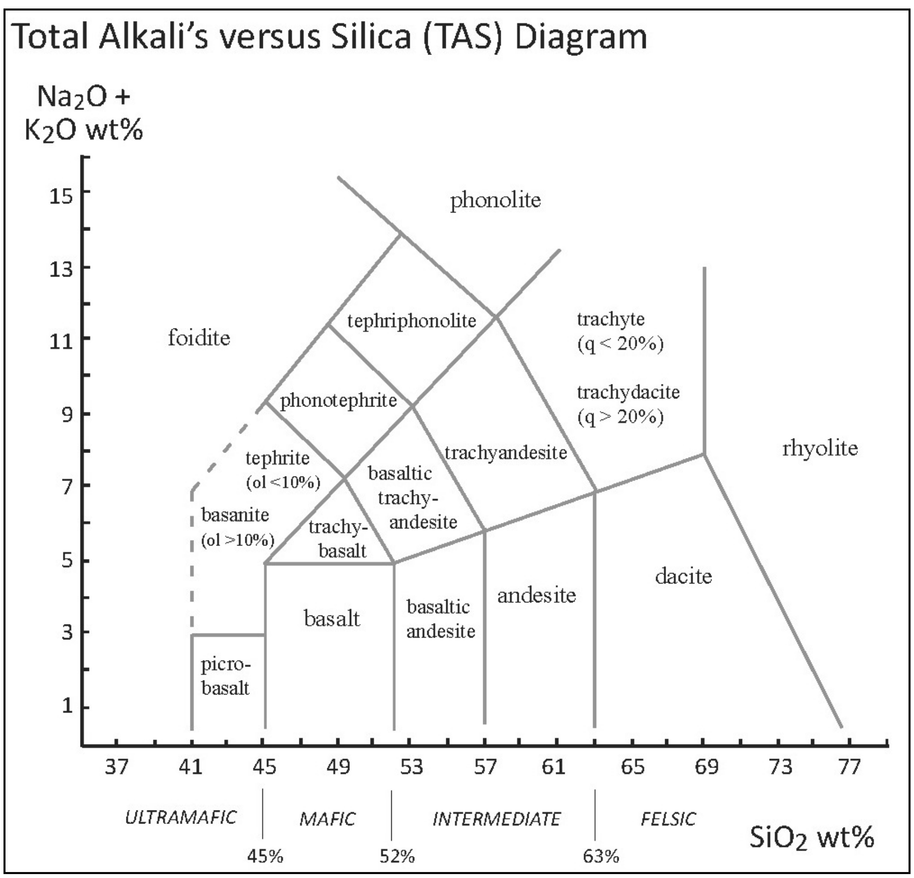
V) Examine the IUGS diagrams for volcanic rocks (Fig 4A). A mysterious **Sample D** has been marked on the ternary diagram. Based on your past experiences with intrusive rocks of similar compositions, what minerals would you expect to see? List the minerals. (4 Marks)

Notes from Lab 5:

Lab 5 Reading: Classification of Igneous Rocks

Volcanic rocks for which a mineral mode can be determined are treated in the same way as plutonics in the original IUGS classification if phenocrysts can be identified (IUGS Mineral Mode Diagram, Figure 4A). The matrix of many volcanics is composed of minerals of extremely fine grain size and may even consist of a considerable proportion of vitreous (glassy) or amorphous material. Thus it is commonly impossible, even in thin section, to determine a truly representative mineralogical mode. According to Bowen's reaction series the first minerals to crystallize do not necessarily represent the mineralogy of the rock as a whole. *When the mineralogical information for a rock is inconclusive, geochemical data can be used to classify the volcanic rocks. This can then be plotted onto the total alkalis versus silica (TAS) diagram (**Figure 5, below**)*

The TAS graph (below) is used to classify volcanic rocks geochemically, according to the percentage of total alkalis (Na2O + K2O) versus the silica percentage (SiO2). This relationship is important as the relative proportions of alkalis and silica play an important role in determining the actual mineralogy of a rock. As igneous rocks evolve beneath the surface their compositions tend to move upwards and rightwards on this diagram, this coincides with the *Bowen's Reaction Series*.

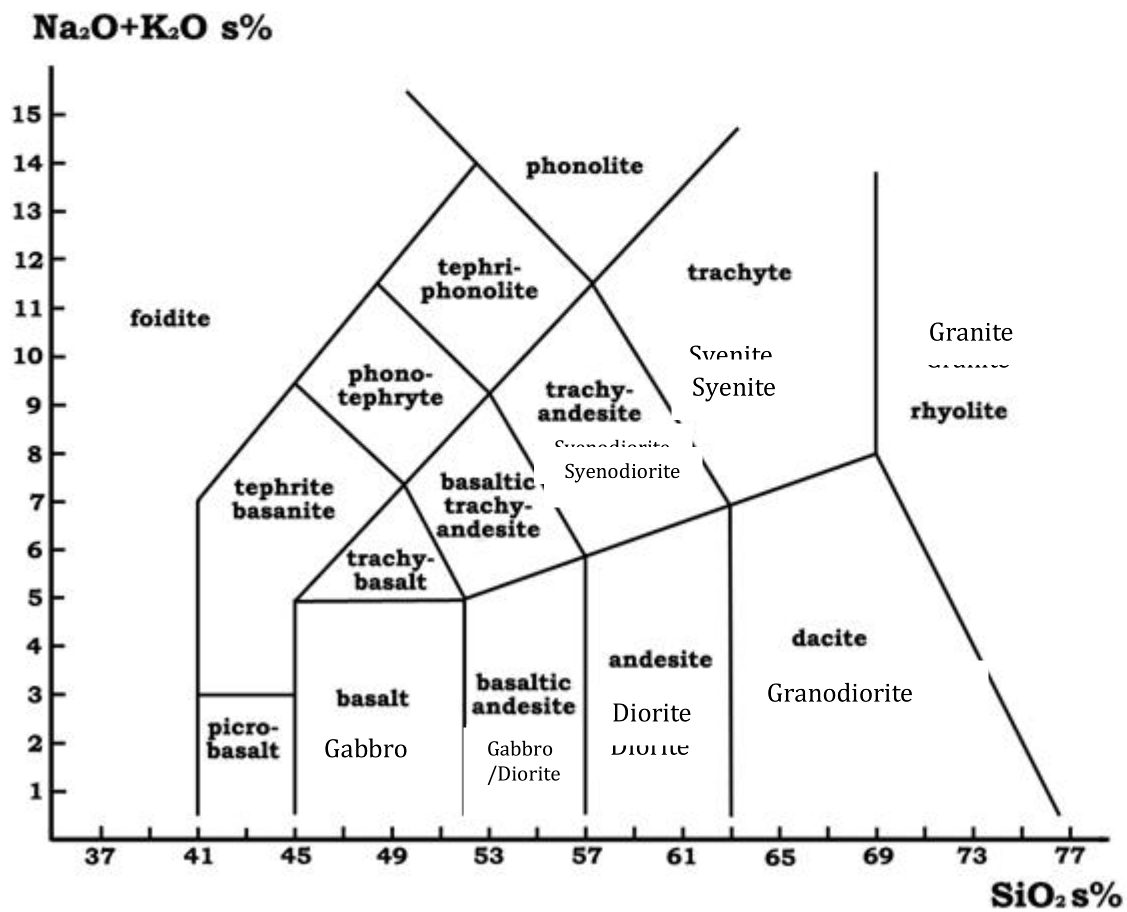


Lab 6: Practice Lab Midterm: TVZ!

Learning Goals

1. Practice what you will be expected to do during the exam and draw and describe one thin section.
   Section 1: Petrographic Descriptions
2. Identify the rock type that the thin section comes from
   Section 2: Classify the TVZ thin section
3. Interpret the mineralogy and textures of the sample in terms of magma processes and the TVZ.
   Section 3: Essay Question
4. Split into groups and work together to re-sit the exam, combining everyone's knowledge.

GEOL242 2017 Practice Midterm Lab Exam **Date/Time:** **Student Number:**

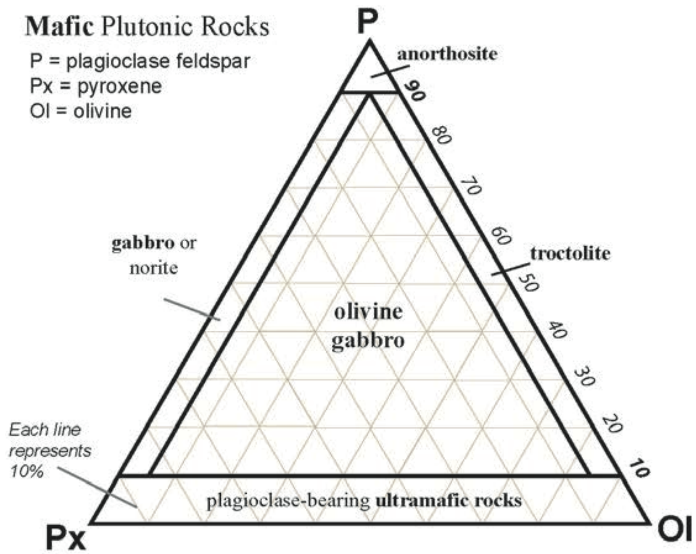


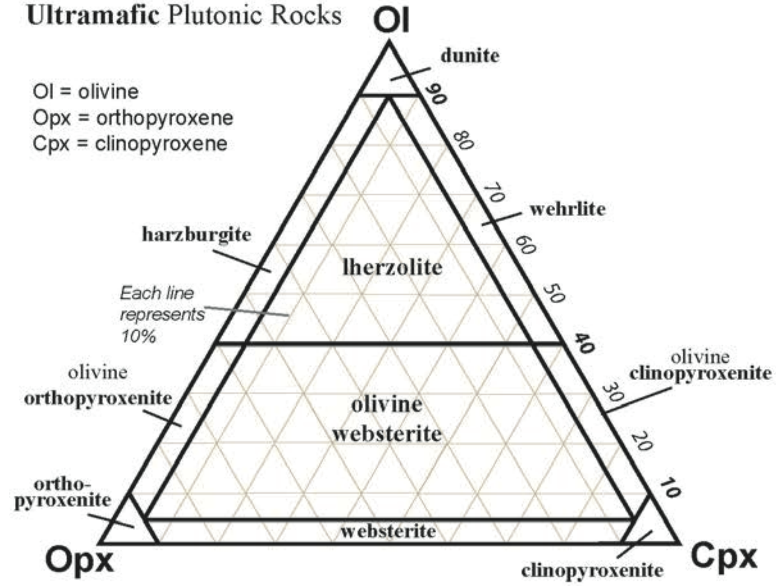
Composition wt%

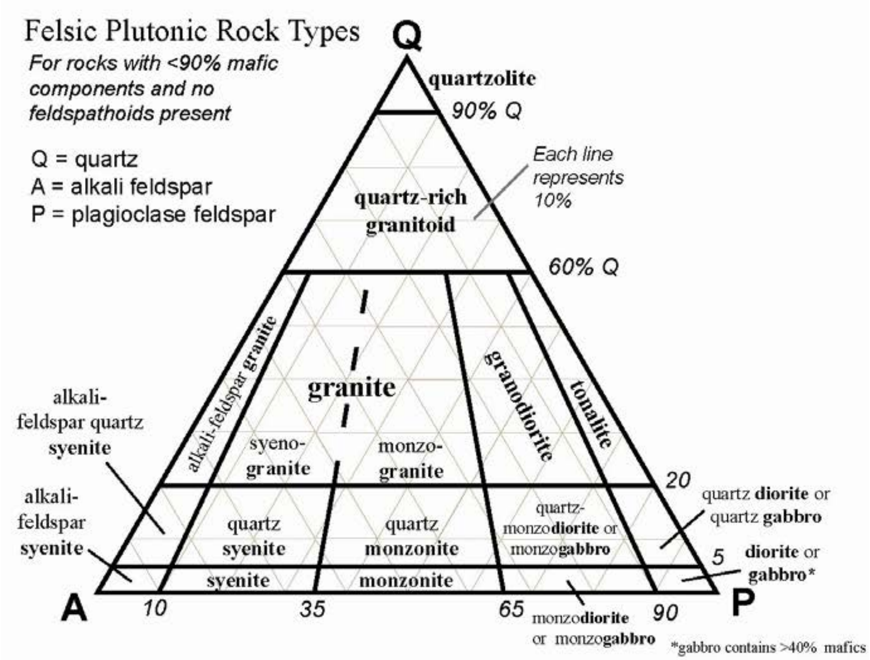
SiO2	
Al2O3	
FeO	
CaO	
MgO	
MnO	
Na2O	
K2O	
TiO	
H2O	

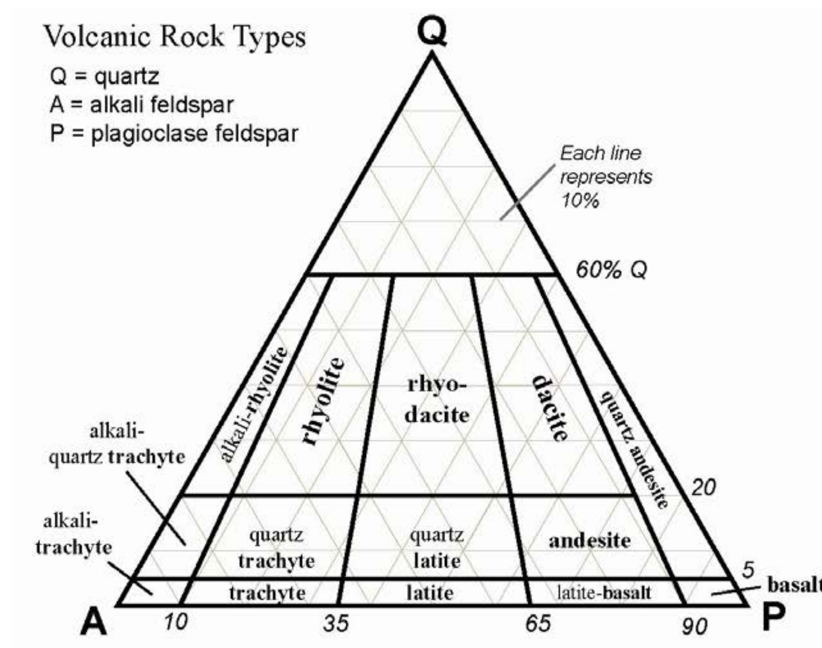
TAS diagram volcanic (extrusive) names in bold plutonic (intrusive) not bold

IUGS **MAFIC** PLUTONIC Rocks Ternary Plots





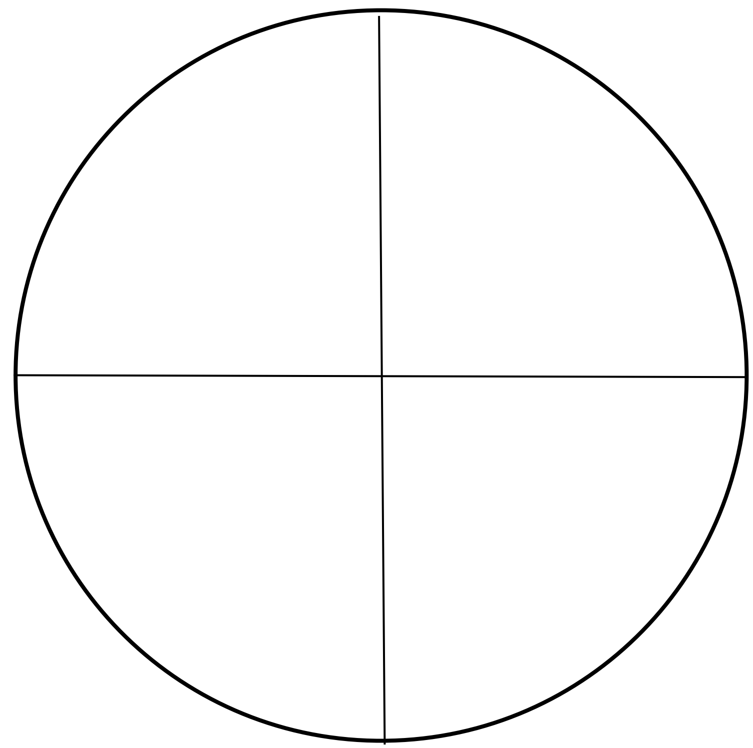




Question 1: Draw a labeled sketch of **thin section** __________ (half in ppl and half in cpl). **(35 marks)**

➔ Use the table to describe the mineralogy and textures and to label the sketch (10 marks for sketch)

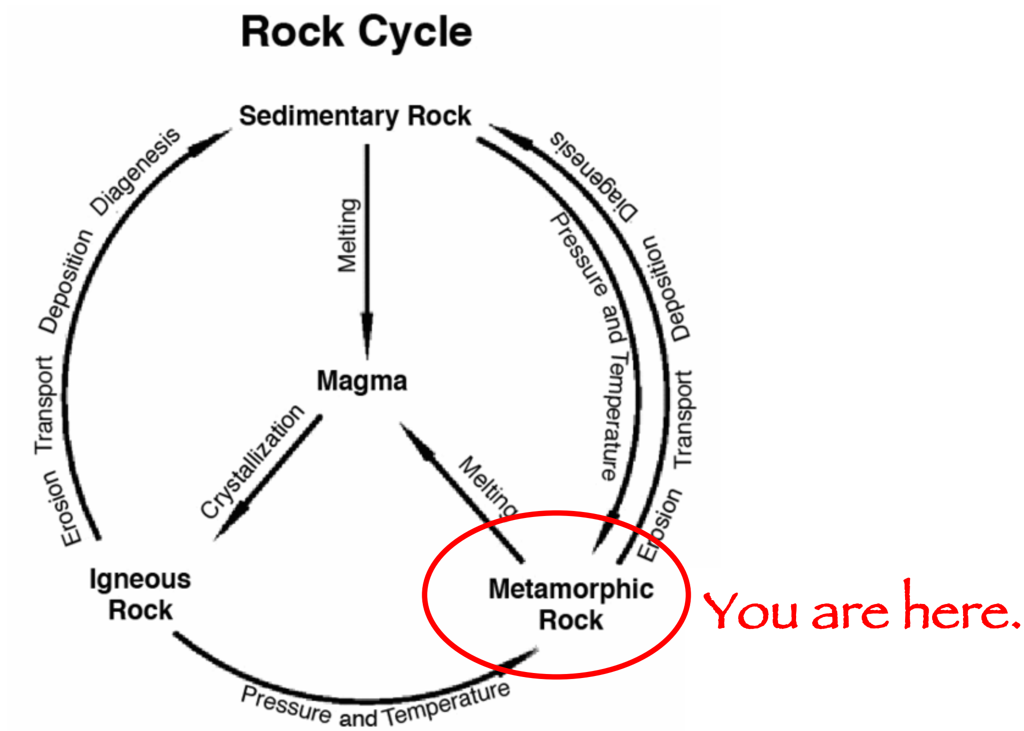
Mineral Name	%	% nml	Diagnostic Properties (Description)
Marks (5)	**2.5**	**2.5**	**10**
Textures that help with interpretation (5 marks):			



Q2. A) Name the rock using a mineralogical classification diagram and chemical composition and TAS diagram (label on diagrams) and textural descriptor (useful in hand sample)
e.g. **Micro vesicular olivine porphyritic**, ("textural descriptor") **Basalt** (rock classification from diagram) **(5marks).**

B) Use your textures (listed above) (and hand sample observations) to interpret how the rock formed starting with the tectonic environment and ending when it fully cooled. Use theoretical diagrams and textural sketches where appropriate **(20marks).**

Part II: Metamorphic Petrology



Lab 7: Metamorphic Minerals and Regional (Foliated) Metamorphic Rocks

Welcome to the second half of GEOL 242! In the coming weeks, we will be focusing on metamorphic rocks as well as related ore-forming rocks/minerals. Today we will focus on identifying common metamorphic and ore minerals not covered in the first half of the semester as well as how these minerals provide structure/texture that then allow us to classify them.

Learning Goals:

1. **Name** and **describe** common **metamorphic minerals**
   Section 1: Hand Sample Mineral Identification
2. **Name** and **describe** common **ore minerals** in hand sample
   Section 1: Hand Sample Mineral Identification
3. **Name**, **describe**, **illustrate** and **explain metamorphic hand sample textures**
   Section 2: Naming of Metamorphic Rocks Based on Textures
4. **Examine** and **describe** the mineralogy and textures in thin sections of **foliated rocks** and use them to **name** the rock.
   Section 3: Description and Classification of Foliated Metamorphic Rocks
   Section 4: Description and Classification of LFFS
5. **Describe**, **identify** and **illustrate** the features of Garnet, Muscovite, Calcite and Zircon
   Section 5: New Minerals
6. **Compare** and **contrast** foliated metamorphic rocks
   Section 6: Review questions

Section 1: Hand Sample Mineral Identification:

Group exercise for mineral identification using minerals listed in the previous pages.

Mineral(s)	Reasoning	Notes
1. **Kyanite**		
2. **Chalcopyrite**		
3. **Hematite**		
4. **Muscovite**		
5. **Sphalerite**		
6. **Garnet**		
7. **Magnetite**		
8. **Tremolite**		
9. What is this mineral?		
10. What is this mineral?		

Section 2: Metamorphic Rocks Based on Texture – In Lab Exercise

Refer to readings provided, as a guide.

List and provide an annotated sketch of hand samples of the four main foliated rock types:

Section 3: Description and Classification of Foliated Metamorphic Rocks

1. Hand sample description

LFP1 **GN1**

2. Petrographic sketch of thin section at 4x magnification. Label observed minerals/textures.

PPL **XPL** **PPL** **XPL**

LFP1 **GN1**

3. Modal Mineralogy

LFP1: Mineral Name	%

GN1: Mineral Name	%

4. Briefly describe and explain the rock and mineral textures you can see in the hand samples and thin sections. (Some of the textures you observe, you may have already seen in igneous rocks – describe them too!). Start adding any new textures to the textures section of your Mineral ID and Textures booklet.

5. Are you able to capture all the textures/foliations under the microscope? If not, how would you try and solve this conundrum? Sketch what you can see.

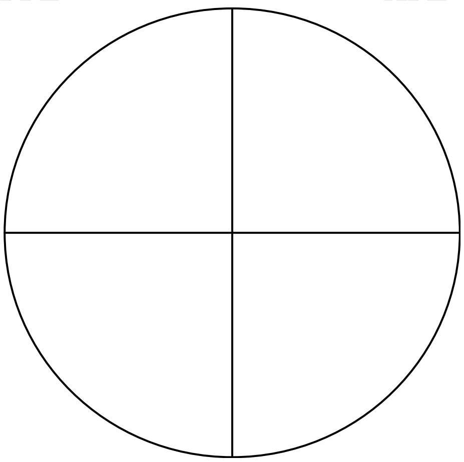
6. Name the rocks based on their texture and mineralogy.
LFP1: **GN1:**

Section 4: Description and Classification of LFFS

1. **Hand sample description** (Modal Mineralogy & Textures)

2. **Petrographic sketch of thin section at 4x magnification. Label observed minerals/textures.**

PPL **XPL** **Other Notes:**



3. **Modal Mineralogy**

Mineral Name	%	Diagnostic Properties

4. Briefly describe and explain the rock and mineral textures you can see in the hand samples and thin sections. (Apply the same principles as for the previous samples). If you recognize any new textures add them to the textures section of your Mineral ID and Textures booklet.

5. Name of rock based on texture and mineralogy:

Section 5: New Minerals: Garnet, Muscovite, Calcite and Zircon

Use the samples provided to correctly identify **Garnet**, **Muscovite**, and **Calcite**. **Zircon** will need to be researched online, as we do not have samples of this mineral.

1. Enter **all new minerals** into your Mineral ID and Textures booklet.
2. Add the metamorphic **textures** identified in these samples to your booklet too.

Section 6: Review Questions:

1. What do a slate and a phyllite have in common?

   How are they distinguished from one another?

   What is responsible for the difference?

2. What does a schist have in common with a slate and phyllite?

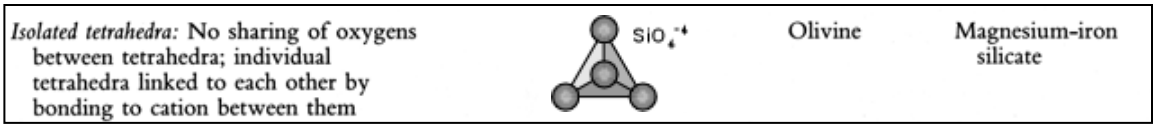
3. How does schistosity differ from cleavage?

4. What distinguishes a gneiss from a schist?

Lab 7 Readings:

Part 1: Mineralogy and Crystal Structure Review

Class: Silicates; Subclass - Nesosilicates (Isolated tetrahedrons SiO_4)



[2]**Garnet Group** **$(A^{2+})_3(B^{3+})_2(SiO_4)_3$**

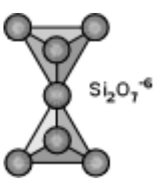
Pyrope	$Mg_3Al_2Si_3O_{12}$
Grossular	$Ca_3Al_2Si_3O_{12}$
Andradite	$Ca_3Fe_2Si_3O_{12}$

[2]**Zircon**	$ZrSiO_4$
[2]**Andalusite**	Al_2OSiO_4 or (Al_2SiO_5)
[2]**Sillimanite**	Al_2OSiO_4 or (Al_2SiO_5)
[2]**Kyanite**	Al_2OSiO_4 or (Al_2SiO_5)
[2]**Staurolite**	$Fe_2Al_9O_6(SiO_4)_4(O,OH)_2$
Sphene (Titanite)	$CaTiSiO_4$
[1]**Olivine**	$(Fe,Mg)_2SiO_4$ (End-Members: **Fayalite** (Fe_2SiO_4) and **Forsterite** (Mg_2SiO_4))

My notes:

Most of these minerals have very specific occurrences. It is good to know these occurrences, and to use that to help you in identification. Andalusite is the toughest to identify in hand specimen, and sphene is usual itsy bitsy. Olivine is usually recognized by its sugary appearance with a conchoidal fracture. Garnets are almost always dioctahedral. Look for the diamond-shaped faces. Staurolite often has a burgundy colour, occurs in similar rocks as garnets; however, it is elongated. Sillimanite occurs as small white needles in Al-rich (muscovite-bearing) schists. Kyanite is blue and bladed.

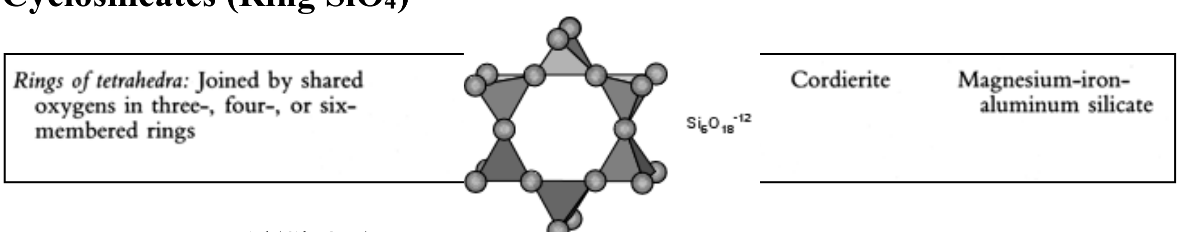
Sorosilicates (Isolated double tetrahedra groups with Si_2O_7)



Two linked tetrahedrons isolated from all other tetrahedrons. Common examples are epidote and lawsonite.

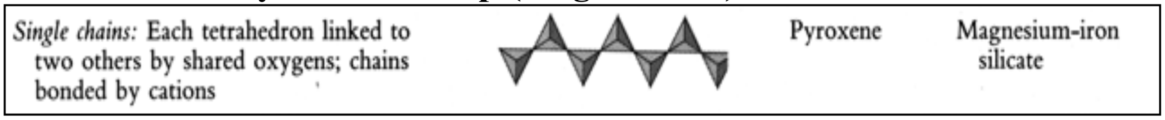
Lawsonite	$CaAl_2(Si_2O_7)(OH)_2 \cdot H_2O$
Epidote Group	$Ca_2(Fe^{3+},Al)Al_2O(SiO_4)(Si_2O_7)(OH)$

Cyclosilicates (Ring SiO_4)



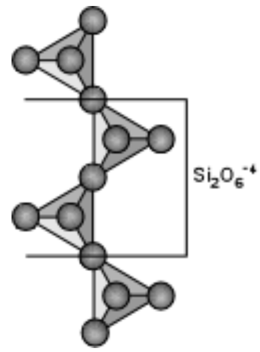
Beryl	Be-Al(Si_6O_{18})
Tourmaline	Every element but the kitchen sink. Note that Li and B are common.
Cordierite	$Mg_2Al_4Si_5O_{18}$

Inosilicates I: Pyroxene Group (Single Chain)



Orthopyroxenes:

A solid solution between:
(Enstatite $Mg_2(Si_2O_6)$ – Ferrsilite $Fe_2(Si_2O_6)$)
Just know **Orthopyroxene** $(Mg,Fe)_2(Si_2O_6)$



Clinopyroxenes:

Augite, Diopside $Ca(Fe, Mg)(Si_2O_6)$

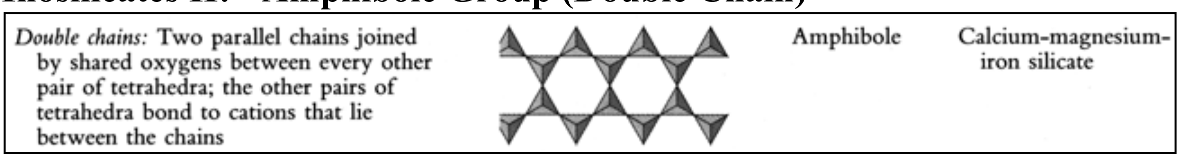
Other Pyroxenes:

[2]**Jadeite** $NaAl(Si_2O_6)$

Pyroxenoids:

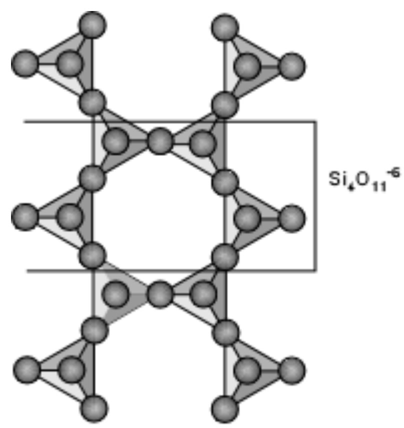
Wollastonite $CaSiO_3$
Rhodonite $MnSiO_3$

Inosilicates II: [1]Amphibole Group (Double Chain)



Orthoamphiboles:

Anthophyllite
$(Mg,Fe)_7Si_8O_{22}(OH)_2$



Clinoamphiboles:

[2]**Tremolite**
$Ca_2Fe_5Si_8O_{22}(OH)_2$
Actinolite
$Ca_2Fe_5Si_8O_{22}(OH)_2$

[1]**Hornblende** Like trem-actin formula, but has Na and Al (Al substitutes for Si)

Sodic Amphiboles (also clino-):
[2]**Glaucophane** $Na_2Mg_3Al_2(Si_8O_{22})(OH)_2$

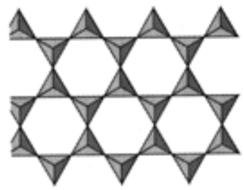
***My Notes**: Be sure you can tell pyroxenes from amphiboles by the stepped cleavage angles. Some other very general rules of thumb (helpful, but fallible) are:*

-If it's black, it's probably hornblende (or biotite (see below), if flaky and shiny). See tourmaline below.
-If it's green, it's probably augite (if stubby) or actinolite (if more elongate), but I'd look hard for cleavages here. Augite is the most common pyroxene in igneous rocks.

-If it's brown and stubby, it's probably orthopyroxene.
-Diopside and tremolite are aided by occurrence (in calc-silicates), so they commonly have carbonates or other calc-silicate minerals with them.
-Tourmaline can often be recognized by the slightly swollen triangular cross-section.

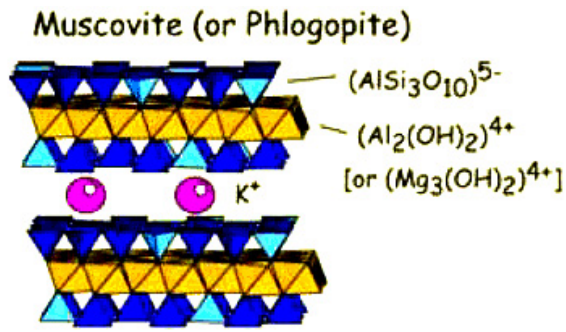
Phyllosilicates (Sheets of SiO_4)

Sheets: Each tetrahedron linked to three others by shared oxygens; sheets bonded by cations	Kaolinite	Aluminum silicate
	Mica (muscovite)	Potassium-aluminum silicate



Clay Minerals

[2]**Serpentine Group**	$Mg_3Si_2O_5(OH)_4$
Kaolinite	$Al_2Si_2O_5(OH)_4$
[2]**Talc**	$Mg_3Si_4O_{10}(OH)_2$
Pyrophyllite	$Al_2Si_4O_{10}(OH)_2$



Micas

[2]**Muscovite**
$KAl_2(AlSi_3O_{10})(OH)_2$

[1]**Biotite**	$KFe_3(AlSi_3O_{10})(OH)_2$
Phlogopite	$KMg_3(AlSi_3O_{10})(OH)_2$

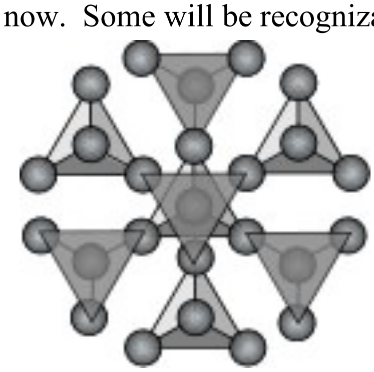
[1]**Chlorite** $(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2$-$(Mg,Fe)_3(OH)_6$

Tectosilicates (Corner Sharing; Framework SiO_4)

Frameworks: Each tetrahedron shares all its oxygens with other SiO_4 tetrahedra (in quartz) or AlO_4 tetrahedra	Feldspar (orthoclase)	Potassium-aluminum silicate
	Quartz	Silicon dioxide

[1]**Quartz (SiO_2)**

Be aware of the SiO_2 *polymorphs*. Without context, they cannot be distinguished in hand specimen. We'll call all of them quartz for now. Some will be recognizable once we start doing optical mineralogy.



Other hydrated varieties **($SiO_2 \cdot nH_2O$)**

Chalcedony (kal-SID-ney)
Jasper
Chert/flint

Opal (Hydrated SiO_2 or $SiO_2 \cdot nH_2O$)

[1]***K-Feldspar***

K-feldspar ($KAlSi_3O_8$)

Be able to distinguish **microcline** when it is green and **orthoclase** when it is pink/salmon. Otherwise simply call it "potassium feldspar" or "Kspar." **Sanidine** (sometimes blue) is readily recognized with the microscope.

[1]***Plagioclase***

Plagioclase is a mineral of variable composition. In this case it is a *solid-solution* between two *end-member compositions*. The end members are:

Albite ($NaAlSi_3O_8$)
Anorthite ($CaAl_2Si_2O_8$).

Plagioclase can have any composition intermediate between these two extreme values. Note that it is usually milky white, but more calcic varieties can be gray, or even black (as in the rocks *basalt* and *gabbro*). Make sure you see the striations characteristic of plagioclase!

Feldspathoids (Silica-deficient feldspar analogs)

Leucite (silica deficient Kspar equivalent) $KAlSi_2O_6$
Nepheline (silica deficient K-Na (Kspar-Albite) mix) $(Na,K)AlSiO_4$
Sodalite (silica deficient albite: Na) $Na_8(AlSiO_4)_6Cl_2$

Zeolites

Be familiar with the names (example: **natrolite**, **stilbite**, and **laumontite**) and variety, but you will only be responsible for recognizing the family as a whole.

Non-silicates!

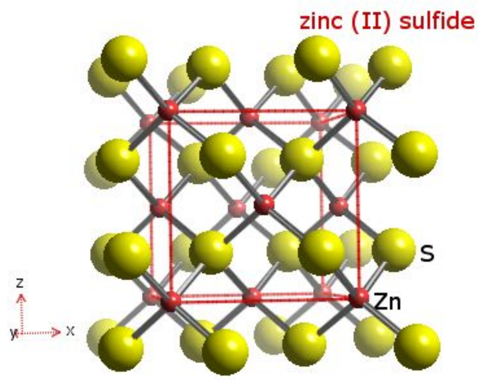
Non-silicates have different anionic complexes (much more simple) and have very different physical and optical properties. Review the mineral forumale below, and test the hand samples for simple diagnostic properties.

Class: Sulphides (Sulphur anion)

These are opaques.

Galena	PbS
Sphalerite (*isotropic*)	ZnS
Chalcopyrite	$CuFeS_2$
Bornite	Cu_5FeS_4
Cinnabar	HgS
Realgar	AsS
Orpiment	As_2S_3
Pyrite	FeS_2
Molybdenite	MoS_2

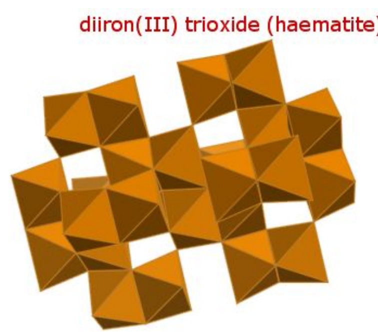
Sphalerite



Class: Oxides (Oxygen anion)

These are opaques.

Corundum	Al_2O_3
Hematite	Fe_2O_3
Magnetite	Fe_3O_4
Rutile	TiO_2
Spinel	$MgAl_2O_4$
Chromite	$FeCr_2O_4$



Part 2: Metamorphic Rocks Based on Texture; Foliated Rocks

(*From John Winter's Principles of Igneous and Metamorphic Petrology*)

As with any rocks, metamorphic rocks are classified on the basis of *texture* and *composition* (either mineralogical or chemical). Although we all-too-often consider deriving a proper name for a rock as an exercise in finding the right pigeon-hole, we are much better served by considering a good name as a concise way of imparting information about a rock. Unlike igneous rocks, which have been plagued by a proliferation of local and specific names, metamorphic rock names are surprisingly simple and flexible. We may choose some prefix-type modifiers to attach to names if we care to stress some textural or mineralogical aspects that we deem important or unusual.

Foliated and Lineated Rocks.

Foliation and **lineation** refer to planar and linear fabric elements, respectively, in a rock, and have no genetic connotations. In the present context, however, the rock must first be judged not to be a high-strain rock, some of which may be foliated, because they are treated separately. In the next chapter we shall discuss the textures in more detail, including mechanisms by which they may be generated. For now we shall discuss the textures only to the extent that we can identify them and use them to aid in classification. Rocks with multiple foliations and/or lineations are also possible.

In general, foliation in non-high-strain rocks are due to orogeny and regional metamorphism, and the type of foliation varies with metamorphic grade. In order of increasing grade they are:

> **Cleavage**- Traditionally: the property of a rock to split along a regular set of sub-parallel, closely-spaced planes. A more general concept adopted by some geologists is to consider cleavage to be any type of foliation in which the aligned platy phyllosilicates are too fine to see with the unaided eye.
>
> **Schistosity**- A preferred orientation of inequaint mineral grains or grain aggregates produced by metamorphic processes. Aligned minerals are coarse enough to see with the unaided eye. The orientation is generally planar, but linear orientations are not excluded.
>
> **Gneissose structure**- Either a poorly developed schistosity or segregated into layers by metamorphic processes.

The rock names that follow from these textures are given below. Again, these names are listed in a sequence that generally corresponds with increasing grade.

1. **Slate**. A compact, very fine-grained, metamorphic rock with a well developed cleavage. Freshly cleaved surfaces are dull.
2. **Phyllite**. A rock with a schistosity in which very fine phyllosilicates (sericite/phengite and/or chlorite), although rarely coarse enough to see unaided, impart a silky sheen to the foliation surface. Phyllites with both a foliation and lineation are very common.
3. **Schist**. A metamorphic rock exhibiting a schistosity. By this definition schist is a broad term, and slates and phyllites are also types of schists. The more specific terms, however, are preferable. In common usage, schists are restricted to those metamorphic rocks in which the foliated minerals are coarse enough to see easily in hand specimen.
4. **Gneiss**. A metamorphic rock displaying gneissose structure. Gneisses are commonly layered (also called banded), commonly with alternating felsic and darker mineral layers. Gneisses may also be lineated, but must also show segregations of felsic mineral- rich and dark-mineral-rich concentrations.

Lab 8: Contact and other Non-Foliated Metamorphic Rocks

Learning Goals:

1. **Identify**, **describe**, **characterise** and **name non-foliated metamorphic rocks**
   Section 1: Non-Foliated Metamorphic Rocks
2. **Describe** and **recognise** minerals and textures of the samples in thin section.
   Section 2: Metamorphic Rocks: Sample **6 or 18** and **7143**
3. Use the mineralogy and texture to **name** the rocks and **deduce** the **temperature and pressure conditions** under which the rock formed.
   Section 2: Metamorphic Rocks: Sample **6 or 18** and **7143**
4. **Identify**, **describe** and **recognise** new metamorphic minerals
   Section 3: New Minerals

Section 1: Describing and naming non-foliated metamorphic rocks

Instructions: Get into a group, and work through mineral identification, textures and descriptions using rocks listed below. ***Use the reading at the end of this lab to help you!***

Rock Names: Marble, Serpentinite, Hornfels, Quartzite, Amphibolite, Greenschist, Talc Schist and Spotted Hornfels

Rock	Characteristics	Notes
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		

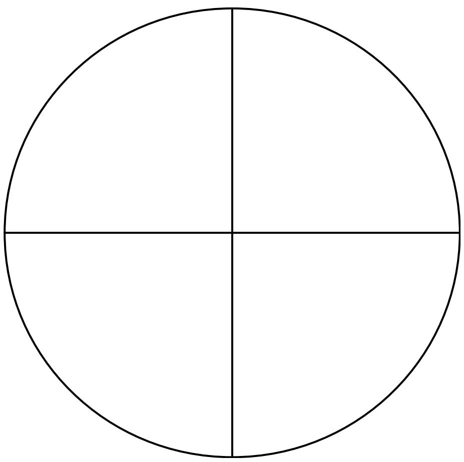
Section 2: Description, Classification of Metamorphic Rocks and determining the PT conditions of formation (samples 6 or 18, and 7143)

Refer to the reading for this lab to help with naming the rocks provided. Complete the sections below.

Sample:

1. Petrographic sketch of thin section. Label observed minerals/textures.

PPL **XPL**



2. Modal Mineralogy

Mineral Name	%	Diagnostic Properties

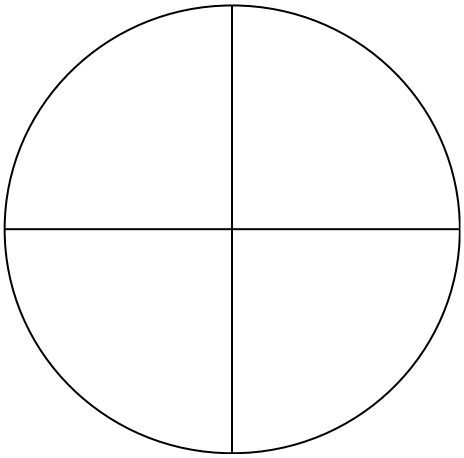
3. Briefly describe and explain the rock and mineral textures you can see in the hand samples and thin sections. Give a grain size for each mineral and make it clear which minerals define the textures you have observed. Add any new textures to the textures section of your Mineral ID and Textures booklet. Apply the same principles as last week.

4: Based on the mineralogy and textures you have observed give a name for this rock.

Sample:

5. Petrographic sketch of thin section. Label observed minerals/textures.

PPL **XPL**



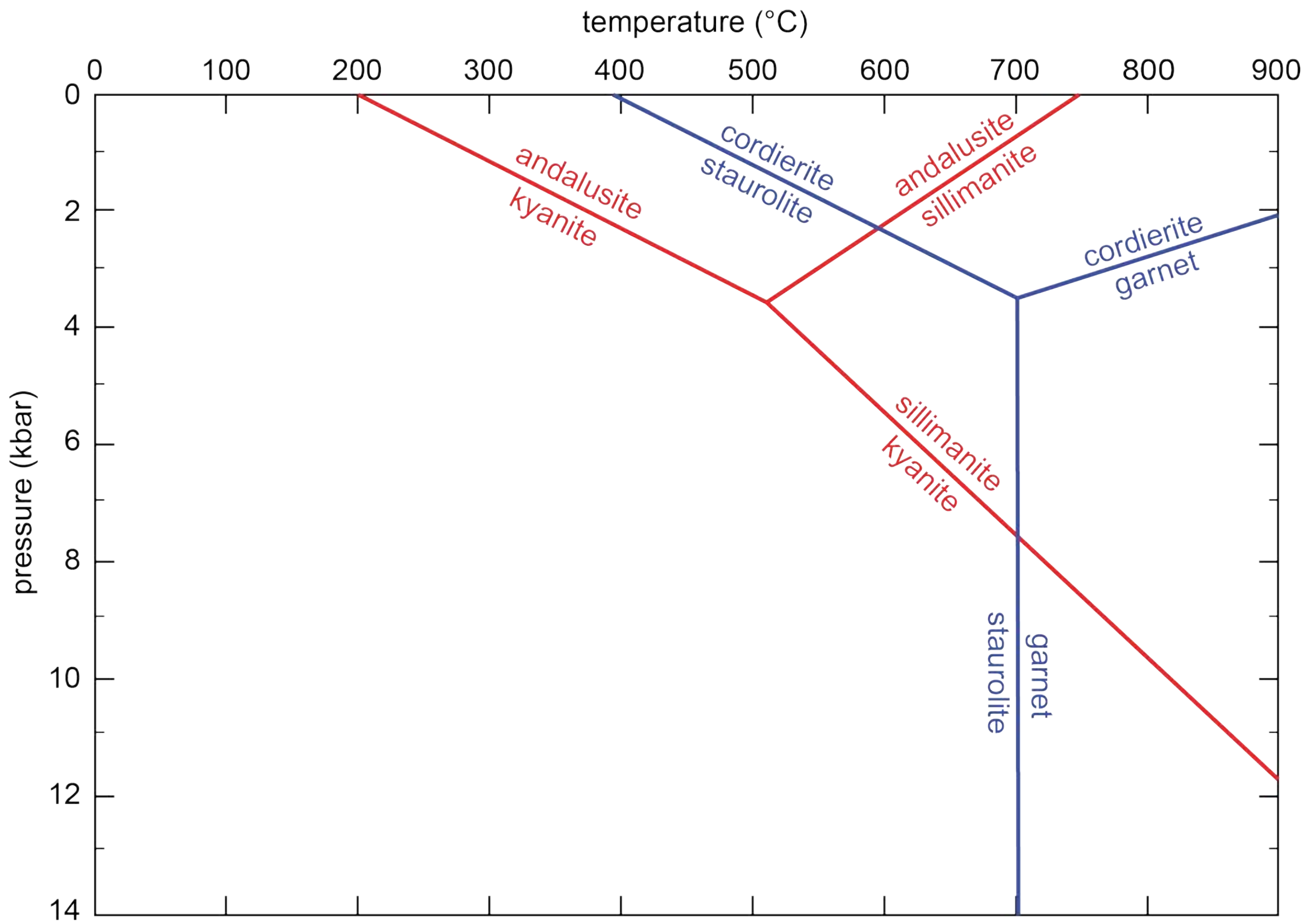
6. Modal Mineralogy

Mineral Name	%	Diagnostic Properties

7. Briefly describe and explain the rock and mineral textures you can see in the hand samples and thin sections. Give a grain size for each mineral and make it clear which minerals define the textures you have observed. Add any new textures to the textures section of your Mineral ID and Textures booklet. Apply the same principles as last week.

8. Based on the mineralogy and textures you have observed give a name for this rock.

9. What can you infer about the P-T regime based on the occurrence of the specific minerals found in each rock? Label on the P-T diagram the conditions you expect the two rocks to have formed in. What type of metamorphism do you think the rocks were affected by?



Section 3: New Minerals: Kyanite/Andalusite/Sillimanite, Cordierite, Staurolite, Sericite, Serpentine Group, Tremolite-Actinolite and Talc

Use the samples you have looked at today to correctly identify **Andalusite**, **Sillimanite**, **Cordierite, Staurolite** and **Sericite**. Optical properties of **Kyanite, Tremolite-Actinolite** and **Talc** will need to be researched online, as we do not have samples of this mineral will need to be researched online, as we do not have samples of this mineral in thin section.

1. Enter **all new minerals** into your Mineral ID booklet.
2. Update new metamorphic **textures** identified in these samples.

Lab 8 Reading: Non-Foliated Metamorphic Rocks

(*From John Winter's Principles of Igneous and Metamorphic Petrology*)

Non-Foliated and Non-Lineated Rocks.

A comprehensive term for any isotropic rock (a rock with no preferred orientation) is a **granofels**. **Granofels**(ic) **texture** is then a texture characterized by a lack of preferred orientation. An outdated alternative is *granulite*, but this term is now used to denote very high grade rocks (whether foliated or not), and is not endorsed here as a synonym for granofels. A **hornfels** is a type of granofels that is usually very fine-grained and compact, and occurs in contact aureoles. Hornfelses are tough, and tend to splinter when broken.

Specific Metamorphic Rock Types.

As mentioned above, some rock types are sufficiently common that they have been given special names, based most often on a specific protolith, but many also imply a specific range of metamorphic grade. It is also proper to name a metamorphic rock by adding the prefix **meta-** to a term that indicates the protolith, such as meta-pelite, meta-ironstone, etc. The commonly used names that specify a particular rock type are listed below. As a rule, these names take precedence over the textural names described above.

Marble. A metamorphic rock composed predominantly of calcite or dolomite. The protolith is typically limestone or dolostone.

Quartzite. A metamorphic rock composed predominantly of quartz. The protolith is typically sandstone. Some confusion may result from the use of this term in sedimentary petrology for a pure quartz sandstone.

Greenschist/Greenstone. A low-grade metamorphic rock that typically contains chlorite, actinolite, epidote, and albite. Note that the first three minerals are green, which imparts the color to the rock. Such a rock is called greenschist if foliated, and greenstone if not. The protolith is either a mafic igneous rock or graywacke.

Amphibolite. A metamorphic rock dominated by hornblende + plagioclase. Amphibolites may be foliated or non-foliated. The protolith is either a mafic igneous rock or graywacke.

Serpentinite. An ultramafic rock metamorphosed at low grade, so that it contains mostly serpentine.

Blueschist. A blue amphibole-bearing metamorphosed mafic igneous rock or mafic graywacke. This term is so commonly applied to such rocks that it is often used even to non-schistose rocks.

Eclogite. A green and red metamorphic rock that contains clinopyroxene and garnet (omphacite + pyrope). The protolith is typically basaltic.

Skarn. A contact metamorphosed and silica metasomatized carbonate rock containing calc-silicate minerals

Granulite. A high grade rock of pelitic, mafic, or quartzo-feldspathic parentage that is composed of dominantly OH-free minerals. Muscovite is absent and plagioclase and orthopyroxene are common.

Migmatite. A composite silicate rock that is heterogeneous on the 1-10 cm scale, commonly having a dark gneissic matrix (melanosome) and lighter felsic portions (leucosome) that may be segregations or form a network of vein-like appearance.

For a more comprehensive description of these rock types and their textures, see Chapter 2 of Shelley (1993).

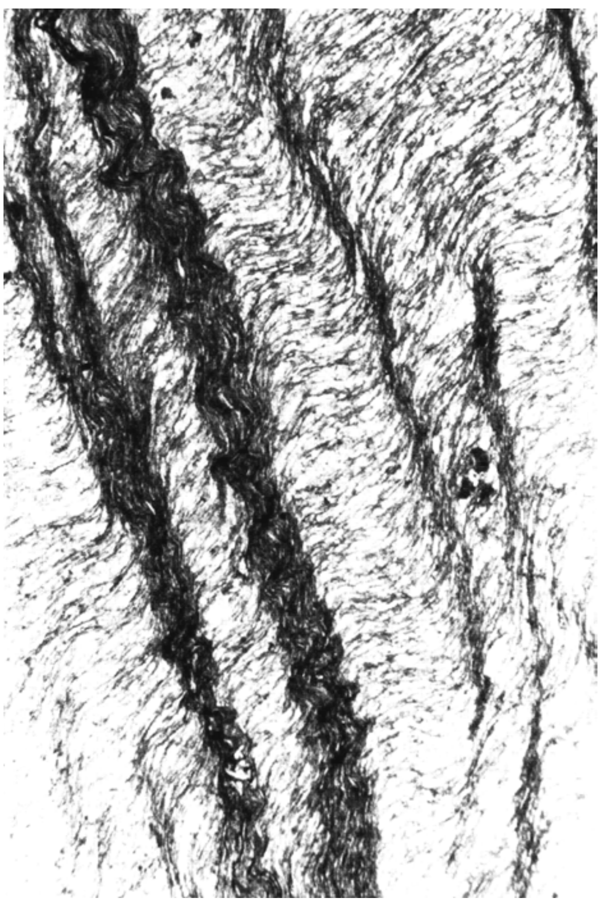
Additional Modifying Terms.

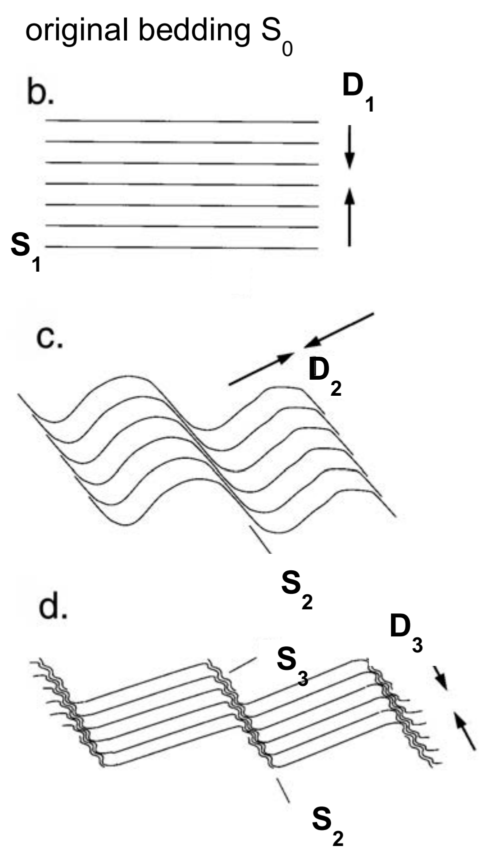
Porphyroblastic means that a metamorphic rock has one or more metamorphic minerals that grew much larger than the others. Each individual crystal is a **porphyroblast**. If you want to call attention to this texture in a sample, you may use a name such as *kyanite porphyroblast schist*. Some porphyroblasts, particularly in low-grade contact metamorphism, occur as ovoid "**spots**" (Fig. 23-4). If such spots occur in a hornfels or a phyllite (typically as a contact metamorphic overprint over a regionally developed phyllite), the terms **spotted hornfels**, or **spotted phyllite** would be appropriate. Some gneisses have large eye-shaped grains (commonly feldspar) that are derived from pre-existing large crystals by shear (as described in Section 23.1). Individual grains of this sort are called **auge** (German for *eye*), and the (German) plural is **augen**. An **augen gneiss** is a gneiss with augen structure. Two common prefixes that pertain to protolith are the terms ortho- and para-. **Ortho-** indicates an igneous parent, and **para-** indicates a sedimentary parent. The terms are used only when they serve to dissipate doubt. For example, many quartzo-feldspathic gneisses could easily be derived from either an impure arkose or a granitoid rock. If some mineralogical, chemical, or field derived clue permits the distinction, terms such as *orthogneiss, paragneiss,* or *orthoamphibolite* may be useful.

Lab 9: Metamorphic Textures

Learning Goals:

1. **Identify, describe** and **illustrate textures** in **foliated metamorphic rocks.**
   Section 1: Textures in Foliated Metamorphic Rocks (Sample GN1)
2. **Identify, describe** and **illustrate textures** in **non-foliated metamorphic rocks.**
   Section 2: Texture in Non-Foliated Metamorphic Rocks (Sample 7996)
3. **Fully identify, describe** and **illustrate mineralogy and textures of a metamorphic rock** (begin to understand what will be expected from you in the metamorphic part of the lab exam).
   Section 3: Full Description and Interpretation of a Metamorphic Rock (Sample GB20)
4. **Interpret** the mineralogy and textures of metamorphic rocks to provide an account, supported by evidence in the rock and thin section, of its **metamorphic history**.
   Section 1: Textures in Foliated Metamorphic Rocks (Sample GN1)
   Section 2: Texture in Non-Foliated Metamorphic Rocks (Sample 7996)
   Section 3: Full Description and Interpretation of a Metamorphic Rock (Sample GB20)





Section 1: Textures in Foliated Metamorphic Rocks (sample GN1)

1 Re-evaluate the rock and mineral textures in sample GN1. Describe in more detail, sketch and explain the textures you observe. Add any new textures you see to your Mineral ID and Textures booklet. (Textures that you have seen in igneous rocks may also be in metamorphic rocks and need to be described.)

1. Give a grain size for each mineral.
2. Show and label in your sketches which minerals define the textures you have observed.
3. Look for evidence of recrystallisation of the quartz grains and try and identify as many of the recrystallisation textures as possible (refer to the Lecture on recrystallisation and Mineral ID and Textures booklet page 37).

2. Explain how deformation played a role with regards to the formation and modification of foliation in GN1. Use sketches and arrows to show the plane(s) of foliation (S_0, S_1, S_2 etc.) and the planes(s) of deformation (D_1, D_2, etc) that formed them and how they relate to one another.

3. Using the mineralogy (Lab 7) and textures you have observed write an essay (up to ~10 sentences) about the metamorphic history of GN1.

Include in the essay:

- The type(s) of metamorphism the rock has undergone.
- The different phases of deformation that the rock has experienced.
- The metamorphic facies you think the rock has experienced.
- The possible tectonic setting(s) in which it formed.
- The composition of the protolith.

…and the evidence from the rock and thin section to support your inferences.

Section 2: Textures in Non-Foliated Metamorphic Rocks (sample 6 or 18)

1 Re-evaluate the rock and mineral textures in sample 6 or 18. Describe in more detail, sketch and explain the textures you observe. Add any new textures you see to your Mineral ID and Textures booklet. . (Textures that you have seen in igneous rocks may also be in metamorphic rocks and need to be described.)

1. Give a grain size for each mineral.
2. Show and label in your sketches which minerals define the textures you have observed.
3. Look for evidence of recrystallisation of the quartz grains and try and identify as many of the recrystallisation textures as possible (refer to the Lecture on recrystallisation and Mineral ID and Textures booklet page 37).

2. Using the mineralogy (Lab 8) and textures you have observed write an essay (up to ~10 sentences) about the metamorphic history of sample 6 or 18.

Include in the essay:

- The type(s) of metamorphism the rock has undergone.
- The metamorphic facies you think the rock has experienced (PT sketch).
- The possible tectonic setting(s) in which it formed.
- The composition of the protolith.

…and the evidence from the rock and thin section to support your inferences.

Section 3: Full Description and Interpretation of a Metamorphic Rock (sample GB20)

1. **Hand sample description** (Modal Mineralogy & Textures)

2. **Modal Mineralogy**

Mineral Name	%	Diagnostic Properties of this mineral, in this sample

3. Describe, sketch, name and explain the rock and mineral textures you observe. (Textures that you have seen in igneous rocks may also be in metamorphic rocks and need to be described.)

- Give a grain size for each mineral.
- Show and label in your sketches which minerals define the textures you have observed.
- If applicable show the foliation planes (S_0, S_1, S_2 etc.) and the principal axes of deformation (D_1, D_2, etc) and how they relate to one another on your sketches.
- Look for evidence of recrystallisation of the quartz grains and try and identify as many of the recrystallisation textures as possible (see Lecture on recrystallisation and Mineral ID and Textures booklet page 37).

4. Name of GB20 based on texture and mineralogy.

5. Using the mineralogy and textures you have observed write an essay (up to ~10 sentences) about the metamorphic history of the rock.

Include in the essay:

- The type(s) of metamorphism the rock has undergone.
- Describe and show in your sketches above the different phase(s) of deformation that the rock has experienced.
- The metamorphic facies, if applicable, you think the rock has experienced (PT sketch).
- The possible tectonic setting(s) in which it formed.
- The composition of the protolith.
  …and the evidence from the rock and thin section to support your inferences.

Remember: The importance of Protolith!!!

Table 9.2 Major Minerals of Metamorphic Facies Produced from Parent Rocks of Different Composition

Facies	Minerals Produced from Shale Parent	Minerals Produced from Basalt Parent
Greenschist	Muscovite, chlorite, quartz, sodium-rich plagioclase feldspar	Albite, epidote, chlorite
Amphibolite	Muscovite, biotite, garnet, quartz, plagioclase feldspar	Amphibole, plagioclase feldspar
Granulite	Garnet, sillimanite, plagioclase feldspar, quartz	Calcium-rich pyroxene, calcium-rich plagioclase feldspar
Eclogite	Garnet, sodium-rich pyroxene, quartz	Sodium-rich pyroxene, garnet

Lab 10: Dynamic and Contact Metamorphic Rocks

Learning Goals:

1. **Recognise textures** in hand sample and thin section that **indicate rocks that have undergone dynamic metamorphism**.
   Section 1: Dynamic Metamorphic Rock (sample PCC)
2. **Identify**, **describe**, **characterise** and **name rocks that have undergone dynamic metamorphism.**
   Section 1: Dynamic Metamorphic Rock (sample PCC)
3. **Recognise textures** in hand sample and thin section that **indicate rocks that have undergone contact metamorphism**.
   Section 2: Contact Metamorphic Rock (sample 7996)
4. **Identify**, **describe**, **characterise** and **name rocks that have undergone dynamic metamorphism.**
   Section 2: Contact Metamorphic Rock (sample 7996)
5. **Interpret** the mineralogy and textures of metamorphic rocks to provide an account, supported by evidence in the rock and thin section, of its **metamorphic history**.
   Section 1: Dynamic Metamorphic Rock (sample PCC)
   Section 2: Contact Metamorphic Rock (sample 7996)
6. **Time management for exam**, two hand samples and their thin sections to be fully described and interpreted (same as exam).

Section 1: Dynamic Metamorphic Rock (sample PCC)

1. **Hand sample description** (Modal Mineralogy & Textures)

2. **Modal Mineralogy**

Mineral Name	%	Diagnostic Properties of this mineral, in this sample

3. **Describe, sketch, name and explain the rock and mineral textures you observe.**
    - Give a grain size for each mineral.
    - Show and label in your sketches which minerals define the textures you have observed.
    - If applicable, show the foliation planes (S_0, S_1, S_2 etc.) and the principal axes of deformation (D_1, D_2, etc) and how they relate to one another on your sketches.
    - Look for evidence of recrystallisation of the quartz grains and try and identify as many of the recrystallisation textures as possible (see Lecture on recrystallisation and Mineral ID and Textures booklet page 37).

4. Name of PCC based on texture and mineralogy.

5. Using the mineralogy and textures you have observed write an essay (up to ~10 sentences) about the metamorphic history of the rock.

Include in the essay:

- The type(s) of metamorphism the rock has undergone.
- Describe and show in your sketches above the different phase(s) of deformation that the rock has experienced.
- The metamorphic facies, if applicable, you think the rock has experienced.
- The possible tectonic setting(s) in which it formed.
- The composition of the protolith.

  …and the evidence from the rock and thin section to support your inferences.

Section 2: Contact Metamorphic Rock (Sample 7996)

1. **Hand sample description** (Modal Mineralogy & Textures)

2. **Modal Mineralogy**

Mineral Name	%	Diagnostic Properties of this mineral, in this sample

3. Describe, sketch, name and explain the rock and mineral textures you observe.

- Give a grain size for each mineral.
- Show and label in your sketches which minerals define the textures you have observed.
- If applicable, show the foliation planes (S_0, S_1, S_2 etc.) and the principal axes of deformation (D_1, D_2, etc) and how they relate to one another on your sketches.
- Look for evidence of recrystallisation of the quartz grains and try and identify as many of the recrystallisation textures as possible (see Lecture on recrystallisation and Mineral ID and Textures booklet page 37).

4. Name of 7996 based on texture and mineralogy.

5. Using the mineralogy and textures you have observed write an essay (up to ~10 sentences) about the metamorphic history.

Include in the essay:

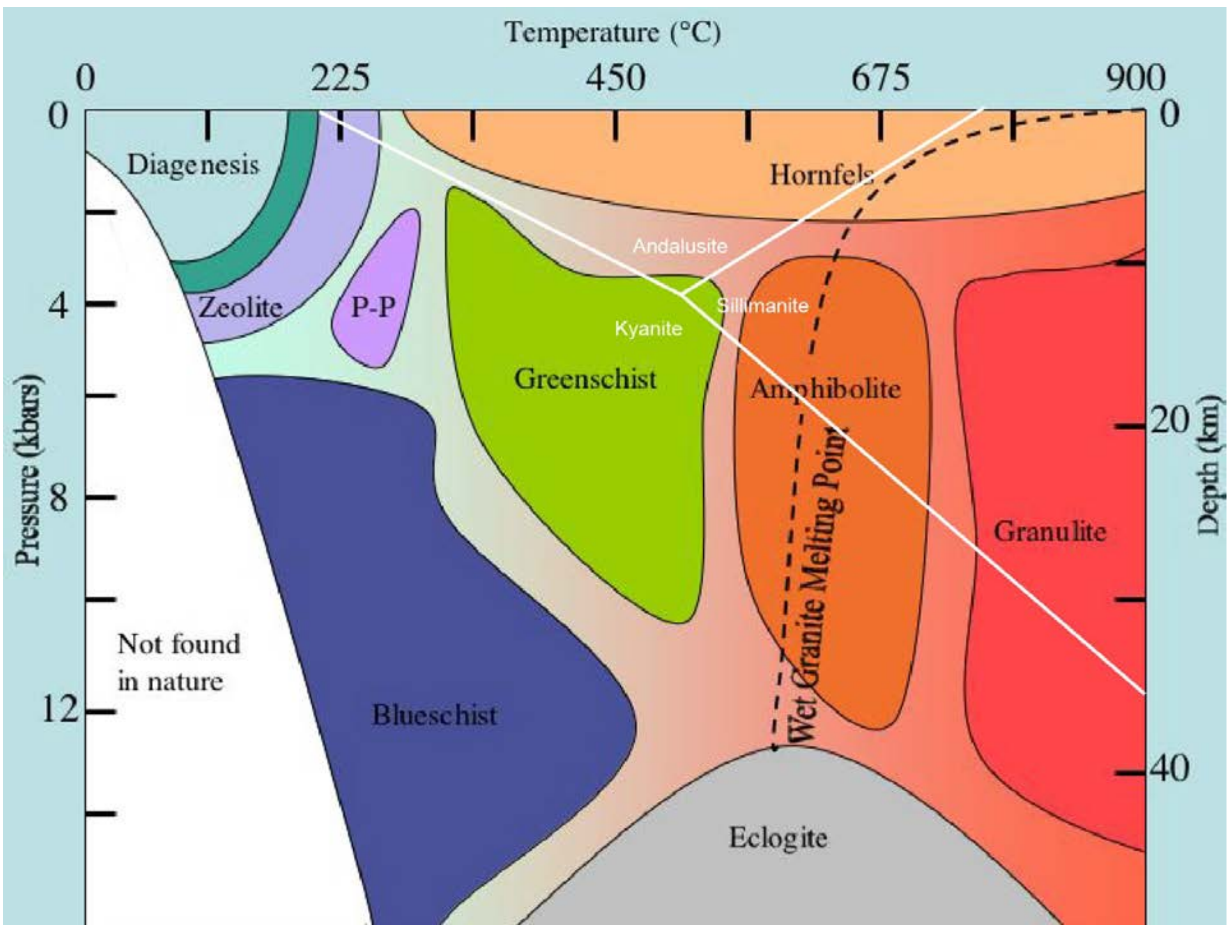
- The type(s) of metamorphism the rock has undergone.
- Describe and show in your sketches above the different phase(s) of deformation that the rock has experienced.
- The metamorphic facies, if applicable, you think the rock has experienced.
- The possible tectonic setting(s) in which it formed.
- The composition of the protolith.

  …and the evidence from the rock and thin section to support your inferences.

Lab 11: High-Grade Metamorphic Rocks and Minerals

Learning Goals:

1. **Name** a rock sample, based on the petrographic (**minerals** and **textures**), hand sample, and compositional data. **Describe, sketch** and **recognise** observed metamorphic textures.
   Sections 1 and 2: Metamorphic Rock descriptions
   Section 4: Review Questions
2. **Interpret** the petrographic data, and **deduce** the metamorphic history of the rock (including the PT conditions/metamorphic facies the rock experienced)
   Sections 1 and 2: Metamorphic Rock descriptions
3. **Identify**, **describe** and **illustrate** new minerals
   Section 3: New minerals
4. **Review** the naming of metamorphic rocks:
   Section 5: Rock naming homework



Section 1: Sample L2NE

1. **Hand sample description** (Modal Mineralogy & Textures)

[5%]

2. **Modal Mineralogy**

[20%]

Mineral Name	%	Diagnostic Properties

3. Describe, sketch, name and explain the rock and mineral textures you observe. (Follow the same principles as in previous labs.)

[35%]

4. Name of rock based on texture and mineralogy:

[5%]

5. Based on the mineralogy and textures you have observed write an essay (up to ~10 sentences) about the metamorphic history of the rock.

[35%]

Section 2: Sample L3FG

1. **Hand sample description** (Modal Mineralogy & Textures)

[5%]

2. **Modal Mineralogy**

[20%]

Mineral Name	%	Diagnostic Properties

3. Describe, sketch, name and explain the rock and mineral textures you observe. (Follow the same principles as in previous labs.)

[35%]

4. Name of rock based on texture and mineralogy.

[5%]

5. Based on the mineralogy and textures you have observed write an essay (up to ~10 sentences) about the metamorphic history of the rock.

[35%]

Section 3: New Minerals: Glaucophane, Lawsonite, Tourmaline and Epidote

Use the samples provided to correctly identify **Glaucophane, Lawsonite, Tourmaline** and **Epidote**.

1. Enter **all new minerals** into your Mineral ID booklet.
2. Update any new metamorphic **textures** identified in the samples looked at today.

Section 4: Review Questions

What would you name the following rocks?

1. An incipiently metamorphosed siltstone in which the original texture and mineralogy is largely intact:
2. A rock with good cleavage and looks like a shale but rings when you hit it with a hammer:
3. A rock composed of chlorite and actinolite with a pronounced alignment of the minerals:
4. A rock dominated by sub-equal amounts of hornblende and plagioclase with a random fabric:
5. A rock with the same mineralogy as the previous rock, but with an obvious foliation:
6. A rock containing quartz, orthoclase, plagioclase, and biotite, with a discontinuous metamorphic banding of dark and light layers (include an indicator of composition in your name):
7. The same rock as the previous one but with large eye-shaped grains of orthoclase in a finer matrix:
8. A rock composed of coarse calcite grains with a slight foliation:
9. A rock composed of 20% biotite, 35% quartz, 15% muscovite, 5% plagioclase, and 10% garnet, with good foliation:
10. A slate-like rock with a satiny sheen on the cleavage and 5-mm-sized ovoid blobs of cordierite:
11. A fine-grained rock with random fabric and splintery fracture:
12. A green clinopyroxene granofels with red garnets:

Section 5: Rock Naming *Homework*

Instructions: Fill out the following table, and practice naming rocks. Use mineralogy AND textures!

FOLIATED ROCKS – Rock fabric Identifiable in hand sample.

Rock Name	Minerals Present (Diagnostic)	Textures
Slate		h.s. t.s.
Phyllite		h.s. t.s.
Schist Greenschist Amphibolite schist Blueschist Talc schist	e.g. Staurolite-garnet Schist	h.s. t.s.
Gneiss Augen Gneiss Amphibolite gneiss Granulite Migmatite Mylonite		h.s. t.s.

NON-FOLIATED ROCKS – No discernible Rock fabric Identifiable in hand sample.

Rock Name	Minerals Present (Diagnostic)	Textures
Hornfels		h.s. t.s.
Spotted Hornfels		h.s. t.s.
Marble		h.s. t.s.
Quartzite		h.s. t.s.
Greenstone		h.s. t.s.
Amphibolite		h.s. t.s.
Eclogite		h.s. t.s.
Blueschist		h.s. t.s.
Granulite		h.s. t.s.
Serpentinite		h.s. t.s.

Lab 12: Lab Exam

For the metamorphic part of the exam you will be asked to describe one hand sample and thin section in exactly the way you have described the samples in Labs 10 and 11.

Things students can bring:
One-side cheat sheet, hand-written, hand-drawn
Interference colour chart
David Shelley book
Mineral Comparison Charts
Mineral ID Booklet that you have completed, with Texture templates included
Calculator

Things students cannot bring/use:
Mobile phones
Lecture material
Classification material or rock-naming material
Internet materials

Remember the total exam time is 2 hrs 15 mins and you will need to describe two rocks, one igneous and one metamorphic.

Good luck!