D.N.R.COLLEGE (AUTONOMOUS), BHIMAVARAM
II B.Sc., GEOLOGY
IGNEOUS PETROLOGY

CLASSIFICATION OF IGNEOUS ROCK: The igneous rocks show great variations both in chemical and mineralogical compositions as well as in textural characteristics. We have learnt about textures, structures and forms of igneous rocks in Unit 2 of this course. Let us discuss about classification and nomenclature of igneous rocks. Time to time attempts has been made by petrologists to classify igneous rocks. The classification of igneous rocks has been the subject of debate amongst the petrologists. Over the past decade, most geologists have accepted the IUGS (International Union of the Geological Sciences) classification as the standard. Since this classification is being widely adopted which we will discuss later in this unit.

Igneous rocks have been classified on the basis of their texture, mode of occurrence, mineralogy, and chemical composition. We have already learnt about the classification of igneous rocks based on texture and mode of occurrence in Unit 2. Remember that the classification of igneous rocks is based on their mode of occurrence, i.e., plutonic, hypabyssal and volcanic rocks and texture as phaneritic, aphanitic and fragmental. Let us discuss about the classification of igneous rocks based on their mineralogy and chemical composition in this unit.

Expected Learning Outcomes : After reading this unit you should be able to:
❖ explain the classification of igneous rocks in the field;
❖ classify igneous rocks based on their mineralogical composition; and
❖ discuss the classification of igneous rocks based on their chemical composition.

Now let's look at a much simpler classification. We call this as field classification because it requires little detailed knowledge of rocks and can be easily applied to any igneous rock, we might pick up during the field trip. Field classification utilises the characters like texture, mineralogy and colour. Though identification of igneous rocks on the basis of colour is unreliable however in the classification of certain fine grained (aphanitic) igneous rocks which contain no visible mineral grains, colour is the only other available property. Learners are thus cautioned to use colour only as a last resort. In order to use this classification during the fieldwork, you must first determine the rock's texture. According to field classification there are five basic textures; phaneritic (coarse), aphanitic (fine), vesicular, glassy and fragmental. Now examine the rock sample collected by you and determine its textural group in the following manner. Refer to Table. 3.1. If it is glassy, vesicular or fragmental you cannot determine mineralogy and hence the name is simply obsidian for a glass, tuff for a fragmental or pumice/scoria for a vesicular rock. In case of phaneritic and few aphanitic rocks you can determine the mineralogy. Identify one or two key minerals, not all of the minerals in the rock. For instance, granites and rhyolites will have quartz and potassium feldspar (K-feldspar). Amphibole is only abundant in diorite or andesite. If the rock is coarse-grained (phaneritic) then it must be one of the rocks in the row labelled as coarse grained, i.e. granite, diorite, gabbro or peridotite.

CLASSIFICATION BASED ON MINERALOGICAL COMPOSITION You have read that minerals are the building blocks of rocks in the BGYCT-133 course. The classification of the rocks based on minerals forms the fundamental basis of mineralogical classification. Let us discuss following classification schemes based on mineralogy of igneous rocks. They can be
• Based on composition and proportion of minerals

• Based on colour index
• CIPW classification • Tabular classification
• IUGS classification 3.3.1 Composition and Proportion of Minerals The minerals occurring in igneous rocks can be classified as primary and secondary minerals.

a) Primary minerals: They are formed at the time of formation of the rocks or in other words formed during the cooling and crystallisation of magma. Primary minerals may be further subdivided into: 1. Essential minerals are those minerals whose presence are necessary and considered to be essential for naming or nomenclature of the particular rock. For example, quartz, orthoclase and plagioclase should be present for naming a rock as granite; minerals augite and labradorite are necessary for a rock to be named as basalt. Quartz and orthoclase minerals in granite; augite and labradorite in basalt are considered as essential minerals. 2. Accessory minerals are also formed at the time of primary crystallisation of magma but their presence is not necessary and not used in naming the particular rock, e.g. magnetite, apatite, zircon. They are present in small quantity. Some minerals are present in very small quantity but they can
be used in naming the rock such as hornblende or biotite granite. Hornblende or biotite can be prefixed with granite and named as biotite granite or hornblende granite, depending on the mineral present. b) Secondary minerals: They are formed by alteration of primary minerals which may be primary or secondary such as clay minerals, biotite, chlorite, xeolite. Primary alteration refers to the alteration of primary minerals by water vapours at the time or subsequent to the cooling and crystallisation of magma, whereas, secondary alteration is due to secondary processes such as weathering and alteration. In this process, primary minerals alter into secondary minerals. For example, pyroxenes changes into chlorite, plagioclase changes into clay minerals on weathering. This is one of the oldest criteria used for classification of igneous rocks, but it is still in use. Igneous rocks can also be classified on the basis of minerals present. Since colour of the rock depends upon the minerals present in it, in addition to the grain size to some extent. Depending on the commonly occurring minerals the igneous rocks, it has been broadly classified into:

• felsic rock, e.g. granite, rhyolite.
• mafic rock, e.g. basalt, gabbro.

The word felsic (feldspar and silica) is used for minerals that are lighter in colour. Silica and feldspar have low melting point, low specific gravity and are lately crystallised. Mafic or ferromagnesium rocks comprise minerals dark in colour, e.g. olivine, pyroxene, amphibole and biotite. Mafic minerals have high specific gravity, higher melting point and are early crystallised. As discussed above, the colour of the rock is also governed by grain size. Granite is a coarse-grained rock consisting of light-coloured minerals, but, when the rock of the same composition cools rapidly and forms glassy rock, it is known as obsidian which is dark in colour and if bears pitch-like or luster of an asphalt, called as pitchstone. Let us read some examples of felsic-light coloured and mafic-dark coloured minerals: Felsic minerals: Quartz, feldspar, feldspathoid, muscovite, etc. Mafic minerals: Pyroxene, amphibole, olivine, biotite, iron oxide, etc. 3.3.2 Colour Index This classification is based on the percentage volume of ferro-magnesium or dark coloured minerals present in the rock. The groups are:

• Leucocratic: 'Leuco' means light 'cratic' means coloured. When the rock is dominantly composed of light-coloured minerals and poor
• Mesocratic: 'Meso' means medium, when the dark coloured minerals vary between 33-67%. It represents intermediate colour, i.e. neither dark nor light in appearance.
• Melanocratic: 'Melano' means dark, when the dark coloured minerals are more than 67% in the rock.

CIPW Classification This classification scheme is quite old and is based on the normative calculation from the bulk chemistry of the rocks. This is quasi-chemical method of classifying rocks. Thus, it is also known as norm classification. A norm is a means of converting the chemical composition of an igneous rock to an ideal mineral composition. This method of classification was devised by four Americans (Cross, J.P. Iddings, V. Pirsson and H.S. Washington) in 1931. This system of rock classification is abbreviated as 'CIPW' classification and is widely accepted by the petrologists. The basic principle of classification is to understand relationship between major element chemistry and possible mineralogical composition of the investigated rock. Norms are series of arbitrarily selected minerals that are formed from chemical composition of rocks. The series of standard rules governing formulation of major minerals which generally follow the Bowen's reaction series are used for norm calculation. This is a theoretical exercise and the norms calculated may or may not tally with the mode (actual individual minerals percentage by, calculated by determining volume of the minerals and converting them into their weight by multiplying density and recalculating by 100%). The norm is divided in to sialic and a femic group, important minerals of each group is mentioned in Table 3.2. Table 3.2: List of sialic (rich in silica and aluminum) and femic (rich in iron and magnesium) minerals. Sialic Minerals Femic Minerals Minerals Composition Minerals Composition Quartz SiO2 Wollastonite CaO.SiO2 Corundum Al2O3 Enstatite MgO.SiO2 Orthoclase K2O.Al2O3.6SiO2 Ferrisilite FeO.SiO2 Albite Na2O.Al2O3.6SiO2 Diopside CaO(Mg.Fe)SiO2 Anorthite CaO.Al2O3.2SiO2 Hypersthene (MgFe)OSiO2 Leucite K2O.Al2O3.4SiO2 Forsterite 2MgO.SiO2 Nepheline Na2O.Al2O3.2SiO2 Fayalite 2FeO.SiO2 Kalsilite K2O.Al2O3.2SiO2 Acmite Na2O.Fe2O3.4SiO2 Magnetite FeO.Fe2O3 Limonite FeO.TiO2 Apatite 3(CaO.P2O5)CaF2 This classification system is in use from several years and has been revised. Earlier the process of calculation was done manually and time taking and tedious. Now the calculation of norm is carried using computer codes. Let us discuss advantages and limitations. CIPW classification uses several chemical constituents normally present in the rock. Fine grained and glassy rocks can also be classified using this classification. CIPW norms of slightly altered igneous and metamorphic rock

List of sialic (rich in silica and aluminum) and femic (rich in iron and magnesium) minerals.

Sialic Minerals		**Femic Minerals**	
Minerals	**Composition**	**Minerals**	**Composition**
Quartz	SiO_2	Kalsilite	$K_2O.Al_2O_3.2SiO_2$
Corundum	$Al2O_3$	Enstatite	$MgO.SiO_2$
Orthoclase	$K_2O.Al_2O_3.6SiO_2$	Ferrisilite	$FeO.SiO_2$
Albite	$Na_2O.Al_2O_3.6SiO_2$	Diopside	$CaO(Mg.Fe)SiO_2$
Anorthite	$CaO.Al_2O_3.2SiO_2$	Hypersthene	$(MgFe)OSiO_2$
Leucite	$K_2O.Al_2O_3.4SiO_2$	Forsterite	$2MgO.SiO_2$
Nepheline	$Na_2O.Al_2O_3.2SiO_2$	Fayalite	$2FeO.SiO_2$
Kalsilite	$K_2O.Al_2O_3.2SiO_2$	Acmite	$Na_2O.Fe_2O_3.4SiO_2$
		Magnetite	$FeO.Fe_2O_3$
		Limonite	$FeO.TiO_2$
		Apatite	$3(CaO.P_2O_5)CaF_2$

This classification system is in use from several years and has been revised. Earlier the process of calculation was done manually and time taking and tedious. Now the calculation of norm is carried using computer codes. Let us discuss advantages and limitations. CIPW classification uses several chemical constituents normally present in the rock. Fine grained and glassy rocks can also be classified using this

classification. CIPW norms of slightly altered igneous and metamorphic rock can give hint to their original nature. The disadvantage is that the chemical composition is essential for calculating norms. The calculated norms may not match with the actual mineralogy, i.e. mode, as norm is a hypothetical mineralogy.

Tyrrell Tabular Classification This classification takes into consideration both the silica content and relative proportion of feldspars, i.e. alkali feldspar and plagioclase. Let us look at Table which portrays tabular classification.

This classification scheme takes into consideration

(i) the mode of occurrence, (ii) SiO2 percentage and free quartz, (iii) proportion of K-Feldspar, lime (calcic) and sodic (Na) plagioclase. Apart from these, on the basis of silica saturation 3 categories have been made: • oversaturated • saturated and • undersaturated Further, oversaturated is divided into two groups, i.e. Group I and II; saturated in one group, i.e. Group III; undersaturated in three groups, i.e. Group IV, V and VI.

TYRRELL CLASSIFICATION

		Oversaturated			Saturated			Undersaturated		
		I Quartz	II Quartz + Feldspars		III Feldspar			IV Feldspar + Feldspathoids	V Felspathoids	VI Mafic Minerals Predominant
			Predominant ORTHOCLASE	Predominant PLAGIOCLASE	Predominant ALKALI FELDSPARS (Or, Ab)	Predominant LIME PLAGIOCLASE	Predominant LIME SODA PLAGIOCLASE			
PLUTONIC	FELSIC	Igneous Quartz Veins (Arizonite; Silexite)	GRANITE	GRANODIORITE (TONALITE)	SYENITE	DIORITE	ANORTHOSITE	NEPHELINE – SYENITE	X	
PLUTONIC	MAFELSIC		X	X	X	X	GABBRO	THERALITE and TESCHENITE	IJOLITE	
PLUTONIC	MAFIC				X	X	X	X	X	PERIDOTITE PICRITE
HYPABYSSAL			←----------APLITES----------→							
HYPABYSSAL			←----------PORPHYRIES----------→							

SSAL				←----------LAMPROPHYRES----------→						
			GRANOPHYRE FELSITE				DOLERITE	TINGUAITE		
			←----------PITCH STONE----------→				TACHYLYTE			
VOLCANIC			RHYOLITE	DACITE	TRACHYTE	ANDESITE	BASALT	PHONOLITE	LEUCITOPHYRE	OLIVINE-RICH BASALTS
									NEPHELINE - BASALT	
									LEUCITE -BASALT	
			←----------PITCH STONE----------→				TACHYLYTE			LIMBURGITE
			←--------OBSIDIAN--------→							
Average Silica Percentage		90	72	66	59	57	48	54.5	43	41

1. alkali feldspar, 2. soda lime plagioclase, and 3. lime soda plagioclase. The unsaturated igneous rocks are divided into three predominant subgroups

1. feldspars and feldspathoids 2. feldspathoids 3. mafic minerals Tabular classification also takes into consideration, the mode of occurrence. The plutonic division in the first column of the tabular classification has been divided into felsic and mafic.

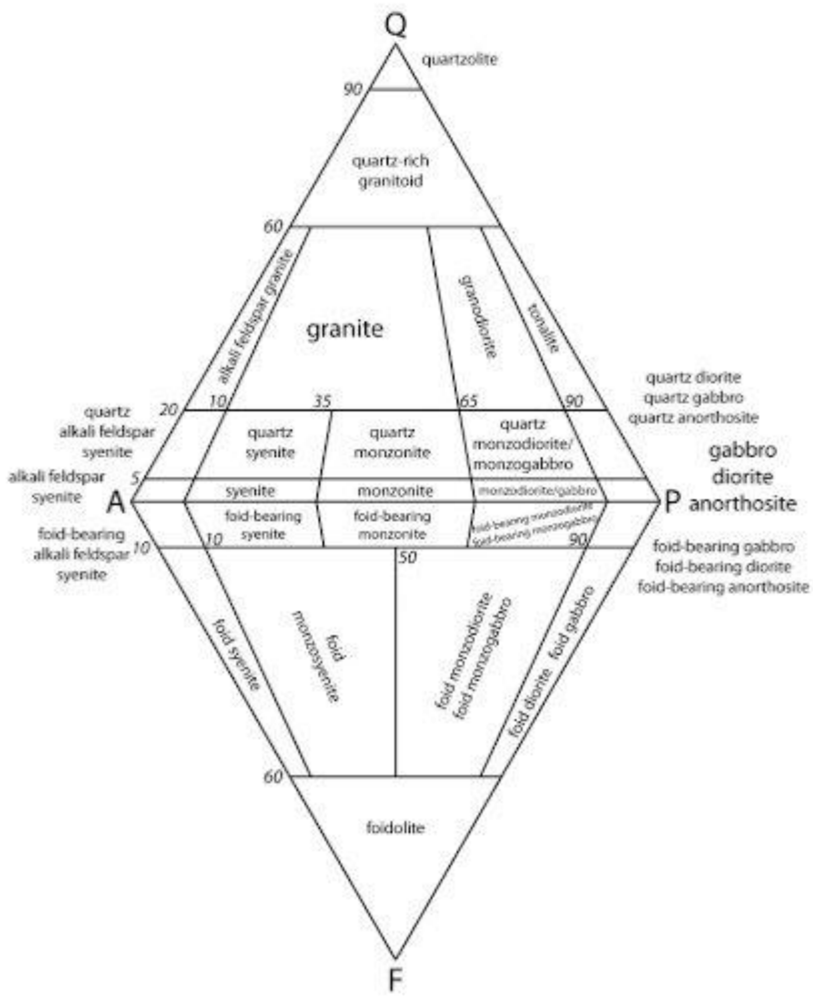
IUGS Classification Let us discuss IUGS classification. This classification has brought uniformity and rationality in the field of classification of igneous rock. IUGS stands for International Union of Geological Sciences. IUGS established a sub-commission for classifying plutonic rocks. This classification was recommended by IUGS in 1973 which was further elaborated by Le Bas and Streckeisen in 1991. The rocks are classified and named on the basis of their actual mineral contents measured in volume percent, i.e., on the basis of their quantitative modal composition. The modal composition is usually determined from a number of thin sections of the same rock by point counting on a grid pattern.

IUGS classification is strictly a quantitative mineralogical classification. To classify a rock correctly on the basis of modal proportions of minerals, the percentages of five minerals must be determined, such as: • Q- Quartz and polymorphs of SiO_2.

- A- Alkali feldspars includes albite
- P- Plagioclase feldspars more calcic
- F- Feldspathoids (foids)
- M- All other phases (mafics) The mineralogy of a rock reflects its chemical composition,
- rocks which contain free quartz are rich in silica could be granite,

• rocks with plagioclase dominant feldspar are high in calcium may be gabbro or diorite, etc.
• rocks dominated by mafic minerals contain considerable magnesium and iron may be peridotite or dunite, etc. The IUGS classification distinguishes the common rocks first on the basis of the grain size i.e. plutonic (coarse-grained) and volcanic (fine-grained). The rocks with mafic minerals less than 90% are classified according to their lightcoloured constituents, i.e., quartz, plagioclase, alkali feldspar (orthoclase, microcline, albite) and feldspathoid minerals.

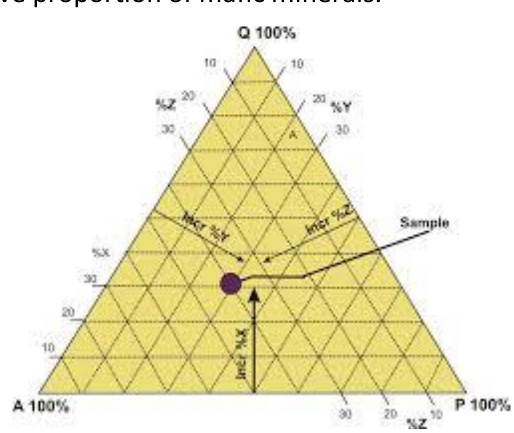
The quantitative mineralogical composition is plotted in QAPF double triangle joined at A-P base for classification purpose the composition is recalculated on the percentage basis and projected on QAPF plane so that Q+A+P=100 or F+A+P=100.



IUGS classification of plutonic (phaneritic) rock.

The rocks with 90-100% are ultramafic rocks and are classified on relative proportion of mafic minerals.

A small number of plutonic igneous rocks are low in silica and contain feldspathoids (foids) rather than quartz. Second classification triangle is used for these rocks i.e., FAP. A rock cannot appear on both triangles because quartz and feldspathoids are chemically incompatible when mixed they will react to form feldspar of intermediate silica content. Let us learn how to calculate? The triangle permits classification of plutonic rocks that contain a little as 10% QAP; the rest of the rock consists of mafic minerals. The technique used is to determine percentages of the Q, A, P, minerals



along with the mafic constituents. Now assume that a rock has 50% mafic minerals, 15% Q, 20% A, and 15% P. We have learnt that the mafic minerals are not included in classification triangle. The Q, A, P, are so recalculated as to equal 100 thus giving Q-30%, A-40%, P-30%.
The drawbacks of IUGS classification is that there is no place for texture of the rock except for making distinction in phaneritic and aphanitic rocks. Rocks like serpentinite, kimberlite do not fit into IUGS classification. Learners, you have learnt about the classification of igneous rocks based on mineralogical composition. Before discussing about the classification based on chemical composition spend few minutes to perform an exercise to check your progress.

CLASSIFICATION BASED ON CHEMICAL COMPOSITION :

We have studied in course BGYCT-133 that the minerals have fixed chemical composition and the rocks are the aggregate of minerals. But here we are concerned with the chemical composition or the chemistry of rocks. Since minerals are made up of chemical elements, therefore using chemical composition is most ideal way of classifying rocks. Chemical classification.
requires partial or complete analyses. A number of chemical classifications of igneous rocks have been devised.

Few are listed below:

- Silica percentage
- Silica paturation
- Total Alkali Silica (TAS)
- Alumina saturation
- Alkali lime index

Silica Percentage :

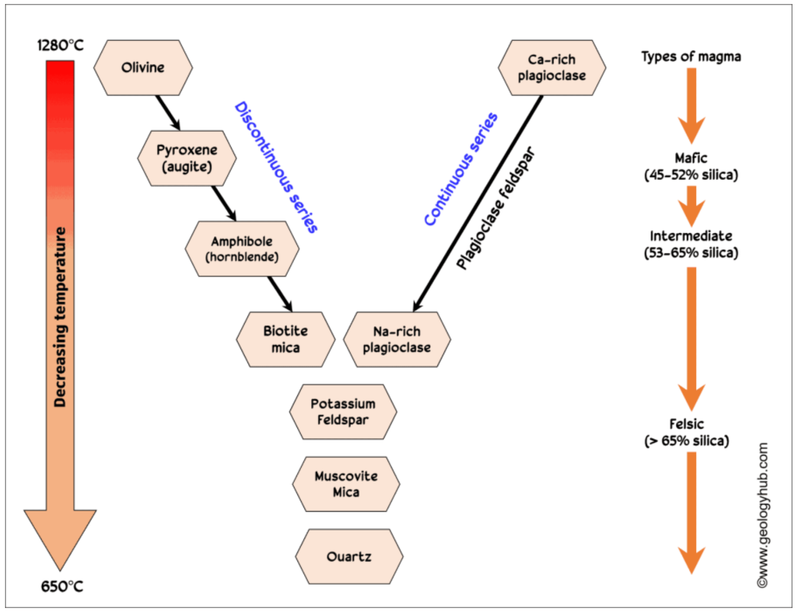
Shand and Holmes (1935) devised a method of classification on the basis of the silica content present in the rock. The igneous rocks vary between wide limits in their chemical composition. Thus, rock such as granite may contain about 70 to 80% of silica and very little quantity of iron, magnesium and lime while at the other end, there are rocks like peridotite dunite, etc. which may contain about 35 to 40% of silica and larger quantities of iron, magnesium and lime. Thus, igneous may be classified as: 1. Acid igneous rocks: These rocks have more than 66% SiO2 content. They are also called felsic or silicic rocks, e.g. granite, rhyolite. 2. Intermediate igneous rocks: These rocks having 52 to 66% of SiO2, e.g. syenite or diorite, trachyte, andesite. 3. Basic igneous rocks: The SiO2 content in these rocks vary between 45 to 52%. They are also called mafic rocks, e.g. gabbro and basalt. 4. Ultrabasic igneous rocks: In these rocks SiO2 contents is less than 45%. They are also called ultramafic rocks. They have high Mg content, e.g. dunite, peridotite, pyroxenite. This is the classification of igneous rocks based on percentage of silica. The grouping of rocks on the basis of their silica contents is a chemical parameter. Let us summarize, the classification scheme based on silica percentage as given in Table

SiO2 (in wt%)	Rock types	Examples
75-66	Acidic/ felsic	granite, rhyolite
52-66	Intermediate	granodiorite, andesite
45-52	Mafic/basic	diorite, gabbro, basalt
<44	Ultrabasic/ultramafic	peridotite, dunite

Silica Saturation :

Shand in 1913 and Holmes in 1917 classified igneous rocks on the basis of free silica into three groups:
1. Silica oversaturated rocks contain more than 66% SiO2, i.e. free quartz mineral is found. Such rocks are also known as acidic or felsic rocks.
2. Silica saturated rocks are typically those which have sufficient silica to form stable silicate mineral but seldom free quartz occur. They contain more than 52 - 66% SiO2.
3. Silica undersaturated rocks contain insufficient silica and silica deficient minerals like olivine, nepheline, leucite and are devoid of quartz mineral. Rocks contain 45 - 52% SiO2.

Bowen's reaction series is a means of ranking common igneous silicate minerals by the temperature at which they crystallize. Minerals at the top have a relatively high crystallization temperature, which means that they will be the first minerals to crystallize from a magma that is cooling. IF they are chemically compatible with the magma as it continues to cool, they will grow larger by addition of external layers of additional material. [They then may become the phenocrysts in a porphyritic igneous texture.] If they are chemically incompatible, they will react with the melt. What ultimately determines this chemical compatibility is in large part the total silica content of the melt. Minerals on the left part of the "Y" of the diagram are what are called ferromagnesian minerals, because they contain iron (Latin: ferrum) and magnesium in their composition. This part of the series is referred to as the discontinuous series, since these minerals, if chemically incompatible with the melt as it cools, will usually completely react to form totally new minerals with different crystal structures: an olivine (island silicate) completely re-reacting with the melt may recrystallize into pyroxene (single-chain silicate), and a pyroxene may completely recrystallize into a hornblende (a double-chain silicate) or ultimately a biotite (a sheet silicate), IF enough free silica (and time!) is available during cooling. Thus, a rock that contains both olivine and hornblende is not in an equilibrium state, because these minerals form and are stable under different conditions; olivine and pyroxene are stable pairs, as are pyroxene and hornblende or hornblende and biotite. Biotite is the lowesttemperature iron-bearing silicate mineral that can form from a melt, and will be found only in rocks relatively rich in silica (e.g., in granites, or sometimes as phenocrysts in rhyolites, their volcanic counterpart). The minerals on the right arm of the "Y" are the plagioclase feldspars, which form a continuous series from 100% Ca-plagioclase (anorthite) with the highest melting point, to 100% Na-plagioclase (albite) with the lowest melting point. The first crystals forming may entirely or only partially re-react with the melt, but without destroying the basic feldspar crystal structure. Very often, large plagioclase crystals in an igneous rock will have cores that are more calcium-rich than the outer layers, and this layering (called zonation) can be clearly seen under the microscope, or sometimes even with the naked eye for particularly large crystals – such as some of those in the steps in front of Miller Library. The lower portion of Bowen's Reaction Series is dictated more by chemistry than is the upper part. Biotite, orthoclase feldspar and muscovite are the only minerals here that contain large amounts of potassium. These also have much higher silica contents than the minerals at the top of the series (e.g., pure olivine is about 38% SiO_2, while pure orthoclase is 65% SiO_2). It is this increase in silica content that lowers the melting point; note that quartz, at the bottom of the series, is, of course, 100% SiO_2, and has the lowest melting point (about 700°C). As a result, rocks that crystallize from mafic melts (45-55% silica) will tend to be made up of minerals that are high in Bowen's reaction series - such as olivine, pyroxene and Ca-rich plagioclase feldspar. Rocks from felsic melts (>65% silica) will be composed mostly of minerals from the bottom of the series - biotite, Na-plagioclase, muscovite, orthoclase and possibly quartz. Rocks from intermediate magmas will contain



minerals from the middle of the sequence. Worth noting is that these are the major minerals that will appear in the rocks; there will be numerous accessory minerals present that are not in Bowen's reaction series, such as magnetite ($Fe3O4$) or zircon ($ZrSiO4$); these are present in small quantities only in most cases, but can be very informative about fine details of the rock history and properties. The low melting points of minerals at the bottom of Bowen's Reaction Series means that at surface temperatures and pressures on Earth, they are closer to their normal fields of stability. Quartz, in fact, is completely stable at 20°C (68°F). Olivine, however, is not, and given the presence of water it will weather (break down) relatively rapidly. As a result, it is rare to find olivine in sediments or sedimentary rocks. Clays and iron oxides and hydroxides (e.g., hematite, limonite) are the weathering products of iron-rich silicate minerals, and are the mineral forms that are stable at low temperatures and pressures. Thus, the lower minerals are in Bowen's Reaction Series, the more resistant they are to chemical weathering: this means that the rate at which they weather is slower than for minerals higher in the series. Quartz is subject only to dissolution, and in rare instances muscovite can actually form in soils as a weathering product from other minerals. All the other minerals in Bowen's Reaction Series, however, continually weather in the geologic environment, to forms that are more stable at the low temperatures and pressures of the Earth's surface, such as clays or iron and aluminum oxides and hydroxides (e.g., hematite, limonite, bauxite).