UNIT 3

CLASSIFICATION OF IGNEOUS ROCKS

Structure

3.1 INTRODUCTION

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.

Now we will discuss and introduce to you much simpler classification that will allow to easily identify the more common igneous rocks.

Classifications in the Earth sciences are designed to reduce complexity. Most classifications are what we use are genetic. For example, aphanitic rocks are or volcanic origin while phaneritic rocks are plutonic.

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.

3.2 Field Classification

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.

Table 3.1: Field classification.

Grain size	Felsic (light colour)	Intermediate	Mafic (dark colour)	Ultramafic
Coarse	Granite	Diorite	Gabbro	Peridotite
Fine	Rhyolite	Andesite	Basalt	
Vesicular	Pumice		Scoria	
Glassy	Obsidian			
	Minerals Present			
	Quartz K-feldspar Sodic plagioclase	Sodic & calcic plagioclase	Calcic plagioclase Pyroxene	Pyroxene Olivine

3.3 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 (<0.33%) in dark coloured minerals it is known as leucocratic.
- **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.

3.3.3 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 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.

3.3.4 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 3.3, 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.

Table 3.3: Tabular Classification (source : Tyrell, 1973).

	OVERSATURATED			SATURATED			UNDERSATURATED		
	I Quartz	II Quartz + Feldspars		III Feldspars			IV Feldspars + Feldspathoid	V Feldspathoid	VI Mafic minerals predominant
		Predominant Orthoclase	Predominant Plagioclase	Predominant Alkali Feldspar	Predominant Soda-Lime Plagioclase	Predominant Lime-Soda Plagioclase			
PLUTONIC Felsic	Igneous quartz veins	Granite X	Granodiorite (tonalite)	Syenite X	Diorite X	Anorthosite	Nepheline syenite	X Ijolite	
PLUTONIC Mafic			X	X	X	Gabbro X	Theralite & Teschenite X	X	Peridotite Picrite
HYPABYSSAL		← Aplites → (to IV) ← Porphyries → (to V) Granophyre Felsite ← Pitch stone → (to Lime-Soda)	← Lamprophyres → (to VI)		Aplites Porphyries Lamprophyres	Dolerite Tachylite	Tinguaite		
VOLCANIC		Rhyolite ← Pitch stone → ← Obsidian →	Dacite	Trachyte	Andesite	Basalt Tachylite	Phonolite	Leucitophyre Nepheline basalt Leucite basalt	Olivine-rich Basalts Limburgite
Av. Silica %	90	72	66	59	57	48	54.5	43	41

Let us discuss, for example oversaturated igneous rocks which contain quartz and feldspar (Table 3.3). They are sub-divided into two predominant types:

1. quartz
2. quartz and feldspar.

Similarly, you can observe for saturated igneous rocks. They comprise three predominant sub-groups-

1. alkali feldspar,
2. soda lime plagioclase, and
3. lime soda plagioclase.

The unsaturated igneous rocks are divided into three predominant sub-groups-

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.

3.3.5 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 (Fig. 3.1). 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 $SiO2$.
- 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, for example:

- 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 light-coloured 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.

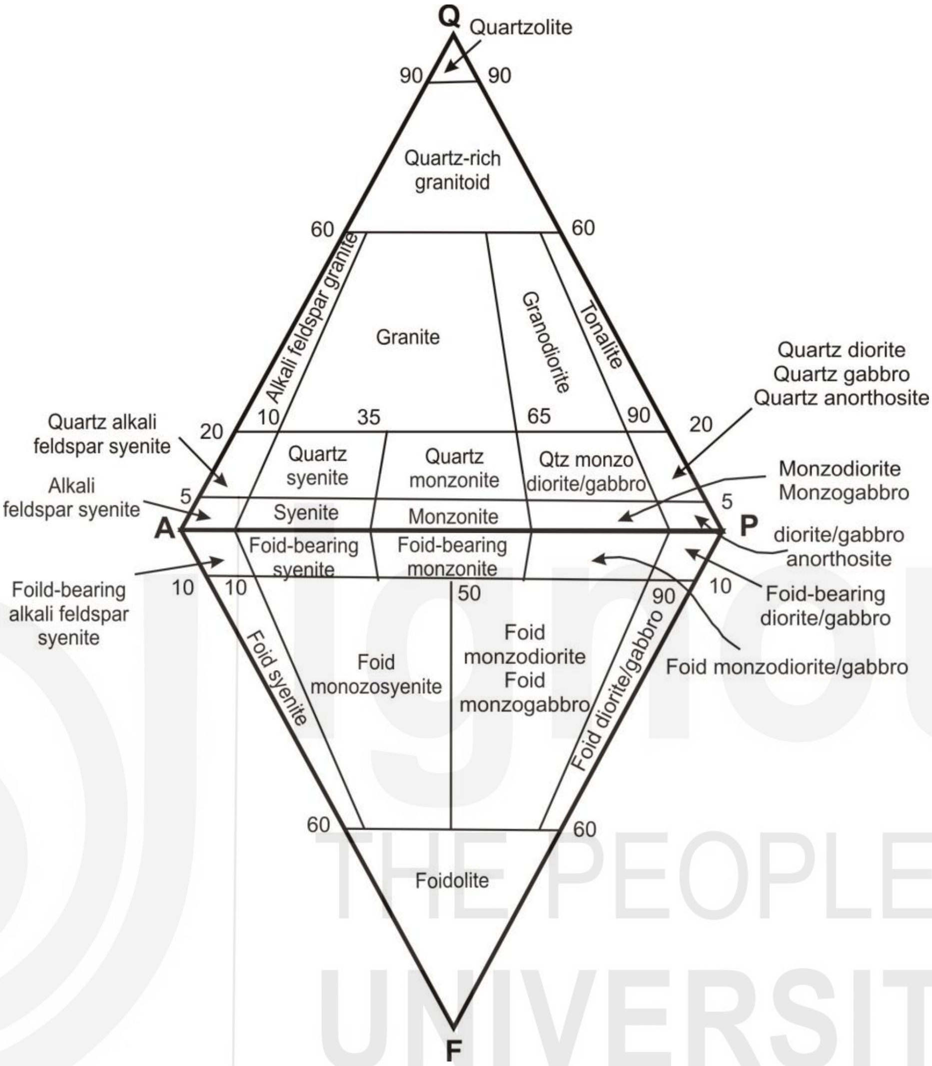

Fig. 3.1: IUGS classification of plutonic (phaneritic) rock.

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% (Fig. 3.2).

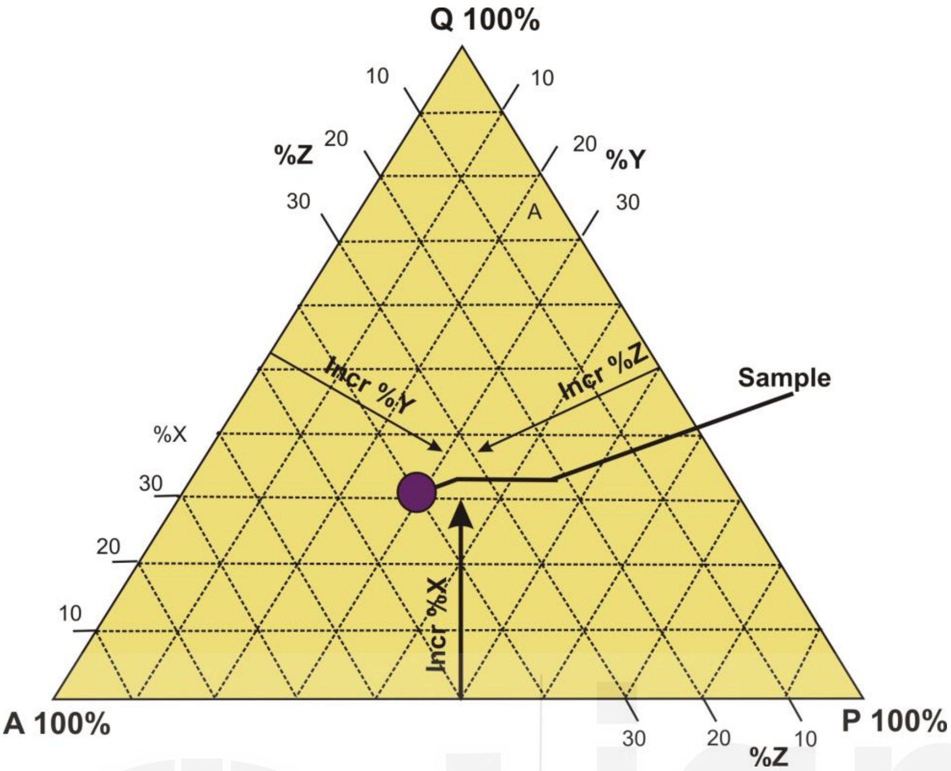

Fig. 3.2: Plotting the sample in IUGS diagram; lines parallel to base represents percentage of quartz (Q), that parallel to right side alkali feldspar (A) and the one parallel to left, plagioclase feldspar (P). The modal percentage of these minerals is recalculated to 100 and plotted. Purple point depicts A-40%, Q-30%, 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.

SAQ 1

a) What are the primary minerals? Give examples.

b) What are the felsic and mafic rocks?

c) Give an example of dark coloured rock, consisting of silica and orthoclase.

d) Why CIPW is known as quasi-chemical method of classifying rocks?

3.4 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
- Alumina saturation
- Alkali lime index
- Total Alkali Silica (TAS)

3.4.1 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 3.4.

Table 3.4: Igneous rock classification based on silica percentage.

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

3.4.2 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.

3.4.3 Alumina Saturation

You have read that silica is the most abundant oxide constituent in igneous rocks. Next to silica, alumina is the most abundant oxide present in the rocks. Shand in 1943 devised classification based on alumina saturation.

$$A/CNK=\frac{Al_2O_3}{CaO+Na_2O+K_2O}\ [mol\%]$$

$$A/NK=\frac{Al_2O_3}{Na_2O+K_2O}[mol\%]$$

On the basis of alumina, the rocks have been divided into three subtypes:

1. **Peraluminous**: This group contains excess of alumina than required for formation of feldspars, which can be chemically expressed as: Al2O3>(CaO+Na2O+K2O)

   A/CNK>1

   Minerals like muscovite, corundum, kyanite should be present.

2. **Metaaluminous**: Molecular percentage of this category is expressed in the form:

   Al2O3<(CaO+Na2O+K2O) and Al2O3>(Na2O+K2O)

   A/CNK<1 and A/NK<1

   This group does not contain alumina rich minerals and also lack alkali pyroxene and amphibole. This group is quite common in igneous rocks.

3. **Peralkaline**: This group is alumina poor and oversaturated with alkalis. On a molecular basis will be expressed as: Al2O3<(Na2O+K2O)

   A/NK<1

3.4.4 Alkali Lime Index

In 1931 a petrologist by name Peacock examined suites of rocks throughout the world. He used this classification for a related series of igneous rocks using SiO2, Na2O, K2O and CaO data. He plotted CaO vs SiO2 and (Na2O+K2O) vs SiO2. Commonly CaO decreases and Na2O + K2O increases with respect to SiO2. Peacock noted that the two curves intersect at different values of SiO2 for different suites. He used the value of SiO2, where the two curves intersect known as the **Peacock Index** or **Alkali Lime Index**, to divide the rock suites into following:

Name of Suite	Peacock Index
Alkalic	<51
Alkali-Calcic	51-56
Calcic-Alkalic	56-61
Calcic	>61

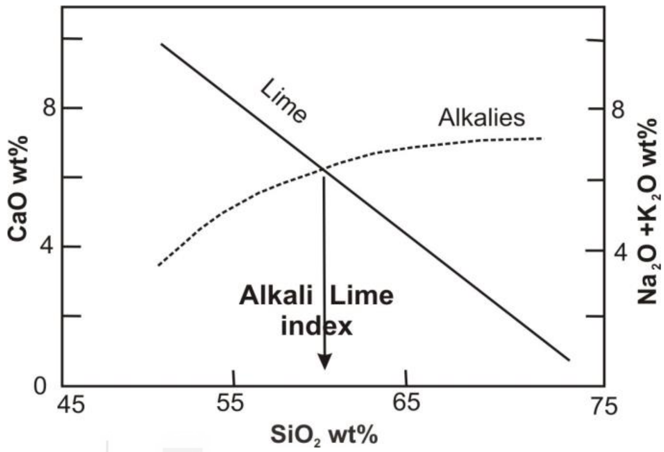

Fig. 3.3: Silica versus lime and alkali plot.

Learners, you have learnt about the schemes using chemical composition for classifying igneous rocks. Before discussing about the TAS classification spend few minutes to perform an exercise to check your progress.

3.4.5 Total Alkali Silica (TAS)

The most popular chemical classification scheme is total alkali silica contents based (TAS) diagram was given by Le Bas and others in 1986 (Fig. 3.4). The TAS (Total Alkalis vs Silica) classification scheme uses major chemistry to classify igneous rocks. It is a simple X-Y graph with the X-axis showing silica (SiO2) wt% and the Y-axis showing alkalis (Na2O+K2O) wt%. A boundary line separates alkaline rocks from subalkaline rocks (Fig. 3.4). This is the most acceptable chemical classification based on major oxides. The TAS plot help in classifying the rocks ranging from rhyolite to picrobasalt, phonolite.

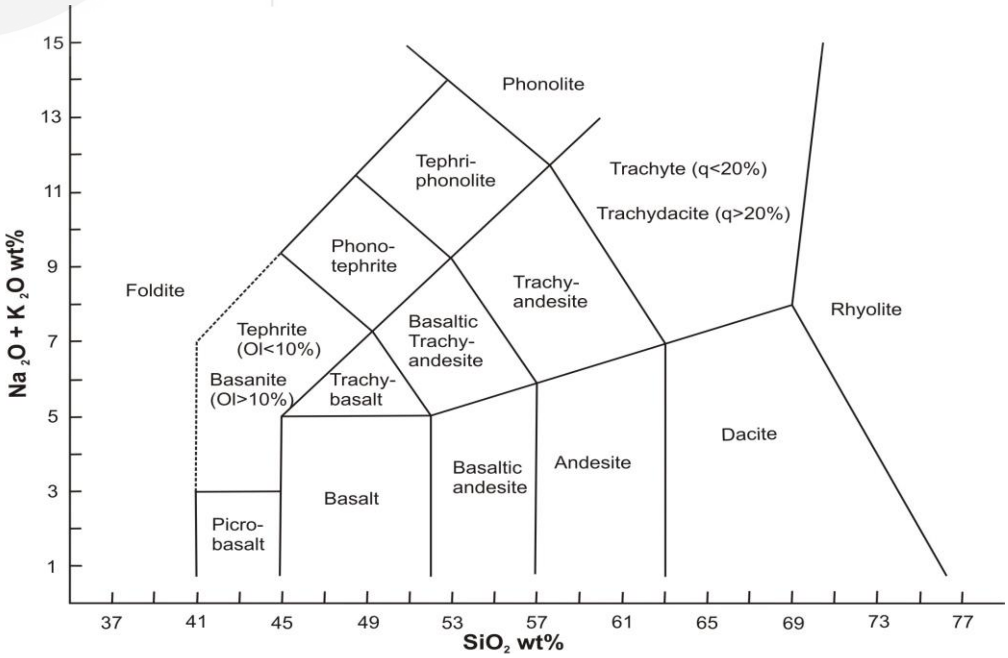

Fig. 3.4: Total Alkali silica (TAS) diagram.

SAQ 2

a) List the classification of igneous rocks based on silica percentage.

b) List the igneous rocks based on silica saturation.

c) List the igneous rocks based on alumina saturation.

d) What is alkali lime index?

3.5 SUMMARY

In this unit we have learnt an art of classification of igneous rocks. Let us summarise about what we have learnt in this unit:

- Igneous rocks can be classified on the basis of mineralogical composition and chemical composition.
- Mineralogical classification is based on the composition and proportion of minerals present in the rock. This classification is based on colour index, modal percentage as in IUGS classification or quasi-chemical classification, like CIPW.
- Tabular classification combines principles of mineralogical and chemical classification. It considers the silica content, and relative proportion of feldspars, i.e. alkali feldspar and plagioclase and mode of occurrence.
- Chemical classification is based on percentage of silica, saturation of silica and aluminium in rocks and alkali lime.
- Total Alkali Silica (TAS) diagram uses (Na2O + K2O) and SiO2. percentage.

3.6 ACTIVITY

1. Explore rocks around you and collect different igneous rocks and try to classify them on the basis of their colour index.

3.7 TERMINAL QUESTIONS

1. Discuss the mineralogical classification based on colour index of rocks.
2. Explain the concept of CIPW classification.
3. Discuss the basis of tabular classification.
4. What is the basis of IUGS classification?
5. Discuss the TAS classification.

3.8 REFERENCES

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3.9 FURTHER/SUGGESTED READINGS

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3.10 ANSWERS

Self Assessment Questions

1 a) Essential minerals are those whose presence is necessary in the bulk mineral composition and are considered to be essential for naming or nomenclature of the particular rock. Give example of granite and basalt.

b) Felsic rocks comprise light color minerals like silica and feldspar. These minerals have low melting point, low specific gravity and are late crystallised. Mafic or ferromagnesium rocks comprise of minerals dark in colour, e.g. olivine, pyroxene, amphibole and biotite. Mafic minerals have high specific gravity, higher melting point and are early crystallized.

c) Obsidian is a glassy rock with dark in colour and same composition as granite.

d) This classification is based on the calculation of norm from the bulk chemistry of rocks.

2 a) Please refer Table 3.3.

b) Silica oversaturated rocks contain more than 66% SiO_2; silica saturated rocks contain more than 52-66% SiO_2; silica undersaturated rocks contain 45-52% SiO_2.

c) Peraluminous, peralkaline, metaaluminous.

d) The value of SiO_2 of where the two curves [CaO and alkali (K_2O+ Na_2O)] intersect known as the Alkali Lime Index or Peacock Index.

Terminal Questions

1. Please refer to the subsection 3.2.2.
2. Please refer to the subsection 3.2.3.
3. Please refer to the subsection 3.2.4 and Table 3.3.
4. Please refer to the subsection 3.2.5.
5. Please refer to the subsection 3.2.5.

GLOSSARY

Aa : It is Hawaiian word used for Blocky lava for "ouch, this hurts" when you walk on it barefoot.

Aphanitic : It consists of a mosaic of crystals too small to be seen without magnification. They can be either cryptocrystalline or microcrystalline.

Aphyric : Nonporphyritic, aphanitic texture.

Archaean : Eon defined as the time between 4 billion years ago to 2.5 billion years ago. Most of the oldest rocks on Earth, including large portions of the continents, formed at this time.

Asthenosphere : A ductile physical layer of the Earth, below the lithosphere. Movement within the asthenosphere is the main driver of plate motion.

Batholith : A large intrusion of igneous rock, usually granite, formed deep beneath the surface of Earth so the rock cooled very slowly.

Bowen's Reaction Series : A series of mineral formation temperatures that can explain the minerals that forms in specific igneous rocks.

Columnar jointing : Type of joints in which rock divides into columns. This type of jointing results due to contraction in basaltic rocks.

Columnar structure : A common geological structure found in basaltic and other types of lava. In this rock has been divided into prisms and columns. Commonly it has six sides but sometimes 8 sides can also develop.

Continental crust : The layers of igneous, sedimentary, and metamorphic rocks that form the continents. Continental crust is much thicker than oceanic crust. Continental crust is defined as having higher concentrations of very light elements like K, Na, and Ca, and is the lowest density rocky layer of Earth. Its average composition is similar to granite.

Crystallisation : The process by which crystalline phases are separated from liquid, viscous or dispersed state.

Cumulate : Accumulation of crystals produced by crystal-melt fractionation.

Cumulophyric	:	A type of porphyritic texture in which several phenocrysts are aggregated together, the matrix is usually glassy or aphanitic.
Deccan Traps	:	Large flood basalt province in India that occurred around the same time as the K-T Extinction, 66 million years ago.
Extrusive	:	Igneous rocks formed by eruptions on the Earth's surface.
Fayalite	:	A mineral belonging to olivine group having the composition of Fe_2SiO_4. It is found both in crystalline and massive form.
Flood basalt	:	Rare very low viscosity basaltic eruption that covers vast areas.
Glassy	:	Term used for glass like texture developed in volcanic rocks.
Groundmass	:	General term for the fine-grained. In igneous rocks, this is the part of the rock that is not phenocrysts. In sedimentary rocks, it typically refers to the fine-grained components, namely mud. In metamorphic rocks, it is usually referring to material between porphyroblasts or a low-grade rock with only microscopic mineralisation.
Holocrystalline	:	Igneous rocks which are entirely composed of complete crystals.
Intrusive rocks	:	Igneous rocks which crystallise below the surface of the Earth, e.g. dyke, sill, stock and batholih.
Lava	:	Molten rock erupted on the surface of Earth from a volcano.
Magma	:	Molten rock with dissolved volcanic gases, beneath the Earth's surface.
Magma chamber	:	A reservoir of magma below a volcano.
Melanocratic	:	A term used for those rocks which contain more than 66% dark coloured minerals.
Mineralisation	:	The process of inclusion of ore minerals in pre-existing rock bodies.
Obsidian	:	Dark-colored volcanic glass, with extremely small microscopic crystals or no crystals. Typically form from felsic volcanism.
Oligoclase	:	A kind of feldspar with composition between albite and

anorthite but its chemical composition is closer to albite.

Olivine : It is an orthosilicate with chemical composition $(Mg Fe)_2SiO_4$. Its hardness ranges between 6.5-7 and specific gravity is between 3.27-3.37. Colour of olivine is typical olive green, grayish green or brown. It is an important rock-forming of specifically mafic and ultramafic rocks.

Ophitic texture : Rock texture where lath shaped crystals of plagioclase are completely or partially surrounded by augite crystal. This texture is found in ultrabasic or volcanic rocks.

Pahoehoe : Hawaiian word for a "ropy" surface formed due to cooling of lava.

Perlitic : Texture made of concentric cracks in silicic glass.

Phenocryst : They are the bigger crystals present in porphyritic rocks as compared to crystals of other minerals.

Pillow lava : Lava that has been erupted beneath the sea, forming characteristic "pillow" shapes as it comes into contact with cold water.

Plagioclase : They are the common rock-forming minerals of albite-anorthite isomorphous series.

Pyroclastic : Rocks or rock textures that are formed from explosive volcanism.

Pyroclastic flow : A collapsed part of the eruption column that travels down at very hot temperatures at very fast speeds.

Pyroxene : A group of important rock-forming minerals dominantly composed of iron, magnesium and calcium sometimes sodium, potassium. Important rock forming minerals of this group are enstatite, bronzite, hypersthene, diopside, diallage, augite, aegirine.

Texture (Igneous rocks) : Physical appearance of rock as it appears from size, shape and fabric of constituent particles.

Vesicles : Bubbles formed by volcanic gases in lava, which become "frozen in" as the lava cools.

Viscous : Viscous refers to magmas that are thick and move very slowly.

Vitric : Glassy.

Vitrophyre : Texture in which large crystals (phenocrysts) are surrounded by glassy matrix.

Volcanic ash : Volcanic tephra that is less than 2 mm in diameter.

Xenolith : Rock fragment/block which are originated from older rocks and included in igneous rocks. They do not have genetic relationship with host rock. Example: sandstone in granitic rock.