SECTION 3

LECTURE 5.

5.0 NATURE AND CLASSIFICATION OF IGNEOUS ROCKS

5.1 INTRODUCTION

Welcome to lecture 5. You have now successfully completed section 1 and 2 of this unit. You can now state the basic concepts concerned with the formation of the Earth and illustrate its complete structure and composition. You can now describe and derive the basic concepts in elementary crystallography and mineralogy. Through that knowledge you can now distinguish the physical properties of at least a few mineral species. At this level you can define crystals and minerals and outline their classification. Equipped with this knowledge, you are now ready to go to the next step to learn more about rocks. Rocks are the most common materials of the Earth. Rocks by nature are classified according to their mode of formation. The three major rock types are igneous, sedimentary and metamorphic rocks. Igneous rocks are by far the most abundant rocks in the earth's crust. In lecture 5, we shall discuss the nature and classification of igneous rocks.

OBJECTIVES

At the end of this lecture, you should be able to:

(a). Define what a rock is?

(b). Describe the mode of formation of an igneous rock.

(c). Summarize the main differences between volcanic and plutonic rocks.

(d). Illustrate and explain the common textures of igneous rocks

(e). Discuss the classification and mode of occurrence of igneous rocks.

(f). Give examples of common igneous rocks.

5.2 ROCKS DEFINED

A rock is defined as a solid, cohesive aggregate of one or more minerals, or mineral materials. They are natural materials commonly lacking the uniformity of man-made materials such as steel. Most rocks are aggregates of mineral particles, which are crystals, more or less perfectly formed or fragments of crystals. The properties of rocks are important in determining their suitability for particular applications, such as for construction materials or for the base of a building foundation. The size of the particles, their arrangement, and the proportion of each mineral present serve as the basis for the geological classification of rocks. The three broad categories of rocks – **igneous**, **sedimentary** and **metamorphic** – are distinguished by the processes of their formation. The igneous rocks are formed from magma; the sedimentary rocks are formed from low temperature accumulations of particles or by precipitation from solution; and the metamorphic rocks are formed from pre-existing rocks through application of heat and pressure.

5.3 IGNEOUS ROCKS

What is an igneous rock?

An **igneous rock** is a rock formed by the solidification and crystallization of cooling magma. (*Igneous* is derived from the Latin term *ignis*, meaning "fire"). At high temperatures, rocks and minerals can melt. **Magma** is the name given to naturally occurring hot melted rock. As a result of crystallizing from a liquid melt, the rocks are made up of interlocking crystals of the component minerals (except for natural glasses). Igneous liquid melts range in temperature from 1200-1800^{o}C and crystallization is usually complete by 700^{o}C. Elements in the igneous melts mostly combine with silica to form silicate minerals e.g. olivine, pyroxene, mica, quartz, etc.

5.4 TEXTURES OF IGNEOUS ROCKS

Texture of igneous rocks defines the shape, size and mutual relationship of the constituent minerals. The texture in igneous rocks depends on the following four factors:

i) Viscosity of magma

ii) Rate of cooling

iii) The order of crystallization of the constituent minerals.

iv) The relative rates of growth of the constituent minerals.

5.4.1 Magmatic Viscosity

Magmatic viscosity defines the degree of fluidity of the magma, e.g. water has low viscosity and will flow easily while glue has high viscosity and will flow very slowly. As a crystal crystallizes in the magma, ions of its chemical composition must diffuse through the magma to the crystal. This diffusion is slower in more viscous magma and vice versa in less viscous magma.

5.4.2 Rate of Cooling

In most cases, the more slowly a crystal grows, the larger it becomes. Therefore slow cooling gives rise to a **Coarse Grain** (>1 cm) or coarsely crystalline (**holocrystalline**) texture. Faster cooling produces a **Medium Grain** size (1 cm –1mm). Further faster cooling produces a very **Fine Grain** size (**crypto-crystalline**) rock (crystals below 1 mm) where the mineral grains are not visible by the naked eye but can be seen by a hand lens or a microscope. A very fast cooling or chilling leave no time for crystals to form and produces a **Glassy** rock or **natural glass**, e.g, obsidian. Hence gradation in grain size in igneous rocks produces:

- Coarse grain/ crystal size (> 1 cm)
- Medium grain size (1 cm – 1mm)
- Fine grain size (< 1mm)
- Natural glass.

NB. **Pegmatite** is a term used for very coarse grain size. Pegmatites are formed from the last material to solidify after an igneous intrusion. The magma at this stage has its main constituents plus a larger than normal amount of various gases, and considerable amounts of water vapour.

5.4.3 The Order of Crystallization

Suppose mineral A and B are present in a melt (Figure 5.1). As the melt temperature falls during cooling, mineral A starts to crystallize, at for example 1000 ºC. Mineral B is still in solution in the melt. Because the melt offers little resistance to the crystallization of mineral A, the crystals of A grow large and attain perfect crystal shape as shown in Fig. 5.1

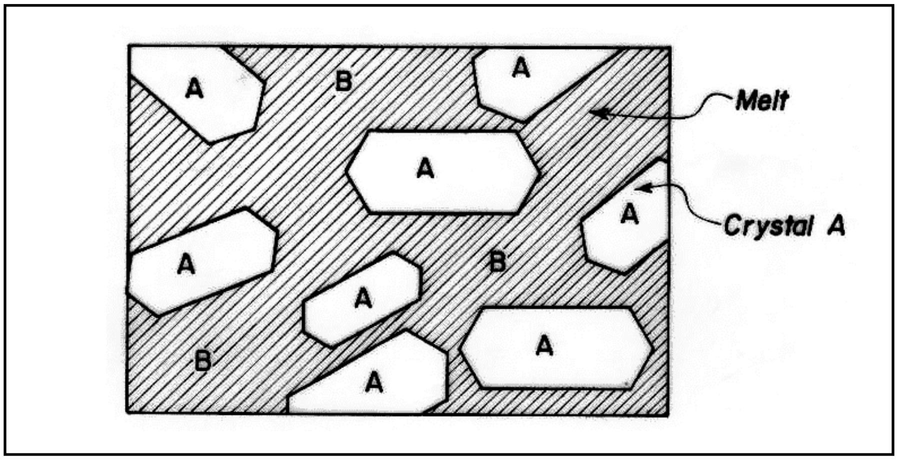

Figure 5.1 The order of crystallization for mineral A and B.

When the temperature is low enough for mineral B to crystallize, its crystallization will be hindered by the already existing crystals of mineral A. Therefore B will not be able to develop perfect crystal shape and will not grow so large. B crystals will fill up the spaces between the A crystals.

Well formed crystals that show complete or nearly complete development of crystal shape are called **Euhedral** crystals e.g. mineral A. Less developed crystal faces produces **Subhedral** crystal form. Those without crystal faces or irregular forms produce **Anhedral** crystals.

5.4.4 The Relative Rates of Crystal Growth

If mineral A and B are to commence crystallization together at the same time, but A grew much faster than B, then A would still have attained a good crystal shape before B crystallizes. This could produce a texture similar to the diagram described above.

5.5 PHENOCRYSTS AND GROUNDMASS

If all crystals in an igneous rock are roughly of the same size, then the rock is said to have a uniform grain size. If some of the crystals or one or more minerals are much larger than the rest, these large crystals are called **Phenocrysts** while the fine material in between is the **Groundmass**. A rock without phenocrysts is said to have **Aphyric** texture, while the one with phenocrysts is said to have **Porphyritic** or **Phyric** texture. If the phenocrysts are abundant and consist mainly of, e.g. feldspar grains, then the rock is referred to as feldspar phyric rock. Microphenocrysts occur in very fine grained rocks and the grains are only visible with a microscope. Phenocryst formation usually reflects changes in magmatic conditions e.g. slow cooling to produce the phenocrysts, and faster cooling to produce the groundmass.

5.5 VESICLES

What is the origin of vesicular texture.

Magma and lavas contain gases in solution. Under low pressure these gases come out of the solution to form bubbles in liquid rock. If the rock now solidifies, the bubbles preserved or cavities are called vesicles, and the resultant texture is referred to as **vesicular** texture. If the cavities are later filled by other secondary minerals in solution i.e. after the main cooling of the rock, then this type of vesicle is referred to as **Amygdale**.

5.7 FLOW TEXTURE

Liquid rock can flow, and lavas in particular show flow effects on a large scale which are referred to as lava flows. We have two main types of flow textures:

- Alignment of constituent minerals.
- Originally spherical crystals may be stripped out by flow (see Fig. 5.2)

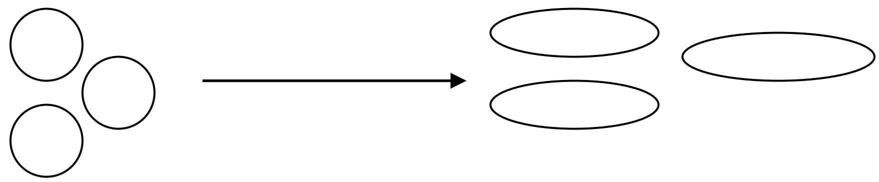

Figure 5.2. The stripping out of originally spherical crystals by lava flow.

5.8 PYROCLASTIC ROCKS

Pyroclastic rocks are formed by fragmentation of existing rock and erupting lavas during explosive volcanic eruptions. They are thrown out of the volcano and settle on the ground surface in a similar way sediments settle in water. These rocks are intermediate between igneous and sedimentary rocks. The fine grain dust material is called **Volcanic Ash** while the coarse angular grains embedded in the finer matrix of ash is called **Agglomerates.** In other instances agglomerates may consist of coarse angular blocks.

5.9 XENOLITHS

Xenoliths are foreign fragments taken into the magma. There are two types of Xenoliths:

- Wall-rock xenoliths
- Mantle derived xenoliths

Wall-rock xenoliths – These are usually incorporated into the magma at a relatively high level in the crust e.g., fragments of the walls of the magma chambers or the volcanic feeder pipes may consist of sedimentary rocks.

Mantle-derived Xenoliths – These are thought to originate at much greater depth within the earth as they only contain minerals that are stable at high pressures. Thus they were derived from deep levels. They are thought to be fragments of the mantle, an inner shell of the earth from which magma is derived.

5.10 DISTINCTION BETWEEN LAVA FLOWS AND SILLS

How do you distinguish a lava flow from a sill?

Both sills and lava flows could appear as horizontal and concordant igneous sheets of fine grain size. However the major distinctions between these two features are as shown in Table 5.1

Table 5.1 Distinction between sills and lava flows.

SILLS	LAVA FLOWS
-The upper surface is compact and fine grained/glassy, vesicles are rare	-Upper surface is ropey and of visible Vesicles
-Metamorphism occurs on adjacent rocks at upper and lower contacts	-Metamorphism occurs only on the bottom contact
- Usually small veins of igneous rock that penetrate upward into adjacent rock	- Veins are absent
- Upper surface usually does not show effects of atmospheric weathering e.g. the reddening associated with the oxidation of ferrous compounds.	- Effects of weathering present

5.11 OCCURRENCE OF IGNEOUS ROCKS

There are two main types of igneous rocks:

- **Plutonic or intrusive** igneous rocks that are formed when magma or red-hot liquid rock cools down and hardens before it reaches the surface of the Earth, e.g. granite

- **Volcanic or extrusive** igneous rocks that form when the liquid magma erupts during volcanic activity and cools and hardens on the Earth's surface, forming e.g. basalt or andesite lava.

5.11.1 Plutonic Rocks

Recall that an igneous rock is a rock formed by the solidification and crystallization of a cooling magma. If a magma remains well below the surface during cooling, it cools relatively slowly, insulated by overlying rock and soil. Under these conditions, the crystals have ample time to form and to grow very large, and the rock eventually formed, has mineral grains large enough to be seen individually with the naked eye. Such a rock that crystallizes below the earth's surface is referred to as **Plutonic** rock (The name is derived from Pluto, the Greek god of the lower world.) Sometime plutonic rocks are referred to as **Intrusive** rocks. ***Granite*** is probably the most widely known example of a plutonic rock. Compositionally, a typical granite consists of quartz and feldspars, and it usually contains some ferromagnesian minerals or other silicates. The proportions and compositions of these constituent minerals may vary, but all granites show the coarse, interlocking crystals characteristic of a plutonic rock.

The three basic characteristics of plutonic rocks are:

- They cut across older rocks
- They are coarse grained, often with chilled margins
- They are formed underground

Can you now explain why granites have a coarse grained texture?

5.11.2 Volcanic Rocks

Volcanic rocks (or **extrusive** rocks) are those rocks that crystallize on or slightly under the earth's surface. A magma that flows out on the earth's surface while still wholly or partly molten is called **lava**. Lava is a common product of volcanic eruptions. Magmas that crystallize very near the surface cool more rapidly. There is less time during crystallization for large crystals to form from the melt, so volcanic rocks are typically fine-grained, with most crystals too small to be distinguished with the naked eye. In extreme cases where the cooling occurs very fast, they form a non-crystalline solid referred to as natural glass. The most common volcanic rock is ***basalt,*** a dark rock rich in ferromagnesian minerals and feldspar. The ocean floor consists largely of basalt.

The three basic characteristics of volcanic rocks are:

- They crystallize at the surface of the earth.
- They are usually fine grained.
- They do not cut across older rocks, but rest on top of them.

NB. Regardless of the details of their compositions or cooling histories, all igneous rocks have some textural characteristics in common. If they are crystalline, their crystals, large or small, are tightly interlocking or inter-grown. The individual crystals tend to be angular in shape, not rounded. There is usually little pore space, little empty volume that could be occupied by such fluids as water. Structurally, most igneous rocks are relatively strong unless they have been fractured, broken or weathered.

Can you distinguish between plutonic and volcanic rocks?

5.12 THE FORMS OF IGNEOUS INTRUSIONS

Dykes (or **Dikes**): These are tabular, or wall-like igneous intrusions that are usually steeply inclined and cut across the bedding or foliation of the country rocks (see Figure 5.3).

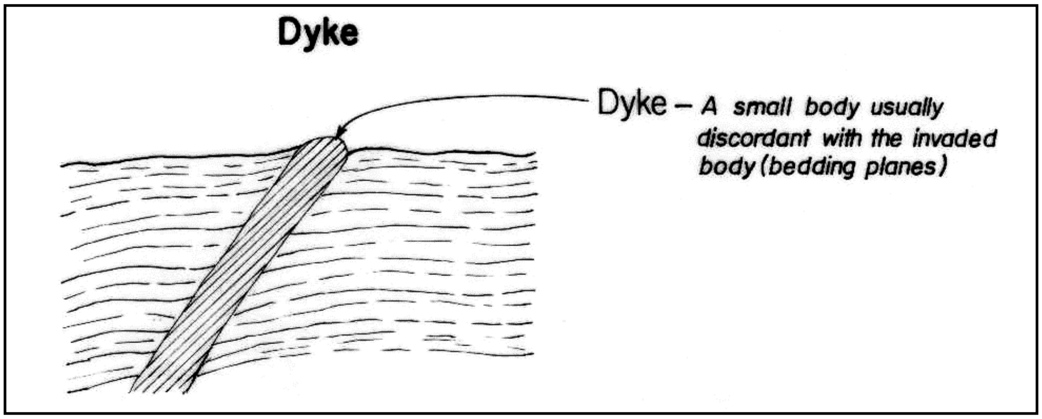

Figure 5.3 A dyke structure cutting across the invaded body.

Sills: These are tabular igneous bodies that are flat-lying, and have been intruded parallel to the planar structures in the surrounding rocks (Figure 5.4). They are generally injected between bedded units, at relatively shallow depths within the upper crust.

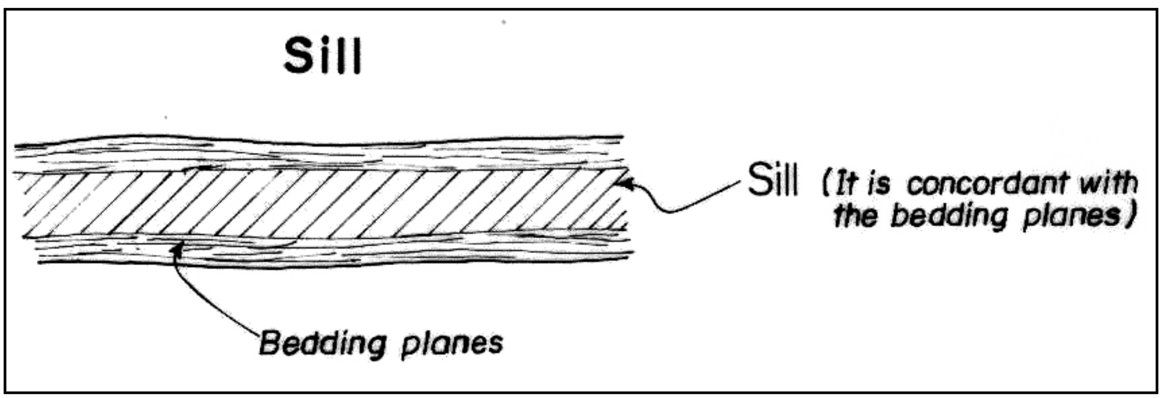

Figure 5.4. A Sill structure that is concordant with the invaded body.

Batholiths: These are large, generally discordant bodies of plutonic rocks that have an outcrop area that is greater than 100 km^2 (Classical Greek, *bathos*, depth).

Stocks: These are small, generally discordant bodies of plutonic rock that have an outcrop area that is less than 100 km^2.

Lapoliths: These are large, generally concordant bodies of plutonic rocks that have a plano-convex or lenticular shape. They differ from sills in that they are depressed in the center (Classical Greek, *lopas,* a basin).

Cone Sheets: These are conical dykes that converge towards a central point. In plan they usually occur as concentric sets of dykes arranged about and dipping towards a center of igneous activity (see Figure 5.5).

Ring Dykes: These are dykes that are arcuate or circular in plan. Their dip is vertical or inclined away from a local center of igneous activity (Figure 5.5).

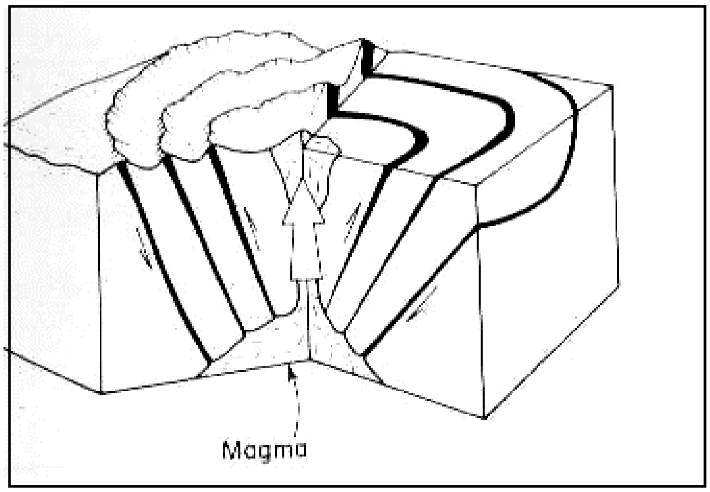

Figure 5.5 An igneous source exposed by erosion and revealing cone sheets where magma has filled up conical fractures opened up by vertical pressure.

5.13 CLASSIFICATION OF IGNEOUS ROCKS

There are a number of ways of classifying igneous rocks. These include:

5.13.1 Silica Content Classification

The silica (SiO_2) content classification uses the amount o SiO_2 composition in a rock. Silica is the principal constituent in igneous rocks. The degree of silica saturation depends upon the concentration of silica relative to the concentration of other chemical constituents in the rock that combine with it to form silicate compounds. With few exceptions, silica (SiO_2) is the principle oxide constituent of igneous rocks. The classification involves the analysis of the chemical composition in the igneous rock. The classification utilizes the concentration of SiO_2 as presented in Table 5.2 here below:

Table 5.2 Classification of igneous rocks using the silica content.

CLASSIFICATION NAME	SILICA CONTENT (SiO_2 Wt.%)	ROCK EXAMPLE
Acid	>66	Granite
Intermediate	52-66	Andesite
Basic	42-52	Gabbro
Ultrabasic	<45	Peridotite

A comprehensive summary of the igneous rocks classification using the silica content criteria, geological occurrence and texture is presented in Table 5.3

5.13.2 Colour Classification

- **Felsic – Mafic classification**

The colour classification in igneous rocks is equivalent to the Felsic–Mafic classification.

The principle of this method lies on the following parameters.

Felsic minerals by nature are of light colour and of low density, e.g. quartz, feldspar, feldspathoids. On the other hand, **Mafic** minerals are usually darker in colour and of high density, e.g. biotite, pyroxene, olivine and amphiboles. Therefore igneous rocks can be classified from the range of Felsic–Intermediate–Mafic on visual estimate of the proportion of mafic to felsic minerals. Roughly speaking, the acid to ultrabasic rock classification is equivalent to felsic to mafic classification since felsic rocks tend to contain more silica rich minerals.

- **Leucocratic-Melanocratic classification**

Leucocratic rocks – These are pale coloured rocks enriched with light minerals, while Melanocratic rocks – are the dark coloured rocks dominated by dark coloured minerals. Once again, the leucocratic – melanocratic classification is equivalent to the acid to ultrabasic classification. The leucocratic to melanocratic range is also similar to felsic-mafic classification. The pale felsic rocks are termed **Leucocratic** whereas dark mafic rocks are called **melanocratic** rocks. The leuco- to melanocratic scale range is equal to acid to ultrabasic classification.

NB. In all of these classifications, rocks between the end members are called **intermediate.** Even if individual mineral grains are not visible (i.e. fine grained rock) the overall colour can still be used. However the colour classification may not apply to certain igneous glasses (i.e. glasses may not have minerals in them).

5.13.3 Classification Based on Silica Saturation of Minerals

Formally, there are two classes of minerals recognized in this classification, viz:

Silica saturated minerals: these are compatible or can exist in equilibrium with free quartz or its polymorphs. Saturated minerals include feldspar, enstatite, hypersthene, amphiboles, micas, Fe-Ti oxides, Fe-olivine, sphene, etc.

Silica- unsaturated minerals: these are incompatible and never found, except by accident, with quartz. Unsaturated minerals include feldspathoids (nephelene), Mg-olivine, corundum, melilite.

e.g. Mg-olivine (forsterile) + silica = enstatite (pyroxene)

$$Mg_2SiO_4 + SiO_2 = 2MgSiO_3$$

From the silica saturation classification, three classes of rocks are recognized:

- **Silica oversaturated rocks** – contain quartz or its polymorphs e.g. granite is an over-saturated rock.
- **Silica saturated rocks** – contain neither quartz nor unsaturated minerals e.g. diorite.
- **Silica undersaturated rocks** – contain only unsaturated minerals e.g. nepheline syenite.

Parallel to the silica saturation concept we also have the Al- saturation classification,

5.13.4 Al - saturation Classification

a) Per-aluminous rocks – where the molecular proportion Al_2O_3 > (CaO + K_2O + Na_2O)
b) Aluminium rocks – Al_2O_3 ~ (Na_2O + K_2O)
c) Peralkaline rocks – Al_2O_3 < (Na_2O + K_2O)

Summary

Lecture 5 started by giving a definition of rocks in general. A discussion on the mode of formation of igneous rocks with specific examples together with the main factors controlling their characteristic textures were adequately covered. The different forms of occurrence of these rocks and their methods of classification were also discussed.

By definition rocks are cohesive solids formed from rock or mineral grains or glass. The way in which rocks form determines how the rocks are classified into three major groups: the igneous rocks, formed from magma; sedimentary rocks formed from low temperature accumulations of particles or by precipitation from solution; and metamorphic rocks, formed from pre-existing rocks through application of heat and pressure. Basic physical properties of rocks are controlled by the minerals of which the rocks are composed and by the ways in which the mineral grains or rock fragments are assembled.

Igneous rocks in particular are divided on the basis of origin, into intrusives (plutonic) and extrusives (volcanic). The former are usually coarse grained, the latter, fine grained or glassy. The igneous rocks are also classified as felsic or mafic depending on the kinds and relative amounts of light and dark minerals. Volcanic rocks are further subdivided by texture.

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IGNEOUS ROCKS

MODULE 5: REVIEW QUESTIONS

1. The major difference between intrusive igneous rocks and extrusive igneous rocks is
    a. where they solidify
    b. chemical composition
    c. type of minerals
    d. none of the preceding

2. By definition, stocks differ from batholiths in
    a. size
    b. shape
    c. chemical composition
    d. all of the preceding

3. The difference in texture between intrusive and extrusive rocks is primarily due to
    a. different mineralogy
    b. different rates of cooling and crystallization
    c. different amounts of water in the magma
    d. none of the preceding

4. Which is not an intrusive igneous rock
    a. gabbro
    b. granite
    c. diorite
    d. andesite

5. An igneous rock made of pyroclasts has a texture called
    a. fragmental
    b. vesicular
    c. porphyritic
    d. fine-grained

6. Whether volcanic eruptions are very explosive or relatively quiet is largely determined by
    a. the amount of gas in the lava or magma
    b. the ease or difficulty with which the gas escapes to the atmosphere
    c. the viscosity of the magma
    d. all of the preceding

7. Felsic and mafic are terms used by some geologists to describe
    a. behavior of earthquake waves
    b. composition of continental and oceanic crust
    c. regions in the mantle
    d. none of the preceding

ANSWERS TO MODEL QUESTIONS

Questions:

1. **a**
2. a
3. b
4. d
5. a
6. d
7. b

Complementary notes

TEXTURES OF IGNEOUS ROCKS

In the previous section, we have discussed the factors that influence textures in igneous rocks. In this section we shall discuss the characteristic textures of igneous rocks.

Texture refers to the relative size and arrangement of minerals in a rock. The texture of the component minerals of igneous rocks corresponds broadly to the rocks' mode of occurrence. Wholly crystalline igneous rocks are called ***holocrystalline***. This is typical among intrusive rocks. Entirely glassy rocks are called ***holohyaline*** and partly glassy ***merocrystalline***. The latter two are typical of volcanic rocks. Plutonic (intrusive) rocks, which have cooled slowly under a cover (beneath the earth's surface) are coarsely crystalline or ***phaneritic***. Their component crystals are large (2 to 5 mm or more) and can easily be distinguished by the naked eye. Rocks of medium grain size often have crystals between about 1 and 2 mm, and in fine-grained rocks crystals may be considerably less than 1 mm across.

Phaneritic rocks that have roughly equal grain size are called ***equigranular***, otherwise they are ***inequigranular***. Equigranular rocks with crystals more than 2 cm are ***pegmatitic***. Equigranular rocks form when the magma cools relatively slowly, the slower it cools the bigger the crystals. Inequigranular rocks that have a wide variety of grain sizes are called ***seriate***. Seriate rocks form when the growth rates are different.

For the extrusive rock textures, when the texture is so fine that individual crystals cannot be distinguished without the aid of a microscope it is called ***aphanitic*** or ***microcrystalline***. For extremely fine-grained rocks, where their crystalline character is only revealed by viewing the rock slice through crossed polars of a microscope, the term ***cryptocrystalline*** is used. These textures are all ***even-grained***, or ***equigranular***, i.e. crystals are more or less the same size. Some rocks exhibit a ***porphyritic*** texture in which a number of large crystals are set in a uniformly finer base (or groundmass). The large conspicuous crystals are called ***phenocrysts or megacrysts***, the smaller ones which may include glass comprise ***groundmass***. Porphyritic igneous rocks form when magma cools rapidly trapping the phenocrysts that were floating in the magma at the time.

Extrusive rocks which have cooled rapidly at the earth's surface are often ***entirely glassy or vitreous*** (without crystals), or partly glassy and partly crystalline. Expanding gases in a magma during its extrusion give rise to cavities or vesicles resulting in a ***vesicular texture***. The vesicles may subsequently be filled with secondary minerals and are hence referred to as ***amygdales***. ***Flow structure*** in lavas is a banding produced by differential movement between layers of the viscous material as it flowed.

Igneous rock textures can also be distinguished on the basis of crystal shape. When the crystals are bounded on all sides by well-formed faces the mineral is said to be ***euhedral***. This is often the case when the mineral grows slowly. When only a few faces are developed it is ***subhedral*** and when no crystal faces are evident the mineral is said to be ***anhedral***.