2.1 The earth and lithosphere

The solar system includes the sun and the ten planets including the earth that orbit around the sun, the satellites (moons) of the planets, and comets, meteors, and asteroids. According to generally accepted theories, all the bodies of the solar system were formed stepwise by condensation and contraction of a huge spherical nebula (cloud) of cosmic gases and debris composed mainly of hydrogen and helium.

It is estimated that the earth was formed about 4.5 billion years ago. The gradual cooling of this hot, molten mass over millions of years formed the atmosphere, hydrosphere, and lithosphere. The atmosphere is the gaseous envelope surrounding the hydrosphere (zone of water as oceans and lakes), and the lithosphere (earth's crust), and interior mass. From that time on, the conditions prevailing on the surface of the earth have been much the same as those with which we are familiar today. However, the face of the earth was not the same as we see it today, because many geological processes, of erosion and aggradation, and of earth movements and volcanoes, have been continually changing its surface. The interior of the earth is still very hot; the temperature of its central molten core (metal core) is as much as 8000°C. The core has a radius of 3600 kilometers (km), and gravity of 10 *g* or more. It is composed mainly of nickel and iron and is near the center of gravity of the planet.

Surrounding the molten core is the ***inner shell***, with a temperature of 2200°C. The inner shell consists of silicates of Mg and Fe and is about 3000 km thick, with a gravity of 8 *g* at its inner portion decreasing to 3 *g* near the crust. The outermost solid portion of the earth, called the ***crust***, consists of both rocks and weathered rocks (as soil). It is generally believed to extend downward from the surface to 10–15 km or more.

The chemical composition of the bulk of the earth's crust is fairly simple. Nine of the known elements comprise more than 99% of the earth's crust. The proportions of the principal elements which make up the earth's outer crust are approximately as follows.

Table 2.1 Chemical composition of the earth's crust

Element	Symbol	Percent by weight	Percent by volume
Oxygen	O	46.6	93.8
Silicon	Si	27.7	0.9
Aluminum	Al	8.1	0.5
Iron	Fe	5.0	0.4
Calcium	Ca	3.6	1.0
Sodium	Na	2.8	1.3

Element	Symbol	Percent by weight	Percent by volume
Potassium	K	2.6	1.8
Magnesium	Mg	2.1	0.3
Titanium	Ti	0.6	

Source: After Mason (1966) in Ollier (1969:3)

The remaining mass of less than 1% mainly consists of hydrogen (H), phosphorus (P), manganese (Mn), carbon (C), sulphur (S), chlorine (Cl), barium (Ba), fluorine (Fl) and strontium (Sr), whose individual contribution is 0.1% or less. Oxygen and silicon together comprise approximately 75% of the crust. On a volume basis, oxygen alone constitutes 94% of the crust.

2.2 Rocks

Rocks, the most familiar objects on earth, are made up of minerals. The minerals group themselves naturally to form **rocks**, which can be defined as a natural aggregate of one or more minerals to form an appreciable part of the solid portion of the earth. The rocks of the crust are classified into three types according to their origin: igneous rocks, which have solidified from molten rock or magma; metamorphic rocks, that have been changed generally by high temperature and pressure within the crust; and sedimentary rocks, formed at the surface of the crust by deposition and induration. The relative abundance of these three types of rocks in the earth's crust is: igneous–64.7%, metamorphic–27.4%, and sedimentary–7.9%. However, of the rocks exposed to weathering at the surface, 75% are sedimentary rocks.

2.2.1 Igneous rocks

Igneous rocks are formed by solidification of molten material called **magma,** which originates at considerable depth beneath the earth's surface and is forced by great internal pressure to penetrate the solid, brittle, outer crust of the earth. Magma is a natural, moldable, hot melt composed of rock-forming materials (mainly silicates) and some volatiles (mainly steam) that are held in solution by pressure. It may or may not contain suspended solids. If cooling takes place slowly deep beneath the earth's crust, coarse-grained **intrusive** or **plutonic** igneous rocks result. When magma is forced into cooler regions near the surface of earth or erupted as volcanoes, it cools very rapidly and fine-grained rocks or even glass develop. Rocks formed exterior to the crust are termed **extrusive** igneous rocks. Igneous rocks are specified by their texture, mineral content (rather than composition), and origin. Therefore every intrusive rock has a compositionally identical counterpart among the extrusive rocks. Rocks which contain dark-coloured ferromagnes-

Peeling away of outer surface/ layer of rock is called exfoliation.

ium minerals (amphiboles, pyroxenes, biotite, and olivine) are called **basic** or **mafic** rocks. Rocks containing abundant quartz and feldspars are light-coloured, and termed **felsic** or acidic rocks. Ultrabasic (ultramafic) rocks are very dark and usually consist wholly of olivine with perhaps some pyroxene.

The texture of igneous rocks is specified according to the size of the crystals they contain, such as **glassy** (no crystals), **aphanitic** (fine-grained crystals), **phaneritic** (coarse-grained crystals) and **pegmatitic** (crystals over 1 cm). **Porphyritic rocks** are those rocks in which the ground mass has large crystals (phenocrysts), as in porphyritic granite.

Igneous formations. A **formation** is a rock mass that can be described and mapped as a unit, consisting of one or more rock type(s) that are considered together for geologic reasons. Intrusive igneous rock formations are found in all parts of the world including the northern mountains of Pakistan. Intrusive igneous rocks are **discordant** if they cut across the bedding of the rocks they intrude, and **concordant** if they are more or less parallel to beddings. **Batholiths** are very large discordant intrusions, sometimes extending over 100,000 square kilometers. Their slow cooling leads to uniform and moderate grain size; the chief rock is granite. Batholiths form the core of mountain ranges. **Laccoliths** are thick concordant bodies which sometimes force the overlying sediments to arch up forming dome-shaped hills/mountains. **Sills** are thin concordant bodies which do not noticeably deform sedimentary beds. **Dikes** are tabular, discordant bodies ranging in thickness from a few meters to tens of meters. They are much longer (up to several kilometers) than wide, and form ridges when exposed by erosion.

Volcanoes. Present volcanoes are direct evidence for the existence of magma, and provide a way to learn about igneous rock formation. Volcanoes are land forms formed by the cooling of lava at the earth's surface; they are hills or mountains or even plateaus covering thousands of square kilometers. Examples of such plateaus are the Deccan Plateau of India and the Columbia Plateau of the USA. Present-day volcanoes occur in geologically active areas like the rim of the Pacific Ocean, the Mediterranean Sea, and the Mid-Atlantic Ridge.

Pyroclastic rocks include all deposits of fragments thrown out by volcanoes. In the sudden eruption of low viscosity magma, the expanding gases form a froth, resulting in the light, glassy rock **pumice**. Coarse bubble holes result in the rock **scoria**. If the erupted magma is more viscous, sand-sized or smaller particles are called **volcanic ash**; larger pieces are called **volcanic blocks**. Consolidated ash is called **tuff**; a pyroclastic rock with mainly large fragments is called volcanic **breccia**.

Intrusive igneous rocks. Granite is a widely distributed intrusive rock that makes up the cores of many mountain ranges. It is usually light-coloured, formed mainly of potash feldspar, quartz, and usually small amounts of mica and hornblende. It is acidic, having a high proportion of silica.

Granite is coarse-grained, well-jointed, and without bedding. Frost action splits granite into blocks. Its chemical weathering results in granular disintegration. **Diorite** is a dark-coloured rock containing a large proportion of amphiboles and biotite. It is coarse-grained like granite, but its mineralogy is quite different. Quartz is absent or nearly so, and the feldspar is chiefly plagioclase. **Gabbro** consists mainly of plagioclase (labradorite) and pyroxene with some olivine but no quartz. **Norite** is a gabbro with abundant pyroxene and olivine. A gabbro composed almost entirely of anorthite feldspar is termed **anorthosite**. A fine-grained gabbro typical of small intrusives is called **diabase**. Weathering of gabbro results in the formation of clay and iron oxides, with bases released in solution. Other intrusive igneous rocks are: **peridotite**, a dark, heavy rock composed mainly of olivine with pyroxene but little or no feldspar; **granodiorite**, a granitoid rock formed with magma of composition intermediate between granite and diorite; **syenite**, less common than granite, containing mainly potash feldspar with some mica or hornblende.

Extrusive igneous rocks. **Rhyolite** is a light-coloured acidic rock equivalent to granite. If cooling is rapid, rhyolitic lava forms **obsidian**, a glassy textured rock. On weathering, rhyolite gives rise to sand. **Andesite** is the volcanic equivalent of diorite. It contains little quartz but is rich in ferromagnesium minerals, and is therefore dark-coloured. **Dacite** and **trachyte** rocks are the volcanic equivalents of granodiorite and syenite respectively.

Basalt is a fine-grained, dark-coloured rock. It is the most common and widespread volcanic rock and makes up huge volumes of crustal material in regions of extensive lava flows. Basalt is rich in ferrogmagnesium (pyroxenes and amphiboles) and calcic feldspar minerals, and is typically dark-gray, dark-green, or black. As basalt contains no quartz, the final products of weathering are usually clays.

2.2.2 Sedimentary rocks

Sedimentary rocks are composed of particles derived from previously existing rock, then deposited after transportation by streams, waves or tidal currents, wind, or ice. In addition, sediment may result from chemical reaction and precipitation. As the solid particles settle out, a layer is formed. When the size or composition of the particles changes repeatedly, a series of layers of varied types are formed. Because of pressure, compaction, driving out water, and chemical deposits of calcium carbonate or silicon dioxide cementing the particles together, these layers harden with time into rocks. Because of its layered structure, the rock is said to be stratified. Sedimentary rocks can be subdivided into clastics and non-clastics, carbonates, and evaporites.

Clastics consist of particles that are produced by disintegration of pre-existing rocks through the processes of weathering. Transportation by water or wind sorts these particles into various size grades. According to their particle size they can be subdivided as follows. **Conglomerates** contain more or less rounded pebbles or boulders, but with a large portion of sand filling the interstices. These deposits are often lenticular, but may also be uniformly developed over large areas; they are generally associated with sandstones. **Sandstones** are composed of the most resistant remnants of the weathering process, mainly quartz grains mixed with varying amounts of rock fragments and feldspar particles. The grains fall in the range between 2.0 and 0.0625 mm in diameter. When cementation of a sandstone is of such strength that the grains rupture on breaking, it is termed **quartzite**. Sandstones may form sequences of massive beds, which individually can be up to several meters thick; they also occur frequently as thin or thick beds alternating with shales or limestones. **Siltstones** consist of small mineral grains mainly quartz or feldspar, with a diameter between 0.0625 mm and 0.004 mm. **Shales** are compacted clays or muds greatly increased in density and hardness by the pressure of overlying strata. Shale is formed of minute flakes of clay minerals and very fine particles of quartz and feldspar smaller than 0.004 mm, mixed with variable amounts of organic matter and precipitated carbonates or silicates.

Non-clastics are formed by chemical and/or organic processes. They include precipitates, organic deposits, and evaporites. **Carbonates** are limestones and dolomites, the first mainly consisting of **calcite**, the second largely formed by the mineral **dolomite**, which has replaced the calcite. Dolomitic limestones and calcareous dolomite contain mixtures of both minerals. **Organic limestone** is formed for a great part from the limy parts of corals, algae, clams, and snails. The organic origin is obvious where large shell fragments have been cemented into a variety of limestone termed **coquina,** but less obvious if the organisms are extremely tiny or if the hard parts have been finely pulverized. Limestone may also form by direct chemical precipitation from waters of lakes or oceans heavily charged with lime in solution. The soft lime mud thus formed is termed **marl**. The origin of dolomite is not fully understood, but it is thought that perhaps the calcium of pure limestone is gradually replaced by magnesium through the action of seawater or underground water acting over long periods of geologic time. In most limestones, varying proportions of organic, fragmental, and chemical components are mixed, probably together with certain amounts of clay, sand, or silica.

Evaporates are salts that have been precipitated from waters of shallow desert lakes or constricted bays of the ocean, where evaporation of the water is rapid. They are called **anhydrite** (calcium sulphate), **gypsum** (hydrous calcium sulphate), and **rock salt or halite** (sodium chloride).

2.2.3 Metamorphic rocks

Metamorphic rocks are derived from pre-existing igneous or sedimentary rocks by alternations due to the tremendous pressures and high temperatures that accompany mountain-building movements of the earth's crust. These processes result in recrystallization and with increasing intensity also chemical changes. Metamorphic rocks are usually harder and more compact than their original types, except when the latter are igneous rocks. New structures and even new minerals are formed. But they may still show many characteristics of their parent rocks, exhibiting additional features produced by the metamorphic process, such as **cleavage**, **schistosity** or **foliation**, banding, and fracturing.

Metasediments are metamorphic rocks derived from sedimentary strata. **Slates** are metamorphosed shales; they split neatly into thin plates. The planes of splitting form a structure called **shaly cleavage**, which is a new structure and not merely stratification or bedding. Slate rings when sharply struck. **Phyllite** is an even more metamorphosed shale. Here the thin slabs are wavy or curved, and the rock has a satiny sheen on the cleavage surface (light reflection from tiny mica crystals). **Schist** is the most advanced grade of metamorphosed shale. It has a structure called foliation, consisting of thin but rough and irregularly curved planes of parting in the rock, and the mineral grains are coarse in texture. Mica is abundant, and large scattered crystals of new minerals such as **garnet** and **staurolite** are present.

Quartzite is the metamorphic equivalent of conglomerate sandstone and siltstone, formed by the addition of silica (SiO_2) filling the interstices. **Marble**, a white rock of sugary texture when freshly broken, is the metamorphic counterpart of limestone. The limestone has reformed into larger, more uniform crystals. Bedding planes are observed, and masses of mineral impurities are drawn out into swirling streaks and bands.

Gneiss may be formed either from intrusive igneous rocks, or as a metasediment from strata that have been in close contact with intrusive magmas. Gneisses vary considerably in appearance, mineral composition, and structure. Granitic gneiss resembles granite but has a streaked appearance, called **lineation**, produced by parallelism of dark minerals, which have been drawn out into long, pencil-like shapes in the direction of flow. Still other gneisses are strongly banded into light and dark layers or lenses, which may be contorted into wavy folds.

In Pakistan, the following rocks are found over considerable areas.

Igneous rocks:	Granite, granodiorite, diorite, basalt, andesite, rhyolite, gabbro, syenitic basalt, amphibolite, norite
Sedimentary rocks:	Conglomerate, marl, gypsum, dolomite shale, sandstone, limestone, argillite, graywacke, mudstone, siltstone

Metamorphic rocks: Quartzite, slate, schist, gneiss, marble, phyllite, serpentinite

However, the main soil-forming rocks in Pakistan are limestones, calcareous shales and sandstones, granite, and some calcareous slates.