WEATHERING

14.1 MEANING AND CONCEPT

The process of disintegration and decomposition of rocks in situ is generally called weathering. It means weathering is a static process. According to C.D. Ollier (1969) "weathering is the breakdown and alteration of minerals near the earth's surface to products that are more in equilibrium with newly imposed physico-chemical conditions." According to P. Reiche (1950) "weathering is the response of minerals which were in equilibrium within the lithosphere to conditions at or near its contact with the atmosphere, the hydrosphere, and perhaps still more importantly, the bisophere." It may be pointed out that rocks are never in permanent equilibrium rather they are in equilibrium only momentarily and thus W.D. Keller (1957) has pleaded for the deletion of 'which were in equilibrium' from Reiche's above definition of weathering. B.B. Polynov (1937) has very precisely defined weathering as "the change of rocks from the massive to the clastic state."

Arthur Holmes has presented more elaborate definition of weathering which also includes the processes of weathering. According to him "weathering is the total effect of all the various subaerial processes that cooperate in bringing about the decay and disintegration of rocks, provided that no large-scale transport of the loosened products is involved. The work of rainwash and wind, which is essentially erosional, is thus excluded" (A. Holmes, 1952).

It appears from the above definitions that weathering is essentially the breakdown of rocks due to chemical and mechanical processes at their places. The definition of weathering by B.W. Sparks highlights the above facts. According to him, "weathering may be defined as the mechanical fracturing or chemical decomposition of rocks by natural agents at the surface of the earth."

It is obvious that weathering involves two types of changes in the rocks e.g. (i) **physical or mechanical changes**, wherein rocks are disintegrated through temperature changes (heat factor), frost-action (frost factor), biological activities (biotic factor), and wind actions; (ii) **chemical changes** wherein rocks **are decomposed** through static water, oxygen, carbon dioxide and biological activities. Secondly, the breakdown of rocks occurs at the place of rocks (in situ). Thirdly, there is no large-scale transport of weathered materials except mass movement or masstranslocation of weathered materials (rock-wastes) down the slope under the force of gravity. Weathering, thus, may be defined so as to include all aspects of the mechanism of breakdown of rocks as follows.

"Weathering refers to the breakdown or disintegration and decomposition of rocks in situ through mechanical and chemical changes in the rocks and their minerals effected by water, temperature, wind, different atmospheric gases and organisms provided that there is no large-scale transport of weathered products by denudational processes except mass movement of rockwastes (weathered products) down the slope under the impact of gravity "- Savindra Singh.

14.2 CONTROLLING FACTORS OF WEATHERING

The nature and magnitude of weathering differs from place to place and region to region. Weathering of rocks is affected and controlled by the agents of weathering, lithological and structural characteristics of rocks, height and slope factors. Besides, climatic conditions, topography and reliefs, flora and microfauna also affect different processes of weathering to greater extent. For example, disintegration of rocks is more effective in hot and dry region and in the regions where frost action is more dominant while chemical decomposition is more prevalent in hot and humid and temperate humid regions.

1. Composition and Structure of Rocks

Since weathering involves disintegration and decomposition of rocks and hence mineral composition, joint patterns, layering system, faulting, folding etc. largely affect the nature and intensity of weathering. For example, carbonate rocks (e.g. calcium carbonate, magnesium carbonate etc.) having more soluble minerals are easily affected by chemical weathering. Well jointed rocks are more subjected to mechanical disintegration. Rocks having vertical strata are easily loosened and broken down due to temperature changes, frost action, water and wind actions. On the other hand, the rocks having horizontal beds are more compact and are less affected by the mechanisms of disintegration and decomposition.

2. Nature of Ground Slope

Ground slope controls mechanical disintegration of rocks and mass movement of weathered products down the slope. The rocks in the regions of steep hillslope are easily disintegrated due to mechanical weathering and the weathering materials are instantaneously moved down the hillslope in the form of rockfall, debris fall and slide, talus creep etc. Instantaneous removal of weathering products allows continuous exposure of rocks to atmospheric conditions for further weathering. The regions of gentle and moderate ground slope are less affected by mechanical disintegration.

3. Climatic Variations

Climate is considered to be very important factor of all types of weathering. Climatic geomorphologists are of the view that each climatic type produces definite conditions for a particular type of weathering. For example, chemical weathering is more dominant in humid tropical areas because of more available water and high temperature. Because of abundance of moisture and high temperature **leaching process** and solution of rocks are more effective in the humid tropics. Mechanical weathering is less effective. On the other hand, mechanical disintegration of ricks is more dominant in the tropical and semi-arid regions. Rocks are weakened due to alternate expansion on heating during daytime and contraction on relative cooling during nights because of diurnal change of temperature. It may be pointed out that limestones are very weak rocks in humid climatic regions but they are relatively more resistant to weathering and erosion in hot desert climate. The rocks in dry temperate climates are more susceptible to mechanical weathering than chemical weathering because alternate expansion and contraction of cracks, fractures and joints of rocks due to alternate freeze and thaw of water accumulated in these cracks and fractures weaken the rocks. Rocks are least affected by mechanical disintegration in cold climate but chemical decomposition of rocks may be effective provided that the ground surface is not covered by ice cover for longer duration in a year. Both, mechanical and chemical weathering cease when the ground surface is covered by permanent ice sheets. Not only this, seasonal variations in climate of a region generate different conditions for weathering. For example, in monsoon climate rocks are subjected to mechanical disintegration during hot and dry summer months whereas chemical and biochemical weathering is more dominant during wet monsoon months.

4. Floral Effects

The nature of weathering is largely determined by the presence or absence of vegetations in a particular region. It may be pointed out that vegetation is partly a factor of weathering and partly a protector of rocks. In fact, vegetations bind the rocks through their network of roots and thus protect them from weathering and erosion but the same time the penetration of roots weakens the rocks by breaking them into several blocks. Dense vegetations protect the ground surface from the direct impact of sun rays. The micro-organisms associated with the roots of plants and trees encourage decomposition and disintegration of rocks through physico-biochemical weathering.

14.3 Types of Weathering Processes

Generally, weathering processes are conveniently divided into physical, chemical and biochemical processes but these are so intimately interrelated that it is practically difficult to isolate one process from the other. In fact, "no chemical weathering takes place without the production of physical stresses; disintegration of rock by thermal expansion probably does not occur in the absence of the chemical process associated with the presence of water; in the country of even sparsest vegetation chemical weathering is replaced in part by biochemical (process)" (R.J. Chorley, et al. 1985). Inspite of this limitation one has to divide weathering into physical weathering, chemical weathering and biochemical weathering on the basis of dominant agent of weathering and weathering process. The **weathering agents** are divided into 3 types as follows.

1. Physical or mechanical weathering agents

(i) Moisture and water
(ii) Frost
(iii) Insolation (temperature)
(iv) Wind

2. Chemical weathering agents

(i) Oxygen
(ii) Carbon dioxide
(iii) Hydrogen

3. Biological weathering agents

(i) Vegetation
(ii) Animals, mainly micro-organisms

Thus, weathering processes or simply weatherings are divided, on the basis of weathering agents, into 3 major types.

1. Physical or mechanical weathering

(i) Block disintegration due to temperature
(ii) Granular disintegration due to temperature
(iii) Block disintegration due to frost
(iv) Exfoliation or onion weathering due to temperature and wind

2. Chemical weathering

(i) Oxidation
(ii) Carbonation
(iii) Solution
(iv) Hydration
(v) Chelation
(vi) Hydrolysis

3. Biotic weathering and biochemical weathering

(i) Plant weathering
(ii) Animal weathering
(iii) Biochemical weathering
(iv) Anthropogenic weathering

Physical Weathering

The physical or mechanical weathering leads to fragmentation and breakdown of rock masses into big blocks and boulders, cobbles and pebbles, sands and silts and feldspar and mica minerals are chemically decomposed and clay is formed. Physical weathering may be defined as the disintegration of rocks due to temperature variations, frost action, wind action and unloading of confining superincumbent pressure. Though temperature variation is a key factor in physical weathering but pressure release, freeze and thaw of water and gravity also play major roles.

1. Block disintegration due to temperature change- Temperature changes have been reported to have great impact upon many rocks but there are also some rocks which are least affected by temperature changes such as clastic sedimentary rocks (e.g. shales and sandstones) because the particles are separated by thin cementing laminae of silica. On the other hand, crystalline rocks, like granites, are more affected by temperature changes as particles are closely associated with each other and these particles expand and contract with increase and decrease of temperature respectively. It has been experimentally demonstrated that if the temperature of granite rocks is increased by 65.5°C, the rock contracts by 2.54 cm per 30.48 m distance. Contrary to this Black Welder in 1925 found no impact of temperature change on granite when he dropped granitic blocks into hot oil at the temperature of 200°C. It may be pointed out that contrasting results have been reported about the impact of temperature changes on the rocks.

The products of weathering in hot desert areas are different from those of more humid areas as they are coarser and deficient in clay and organic matter. Generally, it is accepted that the bare rock surfaces are heated during day time due to which their outer layers expand. During nights the rocks are cooled due to relative decrease in temperature which leads to contraction in the outer layer of the rocks. Thus, the repetition of expansion and contraction of outer rock layers due to diurnal range of temperature in the hot desert areas causes tension and stresses which introduce parallel joints in the rocks. The rocks, then, are disintegrated along these joints and broken big blocks of rocks are dislodged from the main rock mass and fall down the slope under the impact of gravity. This process of physical weathering is called **block disintegration.** It may be pointed out that block disintegration should not be considered as the result of only temperature changes, rather unloading of superincumbent load or release of confining pressure also helps in this process.

2. Granular disintegration due to temperature changes - The coarse-grained rocks are more affected by shattering process in those hot deserts which are characterized by high range of daily temperature. If the rocks are coarse-grained and are of different colours, they absorb insolation differently. Thus, the different parts of the same rock mass receive and absorb different amount of insolation, consequently the different parts of the rocks are affected by differential expansion and contraction which cause stresses within the rocks due to which they are disintegrated into smaller particles. Such type of shattering of rocks is called granular disintegration which is more active in hot desert areas.

3. Shattering due to rain shower and heat- The outer shells of the rocks are shattered due to sudden light showers in hot climatic regions mainly in hot desert areas. Griggs has remarked after experiments that small cracks are developed at the outer surface of the highly heated rocks when light drizzles suddenly strike them. It may be mentioned that Griggs' experiments involving purely thermal changes equivalent to diurnal change of 110°C over 244 years could not produce any change in the rock strength and thus could not cause any disintegration of rocks. In another experiment Griggs used water sprinkles to cool highly heated rocks instead of reducing the temperature. The result was imminent as the rocks developed cracks and surface spalling. This process works when there is sudden light showers in the hot desert areas. The highly heated rocks when struck by sudden drizzles develop numerous cracks. The repetition of this mechanism causes **spalling** and granular disintegration of rocks.

4. Block disintegration due to frost- Disintegration of rocks into large size blocks due to freeze and thaw of water is of common occurrence in the temperate and cold climatic regions. In fact, this process is more active in those areas which are very often characterized by alternate process of freezing and thawing of water mainly during night and day respectively. Frost action weakens the rocks in two ways e.g. (i) due to freeze and thaw of water between the particles of the rocks and (ii) due to freeze and thaw of water in the crevices and pore spaces. The more compact and highly consolidated rocks, like granites, are least affected by freeze-thaw actions while less compact and loosely consolidated rocks are more affected by frost actions, for example, sedimentary rocks being more porous are highly susceptible to the mechanism of weathering. Water present between the particles of porous rocks freezes during night due to fall of temperature below freezing point and thus expands due to increase in its volume by about 10 per cent and thaws during day time due to relative increase in the temperature and hence it contracts in volume by 10 per cent. This diurnal freeze and thaw cycle causes alternate expansion and contraction which introduce tension and stresses due to which rocks are disintegrated into smaller particles. This process, known as **granular disintegration due to frost action,** is an exceedingly slow process and rocks are least affected by this process.

Alternatively, alternate expansion and contraction of crevices, pores and cracks in the rocks due to diurnal freeze and thaw of water causes block disintegration of rocks wherein rocks are broken down into larger blocks which are dislodged from the main rock mass. When such process operates over the hillslopes of well jointed massive rocks, the dislodged rock blocks tumble down the slope in the form of rockslides and rock falls and collect at the base of the hillslopes.

The disintegration of rocks due to diurnal freeze-thaw cycles in the **periglacial areas** is called **frost weathering** or **congelifraction** which forms very interesting landforms like frostriven polygons.

5. Exfoliation due to temperature and wind- Exfoliation weathering, also known as **onion weathering,** refers to peeling off concentric shells of rocks due to combined actions of heat and wind in hot arid and semi-arid regions and monsoon lands. Exfoliation is more common over crystalline rocks. The outer shells of rocks become loose due to alternate expansion and contraction due to high temperature during day time and comparatively low temperature during night respectively and these loosened shells are removed (peeled off) by strong winds. Differential heating of outer and lower shells of a rock mass causes **flaking.** The solar radiation penetrates upto a few centimetres only in the rocks having low thermal conductivity. Thus, the outer shells of such rocks expand more than the shells lying just below. This differential expansion of rock shells causes flaking wherein the thin rock sheets are detached from the rock mass. These detached rock sheets are later on removed by strong winds. Thus, sheets after sheets of rocks are peeled off and the rocks continue to be bare. Many of the granitic batholiths, which are exposed above the ground surface, are being continuously affected by exfoliation weathering. **Kanke Dome** near Ranchi city exhibits a fine example of such weathering process.

6. Disintegration and exfoliation due to unloading- The rocks, which are buried under thick covers of overlying rocks, are disintegrated when they are exposed to the surface due to removal of superincumbent load and consequent release of confining pressure. The removal of superincumbent load, very precisely known as **unloading,** may be effected through gradual denudation of overlying rocks. In fact, the burried rocks, when relieved of the confining pressure due to unloading, develop cracks and joints and ultimately breakup along these cracks and joints. Granites, massive sandstones, massive arkose, conglomerates and limestones are more affected by **sheeting, spalling** and block disintegration due to reduction in the confining pressure because of removal of superincumbent load by uplift and erosion.

Sheeting refers to the development of cracks and fractures parallel to the ground surface caused by removal of superincumbent load resulting into reduction of confining pressure. Such parallel cracks and fractures are developed in massive rocks such as granites and other igneous intrusives, quartzites and thickly bedded sandstones because of expansion of rocks consequent upon unloading of superincumbent load. R.H. Jahns (1943) has enumerated seven processes which cause sheeting in the rocks-

(i) Tensional or contractional strains set up during cooling of an igneous mass,

(ii) Local or regional compressional stresses due to tectonic movements,

(iii) Insolation, with attendant daily and secular temperature changes,

(iv) Progressive hydration and formation of chemical alteration products in susceptible minerals,

(v) Mechanical action of fire, frost, and vegetation,

(vi) Diminution of primary confining pressure by removal of superincumbent load, and

(vii) Combinations of the above causes.

Cambering process refers to fracturing of brittle sandstone beds along vertical joints due to expansion caused by unloading of superincumbent load and consequent release of confining pressure. G.W. Bain (1931) has reported the case of flying rock-sheets or spalls known as rockbursts in limestone quarries due to spontaneous mechanical rock expansion caused by unloading of superincumbent load. "As new faces are cut in the walls of (limestone) quarries the dense limestone expands, producing cracks parallel to the surface. In some instances quarries had to be closed down because of the danger of flying rock sheets or spalls" (C.D. Ollier, 1969).

The process of **spalling** refers to the development of platy rock fragments, lozenge shaped or irregular, in the rocks due to unloading of superincumbent load.

7. Other types of physical weathering-Boulder cleaving refers to breaking and splitting of boulders of granites and basalts and complex boulders due to **thermal expansion.** Another type of **insolation weathering** is **'dirt cracking'** wherein the boulders containing **'dirt'** are fractured and split due to thermal expansion and contraction. Fire, mainly **brushfire,** also causes insolation weathering due to thermal expansion and contraction of rocks which cause exfoliation and thus numerous spalls and flakes of rocks are produced. **Slaking weathering** refers to the disintegration of rocks due to alternate wetting and drying of rocks wherein consequent expansion and contraction of rock shells result in the disaggregation of rocks. Disaggregation of rocks due to growth of salt crystals from solution is called **salt weathering** which generally occurs in hot arid areas. It may also be important in the rocks of coastal areas.

Chemical Weathering

Decomposition and disintegration of rocks due to chemical reactions is called chemical weathering wherein the minerals of the rocks weather away. Water vapour and water are the media which activate several types of chemical reactions within the rocks. Pure water, distilled water, is chemically inert but when it mixes with the atmospheric gases, mainly with CO_2, it becomes potent solvent. **Oxidation, carbonation, solution, hydration, chelation, hydrolysis, base exchange** etc. are the important chemical reactions which cause various chemical changes in the minerals of rocks which ultimately lead to decomposition and disintegration of rocks.

1. Solution- Solution is considered to be the first step in the chemical decomposition and disintegration of rocks. Solution refers to the dissolution of soluble particles and minerals from the rocks with the help of water in motion but a thin film of water around a solid particle also leads to chemical dissolution. Solution of rocks depends on the nature of rocks, solubility of rocks or solids and the ratio between the volumes of solvent (water) and the solids. Common salts are most soluble whereas carbonate rocks (limestones-calcium carbonates, dolomites-magnesium carbonates etc.) are of moderate solubility.

Limestones are more susceptible to solution process which depends on temperature, CO_2 (carbon dioxide) content of water and pH of the solution. When rainwater mixes with atmospheric CO_2 it becomes active solvent and when it comes in contact with the carbonate rocks, such as limestones and dolomites, it dissolves the rocks through a set of chemical reactions occurring through various stages. The various stages of the chemistry of limestone solution may be presented in a simplified form as follows.

According to R.M. Garrels (1960) there are seven variables which control the equilibria involved in the solution of limestones-

(i) Partial pressure of CO_2

(ii) $[H_2CO_3]$... carbonic acid

(iii) $\left[HCO_3^-\right]$ ...bicarbonate ion

(iv) $\left[CO_3^{2-}\right]$...carbonate anion

(v) $[H^+]$... hydrogen ion

(vi) $[OH^-]$...hydroxyl ion

(vii) $[Ca^{2+}]$...calcium cation

Calcium hydroxide, $Ca(OH)_2$, is formed due to reaction of calcium oxides (CaO) with water (H_2O) in the following manner of reversible exothermic reaction-

$$CaO + H_2O = Ca\,(OH)_2 \text{ ....eq. 14.1}$$

Calcium carbonates, $CaCO_3$, is formed due to reactions of calcium hydroxide ($Ca\,(OH)_2$) with carbon dioxide (CO_2) in the following manner of reversible exothermic reactions-

$$Ca\,(OH)_2 + CO_2 \leftrightarrow CaCO_3 + H_2O \text{...eq 14.2}$$

Carbonic acid (H_2CO_3) is formed when CO_2 is dissolved in water -

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \text{ .... eq. 14.3}$$

Carbonic acid is also dissociated into positive hydrogen ion and negative bicarbonate ion -

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^- \text{ ....eq. 14.4}$$

Calcium carbonate (limestones) dissociates to limited extent in pure water into a metal cation (Ca^{2+}) and carbonate anion (CO_3^{2-}) during the process of dissolution in the following manner -

$$CaCO_3 \xrightarrow{\text{dissociation}} Ca^{2+} + CO_3^{2-} \text{...... eq. 14.5}$$

It may be pointed out that limestone can be dissolved in water only when it is transformed into calcium bicarbonate, Ca $(HCO_3)_2$, with help of carbonic acid (H_2CO_3) as follows—

$$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2 \text{ ...eq 14.6}$$

or

$$CaCO_3 + H_2CO_3 \rightarrow Ca\,(HCO_3)_2$$

The carbonate ion (CO_3^{2-}) can react with water when it accepts proton from acid and then the carbonate becomes base (which accepts the proton). The ultimate reactions yield hydroxyl ions and thus the calcium carbonate becomes an alkaline substance as follows-

$$CO_3^{2-} + H_2O \xrightarrow{\text{hydrolysis}} HCO^-_3 + OH^- \text{...eq 14.7}$$

The actual quantity of limestone dissolved in water depends on temperature, CO_2 content of water, partial pressure of CO_2, pH of the solution and kinetics of reactions. The solubility of CO_2 is directly related to pressure (partial pressure) and is inversely related to temperature. In other words, the solubility of CO_2 increases and decreases with increase and decrease of partial pressure whereas it (solubility of CO_2) increases with decrease in the temperature and vice versa. On the other hand, the solubility of solids (say limestones) is directly related to temperature i.e. total solution of limestone in creases with increase in temperature and vice versa. More and more limestones can be dissolved in water either by increasing the temperature or CO_2 content of water or by decreasing the pH of the solution. The solution of limestoens and dolomites gives birth to very interesting landscapes known as **karst topography** characterized by various solution holes (sink holes, swallow holes, uvalas, dolines and polje) and various types of caves and galleries.

2. Oxidation - The chemical process of oxidation simply means a reaction of atmospheric oxygen to form oxides. When water is mixed with oxygen its reaction with the minerals of the rocks forms hydroxide. In other words, the atmospheric oxygen after reacting with the rocks produces several types of oxides, iron oxide being the most important, which weakens the rocks to disintegrate. The oxidation of minerals of the rocks by gaseous oxygen becomes possible when oxygen is dissolved in water. Most of the iron bearing rocks commonly contain iron in ferrous state (Fe) e.g. major ironsulphide (pyrite, FeS_2), iron carbonate (siderite, $FeCO_3$), and various iron silicates.

When water mixed with atmospheric oxygen comes in contact with iron bearing rocks, the iron oxidizes to form ferrous oxides (FeO). Further oxidation of ferrous oxides produces ferric oxides (Fe_2O_3) or ferric hydroxides $(Fe(OH)_3)$. The oxidation of iron-bearing rocks reproduces rusts in the following manner-

$$Fe + H_2O + O_2 \rightarrow Fe_2O_3.3H_2O \text{......eq 14.8}$$

(rust)

The rusting of rocks weakens them and ultimately the rocks are disintegrated. The ferric oxides and ferric hydroxides give red and yellow colours to many rocks and soils. The oxidation of iron-rich Vindhyan sandstones of the Kaimur Ranges and Rewa scarps (M.P.) has helped in the block disintegration of massively bedded and well jointed sandstone capping.

3. Carbonation- 'Carbonation is the reaction of carbonate or bicarbonate ions with minerals'. The process of carbonation is also known as **'solution'** wherein atmospheric carbon dioxide after mixing with water forms carbonic acid (H_2CO_3, see equation 14.3) which after reacting with carbonate rocks, say limestones $(CaCO_3)$, forms calcium bicarbonate $(Ca(HCO_3)_2)$ (see equation 14.6) which is easily dissolved in water. The mechanism of solution of carbonate rocks has already been discussed above. The rainwater having dissolved carbon dioxide (Co_2 aq) percolates through the different horizons of the soils to reach underlying limestones. Thus, more and more organic carbon dioxide is dissolved in groundwater which then becomes a more active solvent because dissolution of more carbon dioxide produces more carbonic acids which dissolve more carbonate rocks after transforming calcium carbonates into calcium bicarbonates.

4. Hydration-The process of hydration is related to the addition of water to the minerals. The rocks after having absorbed water undergo the process of positive change of their volume. In other words, the volume of the hydrated rocks (rocks which have absorbed water) increases remarkably. Some times, the increased volume becomes about twice the original volume. Thus, the increase in the volume of rocks due to increase in the volume of minerals causes stresses and strains in the minerals of the rocks which ultimately lead to physical disintegration of rocks. "Hydration is an exothermic reaction, and involves a considerable volume change which may be important in physical weathering-exfoliation and granular disintegration. Hydration prepares mineral surfaces for further alteration by oxidation and carbonation, and enables the transfer of ions to take place with greater ease" (C.D. Ollier, 1969). The process of hydration changes feldspar minerals into kaolinite clays, the process being known as **'kaolinization'**.

5. **Hydrolysis** - "Hydrolysis is a chemical reaction between mineral and water, that is between hydrogen (H) ions or hydroxyl (OH) ions, and the ions of the mineral" (C.D. Olier, 1969). In fact, the hydrolysis is that process wherein both the minerals of the rocks and water molecules decompose and react in such a way that new mineral compounds are formed. Silicate minerals are most affected by hydrolysis. This reaction starts immediately when a mineral comes in contact with water. The hydrolysis of magnesium silicate minerals (Mg_2SiO_4) in contact with 4 ionized water molecules ($4\ H_2O \rightarrow 4H^+ + 4OH^-$) takes place in the following manner-

$$Mg_2SiO_4 + 4H^+ + 4OH^- \xrightarrow{\text{hydrolysis}} 2Mg^{++} + 4OH^-$$
$$+ H_4SiO_4 \text{ (silica acid in solution)}$$

Hydrolysis of potassium feldspar (orthoclase, $2\ KAlSi_3O_2$) with carbonic acid (H_2CO_3) in water is perhaps the most common type of chemical weathering process wherein the end product of the reaction of potassium feldspar with carbonic acid in water is potassium and bicarbonate ions in solution. The mechanism of the hydrolysis of potassium feldspar is given below -

$$2KAlSi_3O_2 + H_2CO_3 + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 +$$

orthoclase + carbonic acid + water kaolinite, a clay mineral

$$4H_4SiO_4 + 2K^+ + 2HCO_3^-$$

silicic acid in solution + potassium and bicarbonate ions in solution

6. **Chelation**- According to D.S. Lehman (1963) "chelation is a complex organic process by which metallic cations are incorporated into hydrocarbon molecules". In fact, the word **'chelate'** means a co-ordination compound in which a central metallic ion is attached to an organic molecule at two or more positions. In other words, chelation means 'holding of an ion, usually a metal, within a ring structure of organic origin' (C.D. Ollier, 1969). We may safely say that chelation is a form of chemical weathering by plants. Plants extract minerals or say nutrients from the soils with the result mineral lattices are disrupted and crystal lattices are fragmented and thus mineral weathering takes place at a much faster rate.

The products of chemical weathering are classed under three categories.

(i) Solutes of sodium, potassium, calcium, magnesium etc. produced by the process of carbonation or solution of carbonate rocks, which are brought to the lakes and seas and are reprecipitated to form limestones, dolomites and other carbonate rocks.

(ii) Clays, derived from the weathering of feldspar and ferromagnesian minerals, form argillaceous sedimentary rocks like shales.

(iii) Mineral residuals, such as silica, unweathered feldspar and mica and other heavy minerals, form clastic sedimentary rocks such as sandstones.

Biotic Weathering

Plants and animals including man largely control the breakdown of rocks. It may be pointed out that in all types of weathering in all climatic regions biotic communities play some roles in one way or the other. This is why B.B. Polynov (1937) believed that completely **sterile weathering** was impossible. It may be mentioned that it does not mean that biotic communities always indulge in destructive work by disintegrating and decomposing the rocks but the burrowing animals definitely help in the transfer of soils from lower to upper and upper to lower horizons and thus the mixing of geomaterials activates weathering. Though vegetations protect the rocks by binding them through their roots but different types of acids (e.g. humic acids, bacterial acids, micro floral acids etc.) produced by them facilitate **biochemical weathering.** Recently, man has become the most powerful weathering agent because of the development of modern technologies. Biotic weathering, thus, is divided into 3 types e.g. (i) **faunal weathering**, (ii) **floral weatheirng** and (iii) **anthropogenic weathering**.

1. Faunal Weathering- The burrowing animals, worms and other organisms help in gradual breakdown of rocks or fragments thereof. Burrowing animals include gophers, prairie dogs, foxes, rabbits, jackals, termites, rats etc. which dug out burrows and tunnels in the rocks and unconsolidated geomaterials as their living places (homes). By doing so they weather the rocks and geomaterials to great extent. Small organisms play more important roles in rock and soil weathering. These organisms repeatedly mix up the soil materials and thus always expose fresh materials to weathering agents. They also help in moving the organic matter downward into the soil profiles and thus extend the weathering at greater depths which otherwise would have not been possible.

It is believed that there are about 1,50,000 creatures, big and small, in one acre of land and these organisms bring about 15 tonnes of soils at the surface from below every year. According to the estimate of Charles Darwin the soil organisms bring about 25.4 thousand kilograms of soil at the surface every year in the English gardens. Termites play very important role in sorting and rearranging the soil materials in the upper horizons of soil profiles in tropical regions. Termitaria are the evidences of soil weathering by termites. According to Ponomareva (1950) earthworms burrow to about 1.5 m and pass 10 tons per acre per year as a mean and 20 tons per acre per year as a maximum of soil materials. Rabbits, prairie dogs etc. destroy the soil structure and they obstruct the leaching and other horizon forming processes by constantly remixing the soil materials.

2. Floral Weathering- Weathering of rocks by vegetations takes place in two ways viz. (i) physical weathering and (ii) chemical weathering which is called as **biochemical weathering**, which will he discussed under separate heading. It may be pointed out that floral weathering does not take place independently rather it helps the physical and chemical processes of weathering. Larger plants affect and control weathering in a number of ways. (i) Cracks are widened by root penetration and consequent root pressure. (ii) Dense vegetation cover generates distinct microclimate at the ground surface. The soil atmosphere is largely affected by root respiration, humus content, increased moisture due to low rate of evaporation, increased content of organic CO_2, low temperature, all of which activate chemical weathering. It may also be mentioned that vegetations also protect the rocks and soils from weathering processes.

3. Anthropogenic Weathering- Man being a biological agent accelerates and decelerates the natural rates of weathering by many folds. The '**economic and technological man**' lashed with modern technologies has become the most powerful weathering and erosion agent. Mining activities for extraction of minerals, blasting of hills and ridges by dynamites for road and dam construction and mineral extraction, quarrying for industrial (limestones for cement) and building material etc. result in such a fast rate of disintegration of geomaterials (rocks) that this may be accomplished by natural weathering processes in thousands to millions of years. Man accelerates the rate of weathering on hillslopes by modifying the ground surface through deforestation which reduces the mechanical reinforcement and cohesion of unconsolidated geomaterials and thus increases slope instability which causes slope failures and mass movement of materials down the slope in the form of landslides, slumping and debris fall and slides.

Biochemical Weathering

Biochemical weathering refers to decomposition and disintegration of rocks due to organic materials of both flora and fauna. A complex set of different biochemical processes such as **cation root exchange, chelation,** solution by root exudates and production of different kinds of organic acids such as humic acids, baterial acids, microfaunal acids etc. produced by organic materials help in the decomposition and disintegration of rocks and soils.

Humic acids activate **chelation** and help in the decomposition of silicate minerals. **Fulvic acids**, humic acids derived from peat, play important role in decomposing rock minerals. Bacterial acids, including lactic, acetic, oxalic and gluconic, attack a wide range of rock minerals important being magnesium carbonate, calcium and magnesium silicates, feldspar and kaolinites. Bacterial acids also produce sulphides, oxidize iron and help in the solution of silica when the rocks are constantly submerged under water (perpetual waterlogging). **Microfaunal acids** such as oxalic and citric acids are produced by fungi and lichens. These acids weather silicate minerals and clays.

Chemotrophic bacteria manufacture sulphides and remove silica in the tropical soils and help in the carbonate mineralization in caves. The colonization by blue-green algae forms **desert varnish** and mobilizes ferrous irons and help in the concentration of oxides on rock surfaces. Microorganisms also form **varnish incrustations** on rocks. Lichens introduce the alteration of minerals composition of rocks both mechanically and chemically. The organic carbon dioxide produced by plants accelerates the rate of carbonation on carbonate-rocks e.g. limestones and dolomites.

14.4 GEOMORPHIC IMPORTANCE OF WEATHERING

1. **Production of rockwastes**—Rocks are disintegrated and decomposed and ultimately are broken down into smaller pieces due to the operation of different weathering, chemical weathering, biotic weathering and biochemical weathering. Thus, different weathering processes produce immense volume of rockwastes or weathered materials. These weathered materials lying over the unweathered fresh rocks are called regoliths. The depth of weathered rocks from the ground surface to the unweathered fresh rocks is called **weathering zone.** The depth of weathering zones varies from place to place and from region to region depending mainly on the depth of water table of groundwater and the duration of weathering. The weathered materials are very important economically because they help in the process of soil formation, they expose minerals etc. Weathering generates mass movement of rockwastes down the hillslope and thus causes damage to human settlements in the foothill zones, causes obstructions in the river flow and thus forms lakes (by damming the rivers through debris fall).

2. **Weathering helps erosional processes**—Weathering loosens the rocks by disintegrating and decomposing them and thus paves the way for erosional processes to operate easily. Different agents of erosion like running water (rivers) in humid regions, wind in hot arid and semi-arid regions, glaciers in cold regions and sea waves operating along coastal zones obtain these weathered materials and move them to other places. The rapid rate of weathering due to mass felling of trees (deforestation) has accelerated the rate of erosion of nude rocks of the hill ranges with the result most of the rivers have become overloaded and sluggish because millions of tonnes of eroded sediments are reaching the major rivers every year. For example, Garhwal and Kumaun Himalayas and other parts of the Himalayas have been extensively deforested and thus the weathered rocks have increased the rate of fluvial erosion, consequently most of the Himalayan rivers like the Yamuna, the Ganga, the Ghaghra, the Kosi etc. have become overloaded in the plains due to supply of huge volume of sediments every year. This process has caused rapid rate of siltation of river beds of major alluvial rivers of north India and the resultant siltation has increased the frequency and dimension of recurring floods.

3. **Lowering of surface**—Continuous removal and transfer of weathered materials through different processes of masstranslocation of rockwastes such as landslides, debris slides, rockfall, rockslides, talus creep etc. and by the agents of erosion causes gradual lowering of the height of the affected area.

4. **Evolution of landforms and their modifications**—Differential weathering helps in the evolution of different types of landforms. Weathering plays important role in the development of stone lattice (in hot deserts), tors, buttes, talus cones, talus fans, sandstone anvils etc. It may be pointed out that weathering and erosion go hand in hand and thus it is not wise to separate the inseparable, so it is difficult to ascertain the quantum of work done by weathering and erosion in the development of a particular type of landform.