WEATHERING PROCESSES AS AN AGENT OF DENUDATION

The term denudation means the exposure of underlying rocks due to the removal of the materials on the surface of the earth. All the external forces such as sun, wind, frost, running water, glacier and sea disintegrate the rocks into the smaller pieces. The upper layer of the rocks is removed exposing the underlying surface. The process of denudation is divided into three types according to the factors affecting the disintegrating rock:

1. Weathering
2. Erosion
3. Mass Wasting/ Movement

WEATHERING

"The process of mechanical disintegration and/or chemical decomposition of rocks that destroys their coherence and breaks them into smaller components / fragments is called weathering".

Weathering is the decomposition of rocks, soils and their minerals through direct contact with the Earth's atmosphere. Weathering occurs in situ, or "with no movement", and thus should not to be confused with erosion, which involves the movement and disintegration of rocks and minerals by agents such as water, ice, wind and gravity.

The materials left over after the rock breaks down combined with organic material creates soil. The mineral content of the soil is determined by the parent material, thus a soil derived from a single rock type can often be deficient in one or more minerals for good fertility, while a soil weathered from a mix of rock types (as in glacial, eolian or alluvial sediments) often makes more fertile soil.

TYPES OF WEATHERING

(a) Physical / Mechanical Weathering

"Mechanical weathering involves the physical disintegration of rock material without any change in its chemical composition".

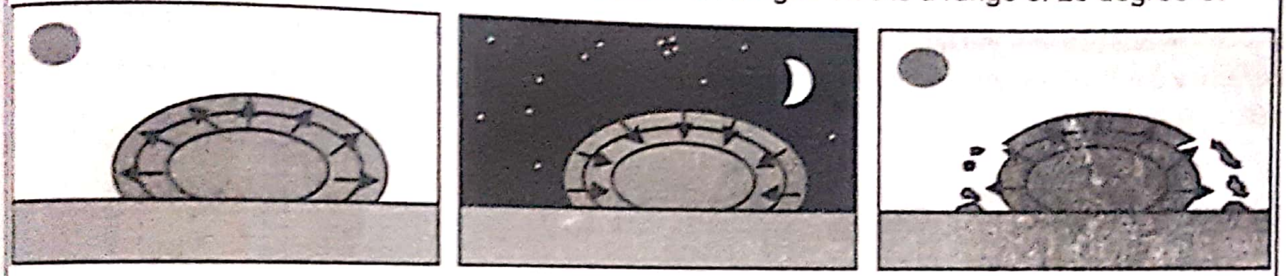
Mechanical weathering is the cause of the disintegration of rocks. The primary process in mechanical weathering is abrasion - the process by which clasts and other particles are reduced in size. However, chemical and physical weathering often goes hand in hand. For example, cracks exploited by mechanical weathering will increase the surface area exposed to chemical action. Furthermore, the chemical action at minerals in cracks can aid the disintegration process.

MODES OF MECHANICAL WEATHERING

1. Thermal Expansion/Insolation

Thermal expansion, also known as onion-skin weathering, exfoliation, insolation weathering or thermal shock, often occurs in areas like deserts, where there is a large diurnal temperature range. The temperatures soar high in the day, while dipping greatly at night. As the rock heats up and expands by day, and cools and contracts by night, stress is often exerted on the outer layers. The stress causes the peeling off of the outer layers of rocks in thin sheets. Though this is caused mainly by temperature changes, thermal expansion is enhanced by the presence of moisture.

In deserts such as the Sahara there is a great diurnal (daily) range of temperature from 35 degrees C during the day to about 10 degrees C at night. This is a range of 25 degree C.



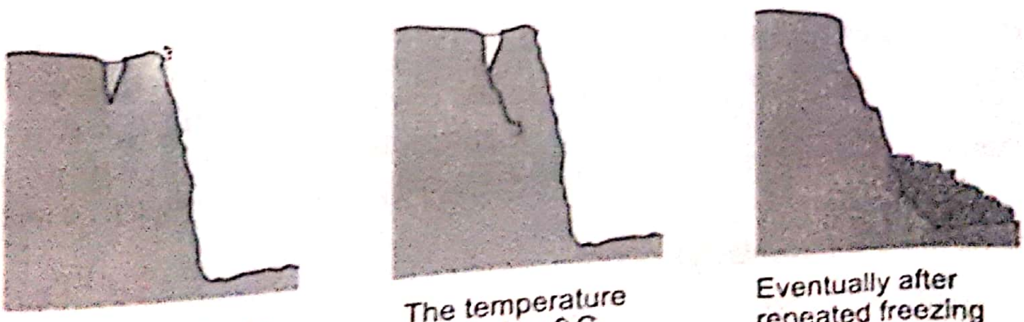
During the day the sun heats up the surface layers of the rock and they expand which forces them outwards

At night the rock cools down and the surface layers contract and are pulled inwards.

After many daily cycles of expansion and contraction the surface layer eventually breaks up and thin layers of rock peel off

2. Freeze Thaw Weathering / Frost Wedging and Frost Heaving

Formerly believed to be the dominant mode, frost wedging may still be a factor for weathering of non-porous rocks, although recent research has demonstrated it less important than previously thought. Frost action, sometimes known as ice crystal growth, ice wedging, frost wedging or freeze-thaw occurs when water in cracks and joints of rocks freezes and expands. Thus, ice produced by water frozen in the joints can produce about 1890 metric tonnes (2100 tones) of pressure for 0.1 m^2($1ft^2$). This pressure is often higher than the resistance of most rocks and causes the rock to shatter.



Rainwater collects in a crack.

The temperature falls below 0 C. The water freezes and expands, making the crack bigger

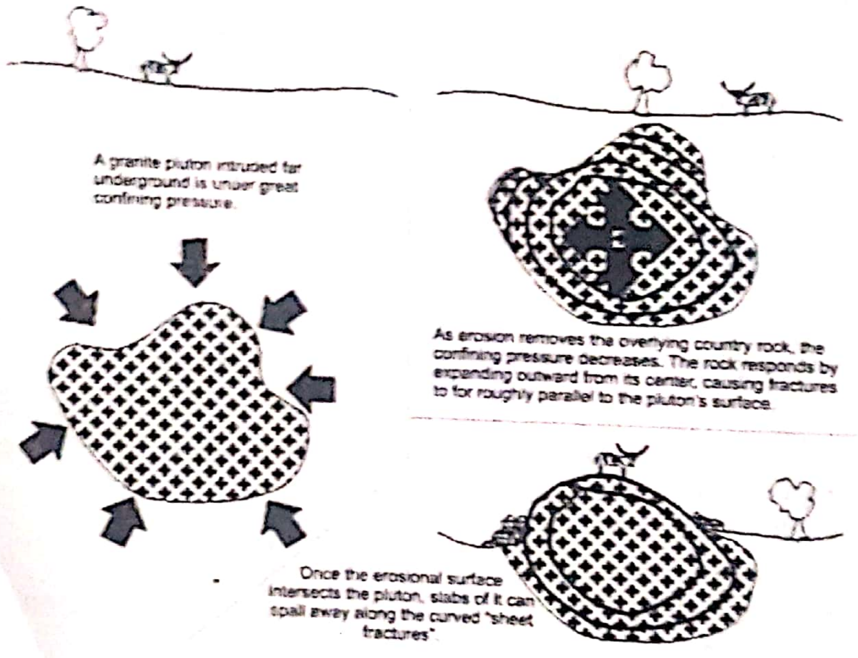
Eventually after repeated freezing and thawing, the rock breaks off.

When water that has entered the joints freezes, the ice formed strains the walls of the joints and causes the joints to deepen and widen. This is because the volume of water expands by 9% when it freezes.

When the ice thaws, water can flow further into the rock. When the temperature drops below freezing point and the water freezes again, the ice enlarges the joints further.Repeated freeze-thaw action weakens the rocks which, over time, break up along the joints into angular pieces. The angular rock fragments gather at the foot of the slope to form a talus slope (or scree slope). The splitting of rocks along the joints into blocks is called block disintegration. The blocks of rocks that are detached are of various shapes depending on rock structure.

3. Pressure Release

In pressure release, also known as unloading, overlying materials (not necessarily rocks) are removed (by erosion, or other processes), which causes underlying rocks to expand and fracture parallel to the surface. Often the overlying material is heavy, and the underlying rocks experience high pressure under them, for example, a moving glacier. Pressure release may also cause exfoliation to occur.



4. Hydraulic Action

This is when water (generally from powerful waves) rushes into cracks in the rock face rapidly. This traps a layer of air at the bottom of the crack, compressing it and weakening the rock. When the wave retreats, the trapped air is suddenly released with explosive force. The explosive release of highly-pressurised air cracks away fragments at the rock face and widens the crack itself.

5. Salt-Crystal Growth (*haloclasty*)

Salt crystallization or otherwise known as Haloclasty causes disintegration of rocks when saline solutions seep into cracks and joints in the rocks and evaporate, leaving salt crystals behind. These salt crystals expand as they are heated up, exerting pressure on the confining rock. Salt wedging is caused by the crystallization of salts from evaporating water in same fashion as frost wedging but it is less significant in its total effect.

The salts which have proved most effective in disintegrating rocks are sodium sulphate, magnesium sulphate, and calcium chloride. Some of these salts can expand up to three times or even more. It is normally associated with arid climates where strong heating causes strong evaporation and therefore salt crystallisation. It is also common along coasts. An example of salt weathering can be seen in the honeycombed stones in sea walls.

(b) Biological Weathering

(i) Through Agency of Living Organisms (Fauna Based)

Living organisms may contribute to mechanical weathering. Lichens and mosses grow on essentially bare rock surfaces and create a more humid chemical microenvironment. The attachment of these organisms to the rock surface enhances physical as well as chemical breakdown of the surface of the rock. On a larger scale, seedlings sprouting in a crevice and plant roots exert physical pressure as well as providing a pathway for water and chemical infiltration. Burrowing animals and insects disturb the soil layer adjacent to the bedrock surface thus further increasing water and acid infiltration and exposure to oxidation processes.

(ii) Through Agency of Plants also Called Root Wedging (Flora Based)

Root wedging occurs when the root of a plant begins to grow into a crack or pore in a rock. As the plant grows larger, so too does its root, until the root breaks the rock apart.

(iii) By Human Actions

Following human actions also result in disintegration of rocks:

1. Air pollution
2. Quarrying and mining
3. Road–cut, dam constructions, underground atomic explosions. etc
4. Ploughing for agriculture

(c) Chemical Weathering

"Chemical weathering involves the decomposition of rocks by the alteration of rock-forming minerals".

Chemical weathering involves the change in the composition of rocks, often leading to a 'break-down' in its form. This type of weathering happens over a period of time.

MODES

1. Dissolution

Rainfall is naturally slightly acidic because atmospheric carbon dioxide dissolves in the rainwater producing weak carbonic acid. In unpolluted environments, the rainfall pH is around 5.6. Acid rain occurs when gases such as sulphur dioxide and nitrogen oxide are present in the atmosphere. These oxides react in the rainwater to produce stronger acids and can lower the pH to 4.5 or even 3.0. Sulphur dioxide, SO_2, which comes from volcanic eruptions or from fossil fuels, can become sulphuric acid within rainwater, which can cause solution weathering to the rocks on which it falls.

One of the most well-known solution weathering processes is carbonation; the process in which atmospheric carbon dioxide leads to solution weathering. Carbonation occurs on rocks which contain calcium carbonate such as limestone and chalk. This takes place when rain combines with carbon dioxide or an organic acid to form a weak carbonic acid which reacts with calcium carbonate (the limestone) and forms calcium bicarbonate. This process speeds up with a decrease in temperature and therefore is a large feature of glacial weathering.

The reaction is as follows:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

Carbon dioxide + water -> carbonic acid

$$H_2CO_3 + CaCO_3 \rightarrow Ca^{2+} + 2HCO_3^-$$

(Calcite + carbonic acid → calcium + bicarbonate)

Carbonation on the surface of well-jointed limestone produces a dissected limestone pavement which is most effective along the joints, widening and deepening them.

2. Oxidation

Within the weathering environment, chemical oxidation of a variety of metals occurs. The most commonly observed is the oxidation of Fe^{2+} (iron) and combination with oxygen and water to form Fe^{3+} hydroxides. This gives the affected rocks a reddish-brown colouration on the surface which crumbles easily and weakens the rock. This process is better known as 'rusting'.

3. Hydration

Hydration is a form of chemical weathering that involves the rigid attachment of H^+ and OH^- ions to the atoms and molecules of a mineral. When rock minerals take up water, the increased volume creates physical stresses within the rock. Hydration also allows for the acceleration of other decompositional reactions by expanding the crystal lattice offering more surface area for reaction.

4. Hydrolysis

Hydrolysis is the weathering reaction that occurs when the two surfaces of water and compound meet. It involves the reaction between mineral ions and the ions of water (OH^- and H^+), and results in the decomposition of the rock surface by forming new compounds, and by increasing the pH of the solution involved through the release of the hydroxide ions. Hydrolysis is especially effective in the weathering of common silicate and alumino-silicate minerals because of their electrically charged crystal surfaces.

FACTORS THAT INFLUENCE WEATHERING

Rock Type and Structure

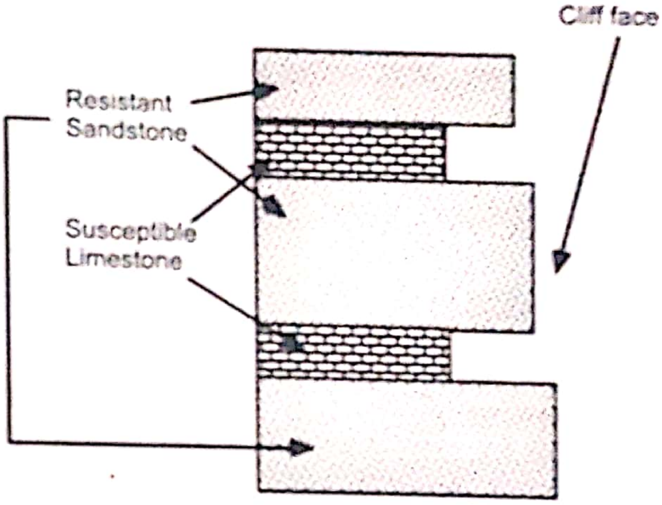
- Different rocks are composed of different minerals, and each mineral has a different susceptibility to weathering. For example, a sandstone consisting only of quartz is already composed of a mineral that is very stable on the Earth's surface, and will not weather at all in comparison to limestone, composed entirely of calcite, which will eventually dissolve completely in a wet climate.
- Bedding planes, joints and fractures, all provide pathways for the entry of water. A rock with lots of these features will weather more rapidly than a massive rock containing no bedding planes, joints or fractures.
- If there are large contrasts in the susceptibility to weathering within a large body of rock, the more susceptible parts of the rock will weather faster than the more resistant portions of the rock. This will result in ***differential weathering***.

Slope

On steep slopes weathering products may be quickly washed away by rains. On gentle slopes, the weathering products accumulate. On gentle slopes, water may stay in contact with rock for longer periods of time, and thus result in higher weathering rates.

Climate

High amounts of water and higher temperatures generally cause chemical reactions to run faster. Thus warm humid climates generally have more highly weathered rock, and rates of weathering are higher than in cold dry climates. Example: limestones in a dry desert climate are very resistant to weathering, but limestone in tropical climate weather very rapidly.



Animals

Burrowing organisms like rodents, earthworms and ants, bring material to the surface where it can be exposed to the agents of weathering.

Time

Since a rate is how fast something occurs in a given amount of time, time is a crucial factor in weathering. Depending on the factors above, rates of weathering can vary between rapid and extremely slow, thus the time it takes for weathering to occur and the volume of rock affected in a given time will depend on slope, climate and animals.

Geographical Significance of Weathering

The process of weathering is of great significance in geography:

- Weathering makes the act of erosion easy which leads to the formation of a large variety of landforms on the surface of the Earth.
- Weathering converts massive rocks into fine grains which lead to the formation of sedimentary rocks.
- The weathered rock material is carried to low-lying areas by different agents of change and is deposited there. Thus weathering provides a base for its formation of rich fertile soils.
- The unconsolidated rocks on the mountains roll down the hill slope under the influence of gravity. This is known as mass wasting. This is done by the lubricating effect of the slum water and snowmelt. Landslides, soil creep and coral flow are its main examples.

WEATHERING IN VARIOUS CLIMATIC REGIONS

The effects of the weather upon rocks vary according to the potency of the different climatic elements:

1. Equatorial Latitudes

In equatorial latitudes, where both humidity and temperature are consistently high, chemical weathering is continuously active, and it is generally much more rapid and effective than the transport and removal of the weathered material.

2. Desert Areas

In desert areas, there is little weathering by ordinary leaching, but considerable mechanical weathering. The chemical weathering takes place by the drawing of strong solutions to the surface by capillary action.

3. Mid Latitudes

In mid latitudes, frost is by far the most powerful agent, while solution, particularly in lime stone areas, exerts great effects.

4. Polar Conditions

Under polar conditions, great areas of permanent snow prevent any ordinary weathering, but where nunataks project from ice-sheets, frost action is rampant. Chemical and organic agencies here seem to be negligible for their effects. CO_2 is more soluble at low temperatures than at high, and as the melted water has higher carbonic acid content, chemical weathering may be quite active under a glacier or at the edge of an ice-sheet.

CONCLUSION

The weathering processes, both physical and chemical, work universally but produce few distinctive large landforms or spectacular activities that would draw the attention of the average person. Nevertheless, these processes are of enormous importance in slope development for they prepare the bedrock for soil formation and for erosional removal by the agents of land sculpture. Without the weathering processes, vegetation could not thrive as we know it today, nor could the great continental land masses be easily reduced by the agents of denudation (exposure).

EXPECTED QUESTIONS

1. What is weathering? Discuss the different processes of weathering in detail.
2. Write a short note on chemical weathering.
3. Differentiate between weathering and erosion. And discuss the process of weathering.
4. Make an analytical study of the various processes of weathering and its part in the development of the Earth's sculpture.
5. Distinguish between rock weathering and erosion. Show how process of weathering in cool humid area differs from those in hot arid region. You may take example from any part of the world.
6. Evaluate physical weathering and its occurrences in different climate areas over the globe.
7. Explain the process and types of weathering. Also discuss the major features produced by wind action.

MASS WASTING/MASS MOVEMENT

Mass wasting can be defined as "down-slope movement of **Regolith** (loose uncemented mixture of soil and rock particles that cover the Earth's surface) by the force of gravity without the aid of a transporting medium such as water, ice, or wind". Still, as we shall see, water plays a key role. It, also known as **mass movement** or **slope movement**, is the geomorphic process by which soil, regolith and rocks move down slope under the force of gravity. Types of mass wasting include creep, slides, flows and falls, each having own characteristic features, and taking place over timescales from seconds to years. Mass wasting occurs on both terrestrial and submarine slopes, and has been observed on Earth, Mars and Venus.

Mass wasting is part of a continuum of erosional processes between weathering and stream transport. Mass wasting causes regolith to move down slope where, sooner or later, the loose particles will be picked up by another transporting agent and eventually moved to a site of deposition such as an ocean basin or lake bed. In order for regolith to move in a mass wasting process, it must be on a slope, since gravity will only cause motion if the material is on a slope.

When the gravitational force acting on a slope exceeds its resisting force, slope failure (mass wasting) occurs. The slope material's strength and cohesion and the amount of internal friction between materials help maintain the slope's stability and are known collectively as the slope's shear strength. The steepest angle that a cohesion less slope can maintain without losing its stability is known as its angle of repose. When a slope possesses this angle, its shear strength perfectly counterbalances the force of gravity acting upon it.

Mass wasting may occur at a very slow rate, particularly in areas that are very dry or those areas that receive sufficient rainfall such that vegetation has stabilised the surface. It may also occur at very high speed, such as in rock-slides or landslides, with disastrous consequences, both immediate and delayed, e.g., resulting from the formation of landslide dams.

RESPONSIBLE FACTORS

A variety of conditions affect the development of mass wasting in a particular area. Gravity, steep slopes, widely varying altitude ranges, the thickness of the loose earth material, planes of weakness parallel to the slopes, under cutting of slopes, frequent freezing and thawing, high water content in the earth material, dry conditions with occasional heavy rainfall, sudden shocks such as earthquake and sparse vegetation are the factors that contribute to the unstable conditions that result in mass wasting. Movements can be triggered by the motion of earthquakes or too much weight added to the upper part of a slope, such as snowpack.

TYPES OF MASS WASTING

Types of mass movement are distinguished based on how the soil, regolith or rock mov down slope as a whole.

1. Creep

Downhill creep is a long-term process. The combination of small movements of soil or ro in different directions over the time is directed by gravity gradually down slope.

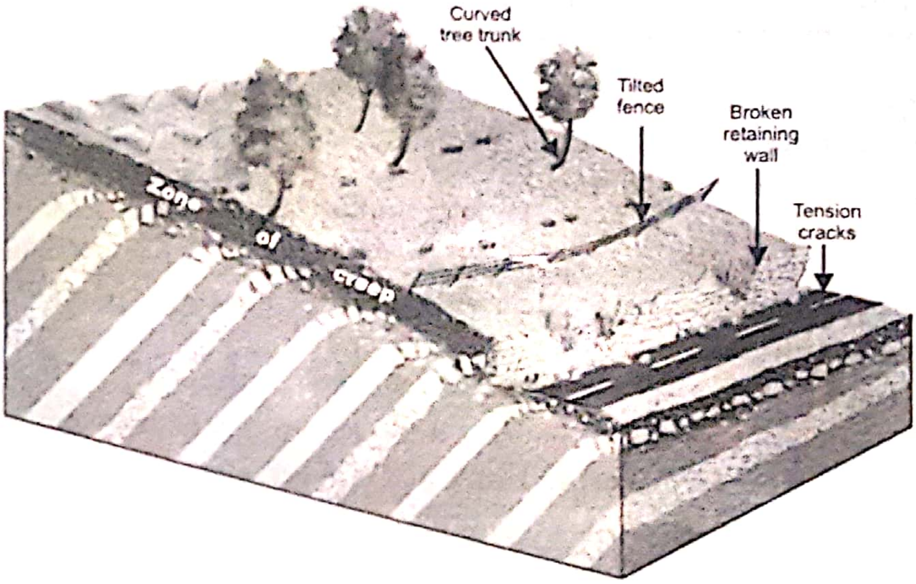


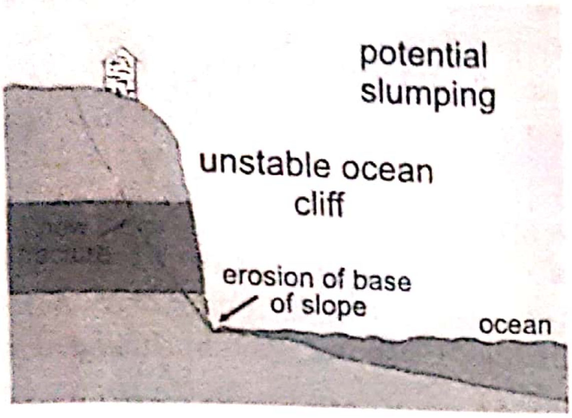
Figure: Soil Creep, a common place evidence of imperceptible down slope creep of soil.

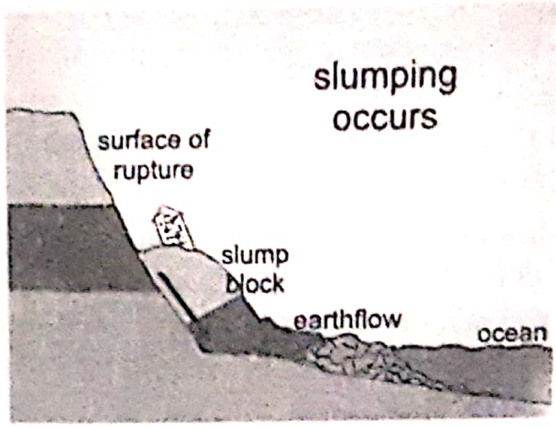
The steeper the slope, the faster the creep. The creep makes trees and other shrubs curve reach the sunlight. These often trigger landslides because the dirt underneath is not very stron The trees most of the times die out because of lack of water and higher insolation, however, th rarely happens in wet climates. Caused by freezing then thawing, or hot then cold temperature, causes surface soils to move up then down, inching its way towards the bottom of the slope. Th happens at a rate that is not noticeable to the naked eye.

2. Slide Movements

Where the mass movement has a well-defined zone or plane of sliding, it is called **landslide.** Whenever rock and soil lie at a high angle on a steep slope, there is a possibility that segment of such material will break away in a landslide or rock slide. The difference betwe landslides and the previously discussed mass movements is the speed with which the slic occurs. Landslides move much faster than flows and sometimes roar down slope with thunderous sound and great force. Here water plays a lesser role, although it does help in th weathering and loosening that has gone before. A landslide is, in effect, a collapse and r lubricants are necessary, although the weight of water saturation certainly does contribute. Th destruction of landslides makes them perhaps the best known of all mass movements. Tens millions of rock debris may break loose at once and, in minutes, bury entire towns.

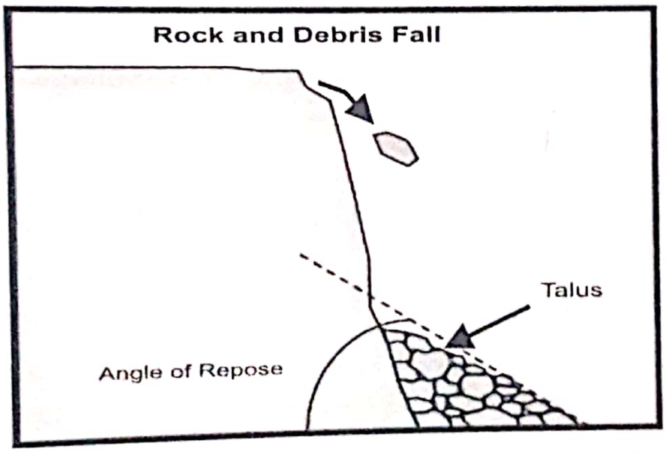
Slumps - types of slides wherein downward rotation of rock or regolith occurs along curved surface. The upper surface of each slump block remains relatively undisturbed, as do th individual blocks. Slumps leave acute scars or depressions on the hill slope. Heavy rains earthquakes usually trigger slumps.





3. Fall Movements

A fall, including rock fall, is where regolith cascades down a slope, but is not of sufficient volume or viscosity to behave as a flow. Falls are promoted in rocks which are characterised by presence of vertical cracks. Falls are a result of undercutting of water as well as undercutting of waves.



Rock fall is one of the most sudden forms of mass movement. Rock fall occurs when blocks of rock shed from a cliff face and collect at the base. **Talus** is a term that is applied to an accumulation of rock by rock fall. Rock falls occur when a piece of rock on a steep slope becomes dislodged and falls down the slope. Debris falls are similar, except they involve a mixture of soil, regolith and rocks. The slope of the talus is controlled by the angle of repose for the size of the material. Since talus results from the accumulation of large rocks or masses of debris, the angle of repose is usually greater than it would be for sand.

4. Flow Movements

Flow Movement of soil and regolith that more resembles fluid behaviour is called a flow. These include avalanches, mudflows, debris flows, earth flow, solifluction and lahars. Water, air and ice are often involved in enabling fluid-like motion of the material.

Debris flows are defined as mass-wasting events in which turbulence occurs throughout the mass. Varieties of these are called earthflows, mudflows and debris avalanches.

When earth material moves down a hillside as a fluid-like mass, it is called an **earthflow**. These flows typically occur in humid areas on steep slopes with thick, clay-rich soil that becomes saturated with water during storms. The earthflow usually leaves a steep scarp behind where it separated from the hillside. Earthflows can be fast (a few hours) or slow (a few months). Velocities range from 1 millimetre per day to metres per day. Intermittent activity can continue for years as the earthflow continues to settle and stabilize. Earthflows typically have rounded hilly fronts. A common trigger for an earthflow is the undercutting of the slope by erosion from wave action or rivers or by construction projects.

A **mudflow** is a liquid mass of soil, rock debris and water that moves quickly down a well-defined channel. Generally, viscous and muddy-coloured, it can be powerful enough to move large automobiles and buildings. Mudflows occur most often in mountainous semi-arid environments with sparse vegetation and are triggered by heavy rainfall that saturates the loose soil and sediment. They are also the natural result of volcanic ash build-ups on flanks of volcanoes and of forest fires that have exposed the soil to rapid erosion. A mudflow originating on a volcanic slope is called a **lahar**. Conditions favourable for the development of mudflows are (1) unconsolidated surface materials, (2) steep slopes abundant but intermittent precipitation, and (3) sparse cover of vegetation. Mudflows tend to be more prevalent in dry regions where vegetation is sparse and heavy rains may form. When set in motion, they occupy stream-cut channels rushing along in a torrential flow of mud. Earth-flows differ from mudflows in that they (1) tend to be slower, imperceptible to the eyes, (2) are not confined to channels, (3) are more common in humid areas than dry, and (4) have a lower water content.

The deadliest variety of debris flow is the **debris avalanche**, a rapidly churning mass of rock debris, soil, water and air that races down very steep slopes. It has been theorized that trapped air may increase the speed of an avalanche by acting as a cushion between the debris and the underlying surface.

The Importance of Mass Wasting

Knowledge of mass movement /mass wasting can help in planning and policy-making. It is quite costly to use public money to build highways in unstable areas. Moreover, many people build houses in locations chosen for their spectacular scenic views, with little or no regard for the stability of the land. Some of these residents have to face huge losses due to mass movements.

In sculpting the land surface, mass movements also perform the important job of exposing new bedrock to the forces of weathering. By the time the material sags and collapses in flow or slide, weathering has become much less effective in attacking deeper rock layers. But the slide removes the weathered material. Thus mass movements are vitally important in the total complex of erosional processes.

Prevention of Mass Wasting

Proper design during construction projects can eliminate the potential for increased mass wasting. Human activities such as undercutting the base of the slope, adding weight to the upper part of the slope by building large structures, removing vegetation, and saturating the ground with water increase the risks of mass wasting. Engineering solutions include barriers and retaining walls, drainage pipes, terracing the slope to reduce the steepness of the cuts, and immediate re-vegetation. Rock falls can be controlled or eliminated by the use of rock bolts cables and screens and by cutting back slopes to lesser gradients.

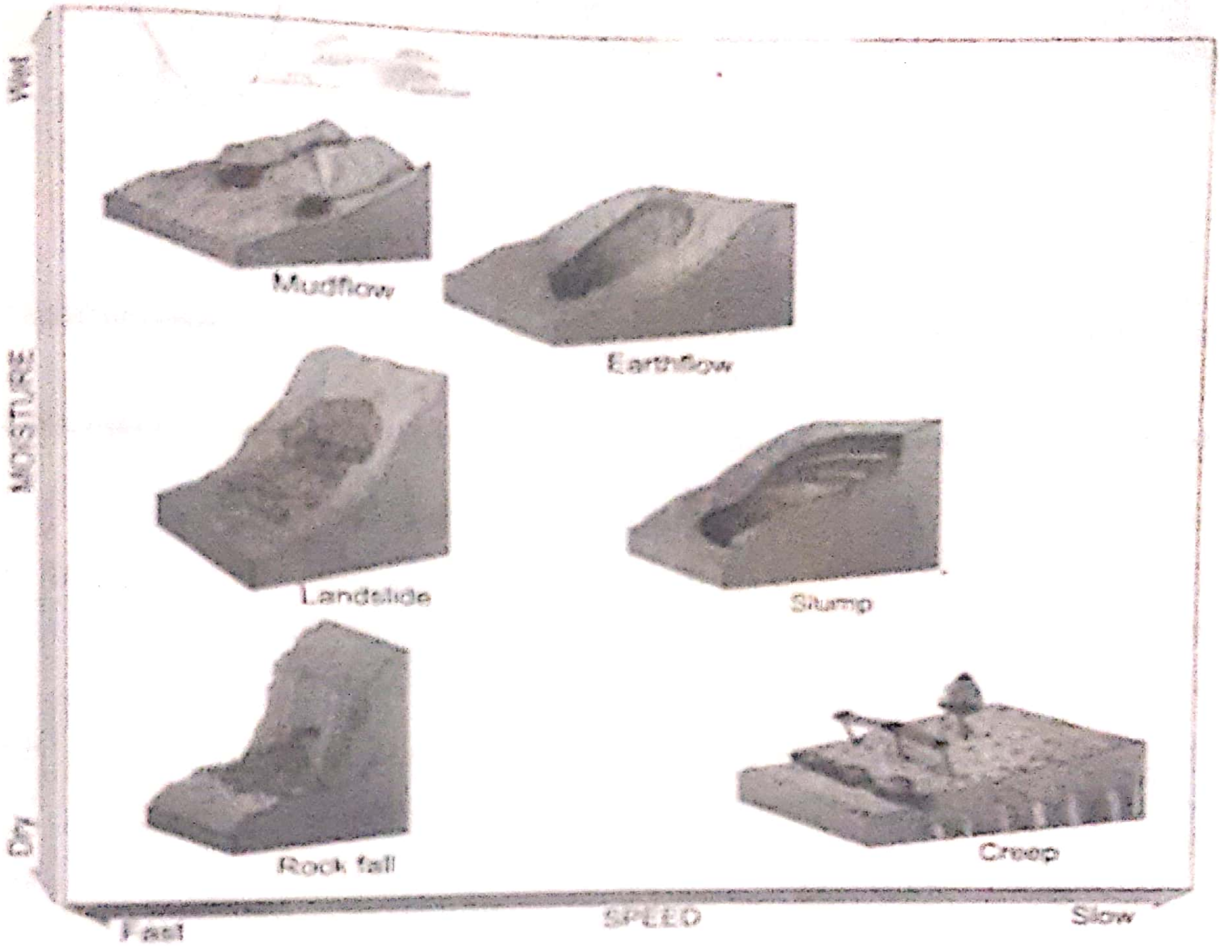


Figure: Relationship among different types of mass movements, their relative rates of movement and moisture limits.

EXPECTED QUESTIONS

1. Explain different types of mass wasting and the development of associated topographic features.
2. Define mass wasting and explain mass wasting in detail.
3. Differentiate between weathering, mass wasting and erosion. Give a detailed classification of mass wasting, types and their areas of occurrence.