ENVIRONMENTAL GEOSCIENCES

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Lecture-12

Summary of Module 2

Welcome to the SWAYAM NPTEL course on Environmental Geosciences. We have already discussed Module Two, in which we discussed the types of weathering, erosion, transportation, and the geological work of wind, rivers, and glaciers. In this lecture, we will cover the summary part of Module Two. The important concepts in this lecture will be the summary of weathering, factors affecting weathering, types of weathering, erosion, erosion by water, erosion control, erosion by wind, and erosion by glaciers. These things we have discussed in Module Two.

Just summarizing the entire Module Two in the way that the various igneous, metamorphic, and sedimentary processes lead to the formation of different rocks on the Earth's surface and below the surface of the Earth's crust. We have seen how tectonic forces, driven by the Earth's internal energy, elevate deeply formed rocks to the Earth's surface. Progression through the geologic cycle now brings us to the processes acting upon or just below the surface of the Earth, which are associated with the action of water, ice, wind, and gravity. These processes are fueled by external energy derived from the sun. Together, they lead to the disintegration and decomposition of continental rocks, followed by the transportation of debris and chemical elements to the ocean basins, where sedimentation precedes the ultimate formation of new continental rocks.

Weathering. Weathering is the mechanical and chemical breakdown of rocks exposed at the Earth's surface into smaller particles that may differ in composition from the original substance. Soil scientists study weathering processes in relation to the genesis of agriculturally productive soils from rocks and unconsolidated deposits. Hydrogeologists investigate the chemical constituents that are released by weathering reactions in the upper few meters of the soil zone and are then carried downward to influence the chemical composition of groundwater. Geologists and engineers have demonstrated the role of weathering in landslides and other types of slope failure. Weathering gradually weakens rocks.

In some climates, the end result is a deep mantle of residual soil with vastly different engineering properties from the parent rock. Factors affecting weathering. The types and intensity of weathering processes that occur in a particular area are primarily the result of climate. Temperature controls the mechanical processes caused by the freezing and thawing of water, as well as influences the rates of chemical weathering reactions. The other main climatic variable is precipitation because water plays a part in both physical and chemical weathering processes. Here you can see in the diagram also, in the x-axis is the mean annual rainfall and the y-axis is the mean annual temperature.

And we can see here the dominant type of weathering that can be expected in a particular climate region. Now, types of weathering are broadly classified into two types: mechanical weathering and chemical weathering. Mechanical weathering includes processes that fragment rocks into smaller particles by exerting forces greater than the strength of the rock. Usually, these forces act within rock masses to overcome the tensile strength of the rock, which is much lower than its compressive strength. Mechanical weathering is principally of the following types: frost action, salt weathering, temperature changes, moisture changes, unloading, and biogenic processes. Frost action is one of the most effective mechanical weathering processes.

When water freezes within a rock mass, its volume expansion exerts pressure potentially greater than the tensile strength of most rocks. The increase in volume is caused by the formation of a hexagonal structure in which the water molecules are farther apart than in their more densely packed condition in liquid water. The maximum pressure exerted by this process occurs at a temperature of -21°C. However, experimental field studies have shown that the temperature rarely reaches this point. Salt weathering, the effects of crystallization of salt within a rock, are somewhat similar to the effects of freezing water.

The expansion and weakening of the rocks caused by salt crystallization is called salt weathering, and it presents one of the most serious threats to the durability and appearance of stone buildings. The salt that crystallizes from solution in the rock includes not only sodium chloride but also a number of chloride, sulfate, and carbonate salts that can enter the rock in several ways. Sedimentary rocks may retain salts from their original deposition. Other dissolved constituents may be contributed by chemical weathering processes. The salt may also be introduced after the rock is quarried.

Now, the temperature changes. Temperature changes have long been suspected as a weathering mechanism because of the observation of cracked boulders on desert surfaces with little evidence of chemical weathering. Early lab experiments involving multiple cycles of heating and cooling did not appear to cause fracturing in rock samples. More recent work, however, suggests that the experiments did not fully duplicate natural conditions and that the mechanism may be significant. The next is the moisture changes. Moisture changes in the form of alternate wetting and drying have experimentally been shown to cause expansion and contraction that may lead to the weakening of the overlying rock.

This mechanism may be even more effective when combined with temperature changes. Only a small amount of water in a rock may be sufficient to accentuate the effects of heating and cooling. Next is unloading. The expansion caused by unloading is often sufficient to fracture the rock along planes parallel to the surface on which stress has been released. This type of weathering, also called exfoliation, produces thin slabs of rock bounded by joints oriented parallel to the ground surface as the overlying material is removed and stress is released.

Next, biogenic organisms participate in both mechanical and chemical weathering processes. The mechanical effects are dominated by plant roots that exploit thin joints or cracks in rocks as they grow. The pressure exerted by the growing roots can wedge apart blocks of rock, leading to the acceleration of other weathering processes in the larger openings. Now, chemical weathering. Most rocks are originally formed under conditions very different from those that exist at the Earth's surface.

In particular, igneous and metamorphic rocks crystallize at very high temperatures and pressures. But when these rocks are exposed to the lower temperatures and pressures present at the surface, they are unstable and tend to react chemically with components of the atmosphere to form new minerals that are more stable under those conditions. The most important atmospheric reactants are oxygen, carbon dioxide, and water. The principal chemical weathering types are solubility, hydrolysis, and oxidation. So this is very important.

In the figure, we can see acidic weathering taking place. We are getting the unweathered zone, weathering zone, and organic matter. Here we can see the type of acidic weathering solution being produced by the formation of CO_2 in the soil zone. So first is solubility.

When a mineral completely dissolves during weathering, the reaction is known as solution. This reaction is known as solution.

The tendency of a mineral to dissolve in weathering solution is described as its solubility. Evaporite minerals dissolve readily in water, whereas carbonate minerals are somewhat less soluble. Even so, the solution of limestone and dolomite is extremely important. When limestone is exposed at the surface, pitting and etching of the rock is obvious. Even more significant is the subsurface solution of carbonate rocks to form caves and types of landscapes known as karst topography.

Second is hydrolysis. Hydrolysis is the reaction between acidic weathering solutions and many of the silicate minerals, including the feldspars. In hydrolysis, a feldspar mineral reacts with hydrogen ions to form several dissolved products as well as a solid product, i.e., the clay mineral kaolinite. Other clay minerals are produced by similar weathering reactions. This reaction is an example of the breakdown of a mineral that is stable at high temperature and pressure to form a new mineral that is stable under conditions near the Earth's surface.

The adsorption of water into the lattice structure of minerals is called hydration. The third one is oxidation. The reaction of free oxygen with metallic elements is familiar to everyone as rust. This process, an example of oxidation, affects rocks containing iron and other elements. In an oxidation reaction, iron atoms contained in minerals lose one or more electrons each and then precipitate as different minerals or amorphous substances.

For example, in the weathering of pyroxene by oxidation, iron is oxidized and hydrated to form the mineral limonite. The presence of limonite in rocks or soil is indicated by brownish or reddish staining. So these are the cases of chemical weathering. Now, rock weathering and its engineering aspects. The degree and pattern of weathering are among the most important factors to be determined in on-site engineering investigations.

The effects of weathering on the engineering properties of rocks include a decrease in strength, a loss of elasticity, a decrease in density, and increases in moisture content and porosity. These detrimental changes can be critical to the suitability of a site for structures such as arch dams, which require maximum strength and elasticity. So, rock weathering plays a very important role. Now, the second concept we have discussed in Module 2 is erosion. The chemical and physical breakdown of rocks by weathering processes leads to the formation of materials that can be easily transported by processes operating at the Earth's surface.

Erosion is the detachment and transportation of surface particles under the action of one or more forces and agents, such as running water (fluvial erosion), wind (aeolian erosion), and glacial ice. The materials that are susceptible to erosion include not only weathered residual products developed from rocks but also any unconsolidated surficial deposit. Now, erosion by water or running water. Throughout the world, erosion by running water is the most important type of erosion in terms of the amount of sediment removed from the land surfaces. Sediment eroded from the land surfaces, particularly from slopes, is subsequently transported by streams to the oceans.

The amount of slope erosion is a complex function of rock type, climate, vegetation, and topography. In its natural state, the amount of soil erosion from a landscape, as measured by the sediment load carried by the streams draining it, can be related to the climate and the vegetation supported by the climate. The highest sediment yield occurs under semi-arid conditions where rainfall occurs as infrequent severe storms with high runoff, and vegetation is too sparse to protect the land surface. Sediment yield decreases in desert environments because there is just too little rainfall to produce runoff. In the figure, you can see the relationship between sediment yield and annual precipitation for landscapes in their natural states.

Here, you can see on the x-axis the rainfall and on the y-axis the average annual sediment yield. And we can see that desert areas have very poor rainfall to produce runoff. The relationship between sediment yield and annual precipitation for landscapes in their natural states is clearly shown in the figure. Erosion of land altered by human activity is much more rapid than erosion of land in its natural state. Unfortunately, agricultural lands are the source of much of the sediment removed by erosion.

The loss of soil productivity caused by the erosion of topsoil is one of the most serious problems facing the human population. Erosion in stream and river channels is also a significant problem. Bridge piers, levees, and other structures can be damaged or destroyed by river erosion. Processes of Erosion Soil erosion by water occurs in a variety of ways.

The initiation of erosion commonly includes the detachment of soil particles from the surface by raindrop erosion. The energy transferred to the surface by the impact of raindrops is sufficient to dislodge individual soil particles from particle aggregates at the soil surface. Downslope movement of particles also begins with the splash of the raindrop. In the early stages of a rainstorm, most of the precipitation infiltrates into the ground. If the duration and intensity of the precipitation are sufficient, a saturated zone develops just below the soil surface, and water begins to pond on the surface.

When ponded water reaches a depth greater than the height of the surface irregularities, water flows downslope in a thin white sheet as overland flow. On soil surfaces, the shallow flow of water can transport detached soil particles and is given the name sheet erosion. Sheet erosion is a rather rare and inefficient erosional process and is soon replaced by rill erosion. Here in the figure, you can see the severe rill erosion on a steeply sloping crop field. The sediment deposition is taking place at the base of the slope.

The channelized flow of water in rills has a higher velocity and a greater ability to transport particles downslope. With time, rills enlarge into gullies, which gradually extend themselves headward and may render the land unfit for agriculture. Not all erosion takes place at the surface. When sediments rich in swelling clays are exposed in valley slopes, vigorous erosion can take place below the surface, and the process is called piping. The combination of clay-rich soils and active erosion both above and below the land surface leads to a distinctive type of topography, and that topography is called badlands. Now, what's the control?

So, erosion control methods we will discuss. The use of erosion control methods must be increased throughout the world in an attempt to combat excessive soil erosion. In agricultural lands, some of the methods are contour farming, strip cropping, terracing, conservation tillage, etc. Their use becomes more important as the slope of the land increases. Contour farming is the orientation of crop rows parallel to the elevation contours of the land.

This practice disrupts overland flow of water and thereby inhibits sheet and rill erosion. Strip cropping is the alternation of strips of erosion-inhibiting crops such as grasses with more erodible row crops. Grasses trap sediment eroded from crop rows and also increase moisture infiltration. When additional erosion control measures are necessary, diversions, bench terraces, and retention basins can be constructed. Diversions consist of channels and ridges designed to collect overland flow and carry it away from the areas that must be protected from erosion or sedimentation.

Bench terraces reduce the length of the slope and reduce erosion. Diversions are often routed to detention basins, which are designed to trap sediment carried by runoff from construction sites. Erosion by Wind. Now, we will discuss erosion by wind. The erosion of soil by wind is similar to erosion by water. Wind is not as effective an erosional agent as water because of its lower density.

Variables in the wind erosion system can be divided into characteristics of the wind and the characteristics of the soil and land surface. Wind variables include wind velocity, duration, and the length of the open area without obstacles over which the wind blows. Important properties of the soil and land surface include particle size, size distribution, moisture content, and vegetation. Particles of typical density within the size range of 0.1 to 0.15 mm in diameter are most susceptible to wind erosion. The distribution of grains upon the surface is also very important.

Soils containing large particles gradually become protected as wind erosion proceeds. As the fine particles are removed, coarser grains become concentrated at the surface, preventing further erosion of the soil. Very fine particles in the soil, including silt and clay, promote the formation of soil aggregates. These clumps, composed of smaller particles, are held together by the cohesion of silt and clay. In order for soil aggregates to be eroded by wind, they must first be broken down by raindrop impact, abrasion by wind-transported sediment, and other processes.

Vegetation is the final soil and land surface variable. Vegetation provides physical protection for the soil. It also holds moisture, increases the roughness of the surface, and adds organic binding agents into the soil. Wind erosion can be greatly reduced by proper farming and land-use practices. Shelterbelts are one of the most common attempts to control wind erosion.

These linear bands of trees or other plants decrease wind velocity and the unobstructed distance over which the wind blows. Farming methods for wind erosion control include strip cropping and the planting of temporary cover crops rather than allowing the soil to remain bare between periods of crop production. In the figure, you can see a shelterbelt planted to minimize erosion of soil by wind. Now, erosion by glacier. Glacial erosion is the process by which glaciers shape landscapes through movement and abrasion.

As glaciers flow, they pick up rocks and debris, grinding against the bedrock beneath in a process called abrasion, which creates smooth, polished surfaces and striations. Glacial erosion is a powerful force, contributing to sediment transport and deposition downstream, shaping ecosystems, and influencing hydrological systems in cold and high-altitude regions. Erosion by glaciers takes place due to plucking, rasping, and avalanching. Plucking may be broadly defined as the loosening and breaking of rock masses by the pressure of glacier ice. It is also called frost wedging or glacial quarrying.

During the summer months, the surface parts of a glacier may partially melt. This meltwater seeps down along the sides of the ice mass, finding its way into the cracks and fractures in the rocks along the edges and at the head of the glacier. At night or when the temperature drops, this water freezes, thereby breaking up the rocks by frost action. Rasping or glacial abrasion is the term used to describe the scraping or abrasion by glacial action. It is the pushing action by the glaciers.

The front edge of the glacier functions as a bulldozer. Pushing and scraping the ground in front of the ice, the ice itself is capable of abrading only the soft rocks. But when it is carrying along its stone fragments and rock pieces, it acts as a powerful abrading medium. Avalanching is the process of mass wasting. Along the margins of a valley glacier, the valley sides are scraped, and blocks are broken off, which become frozen into the ice and are carried away.

This leads to the undercutting of the sides of the valley and paves the ground for slumping, sliding, and debris avalanching, which bring a great quantity of rock waste onto the top surface of the glacier. Thank you very much to all.