Slope elements and Slope development

The **physical landscape is an assemblage of slopes**. Geomorphologists for long been intrigued by the **study of the origin and form of slopes**, it posed a major challenge to the study of landforms. **Various theories and models were formulated** to provide a rational explanation to its origin and form but all had their **own flaws**.

Despite the fact that slope constitutes the core of landform study, it has not received due attention and largely remained neglected. The study of slopes faces a number of challenges.

It becomes difficult to determine its nature, the rate of operation of the processes, and its effect on the slope. It is also very difficult to mark the **whole trajectory of slope development** and t**race changes in its form with the passage of time.**

In a landform study, there are **two aspects** that have always remained in the focus- **the form and the process**. The term **'form' indicates the morphology of a given region at a given time**. The different shape a landform assumes is the focus of the study while **'process means the actual operation of different agents which bring about changes in the physical environment.**

These agents are many and they vary in terms of their role in different regions. The **process includes agents such as soil creep, surface wash, weathering, etc.**

Two approaches were followed to have a proper understanding of the slope development. They are

- **(a) Historical approach**
- **(b) Process-Form approach**

Historical Approach:

- This approach emphasizes the **historical evolution of slopes right from their origin to the present form.** It, however, suffers from the inherent problem of correct reconstruction of the past forms of the slope. **There is no yardstick to measure or verify the correct reconstruction of the past, so it makes the problem of identifying a proper theory that explains the actual forms of the slopes in the past more complex.**
- Tracing the correct historical development of slope forms is therefore not an easy task. Many writers and investigators have taken recourse in the assumption that the present-day slopes have developed from near-vertical cliffs which in course of time have weathered back and modified to new forms and gradients. Such conditions may occasionally occur in nature but in a majority of cases, slopes appear to border river valleys which were never vertical cliffs.
- **It is wrong to generalize that river erosion always produces steep vertical wall-like features due to its high intensity of erosion.** Along with the process of river erosion, there are other processes like **weathering and creep** that tend to consistently modify the slope edges produced by the river and transform them into more complex slope forms.
- **"The concept of initial slope is perhaps a totally unrealistic one" (Small, 1978).**
- Another commonly encountered problem is **determining the age of the slope.** There is **no standard method that can be universally applied to determine the age of slope with accuracy**. Extensive **field surveys** of different slope profiles can give rather more satisfactory results than any other method of study.

- Studying numerous profiles would help the investigator easily distinguish profiles in various stages of their evolution and place them in the proper time sequence. However, this exercise also does not give a completely satisfactory result.
- Determination of slope age based on its form is by no means an easy exercise.
- **Despite all the problems mentioned above many geomorphologists went ahead and formulated diverse theories explaining the process of slope evolution**. But theory formulation and reconstructing the past forms of the slope is still largely based on speculation.

The process-form approach:

- The premise of this approach rests on the assumption that **the form and gradient of the slope is an outcome of a causal relationship between weathering, erosion, transportation, and deposition.**
- These processes of denudation operate in different combinations and in varying rates giving rise to an immense variety of slope forms with varying steepness.
- The variation in rock types, climate, vegetation, etc has a direct bearing on the types of slope forms produced.
- If we take the example of **limestone region** having an adequate amount of rainfall, we observe **convex slope** as the most common form because of the reason that brainwashes is less effective here due to the **porous nature of rock** which in other regions would have resulted in concavity.
- **This approach like the historical approach suffers from several difficulties**. It becomes very difficult to observe the different processes at work on slopes since the process of **weathering, creep, rainwash, etc are extremely slow and not perceptible to the eyes.**
- Thus, it requires state-of-the-art tools and highly accurate methods for recording of the operation of these processes for arriving at accurate results.
- **It is again very difficult to assert very firmly that slope processes have a direct bearing on the form of the denudational slope.**
- Another problem associated with this process-form approach is the possibility that **many slopes of the present times are not an outcome of present-day processes(Small, 1978)**. There have been diverse opinions expressed regarding the relationship between slope form and climate.
- If the slope is controlled by slope processes alone then it is assumed it would give rise to different slope forms in different regions. Some geomorphologists have overstressed this relationship citing several examples in its support. However, the assumption that a certain type of slope will be formed only in a particular kind of climate is not always true. For a long period of time, it was held that pediments are found in desert regions but now many scientists and geomorphologists support the view that it may occur anywhere in the world.

In the above discussed two approaches the **historical approach retraces the sequence of events in the past** and the **process-form approach investigates the processes and their interrelationships that result in diverse slope forms.**

Both the above slope approaches are helpful in the study and understanding of the slopes and their evolution.

Genetic Classification of slopes

Slopes are produced by both **Endogenetic and Exogenetic processes**. Based on these two processes they have been broadly divided into – **Endogenetic Slopes and Exogenetic slopes**

Endogenetic Slopes

- These slopes originate **due to the processes which originate within the earth**. Different earth movements lead to the formation of **folds, faults, rift valleys, etc.** These slopes are also referred to as **tectonic slopes**. Fault scarps are often associated with faults and rift valleys.
- The volcanic eruption which is also an outcome of the endogenetic process going on inside the earth results in the formation of new features. Volcanic Eruptions cause the accumulation of lava and **pyroclastic materials** and give rise to different kinds of volcanic hills, plateaus, and cones.
- The features formed due to the volcanic eruptions or tectonic processes undergo modification by subaerial processes resulting in various slope forms.

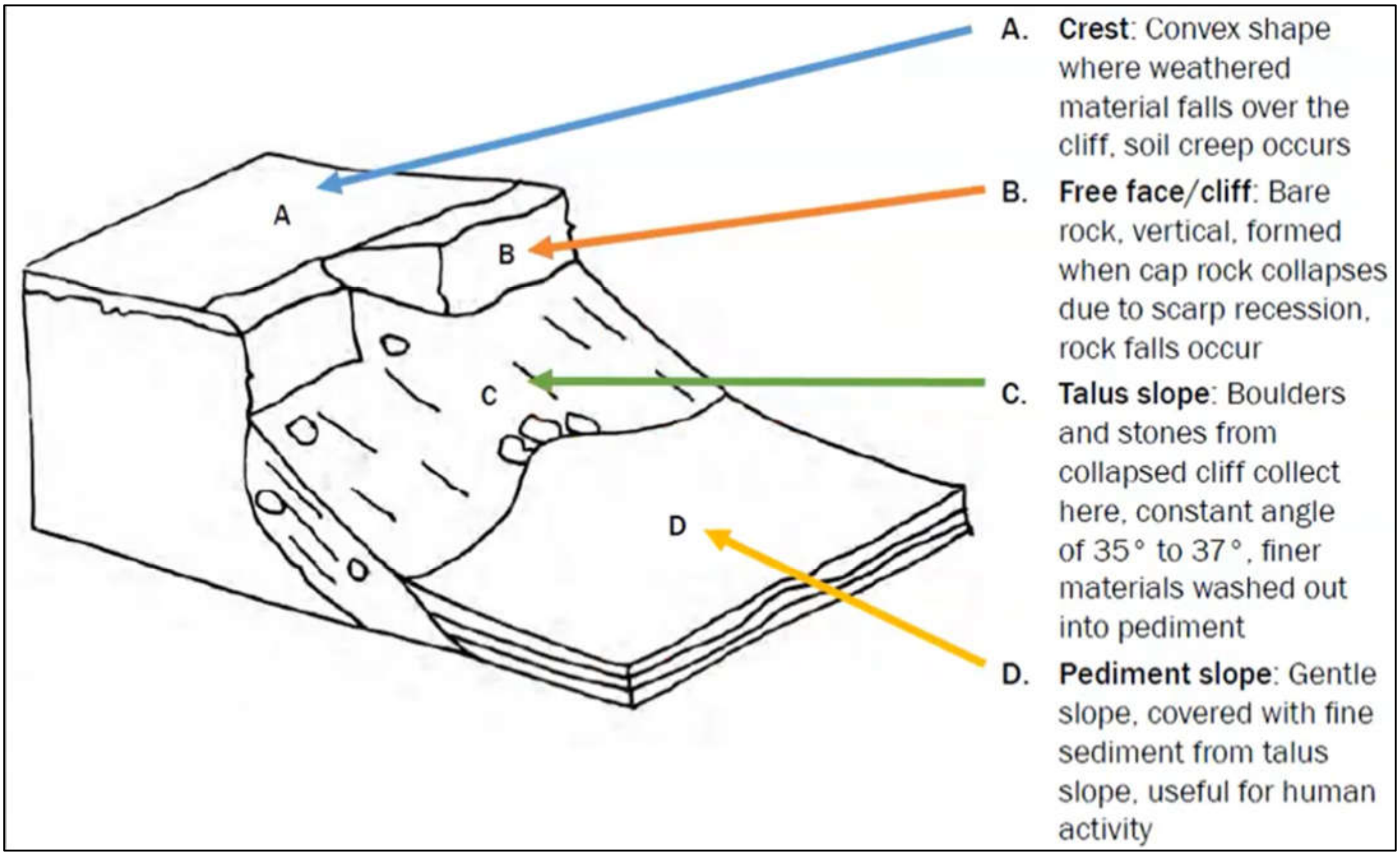
Exogenetic slopes

- These slopes are an **outcome of external processes originating at or near the earth's surface. Processes like weathering, mass wasting, erosion, and deposition** play key role in fashioning a landscape.
- These processes consistently operate upon the surface and **regularly create and modify slope forms**.
- The slopes created by exogenetic processes can broadly be divided into two categories **(a) Erosional or degradational slopes and (b) Depositional or aggradational slopes.**
    - **Erosional slopes** are formed by the action of wind, running water, waves, glaciers, etc. Glaciers and running water produce numerous landforms in their valleys. Features like escarpment, watersheds, river terraces, and cliffs (in the coastal regions) are examples of erosional slopes.
    - **Depositional slopes** are again produced by the same agents. Alluvial fans, natural levees are produced by running water; moraines are produced by glaciers; wind produces sand dunes of various shapes and sizes. Deposition along sea coasts gives rise to sand bars, barriers, and beaches. These are all different depositional slopes produced by the action of water, wind, and glacier.

Slope elements

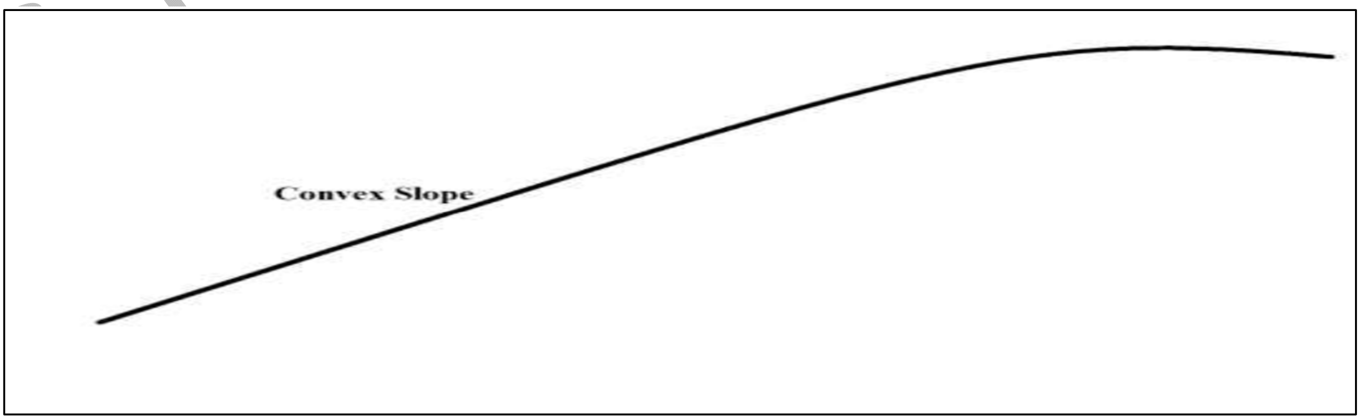
- Slopes have a number of forms or elements. **A slope profile commonly consists of convex (crest), rectilinear and concave slope forms.**
- **Convex slopes are commonly found at the top** and **concave slopes lie at the base of the hillslope**.
- **L. C. King and A.Wood were of the belief that a standard composite slope profile consists of four elements.** The uppermost part is the convex slope or crest. Below the crest is scarp or free face followed by rectilinear slope and at last at the bottom is the concave slope.
- This is the most common composite slope profile, however, in reality, they are found in several combinations. All the elements may not occur in a single slope profile.
- The occurrence of these elements in varying combinations depends on factors like the structure of rock, the nature of the rock, and the processes that operate upon the surface.

- **The four main types of slope elements (forms) have been discussed below in detail.**



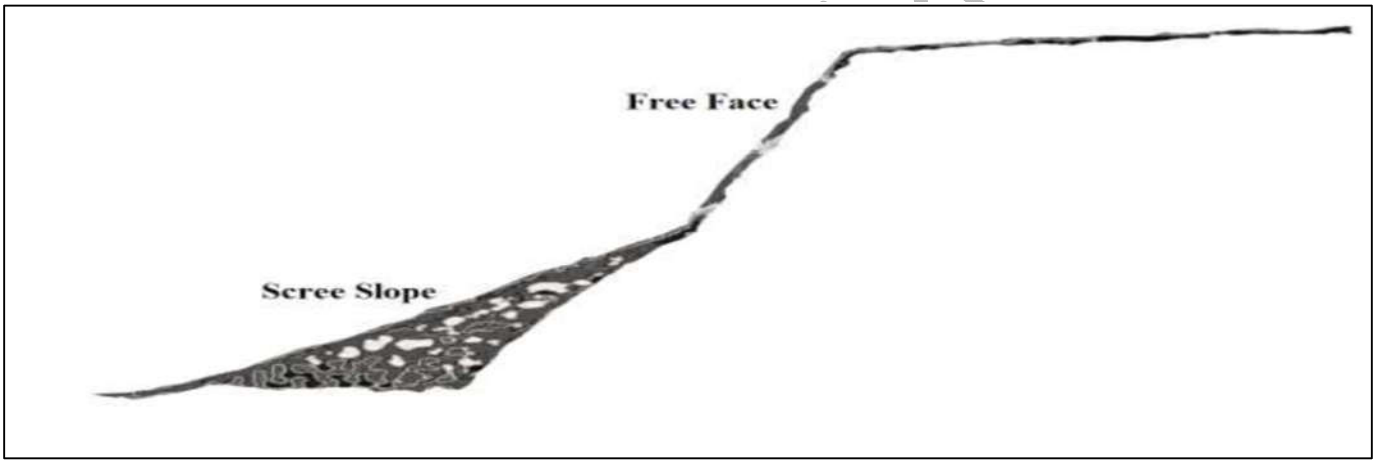
Convex Slope:

- At times an entire slope may assume a convex form but it is most commonly observed on the **upper parts of the slope.**
- Convex slope profile is a result of the **denudation process**; they are assumed to be the characteristic of the **humid temperate region**.
- **In the upper parts of the hill slope, they are often referred to as 'crest' or "summit slope".**
- The **angle of the slope increases downslope from the crest.**
- **Weathering and soil creep** are believed to be the two most active processes which have caused the formation of summital convexity.
- The term **summital convexity is often referred to as 'waxing slope'** after it was used and popularized by a well-known German geomorphologist **W. Penck.**



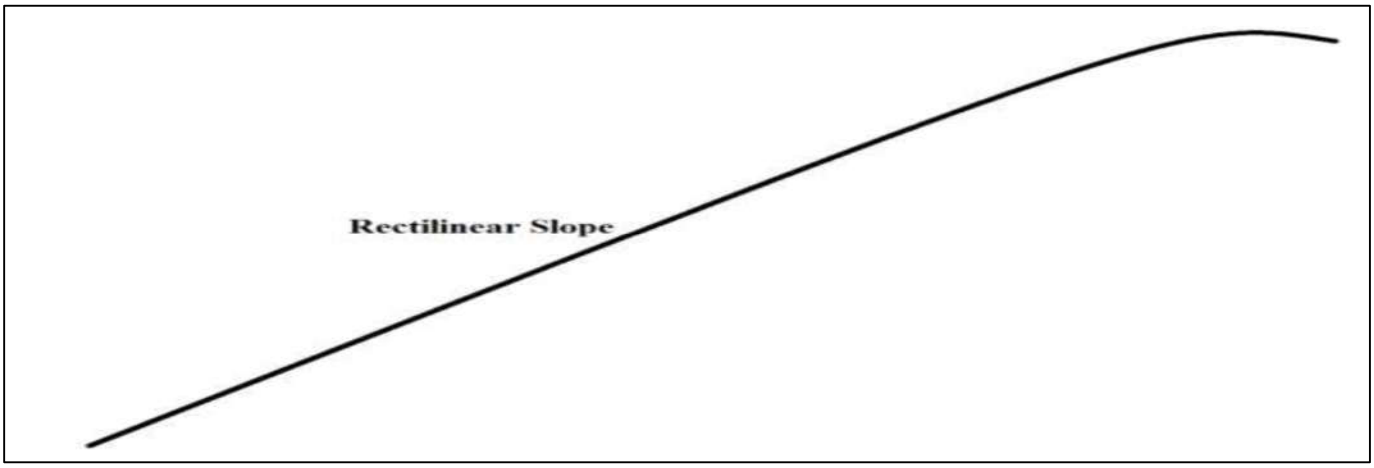
Cliff or Free Face:

- It is a **steep wall-like slope often known as scarp or free face.** It is mostly bare because of its steepness.
- **No regolith or debris can accumulate at such a steep slope** therefore all the material falls down and **accumulate at the foot of the cliff.**
- Since it remains free of any detritus or debris many geomorphologists call it **"Free Face".**
- Cliff develops along the coast (due to undercutting by sea waves), in river valleys, glacial regions, in faulted landscapes, and many other places. As previously mentioned weathered material falls down or slides and accumulates at the base of the free face.
- **This accumulated feature if left untouched by transporting agents will grow in size and result in a new depositional feature which is called a talus slope**. The consistent rise of the slope due to the continuous supply of weathered material would slowly cover the lower parts of the free face and hence protect it from weathering.
- The **talus slope would gradually grow higher causing a reduction in the length of the free face.** Eventually, **a time would arrive when the entire cliff or free face would disappear and will be replaced by an aggradational slope of a lesser angle than the cliff.**



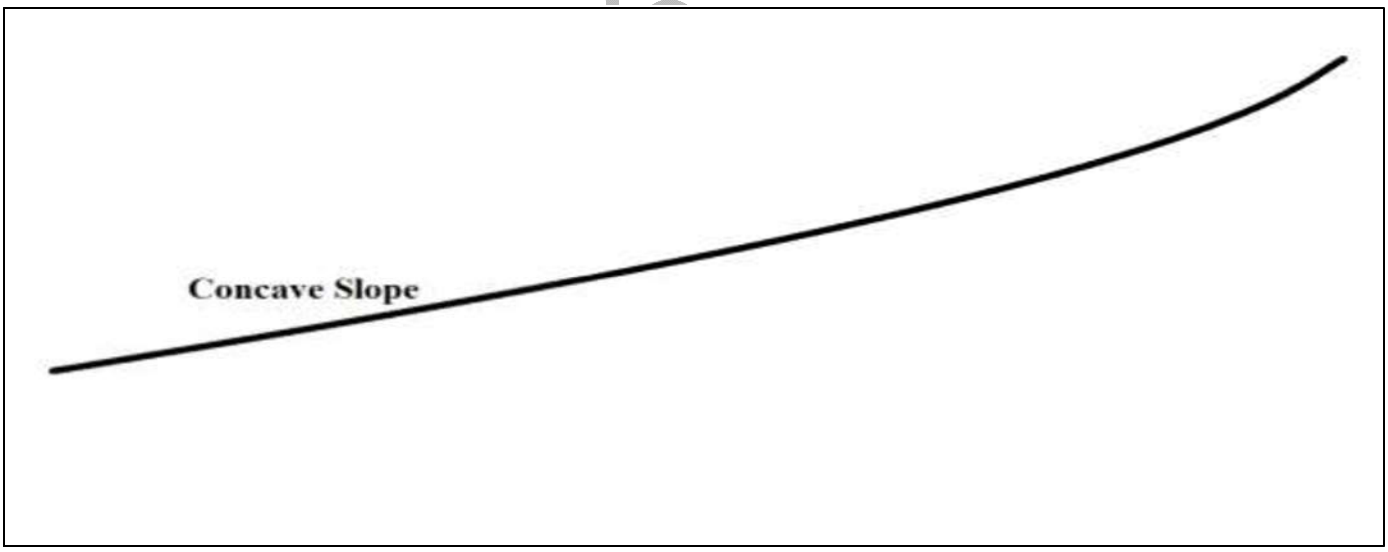
Rectilinear slope:

- **It mostly lies below the cliff or free face**. It is also known as a **constant slope** since the **slope angle largely remains constant.**
- The slope is **straight** in profile. This element varies in its dimension and may also **dominate the entire slope.**
- This slope section is often found extending from the **summit to the bottom of a valley.**
- On many other slope profiles the **rectilinear section lies at the centre of the profile between a broader convexity on the upper part and a larger concavity on the lower section.**
- Many geomorphologists are of the view that rectilinear slopes develop due to aggradation only but this is not the case in many instances.
- In the words of **Small (1978) "rectilinear slopes can be essentially denudation forms, underlain by solid rock and bearing only a veneer of detritus, either at rest or moving very slowly downhill owing to disturbance by frost and other agencies".**
- These slopes are also referred to as **debris-controlled slopes. Strahler (1950) used the term "repose slope" to refer to such slopes.**

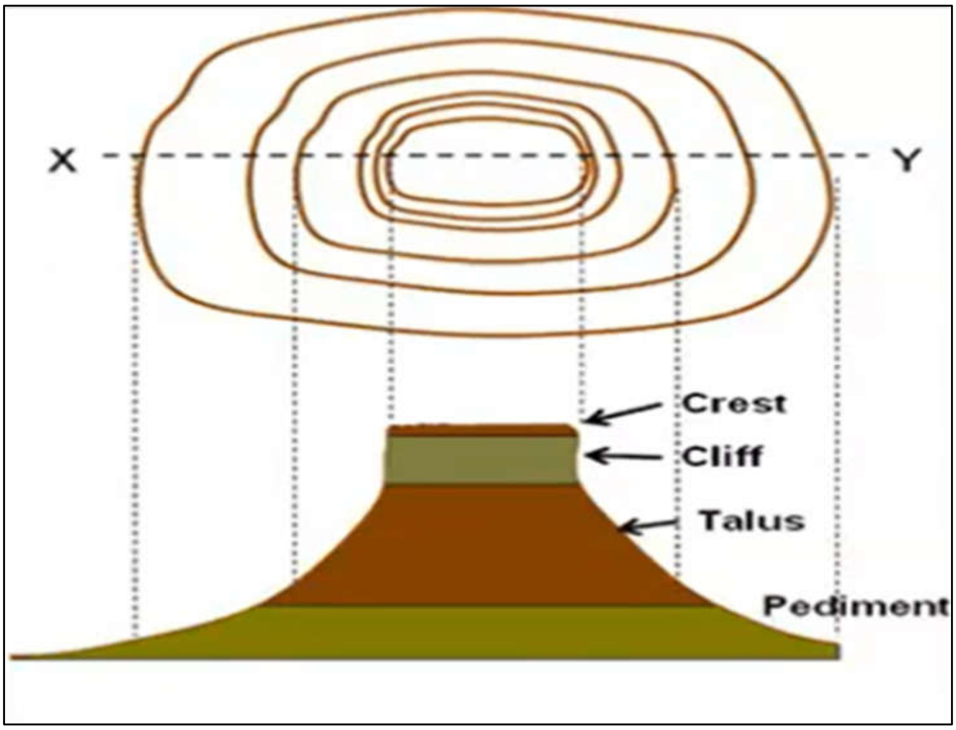


Concave slope:

- The concave slope is observed at the **lowest part of the slope profile**. It is located at the **bottom of a hill slope and extends further down to the river valley**. It is usually **covered with a layer of debris.**
- The accumulated scree due to rainwash spreads the finer particles farther than the coarser ones leading to the development of concavity.
- **Penck used the term waning slope for such slopes.** In **arid and semi-arid regions these slopes display a sharp break of gradient between the lower concave section and the steeper slopes above**. In contrast, in **humid conditions, the basal concavity grades smoothly into the higher slopes.**



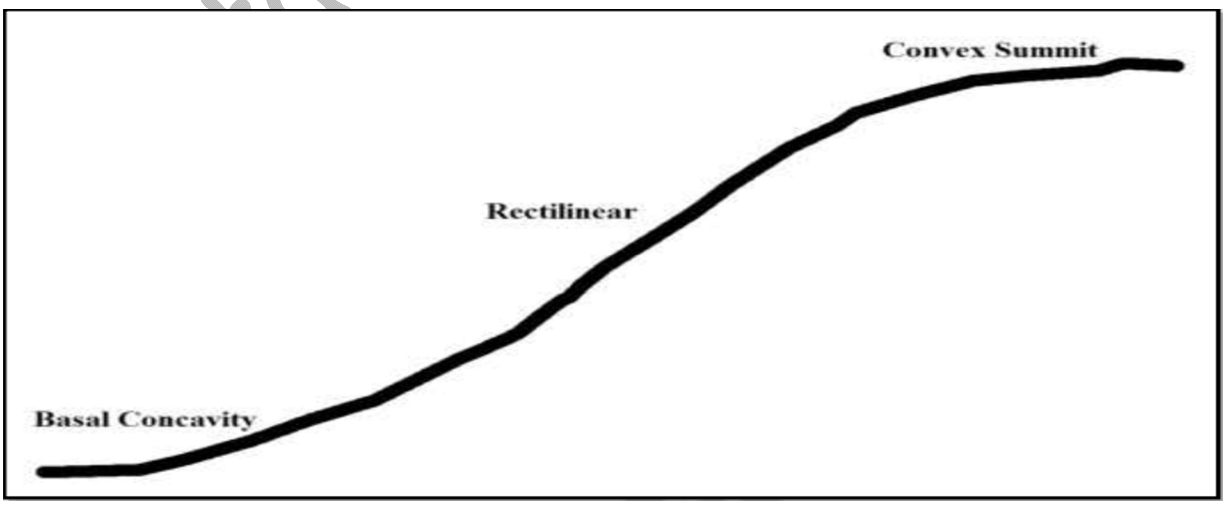
The above-discussed elements are assumed to be present in a standard hill slope but as has been pointed out by many geomorphologists and thinkers that **all four elements may not be noticed in a hill slope. One or more than one element may be missing from the slope profile owing to various reasons.**



A slope profile may have different combinations of elements and one can theoretically assume an infinite number of such combinations. **In reality, there are several combinations that occur frequently and appear very common.**

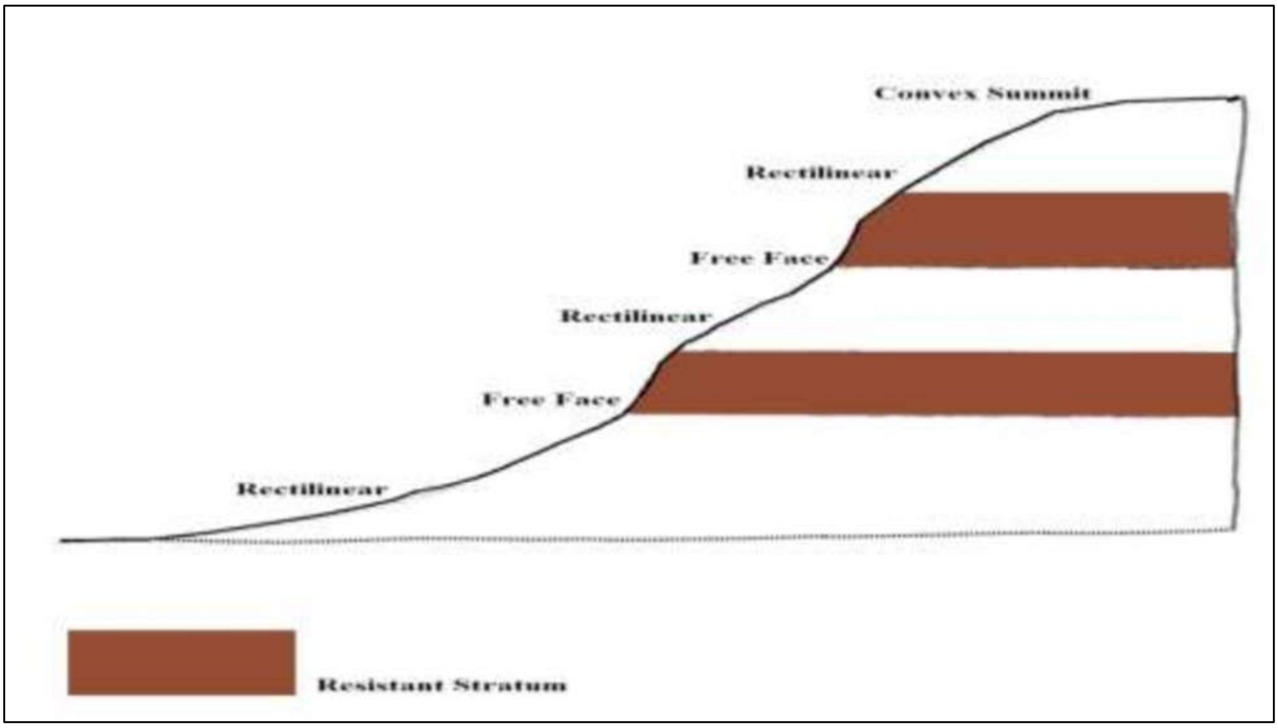
The **three most common combinations of composite slopes have been discussed in the following section:**

- **The convexo-rectilinear-concave slope profile** has **upper convex, middle rectilinear, and lower concave forms.** All three slope elements smoothly grade into each other and give a curving slope profile **(Small, 1978)**. This kind of slope profile is most common in the regions having **weak rock types.** The **lowland England region is full of these types of slope profiles**. Slope profiles with variations in the length of different slope elements are seen in the landscape. However, in those areas where there is a vast diversity of rock types, where hard and soft rocks alternate, or the region has witnessed several rejuvenations there is the likelihood of a very complex slope profile.

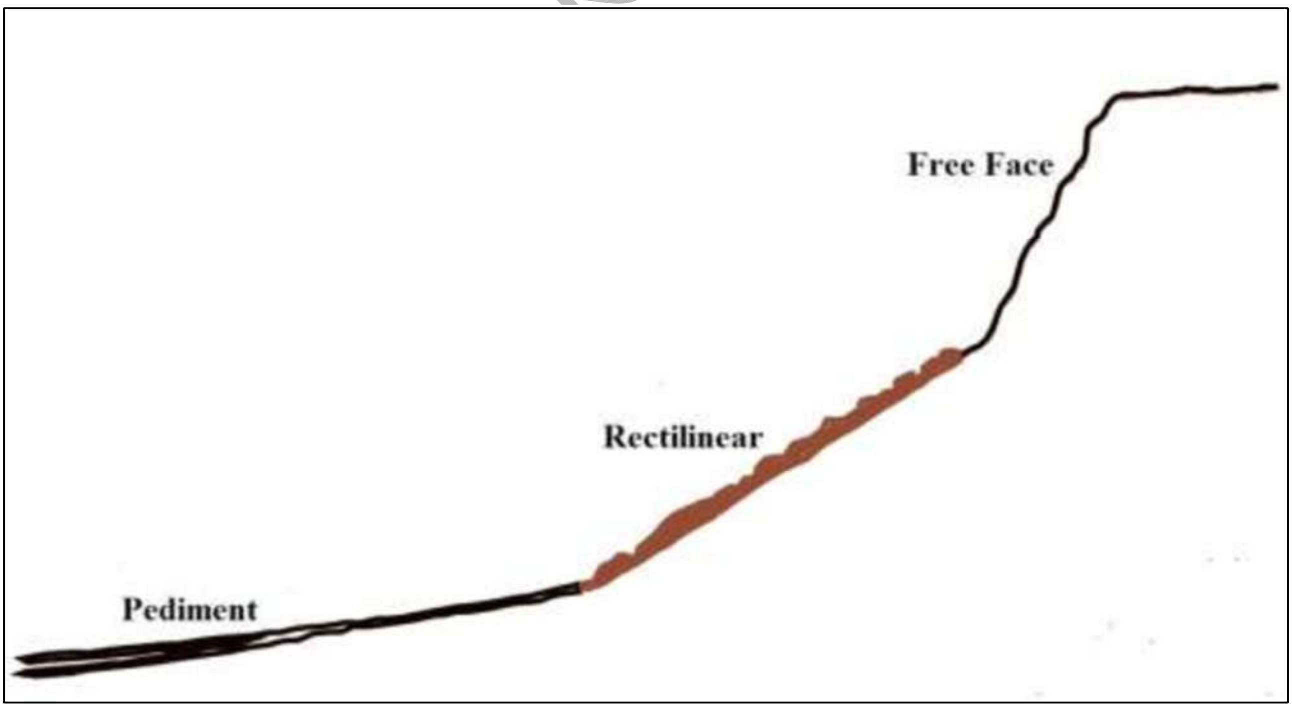


- **In regions where massive and thinly bedded weak strata alternate, where relief is high, valleys are very deep and weathering is active, a very different composite profile will be seen. The profile will have several free faces and rectilinear slopes while summital convexity and basal concavity**

will be very limited in extent or completely absent (Small, 1978). Where there are massive strata it would give rise to free face while weak and thinly bedded rock would result in rectilinear slopes.



- **In arid regions where there is the occurrence of hard crystalline rocks, a composite slope profile develops** which consists of a free face on the upper section with a slope of 40° or more, a mid-section boulder controlled slope with a slope angle of 25° or more(littered by rocks of different sizes) and a concave (pediment) slope in the lower section. The concave slope which lies at the bottom is very gentle with angles below 7 degrees.



Different arguments have been put forward by geomorphologists to account for the reasons for the development of specific slope elements in a slope profile. A lot of attempts were made earlier to relate some processes to particular forms of the slope. **Processes like rainwash and soil creep are related to the development of convex and concave slope forms.**

N. M. Fenneman, an American physiographer explained the most common convexo-concave profiles in terms of the action of running water. He stated that the **upper slopes have lesser runoff during rainfall and that the water would move as a thin sheet. The water gets loaded with the particles as it moves down the slope.** There is an increase of surface water downslope because of the addition of run-off from higher up the slope to that received from rainfall at lower sections of the slope. It can easily be imagined that there is greater erosion in the sections of slope that are away from the summit thus causing convexity to develop after a long period of time.

Fenneman also stated that when the water reaches the lower part of the slope due to an increase in the amount of surface water it gets concentrated into small channels which carve out numerous gullies and lead to the formation of a concave curve. These arguments of Fenneman were opposed by many geomorphologists. They argued that Fenneman's hypothesis does not take into account soil creep which is an important process in shaping the slopes. **However, his hypothesis got support from the works of Horton (1945)**.

Horton stated that on the upper section of the slope there is a certain distance from the crest where erosion by wash is absent because run-off lacks the required energy to erode. This section of sheet flow corresponds to the upper flatter parts of the slopes. Further down the slope with the increase in run-off, the section of no erosion is left behind and erosive action by sheet wash assumes importance.

Gilbert (1909) attributed soil creep as a major factor that causes rounding of hilltop summits and the development of summital convexity. However, his ideas and arguments were considered simplistic. Lawson held rainwash as an important process on the upper slope. But he differed from Fenneman and stated that wash is most effective at the sloping summit.

Besides the above scientists and geomorphologists, there were many others who considered the process of **soil creep and rain-wash** as the most important process that determines the slope form.

They have come up with their own theories based on their understanding to provide proper explanations for particular slope forms. **Besides soil creep and rain-wash, there are many factors that operate and their interplay is highly complex**.

So, it can be said that **there may be a few dominant factors that play a key role in the formation of specific slope forms but there are a number of other factors that too play a role in the development of specific slope forms.**

Models of Slope Development

- Evolution of slope is concerned with the **change of slope forms with the passage of time.**
- Models of slope evolution investigate the processes and mechanisms that **operate to produce a particular slope form.**
- The **second half of the nineteenth century saw some noteworthy work in this direction**.
- In the present module, we are going to discuss about **following models of slope development:**
    - **Davis'** Model of Cycle of Erosion
    - **Penck's** Model of Landform Development
    - **King's** Model of Slope Development
    - Alan Wood's view on slope evolution
    - Strahler's View on Slope Development

Alan Wood's view on slope evolution

Wood (1942) began his evolution of slope taking cliff as the initial form which emerged either due to erosion or earth movements.

The process of weathering would push back the cliff (free face). In other words, **weathering causes the free face to retreat parallel to itself.**

Weathered material would collect at the **foot of the face (scarp);** the scree accumulates and slowly buries the lower parts of the free face thus reducing its height.

Wood regarded the foot of the scarp as the local base level for weathering process. He assumed an ideal case of accumulated **talus** which is not subjected to weathering and has the same volume as parent rock.

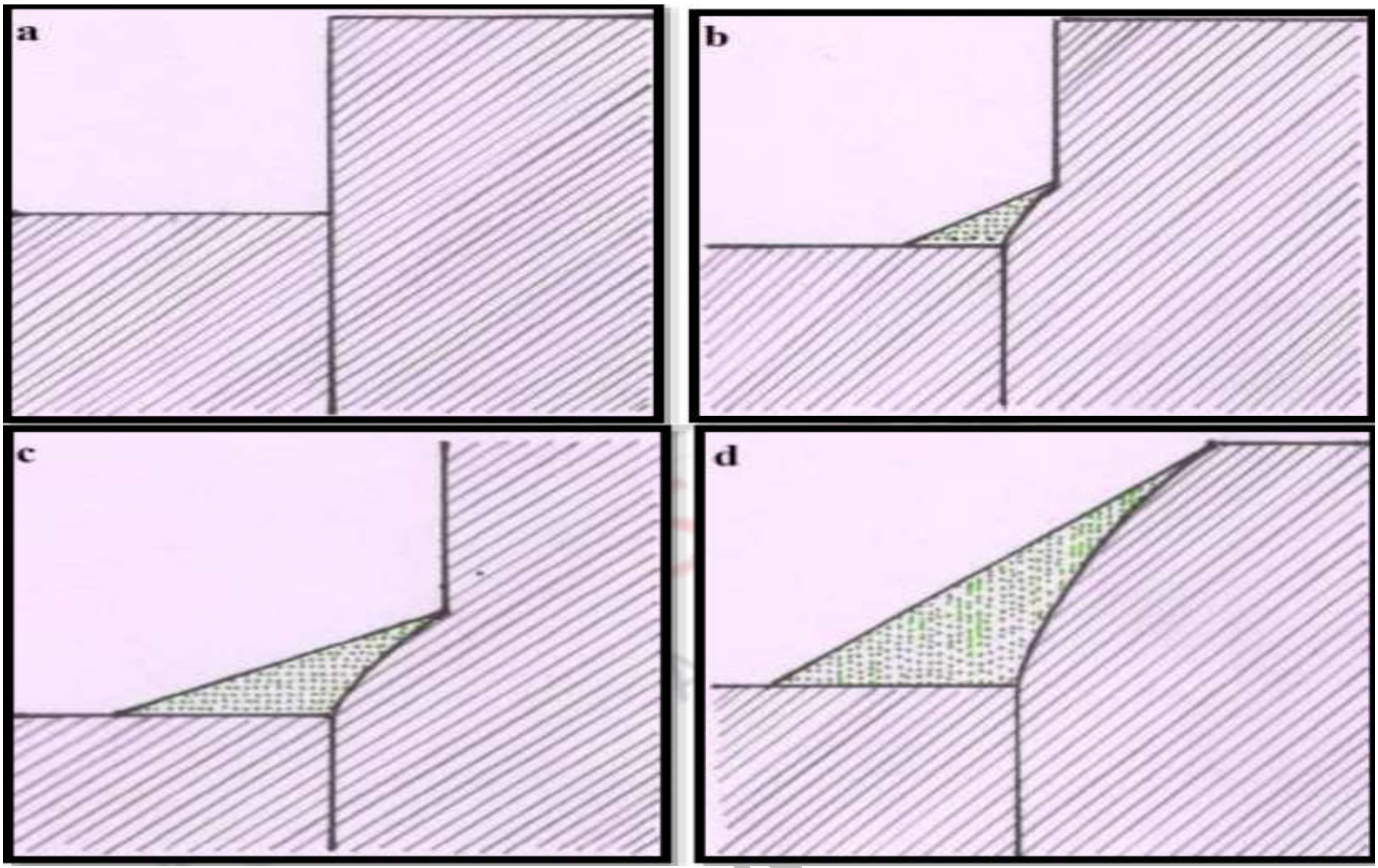
The scree provides protection to the base of the rock face from weathering. The **talus continues to grow and finally, it completely buries the free face** (Fig). The retreating face above leaves behind protrusion under the scree.

The surface of the scree which accumulates at a constant angle is termed as the constant slope (wood, 1942).

Beneath the scree will lie buried the convex slope. While this is an ideal case but in nature, such a process would be highly complex as there are various factors that affect the evolution of slopes.

In nature, the volume of the scree will never be the same as the parent rock rather the volume would be more than parent rock because of the presence of interstitial space. This will cause the upward growth of scree faster than ideal case as a result the buried face will become steeper while still retaining the convex form.

Similarly, if the removal of scree takes place due to the washing out of the fine materials it will have an effect in the opposite direction. The rate of growth of scree will be slowed down and the slope of the buried face will become gentler. It can also be added that the production of more coarse debris will lead to the rapid growth of scree as compared to the rock producing finer debris.



As stated earlier the lower part of the constant slope which is formed by accumulated scree in nature will be weathered and carried by rain-wash away from the foot of the hill slope, resulting in the gradual reduction of the slope and assuming a concave upward form known as waning slope.

The recession of the hill continues till the free face disappears and the constant slope keeps extending upwards. The upper part will then result in a waxing slope. The upper convex, lower concave, and middle-rectilinear slope form will develop. Gradually the rectilinear slope owing to the extension of waxing slope from above and waning slope from below will disappear. Finally, the relief gradually declines due to wasting.

Wood was of the opinion that the manner in which the slopes evolve is not the same for all as a lot depends on climate, structure, and conditions observed at the slope base.