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Component-I (B) Description of Module

Items	Description of Module
Subject Name	**Geography**
Paper Name	**Geomorphology**
Module Name/Title	**Models of Slope Development: Davis, Penck, King Wood and Strahler**
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Objectives	
Keywords	**Slope Decline, Slope Replacement, Parallel Retreat,Convex Slope, Concave and Rectilinear Slope, Free Face, Pediments, Peneplain, Scarp Retreat, Waxing slope Inselbergs,**

Models of Slope Development: Davis, Penck, King Wood and Strahler

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Evolution of slope is concerned with the change of slope forms with the passage of time. Models of slope evolution investigate the processes and mechanism 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 ofslope development:

1. **Davis' Model of Cycle of Erosion**

2. Penck's Model of Landform Development

3. King's Model of Slope Development

4. Alan Wood's view on slope evolution

5. Strahler's View on Slope Development

1. Davis' Model of Cycle of Erosion

Davis through several articles and essays postulated his concept of cycle of erosion. His work on cycle of erosion was published in the year **1899**. Later through a number of papers and articles modified his work several times. Davis envisaged that all the **landforms** of the world pass through **evolutionary sequence**during which denudation processes act upon them to fashion different landforms in different stages of its evolution. Change in landform with the passage of time formed the cornerstone of his **cyclic concept**. The landform would change from 'initial' to 'ultimate form'. The crest (hill tops) will not remain stable for a long period of time rather theirheight and slope will decline with the passage of time. His cycle of landform development was thus **dynamic in nature**.Davis argued that all physical landforms can be analysed in terms of the three variables- structure, process and stage (Small,1978).

(i) Structure- The term structure included more than what its literal meaning. It included the manner of disposition of underlying rocks, level of hardness, porosity, folds and faults etc.

(ii) Process: It includes all types of weathering river, wind and glacial erosion, mass movements etc.

(iii)S**tage**: It means the time duration during which the processes operate on a structure.

Davis used the terminology of **youth, mature and old age** to mark different phase of evolution of landforms. He drew analogy between landscape and living being and therefore compared the life cycle of living being with the life cycle of landforms. He argued every landform undergoes sequential changes through the process of evolution where it passes through youth, maturity and old age. Davis talked about all these stages of life cycle in relative terms. In other words there is no fixed time duration for youth, maturity or old age because the time duration for each stage will depend on many factors. In regions of highly resistant rocks the duration of this cycle will be fairly longer compared with relatively weaker less resistant rock types.

Davis made some assumptions regarding upliftment of landform .He visualised the initial landform as a mass of land uplifted from the sea. The process of **upliftment** was **faster** and the denudation processes acted upon it from the time it almost became a stable mass.His normal cycle represent the case of humid temperate landform in which due to rainfall, several consequent streams would emerge. The velocities and stream direction would be controlled by the surface gradient.

Stages of the cycle

Following section discusses the three stages of Davisian cycle

(i) Youthful stage: The streams after their emergence will begin **rapid downward erosion** resulting in formation of deep valley bounded by **very steep slopes**. In other words V-shaped valley would be formed which will sustain its nature all through its youth. The divide summits are preserved in this stage. During the early beginning of the youth the valley side slopes are steep which by the close of the youthful stage gradually diminish. The rivers extend their valleys by continuous **headward erosion**.
Youthful stage is marked with the development of features like **waterfalls, rapids and gorges** etc. The long profile of the river bear these features hence Davis referred such profiles as degraded.

(ii) The Stage of Maturity: Here the rate of **valley deepening declines** and the **lateral erosion predominates**. In this phase begins the lowering of interfluves summit thereby reducing the relief of the landform. The vertical height between the valley floor and the summit declines faster. The end of mature stage sees decline in slope angles because of wasting divides. The landscape will have relatively smooth slopes. According to Davis this is a stage where slopes reach the **condition of grade**; a state where there exists a balance between the rate of production of weathered material and the rate of its removal. While vertical erosion was dominant in the youthful stage, lateral erosion that slowly erodes the interfluves dominates in maturity.

(iii) The Stage of Old Age: In this stage the process of landform evolution goes at a very slow pace. There is a**marked reduction in the river gradients**. The angle of valley side slopes declines continuously; there is decline in creep and wash as well. The slope gets covered with the detritus and thereby protected from mechanical weathering. The detritus conceals everything beneath it. The streams move on a very gentle gradient and often wander over their floodplain. **This stage lasts longer than previous two stages**. The slopes continue their wasting till they get a very low angle. At the end of the third stage, the relief is almost destroyed and the land surface appears as a flat featureless plain known as '**peneplain**'. The peneplain may have in its fold few hills which have still not lost their existence despite wasting. Davis called these isolated hills as ***'Monadnocks'***.

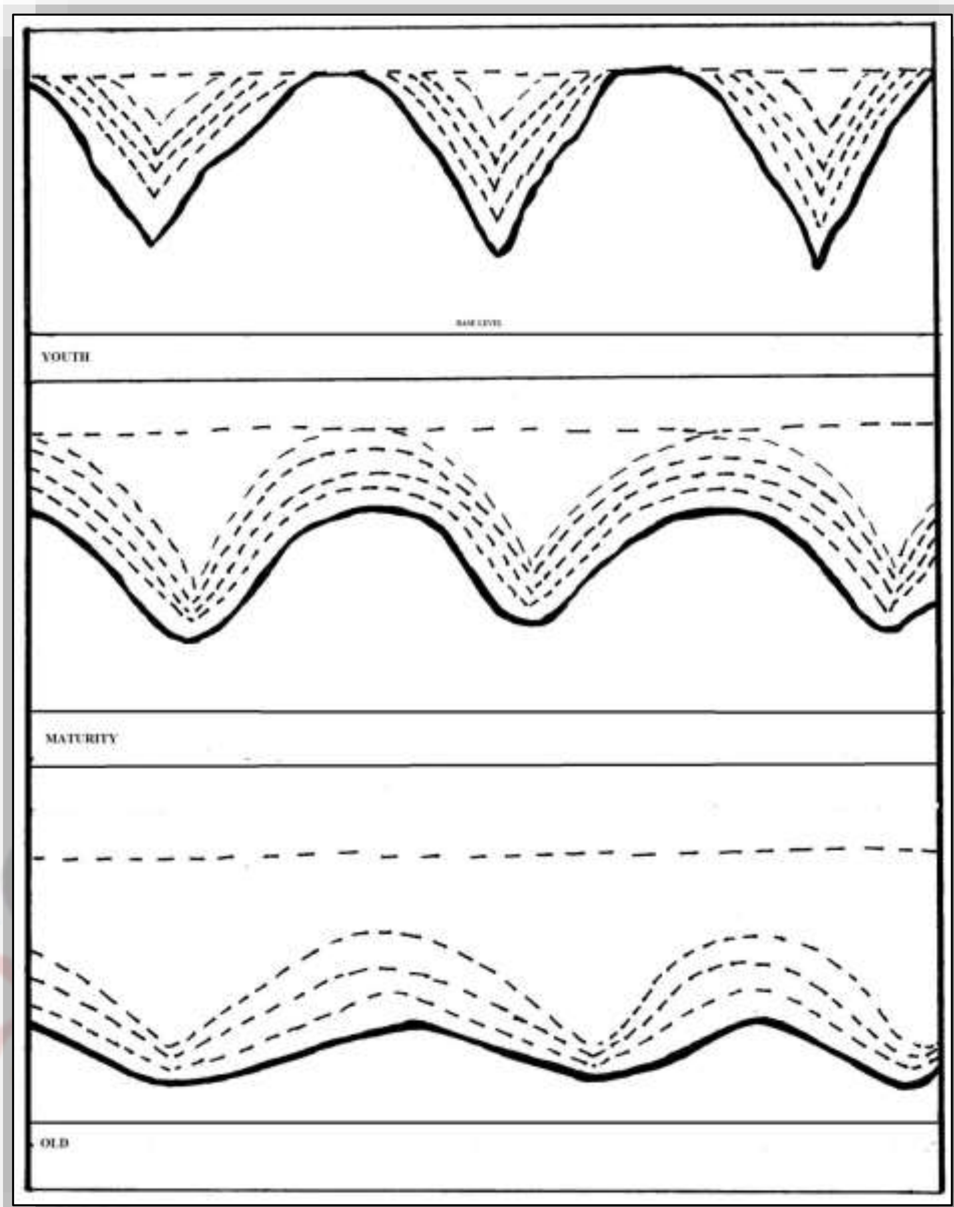

Figure 1. Different Stages of Davis'cycle

Davis on slopes

Davis held that upper convex part of the slope is produced by **soil creep**. He was of the view that creep produces '**rounded contours**'. As one comes down the slope the volume of surface wash increases but near the divide summit ratio of creep to wash is large (Young,1972). He also put forward the concept of **graded waste sheets** and**graded valley** sides (Young, 1972). According to him both rivers and waste sheets are mixtures of water and rock debris in different proportions. The graded condition is first established at the lowest part of the slope then moves upward.

He has equated graded slope with graded waste sheet. A graded waste sheet is one on which there is equality between the supply and the removal of debris while a graded slope has a continuous soil cover. In the words of Davis (1899) "just as graded rivers slowly degrade their courses after the period of maximum load is past, so graded waste sheets adopt the gentler and gentler slopes. When the graded slopes are first developed they are steep, and the waste covering them is coarse and of moderate thickness. In a more advanced stage of the cycle the graded slopes are moderate, and waste that covers them is of finer texture and greater depth than before". Davis further added in his work in **1932** that the retreat of the valley side slope is accompanied by a decline in the steepness of the slope and development of a convex and concave profile at the top and the base respectively.

With the advance of the cycle both the **convexity and concavity** extend and assume a larger radius of curvature. He has also stated that mountain and hills will be worn to gentler and gentler declivities, owing to faster downwash of soil from their upper convex slopes than the removal from the slope base.

Analysis of Davis' cycle

There have been diverse views expressed by different geomorphologists on the concept of **'peneplain'** put forward by Davis. Some regarded peneplain as theoretical landform because they considered that for Davis' cycle to run its full course it requires the landform should remain stable for a very long time. This possibility was very rare in reality where both **endogenetic and exogenetic**forces operate continuously and this may obstruct the smooth course of the cycle. It is also argued that during the period when the river is eroding its valley the removal of the overlying load is compensated by addition of more material to its root as per the principle of **Isostatic adjustment**.This will give a push to the overlying landform thus keeping the process of upliftment continue for an infinite time. Thus the attainment of peneplain stage is questioned as it contradicts the view of isostatic adjustment. Most geomorphologist also believe that Davis' idea of sequential change of landform is too simplistic presentationof landform evolution.Evolution of landform in reality is a far more complex process.

Although Davis cycle has faced a lot of criticism, it still holds its place in the work pertaining to slope evolution owing to its wide appeal and manner of presentation.

2. Penck's Model of Landform Development

Walter Penck was a German. His work appeared a little obscure, nevertheless the arguments which he put forward was based on logic. His work was neglected for long. He was dissatisfied with some of the assumptions of Davis like the process of upliftment of landform which was too short and a prolonged period of its stability where the cycle would run its full course. He offered **alternative model** where landscape would simultaneously be eroded with the process of its upliftment. The rates of denudation would vary and ultimately it would result into a low featureless plain called ***'Endrumpf'***. He attempted to establish a relationship between tectonic history of the region and the nature of slope (Spark, 1986).

Penck in his model took a **straight steep slope** unit bordering a river valley. He assumed equal weathering over the entire slope. The weathered material would fall under the force of gravity and reach the lowest part of the slope. The material lying at the lowest level would not be removed further owing to the fact that there is no gradient below it. In such a situation there would be a parallel retreat of the slope **(fig 2.a**).The unit AB due to weathering and its removal would retreat to position CD. In the next stage the profile would shift further from CD to EF. All the weathered material will not be removed for some must remain at the foot of the unit to provide slope of transport down to the non eroding river (Small, 1978). The subsequent stages would see the retreat of the main slope unit to the position XY. There is marked reduction in the length of the slope unit as it retreats from the position AB to XY.

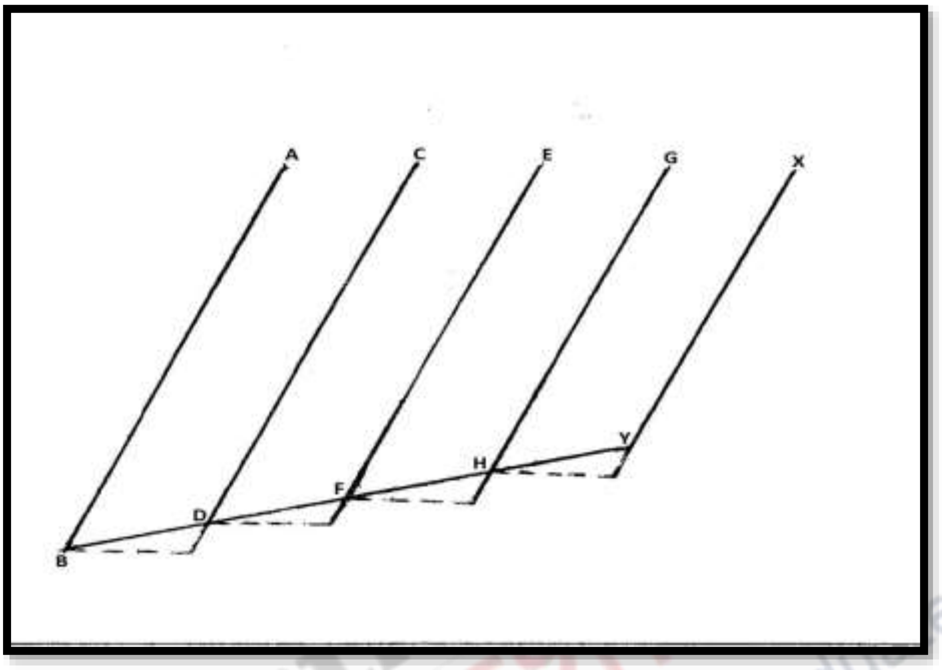

fig 2.a

At each successive stage it leaves behind basal fragments which combine to give a **uniform slope** covered with uniform thick layer of detritus extending from original slope unit down to the river. It is observed that a steep slope retreats upslope, maintains its gradient and gives rise to basal slope of lesser gradient. Now, two slopes have emerged- the upper slope and lower basal slope. Now the basal slope undergoes weathering and its material is reduced to finer particles. The weathered material is removed from basal slope but again the lowest particle is not removedas there is no gradient below it. Therefore, a new slope unit of gentler angle is added below the basal slope. (**fig 2.b)** Over a period of time a lot of new slope units of gentler gradient than the next unit above will be formed at the foot of the slope and undergo migration upslope. The overall result will be the development of **basal concavity** (Small,1978).

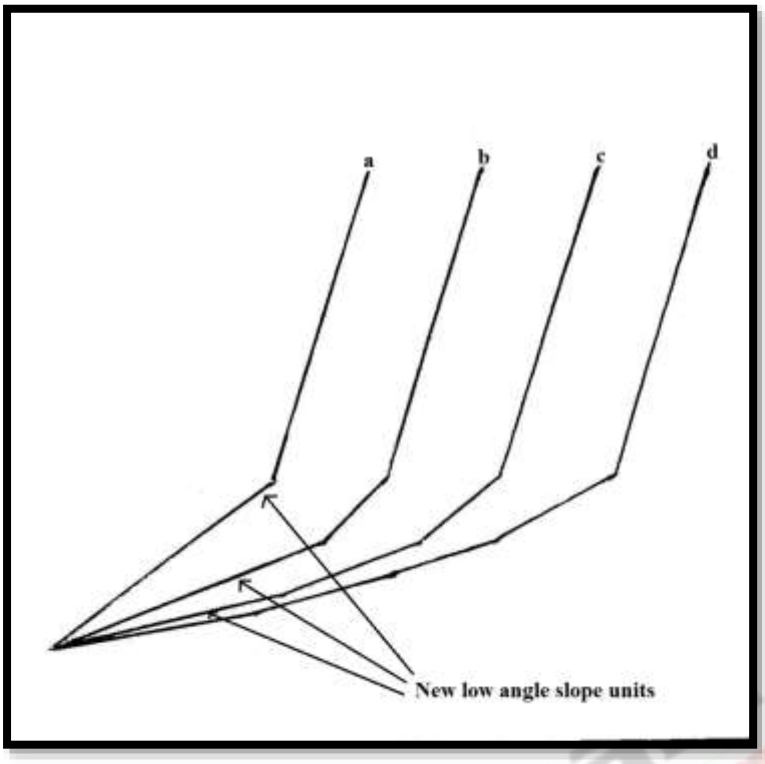

fig 2. b

The original slope will eventually be destroyed, the relief will be lowered , slope angle will decline. Thus it is observed in his model that **flattening of slope takes place** from below upwards. Penck's **model** of the slope evolution is essentially **deductive**. He has elaborated upon the development of slopes under conditions of accelerated and decelerated rate of erosion. According to Penck slope forms and the way they are altered are determined by the rate of river flowing at the base of the slope. According to him:

i. **Convex slopes** develop where the rivers are having an accelerated rate of downward erosion.
ii. **Rectilinear slopes** are formed where rivers are eroding at a constant rate and
iii. **Concave slopes** occur above the rivers which erode at a decelerating rate.

Thus the rateof river erosion forms the overriding factor determining form of slope.

Analysis of Penck's model

The essence of Penck's theory remains, however, that slope form and angle are primarily determined by the rate of erosion by rivers(Small, 1978). No doubt slopes may evolve in response to the river incision in the manner discussed by Penck , other factors like structures, climate and rock type also play important role in it.

3. King's Model of Slope Development

L . C. Kings proposed several theories on slopes as a part of broad scheme of landscape evolution. He proposed several sets of cycles like the river cycle, the hill slope cycle, the landscape cycle etc. King's work on cycle of erosion is based on his **observation of African**

landscape. He held that subtropical and semi humid climates should be regarded as 'normal' instead of humid temperate on which much of the discussion of slope evolution is based. His river cycle bears close similarity with the Davis' cycle of slope evolution.

King made closer examination of African landscape and stated that it is made up of two important elements one is the gentle concave slope that is found in the valley bottoms and border the streams or old water course. They are Pediments which over a period of time slowly extend their area and see the adjoining uplands retreat. Pediments according to king(1953) are normally covered with detritus but pediments themselves are essentially cut rock surfaces. The pediment is the fundamental landform to which **epigene landscapes** tends to be reduced. He termed the entire process of pediment formation as **pedimentation.**

The second element is the steep slopes that bound upland blocks. He called it **'scarps'**. The scarps here have originated by the process of erosion only and maintain steep slopes of **15 to 30 degree**. There is no reduction in their steepness when they are wasted back by weathering or rainwash. This is the process of Parallel Retreat which King called '**scarp retreat'**.

King's cycle of Pediplanation

King's landscape cycle discusses the process of pediplanation which shapes the erosion surface. Different stages of his cycle are discussed below.

Youth

The cycle of pediplanation begins with upliftment of an earlier formed pediplain. The streams carry out a **rapid downward erosion** . As the cycle draws near the end of youth the earlier fast down cutting slows down and witnesses the emergence of pediments in the valley bottoms. These pediments become wider because of the reduction of upland areas by scarp retreat. In the late youthful stage mostinterfluves will be converted into **inselbergs**, many will be rounded off like domes.

Maturity

In the mature stage the process of weathering causes reduction in the number of Inselbergs. There will be widening of pediments of adjoining **valleys which would eventually coalesce**. The few remaining inselbergs preserve the vestiges of the former pediplain (Small,1978).The relief which during the youth saw an increase will now show a decline or may remain constant in maturity

Old age

The old age will see very few **residual hills as relief has mostly been destroyed.** The whole landscape will now be dominated by gently sloping pediments; the '**multi-concave'**surface is the ultimate form of the cycle (Small,1978).

King did not restrict the application of his concept to African landscape only but he extended this to other non arid climates of the world to explain the process of landform evolution operating under most of the climatic conditions.

Thus, king's landscape cycle involves two processes of 'pedimentation' and 'scarp retreat'. It is the operation of these two processes which lead to the formation of erosion surface.

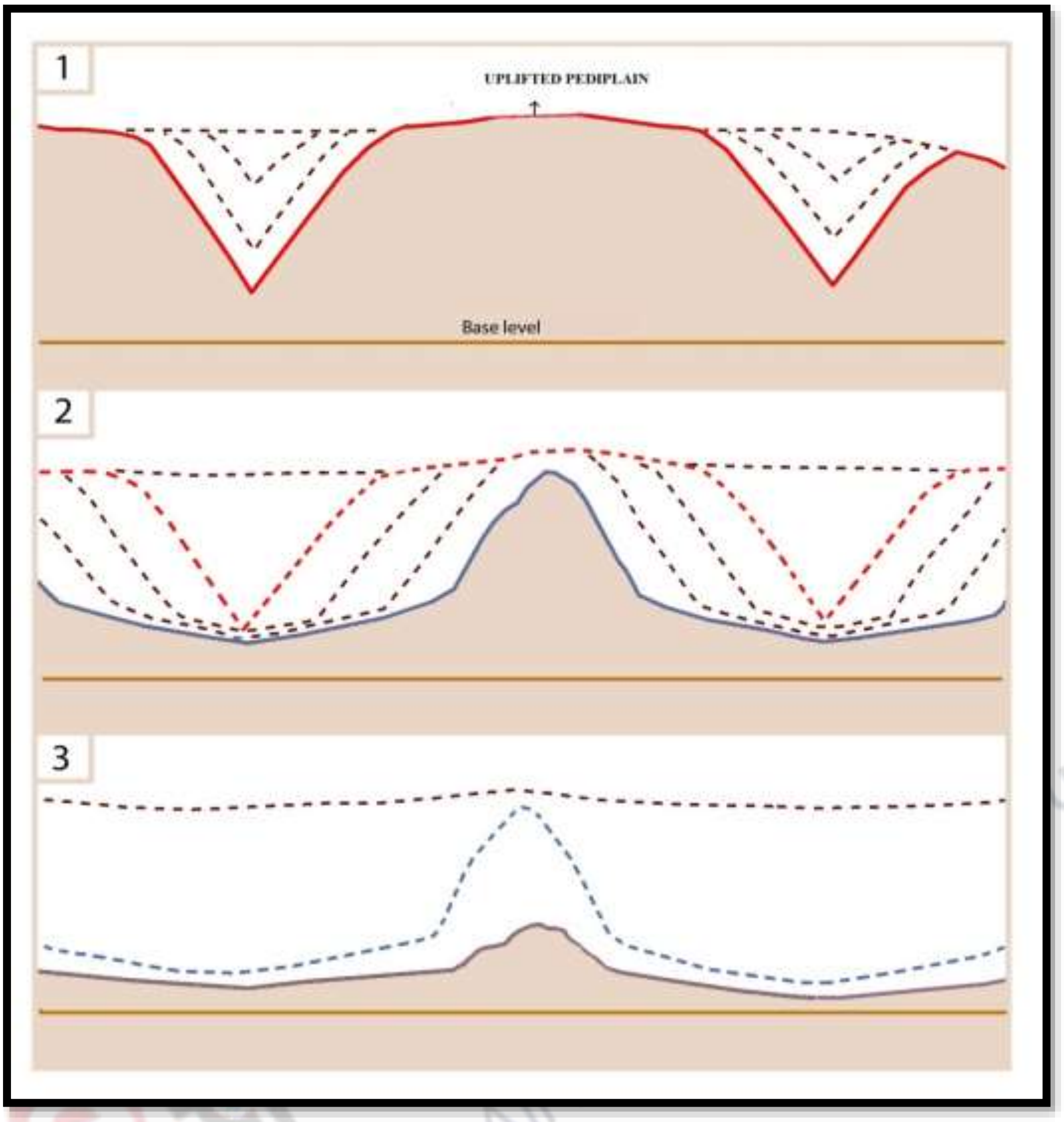

Fig 3

King’s view on slope elements

Hillslope evolution is a function of denudation that involves two phases - Production of landwaste and removal of landwaste. He underlined two principal agents responsible for denudation (a) Flowing Water (b) Mass Movement

King accepted the hillslope elements suggested by wood (1942). He further stated that these elements are product of hillslope evolution. The element are four in number- the **waxing slope, the free face, the debris or talus slope (constant) and the pediment**.

King(1957) was of the view that each element has a semi- independent evolution, they also react upon each other in varying degrees. His definition of the elements are given below

i. The waxing slope is the convex crest of a hill or scarp
ii. The Free face is the outcrop of bare bedrock exposed on the upper part of the hillside. It is the most active element in **backwearing**of the slope as whole.
iii. The debris slope: consists of detritus slipped or fallen from the face and resting at its angle of repose against the lower part of free scarp face.

iv. Pediment : Pediment is a broad concave ramp extending from the base of the other slope elements down to the bank or alluvial plain of the adjacent stream.

King argued ‘these four slope elements are to be found in hillslopes all over the world in all climatic environments; though locally one or more of the elements may be suppressed, such departures afford no contradiction of the normality of full development’.

The following figure illustrates it clearly different elements of the slopes and their relative positions**(figure 4)**

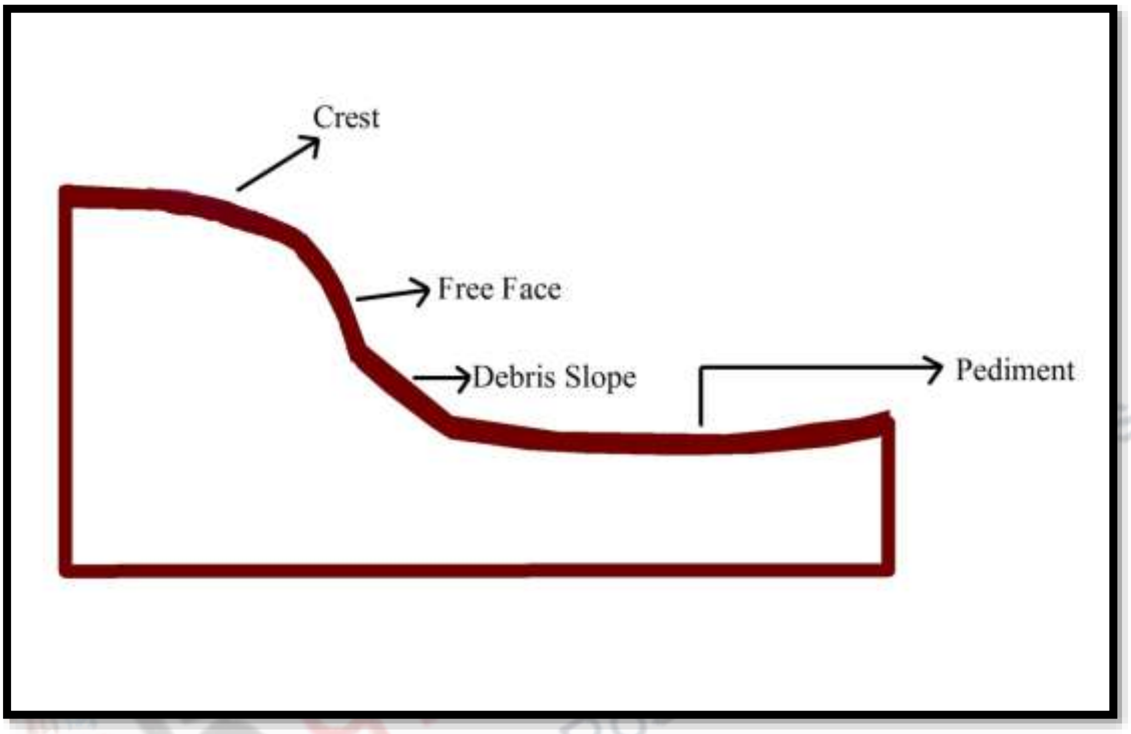

Fig. 4- Slope Elements

As stated earlier he accepted all the four elements of wood that appears in fully developed slope. But full development of slopes with all the four elements depends on other factors as well like a strong bedrock and adequate relief ‘failing these, the free face tends first to disappear, followed of necessity by the debris slope.A decadent **convexo- concave hillslope results’**(king, 1957)

Disaggreing with Davis regarding the ‘normal’ type of landscape, he holds semi arid type as normal landscape and pediplain is the ultimate cyclic landform formed by coalescing pediments. A pediplain is multi-concave upward (1953, King).

4. 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 5)**. The retreating face above leaves behind protrusion under the scree.

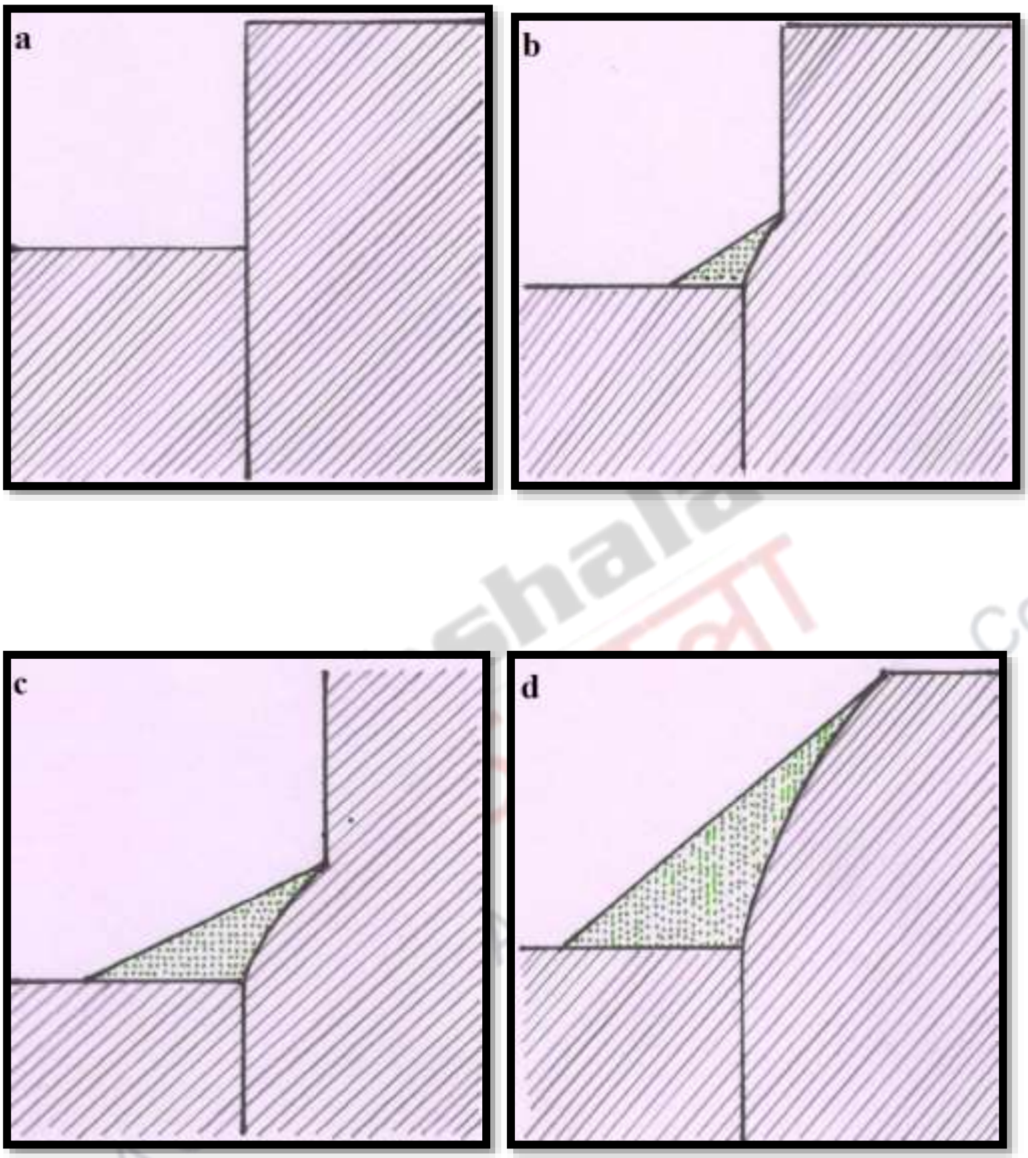

Fig .5 -a,b,c,d (after wood,1942)

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 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 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 buried face will become gentler. It can also be added that production of more coarse debris will lead to 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 rainwash away from 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 waxing slope. The upper convex, lower concave and middlerectilinear 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 same for all as lot depends on climate, structure and conditions observed at the slope base.

5. Strahler's View on Slope Development

The work of Strahler is statistical in nature. His work is based on the data collected from fieldwork in parts of California. Strahler (1950) collected data "with a view to determining

1) If differences in underlying rock types are associated with differences in slope angle.
2) If differences in directional exposure to sunlight and other meteorological factors produce differences in slope angles, and
3) If slopes decline in angle when left to weathering and erosion processes and not accompanied by basal erosion and removal".

He conducted measurements of maximum angles attained by slope and carefully identified the area and ensured it should have uniformity in terms of climate, vegetation, relief and tectonic history. Lithological factors, however, were not same.

He calculated **mean maximum slope angle** for the study area, then assessed the **deviation of slope** from the mean slope by comparing the data of slope collected at different points in the study area.

Strahler argued that if a large number of slopes show very little variation from the mean slope it means that the slopes have developed at approximately the same angle for the reason that this is the angle allowing the steady and efficient removal of the slope debris by slumping, creep and wash. Such slopes are in a delicate **state of equilibrium** (Small,1978). According to Strahler (1950) *"under the equilibrium, slopes maintain an equilibrium angle proportional to the channel gradient of the drainage system and are so adjusted as to permit a steady state to be maintained by the process of erosion and transportation under prevailing conditions of climate, vegetation, soils, bedrock and initial relief"*. Thus one can infer that the equilibrium slopes are governed by different slope controlling factors and change in any of the factors can cause readjustment of the equilibrium angle.

Strahler during the course of his field observation also studied the relationship between valley side slopes and the stream gradient and noted that with the reduction of landmass there is reduction in stream gradient and slopes. They gradually regrade towards the maintenance of equilibrium.

He confirmed the correlation between slope angle and channel gradient (slope adjusts in proportion to the debris obtained from the valley side slopes) where the valley sides slope is steep it will have a steep channel slope and where it is gentle it will have a gentle channel slope. However, there are exceptions to this rule in that the side slopes do not steepen with increase of channel gradient very near the head of streams (Sparks,1986). Strahler also noted that a **bare slope would contribute greater amount of load** than a vegetated slope at a given angle. This will result in steeper channel gradient beneath the bare slope than that below vegetated. This example displays how both the angle of the stream channel and valley side slope modify with the change in controlling factor (i.e.vegetation cover). Through careful measurements of slopes Strahler discovered that **where the river was closer to the foot of the slope it formed a steeper slope** because of removal of debris. But when the stream was away from the slopes they were protected from the basal cutting and had lower angles

Conclusion

The chapter gives an insight into the diverse hypotheses put forward by different geomorphologists. The term '**Slope Decline'** is used by **Davis** to indicate the process of slope evolution where the steepest part of the slope declines with the development of convexity and concavity. **Penck** on the other hand emphasized **'Slope Replacement'**where maximum angle declines due to its replacement by gentler slopes from below causing greater part of the slope profile become concave. **L. C. King** discussed '**Parallel Retreat'**where maximum angle remains constant but the concavity gradually increases in length. **Wood**defined elements of slope and discussed the development of **hillside slope**. **Strahler** used statistical techniques in his work and analysed **factors affecting slope evolution**.