III. GEOMORPHOLOGY

Basic concepts of geomorphology:

Geomorphology means a 'discourse of earth landforms' and is generally defined as a 'Science of Landforms'. It is a systematic study of landforms in relation to the climatological, geological and structural aspects. Study of geomorphology is of particular importance to aerial photo-interpretation as it forms major criteria in deciphering lithology and structure.

In the study of geomorphology several basic concepts must be considered before taking up interpretation of different landforms for their proper evaluation. The ten fundamental concepts are:

1. The same physical processes and laws that operate today, operated throughout the geologic time although not necessarily with the same intensity as at present.

This great principle was enunciated by Hutton who thought that 'Present is the key to the past'. This is also known as the 'Principle of Uniformitarianism'.

2. Geological structure is a dominant control in the evolution of landforms and is reflected in them.

This is the most important concept and has a direct bearing on the formation of a landform. It is an accepted principle that the geologic structures of rocks are much older than the geomorphic forms developed on them.

3. To a large degree the earth's surface possesses relief because the geomorphic processes operate at differential rates.

Though the relief of the earth's surface may primarily be due to variation in lithology and structure, the influence of variation in temperature, moisture, altitude, exposure, topographic configuration and vegetal cover is quite notable. This concept of differential weathering has been made use of in developing the quantitative approach to geomorphic problems.

4. Geomorphic processes leave their distinctive imprint upon landforms and each geomorphic process develops its own characteristic assemblage of landforms.

A geomorphic processes involves many physical and chemical changes by which the earth's crust undergoes changes.

The geomorphic processes are classified as under:

Endogenetic	Exogenetic	Organic	Extra- Terrestrial
Processes Originating Within earth's Crust:	Processes originating outside earth's crust:	Processes due to:	Processes due to:
i. Diastrophism ii. Volcanism	i. Weathering ii. Mass wasting iii. Erosion	i. Human agency ii. Organisms in sea iii. Vegetation	i. Meteoritic impact

Each geomorphic processes produces distinctive landforms and their genetic classification was introduced by Davis.

The complex geomorphic processes and their agents which act under a particular set of climatic conditions have been termed as 'morphogenetic system'. A landscape is usually a result of changing morphogenetic systems associated with changing climates through geological times.

5. As the erosional agents act upon the earth's surface an orderly sequence of landforms are produced.

The erosional agents such as running water, ground water, waves, currents, wind and glaciers acting on the earth's surface under a particular morphogenetic system over a period produce an orderly sequence of landforms. This principle has given rise to the concept of geomorphic cycle wherein the three stages of youth, maturity and old age are recognizable.

Thus it is observed that in the evolution of landform three controlling factors i.e. structure, process and stage play significant role. In addition to this, the role played by diastrophic history of the region is quite distinctive. As a result of this the geomorphic cycle may remain incomplete or may end abruptly at an intermediate stage in tectonically active areas. Some region may remain youthful with continuing uplift or there may be rejuvenation.

6. Complexity of geomorphic evolution is more common than simplicity.

The earth's surface is not developed by a single geomorphic processes or one geomorphic cycle of development. Though most of the present landforms are products of current cycle of erosion, the remnants of previous cycles are always present. Depending on the complexity of the development of landscape the following classification is in vogue (Horberg, 1952).

Simple Landscape

Compound Landscape

Monocyclic Landscape

Multicyclic Landscape

Exhumed / resurrected Landscape

The list of completely developed landscapes would not be complete unless we add another concept, that of 'Polyclimatic Landscape. The cyclic changes in climate during Pleistocene period with repetitive period of glaciation have left their marks on the landforms.

7. Little of earth's topography is older than Tertiary and most of it is not older than Pleistocene.

It has been estimated that at least 90% of land surface has been developed in post Tertiary time and perhaps 99% is of post middle Miocene in age.

8. Proper interpretation of present day landscape is impossible without a full appreciation of the manifold influences of the geologic and climatic changes during the Pleistocene.

The glaciation and inter-glaciation periods during the Pleistocene resulted in eustatic changes in sea levels forming coastal landforms. This also resulted in the formation of most of the lakes and also loess deposits.

9. An appreciation of world climate is necessary to a proper understanding of the varying importance of different geomorphic processes.

The climatic factors such as temperature and precipitation influence the operation of geomorphic processes. The climatic variations influence the geomorphic processes directly or indirectly. Indirect influence is related to vegetal cover, its distribution and density. The direct influence is a result of precipitation and evaporation, daily range of temperature, frequency of temperature falling below freezing point, depth of frost penetration, wind velocity and direction, the other factors being exceptionally heavy rainfalls and their frequency, differences in climatic conditions as related to slopes facing the sun and those not exposed to it, wind-ward and lee-ward sides of topographic features and climatic changes with altitude. Most of the concepts in geomorphology have been evolved in humid temperature regions. Concepts in respect of humid tropical, arctic and sub-arctic regions have yet to be developed. Same is the situation in case of arid and semi-arid regions.

10. Geomorphology, although concerned primarily with present day landscape, attains it maximum usefulness by historical extension.

Geomorphology concerns itself primarily with the study of present landscape but often the landscape has landforms belonging to previous geologic period. Their study is thus imperative and the geomorphologist has to look back into the past by adopting a historical approach. The principle of Uniformitarinism makes this approach possible. This aspect of landform study forms "Palaeogeomorphology".

Climatic influence on geomorphic processes

It is observed that there is a direct relation between the climatic conditions and the higher temperature and moisture content, heavy rainfall and thick vegetal cover. Chemical weathering process is most pronounced whereas in arid climate with large variation in day and night temperature and loss of moisture the physical weathering is most dominant. As such the landforms produced under a particular climatic condition are distinctly different from those produced under another.The dominant effect of climatic conditions is amply borne out by the following examples:-

Limestone country under humid tropical/temperature climate is most susceptible to chemical weathering resulting in characteristic low lying karst topography, solution cavities, sink holes, etc. If the same limestone country happens to experience arid climate where there is less of moisture and dominant geomorphic process is physical weathering, it forms cliffs and ridges. Granitic landforms are also to a large extent shaped by climatic conditions. Under humid tropical climate granite behaves like a weak rock and the chemical and physical processes are dominant. Effect of running water is considerable and granitic terrain forms a depression or low ground. In contrast to this a rugged topography with tors and inselbergs would result on a granitic terrain under arid and alpine climatic conditions where physical weathering processes are dominant.

The concept of morphogenetic regions

The geomorphic processes and their various agents give rise to characteristic landforms. But the effect of climate and the character of parent material brings in further modification in these landforms. It is observed that under a certain climatic condition particular geomorphic processes would predominate and give rise to characteristic landforms and thus the concept of morphogenetic regions has developed.

Based on this concept "Peltier " postulated nine morphogenetic regions considering variation in temperature and moisture and suggesting the dominant geomorphic processes in each, starting from Glacial (0 to 20^0 C temp. and 0 to 45 inches average annual rainfall) to Arid (55^0C temp. and 0 to 15 inches average rainfall).

The concept of peneplain

Peneplain is a low gently undulating plain developed as the ultimate product of the geomorphic processes. If the concept of geomorphic cycle is accepted, development of a peneplain is a natural corollary. Assuming stability of the earth's crust for a sufficient length of time, it seems inevitable that a land mass would eventually be reduced to base level. Considering the instability of the earth's crust peneplain is considered as the near end product and not the end product of the geomorphic cycle.

GEOMORPHIC CYLES AND THEIR LANDFORMS

The various geomorphic cycles are: -

i. Fluvial geomorphic cycle
ii. Arid geomorphic cycle
iii. Glacial geomorphic cycle
iv. Coastal geomorphic cycle
v. Volcanic geomorphic cycle

Fluvial geomorphic cycle

Running water is the most widespread geomorphic agent working on the earth's surface and as such landforms carved out by it are more important than those by other agents. Flow of water takes place down the slope under the influence of gravity and is either laminar or turbulent. Running water erodes the stream bed and sides as well, and transports the material. The process of transportation is done through various modes such as solution, suspension, saltation and shoving. This results in developments of drainage system with streams, rivers and valleys.

V-shape of a valley indicates "youthful stage" of the stream where the stream is more active in down cutting than lateral. As opposed to this in the "maturity stage, lateral cutting is more than vertical. Continuous valley widening produces the wide open valley of old age.

The cross section of a valley is often asymmetrical and the probable reasons are (i) undercut slip off slopes resulting in steeper sides on the outer side of a meander than the

Inner side, (ii) valley development on horizontally disposed alternating strong and weak strata resulting in structural benches, which are not continuous, (iii) in valleys parallel to the strike on inclined strata the stream has a tendency to migrate down dip of beds or even follow the surface of a resistant bed. It is called as homoclinal shifting.

FLUVIAL LANDFORMS

Graded Streams and Associated Landforms:

The longitudinal profile of streams is upwardly concave, with a flattening gradient in the down stream sections or reaches. A stream with an initial irregular gradient passing through water falls, rapids, lakes etc. carves out a gorge or canyon through those sections of resisting rocks to achieve what is called a 'graded' channel. A graded channel is one in which the stream receives and transports sediment to the limit of its capacity. The stream capacity is defined as the maximum load that the stream can carry through any particular cross section and this is expressed in terms of tones per day. On doing the work to the fullest capacity, the period of rapid down cutting by the stream is expected come to an end and a graded profile (without knick points) is said to be achieved. The down stream part of this graded profile ends up in a lake or sea, which is considered the base level of erosion. But this does not truly happen. There is not a single instance where the stream as a whole exhibits a graded profile. However, some reaches of the stream may appear graded.

Graded reaches of rivers exhibit well developed meanders. Coarse material is often deposited as riffles and bars in the river bed; these bars are placed alternatively in the left and in the right side of the river. Meanders are generated by growth of bends resulting from such local points of discordance along the stream channel. Meander bends progressively migrate down stream and are responsible for bank failure, and creation of point bar deposits and meander scars and scrolls.

Laboratory experiments have shown that the cross section of a channel transporting the same volume of water is dependant on the type of bed material – fine material gives a deeper bed, coarse material a flatter broader riverbed.

A river can have a straight, a sinuous, a meandering or a braiding channel. A Meandering river flows in sinuous curves. Meanders are arbitrarily confined to sinuous channels having ration of channel length to valley length equal to or exceeding the value of 1.5. The water in the meander moves as a corkscrew, the so-called helicoidal flow, that means that the flow is downstream but that besides this movement in a perpendicular direction occurs, formed by the centrifugal force on the outer side of the meander and deposition in the inner side. The strongest erosion takes place a short distance after the central part of the bend.

In course of time, meander bends/loops tend to develop meander necks and cut-off, thereby leaving an oxbow lake. The lake gets filled up to give rise to an oxbow swamp. The river also experiences a flood stage once in a year or two, and the over bank flooding creates a flood-plain. As the speed of the floodwater gets retarded on the flood plain, the sediment load is dropped as over bank deposits. Adjacent to the main channel, the coarsest sediment is deposited and by repetition of over bank flooding the coarse sediment builds up into lateral zones of higher ground, called natural levels.

From these natural levees, the flood plain slopes gently away, towards low-lying ashy areas or back swamps, which are the distal points of the flood plain juxtaposed to the sharply rising bluffs carved out earlier by the meander bends.

The zone where the meanders are formed is called meander belt sometimes a relation between the width of the channel and the width of the meander belt exists according to different authors the relation varies between 1:12 and 1:18.

Aggrading Streams and Associated Landforms:

A stream aggrades or raises the level of its entire channel when some of the tributaries bring in more load than the main stream can carry. Such a channel is usually broad and shallow and contains very coarse material that tends to split the stream into a number of channels. These channels unite and divide repeatedly in the manner of braided cords, around alluvial islands or channel bars. The stream flows within a well defined valley or a floods plain, and is called a braided stream. The growth of an island begins as the deposition of a central bar starts. The bar grows downstream and in height and forces the water to pass through the flood channels, which to carry the flow deepen and cut laterally into the banks.

Braiding develops in areas where there is an apple supply of coarse sediment available where discharge changes rapidly and the rate of rise of the hydrograph is rapid, and where slope is high or changes abruptly from high to low, as for example when a river emerges from a mountain range.

1. The difference between meandering and braiding is that a braiding river has a steeper slope than a comparable meandering river.

2. A relation between bank discharge and slope exists as follows:

3. An ideal meander is a sine-generated curve that is a meander from which the channel direction changes as sinusoidal function of distance. For this meander the friction and shear has the smallest value and

4. In a straight reach the bottom is uneven and consists of pools and riffles. Between the riffles the flow of the river is sinuous. The distance between the riffles is 5 – 7 times and width of the channel. The same relation between width and distance exists in a meandering river.

Pediment fans:

Aggradations can take place just as the river emerges from the mountains onto the pediment one building up an alluvial fan. The alluvial fan is in the form of a come with a steepening gradient as well as a coarsening sediment size towards the apex.

The Flood Plain:

The flood plain is a strip of relatively smooth land bordering a stream and overflowed at times of higher water. A typical flood plain will include the following features.

1. The river channel.
2. Oxbows or oxbow lakes representing the cut-off portions of meander bends.
3. Point bars; loci of deposition on the convex side of river curves.
4. Meander scrolls; depressions (swales) and ridges on the convex side of beds formed as the channel migrated laterally down valley and toward the concave bank.
5. Sloughs – area of dead water-formed both in meander scroll depressions and along the valley walls as flood flows move directly down valley, scouring land adjacent to the valley walls.
6. Natural levees; (already described). Where most of the load is find grained or very coarse grained, natural levees may be absent, or nearly imperceptible. A flat flood plain results in such cases.
7. Back swamp deposits; over bank deposits of fine sediments deposited in slack water ponded between the natural levees and the valley wall or terrace bluff.
8. Sand splays, deposits of flood debris usually of courses sand particles in the form of splays or scattered debris, deposited in places where the levee is broken through.
9. Gathering stream: The minor stream that develops from the back swamp of the major stream though a gap in the natural levee.

10. Yazoo: The tributary which should otherwise join the main river direct follows the path along the back swamp, down stream before similarly breaking through the barrier of natural levee to join the main river.

Deltas:

The term delta is derived from the shape of the Nile river delta, which resembles the Greek letter Delta. Deposition of the stream carried sediments in a body of still water like lake or sediment builds up the delta. The delta consists of top set, foreset, and bottom set beds. The top set beds are the levee flood plain deposits, spread by the flooding distributaries, over the foreset beds of steeply sloping layers of coarser sediments laid on the front slope of the delta. The fore set beds grade outward into thin layers of silt and clay as bottom set beds. The zone of topset beds is the delta lain, that of foreset beds is the delta slope and that of bottom set beds is the prodelta.

The form and content of the delta may be different. The arcuate lobate delta like that of the Godavari river consists of coarse, permeable material. The bird foot or digitate delta of the Mississippi river contains very find impermeable sediments forcing the river to change its channel. The cuspate delta with a pointed river mouth bar form is typical of streams with smaller discharge. In the tide nominated deltas such as that of Ganga and Brahmaputra (Meghana) rivers, tidal mud flats and mangrove swamps made up of silt and clay dominate.

The structure of the modern delta of the Mississippi river shows bar fingers of sand upon earlier deposits of marine clay and upon a thin layer of prodelta clays and silts that were laid down seaward of the advancing sands. As the bar fingers grow, clay and silt are deposited between the fingers.

Degrading streams and Associated Landforms:

A stream may degrade or erode its aggraded or graded valley on being subjected to a lower base level of erosion. This leads to carving out of a new valley within an earlier flood plain and creation of alluvial terraces, a succession of steps in the valley sides. They may be paired terraces of equal elevation on either bank or unpaired terraces of successively lower stages represented alternating on either bank. The former represented a stage by stage degradation phase, but the latter is one of a continuous degradation by the alternating sweeps of a meandering stream. On the other hand, degradation followed by deep trenching into bedrock leaves rock terraces, on either bank of the stream channel. At places meandering rivers have steadily degraded their channel resulting in entrenched valleys or winding gorges all along the entrenched meanders. Subsequent cut-off in the meander neck leaves rock arch or natural bridges.

Terraces are the fossil valley floors, the remnants of which now lie above the river bed and run more or less parallel with it, except in cases where the river has changes its course in later times. They can be recognized from (a) their flat surfaces bordered by escarpments (b) their occurrence along the river valleys or along the valleys of abandoned river channels.

The causative factors for river terracing are (1) Eustatic sea-level change, (2) Tectonic uplift, (3) climatic change.

Eustatic sea-level change:

World wide change of sea level is referred to as the eustatic change, implying that sea level rises or drops while the land remains stationary. Such changes are brought about by withdrawal of large amounts of water from the ocean during enlargement of continental ice sheets or may be caused by subsidence if portions of the ocean basins. The effect of eustatic, lowering of base level is to cause streams to incise their channels and begin to degrade them to the new base level.

Tectonic uplift:

Uplift of the land may produce the same effects as lowering of sea level; and tectonic down warping of the land has the same result as a rise of sea level. The increase in gradient of stream courses in an uplifted area gives rise to increased downward erosion and channels become incised below their previous levels. Down warping of the land causes streams to aggrade their channels in order to maintain appropriate gradients.

Climatic Changes:

1. If the annual precipitation in an area increases the discharge of streams in the drainage basin also increases. With increased discharge, streams are able to maintain a given velocity on a lower slope, and the result is down cutting of the stream.
2. If the glaciers enter the headwaters of a drainage basin as a result of climatic changes and contribute large amount of coarse debris, slope requirements of the stream will increase. The effects of increased discharge and increased load are opposite. One tending to cause down cutting the other aggradation.

Terrace Slope Correlation and Numbering:

Normally a terrace level rises up valley. Warping or tilting of an area after terrace development may in rare instances cause terraces to slope upward. Warped terraces are useful in determining the amounts and nature of recent deformation.

The terraces can be correlated

1. With the help of altitude or terrace level.
2. By identification of fossils, pollens, pores, etc.
3. By material correlation such as,

a) Comparative decomposition of boulders;

b) Lithology of the terrace materials,

c) Depth of weathering of terrace materials

d) Mineral assemblage in the material

Correlation of terraces from one valley to another valley is more difficult. The best method is to trace such terraces from the junction of the streams. The youngest and the lowest terraces are numbered as T_0 and the higher and older terraces as T_1, T_2 , T_3, etc.

Valley classification: The valleys carved out by streams have been classified on the basis of – (1) stage of development as (a) young (b) mature and (c) old age, (2) Genetic classification; i.e. (a) consequent valleys developed on initial slope, (b) Subsequent valley which are valleys shifted from consequent slope to more readily erodable surface. They follow the strike of the rock and can be called as strike valleys, (c) Insequent valleys which do not show apparent control of structure or lithology (d) Resequent valleys which are developed on the consequent slope but at a lower topographic level; (3) controlling structures – (a) Homoclinal valleys – are strike valleys, (b) Anticlinal valleys – are those which follow the axes of the breached anticlines (c) Synclinal valley – are those which follow the axes of the breached synclines (d) Fault valleys are the ones which follow the depression consequent upon faulting and (e) Joint valleys which follow the joint planes.

Drainage texture and its implications: Study of drainage texture is an important concept in geomorphology and has wide implications. Drainage texture can be defined in terms of relative spacing of drainage lines. Drainage texture includes drainage density and stream frequency. Drainage density is defined as the total length of the streams in a drainage basin divided by the area of the drainage basin.

Drainage texture is defined in relative terms of fine, medium or coarse. The factors controlling drainage texture are climate including amount of precipitation which directly controls run off. Vegetal cover is another factor governed by climate. The other most important factor that has a bearing on the drainage density is permeability of mantle and bed rock. Drainage density is more over impermeable material than over permeable material the example being shale and sand stone respectively. Drainage texture is also influenced by the relief of the terrain. If the terrain lacks conspicuous relief the drainage density would be low; structural elements of bed rock such as massiveness, joints, fracture and faults also have controlling influence on drainage density.

Badland topography represents fine texture and high density of drainage due to impermeable clays, sparse vegetation and flash rains.

Drainage pattern: Drainage pattern is a plan or design which the stream courses collectively form. Drainage reflects the influence of factors like initial slope, inequalities in rock hardness, structural control, recent diastrophism and recent geologic and geomorphic history of the drainage basin. Study of drainage pattern is of practical importance for a photointerpreter in understanding lithological and structural control over landform evaluation. A description of different drainage patterns and their significance in terms of the bedrock, lithology and structure is given in the following chapter on photointerpretation for geology.

Rejuvenation of fluvial cycle: Multicyclic development of landscape is more common than monocyclic development. As a result of it on a old age topography, youthful features may be superimposed due to rejuvenation. Rejuvenation is caused by dynamic, eustatic or static forces.

Dynamic rejuvenation – is caused by epiorogenic uplift of land mass. Such movements could be of local nature or associated with orogenic movements. These result in steepening of gradient followed by downcutting by streams.

Eustatic rejuvenation – is caused by world wide lowering or raising of sea levels which are directly related to glaciation and inter glacial periods. Diastrophic eustatism has been also responsible for changes of sea level. These result in marine terraces, submergence of land and rejuvenation of rivers at the mouth.

Static rejuvenation – Some times streams show signs of renewed youth forms which are not related to either dynamic or eustatic changes.

Rejuvenation of a stream is indicated by two cycle valleys wherein there is no relation between the old age stage at higher reaches and the youthful lower reaches of the valley. A meandering stream when rejuvenated starts incising the meanders and deepening the channel. The effects of rejuvenation are best depicted by the rock or alluvial terraces which are of cyclic/paired or non-cyclic/unpaired type. Unpaired terraces are observed along meander bends.

Aggradation may result as a result of lowering of surface instead of uplift. The same effect is caused by rise in sea level. This results in alluviation in place of down cutting.

A fluvial cycle nay be terminated by natural reasons due to peneplanation or may be interrupted by lava flow or glacial drift. But the fluvial cycle re-establishes itself as soon as the obstructive activity ceases.

Misfit Rivers – are those, which are not proportionate to the size of the valley they occupy. They may be under-fit or over-fit. Examples of under-fit streams are quite common. Karst geomorphic cycle forms a part of fluvial cycle or specialized branch of fluvial cycle where in ground water is the dominant agent and solution is the dominant process.

Karst landscape may develop as a result of uplift above the base level of limestone terrain on which fluvial erosion is active or uplift of terrain occupied by clastic rocks underlain by limestone. The solution action is most active along joints and weaker planes, which gradually enlarge, and an underground drainage system develops. The landforms in the initial stages are lapis, dolines and sink holes. The inter spaces between the lapis is filled by red clayey soil which also fills the enlarged joints and is called Terra rossa. Caverns, tunnels and natural bridges are the other forms develop. Climate has an influence on development of Karst topography as in humid-tropical regions the solution action is much faster than in humid middle latitudes.

The Arid Geomorphic Cycle

In the arid geomorphic cycle the dominant agent is wind action and the weathering process is physical. There is active dissection of the high land in youth stage and accompanying aggradation of the basin.This results in the formation of landforms like Inselbergs and Bornharts surrounded by vast pediplains. At the base of these outstanding landforms is a gently sloping accumulation of rock debris called the piedmont slope which gradually merges into pediplain. The gentle sloping ground at the base is further divided into pediment (corroded bedrock surface and bajada the accumulation of debris) and both together form the pediment slope having 1 to 70 gradient. Hamada is a rock desert. On the pediplain the Aeolian deposits give rise to various landforms due to wind action. These landforms are sand shadows, sand dunes (Barchan), whale back or sand levees, undulations and sand sheets.

Glacial Geomorphic Cycle

Glaciers at present exist in high latitudes only and are of minor importance as far as shaping of landforms are concerned. But in the geologic past and particularly during Pleistocene, glaciers were rampant and covered over 100 million km of area on the globe. There were four periods of glaciation with inter glacial periods and have left their marks on the landscape as we see it today in North America, Europe and Asia.

The glaciers have been classified into three major groups:

A. Ice Caps
- i. Continental glaciers
- ii. Glacier caps
- iii. High land glaciers.

B. Ice Streams
- i. Valley glaciers – Alpine type
- ii. Transection glaciers
- iii. Cirque glaciers
- iv. Wall aided glaciers
- v. Glacier tongues afloat.

C. Transition type
- i. Foot glacier
- ii. Sheet ice

They are also classified as :

1. Temperate glaciers
2. Poolar glaciers
   - a. High Polar
   - b. Sub-polar

Major landform features resulting from glacial erosion are:

Cirque: It is an amphitheater like basin carved out in high mountain area. These are also referred to as corrie or kejdal.

Horn Peaks: The cirque or corrie developed on sides culminate upward into a sharp peak of the mountain and is called as horn peak.

Glacier trough: These are the 'U' shaped valleys formed by the movement of the glacier in the initial 'V' shaped valleys.

Some other landforms carved out by glaciers are:

i. hanging valleys
ii. arêtes or serrated ridges
iii. truncated spurs and
iv. piedmont lakes

The depositional landforms produced by glaciers are:

i. end moraines
ii. lateral moraines
iii. ground moraines
iv. glacial till deposited by continental glaciers

As the glacier recedes knobs and basin topography develops on the end moraines.

i. Valley train – Sand and gravel extending down valley from end moraines.
ii. Eskers
iii. Kame terraces
iv. Drumlins
v. Kettle

Coastal geomorphic cycle

The process of marine erosion is controlled by waves. The storm waves and tsunamis are the most important agents. In addition to these the other influencing factors are – (i) parent material along shores , (ii) tidal range, (iii) configuration of coast line, (iv) openness of shore to wave attack, (v) depth of water off shore, (vi) presence or absence of protective beach, (vii) abundance and size of abrasive tolls, and (viii) stability of sea level.

The important landforms, carved out by marine erosion are; (i) Wave Cut terraces ; (ii) shore platform; (iii) Coves bays or bights; (iv) Sea arches or caves (v) Sea cliffs, (vi) Fjords ; etc.

The landforms produced as a result of marine deposition are; (i) beaches (ii) bars (iii) spit (iv) tombolo.

Volcanic geomorphic cycle

Landforms due to central type of eruption are:

(i) Volcanic cone; (ii) Calderas and (iii) Plug domes

In the fissure type of eruption the pile of lava flows gives rise to plateau and step like topography. The step like topography develops due to alternating massive and vesicular flows - Massive flow forming a plateau and an escarpment and vesicular flow forming a gentle undulating slope.

INTERPRETATION OF LANDFORMS

The first thing that strikes a photo – imagery interpreter is the morphological layout of the stereo model. The geomorphology of the area carries the imprints of climate and lithology which shape the landform and drainage pattern. The effect of climate is very pronounced as under various climatic conditions same lithology gives rise to different types of landforms.

Lithological conclusions are arrived at on the strength of the morphological outlook of the rocks in relation to the climatological conditions and the stage of geomorphological development, i..e on the mode of occurrence, further in non vegetated areas it is based on the gray tone which depends largely upon the mineral content (acidity). A good knowledge of the indicative landform is a pre-requisite for this kind of work.

Landforms related to intrusive igneous rocks

The landforms and especially the slopes – developed in various types of igneous rocks vary from one rock type to the other. They have however, also much in common, due to their massive character and the dominance of weathering along fractures.

The massive character and comparative homogeneity of larger igneous intrusives is reflected in the morphology by a coarse and regular dissection and a drainage pattern with strong dendritic trends due to absence of any influence of the geological structure. A rectangular or angular trendency may exist, due to jointing. No lineation of vegetation occurs, unless pronounced jointing exists. A bold topography develops if the rock is resistant to erosion, which is the case in many types of climate. Narrow steep sided valleys with convex slopes are characteristic in mountainous areas, because, river incision (vertical) normally proceeds faster than slope recession.

Smaller intrusive bodies are best characterized by the forms and shapes associated with their mode of occurrence. Dykes appear on the air photos, as straight or curved lines or narrow belts. They stretch across other geological features and if their width is sufficient to make them visible from the air, their identification is comparatively easy. Difficulty arises if sills occur in sedimentaries. Many dykes, especially the acid / intermediate ones, are rather resistant and thus ridge forming. Basic dykes in humid climates tend to be chemically weak and form depression and exhibit dark grey tone. Igneous laccoliths, plugs and domes are indicated by the upward bending of surrounding sedimentaries and also by a radial drainage pattern.

The boundaries of intrusive bodies usually form smoothly curved lines and in the case of acid. Intermediate rocks a broad contact metamorphosed belt exists. This is normally more resistant than the intrusive itself, and thus forms marginal belt with relatively higher elevation. Dykes and veins frequently occur in this zone.

The fracture pattern sometimes governs the drainage pattern to such an extent that it becomes characteristic for the rock type and thus is an aid in lithological interpretation: A cellular texture of the terrain is sometimes typically developed in granitic areas of low relief in the humid tropics.

Cleavage which is sometimes clearly visible in Alpine region has quite a different effect on the outlook of granites. Distinction of intrusive granitoids from gneisses sometimes is difficult. Gneissosity increases the resistance of the rocks and makes them stand out more in relief, although more intensely dissected. The landforms carved in basic intrusives are rather similar to those of the more acid rock types, although many of them have a slightly lesser resistance to erosion and thus have somewhat more subdued forms and more gentle slopes.

In sparsely vegetated areas the darker grey tone of the igneous bodies is the best indication. It should be noted, however, that weathering also has an influence on the grey tone as it tends to lighten the tone. The absence of the distinct surrounding contact metamorphic belt is typical of basic intrusives. Smooth, subdued forms are characteristic of ultrabasic rocks (peridotites). This, supported by fracturing explains the fact that these rocks are little or not effected by chemical weathering. Peridotites (and serpentines) are moderately resistant and often form smooth ridges especially in dry climates (SABET, 1963). A cellular texture develops where numerous fractures occur. Gabbros may be strongly dissected and form sharp ridges and spikes in arid terrain. Lithological factors rather than aridity also influence the landform. Fine grained rocks (aplites, porphyries) are more resistant than coarser grained ones (granites, pegmatites etc).

Climate influence on granitic landforms: Granites in moderate climates are resistant to erosion because of the not too intense weathering and the moderate surficial run off.

These rocks stand out boldly in relief with a tendency for convex slopes. If the area suffered a long period of base leveling acts it results in the formation of a peneplain. Such a penepalin is characterized by an intricate pattern of low rolling hills and dense drainage system. Weathering is also concentrated along joints and as a result slightly rounded blocks are found in clayey residual material.

Weathering along joints and woolsacks formation is even more pronounced in the humid tropics due to more intense chemical weathering. The higher parts of the mountains are characterized by rounded crests, steps and often convex valley sides. A cellular texture is characteristic of the old stage of erosion. When the drainage lines are particularly located in fractured zones, the less fractured and little weathered rock sometimes rises abruptly from the surrounding peneplain as "sugar loaf mountain", which develops further by exfoliation.

Completely different landforms occur in monsoon climates where high temperature exists and the influence of running water is considerable as the intensity of rain increases during cloudbursts. Both physical and chemical weathering proceeds at high rates and as a result the granites being weak rocks to physical weathering form depressions in many cases and especially if coarse and have biotite as accessory. Where such granites occur large scale inversion of the relief takes places. In the case of an advanced stage of erosion the slopes do not normally have the convex profile mentioned earlier for the moderate climates, as the vertical erosion is not so dominant. Lateral erosion widens the valley and the more intense chemical weathering produces gentle or even covered concave slopes. The woolstack type of weathering is replaced by another mechanism. The small quantities of rain water occurring percolates into the rocks along joints and subsequent evaporation results in the formation of a resistant crust of minerals resolved in the centre. The interior of the rock thus becomes rotten as the coherence between the grains is reduced. An important aspect of weathering in this climatic belt is the minor importance of vertical erosion as compared to planation. This results in the formation of pediments, etc. Tafoni do not occur in completely arid regions, probably because the humidity is too low and the removal of soluble material from the rock thus cannot proceed adequately. The influence of joints on erosion then becomes important again. The high response to thermal disintegration of most intrusive granites results in their strong reduction in arid climates.

An extremely rugged topography with vertical slopes, needles, etc. is developed in the cold zones (Arctic or Alpine) by strong physical weathering (heating/cooling, frost action) concentrated especially along joints. Chemical weathering is rather unimportant and so is surficial runoff. The latter is only important for transporting the waste. More rounded shapes are only found where glaciation formerly polished the rocks.

Landforms related to extrusive rocks

Extrusive nature of rocks is more conspicuous especially if it is a more recent occurrence. The nature of effusive material is clearly reflected in the forms of the lava. Basalts often are plateau forming due to their low viscosity. The plateau are horizontal or gently inclined, well drained and have a rather uniform appearance. The edges usually are vertical and dented. Columnar jointing is characteristic and scree fans occur below the cliffs. Lava flows of the ropy type occur in more hilly terrain. Flow lines and pressure ridges occur in the middle and lower parts of such flows, hallow lava tunnels formed below solidified crust of the lava and emptied by further down stream flow of the still molten interior are visible in the upper parts of these flows. These tunnels frequently collapse and then appear as distinct grooves on the photos.

These phenomena can also be observed in some andesitic lavas, but in the more acid types, the lava is less viscous and does not usually show pressure rings and flow structures. The surface is more rugged and without a distinct texture. Tholoids are common features and somewhat steeper slopes result due to greater viscosity.

The top parts of such lava flows are smoothly rounded as seen from the air and their slopes tend to be concave in the upper part and convex in the lower portion. Lavas of high gas content sometimes form a fan like flow having a very irregular surface due to the escaping gases. Lava flows are in general resistant to erosion and because they tend to follow terrain depression (valleys), inversion of the relief is a common feature in eroded areas of extinct volcanism.

Fragmentary material produced by volcanoes also has characteristic forms. If deposited near volcano, vent cones' are formed with straight slopes, representing the maximum angle of repose. If the cones are built up by ashes (tuffs), they are intricately dissected but if composed of pervious cinders/scoria, their dissection is negligible.

Tuff plateaux are typified, by their flat surface and vertical valley sides. The material is very resistant after cementation. The vegetation usually is not very dense, except on old weathered tuffs in the humid tropics. If larger volcanoes are mainly composed of fragmentary material, three different parts of the their slopes can be distinguished viz, a steep (35°) upper part; where the maximum angle of repose exists if formed by wet deposition, a much large gentle (10°) median section also formed by wet deposition (volcanic mud flow) and an almost horizontal (1°) bed deposited during fresh deposition. Thus, apparently a concave profile results composed of three sections mentioned above.

Eroded andesitic terrains are moderately dissected and the steepness of the slopes is somewhat greater than in basaltic lavas. The valleys are rather wide with concave sides and the crests are consequently rather narrow and uneven when seen from the air. More acid lavas (rhyolites etc.) form steep sided hills (bocas) with a tendency to have convex forms. It is claimed that in rhyolitic areas, the upper reaches of the rivers are sickle shaped. In arid areas the grey tone is a good criterion for identifying acidic lavas. The lobate forms and the unconformable contact with underlying rocks are an aid in detecting such lavas.

Landforms related to metamorphic rocks

Photo/image interpretation of metamorphic rocks is a difficult subject which, until now, has only received very little attention. Metamorphism tends to make the rocks more resistant and the differential susceptibility of erosion becomes less pronounced. Contact metamorphic zones are the easiest to detect because of the upward swerve of sedimentary around the igneous body and greater resistance of the rock due to frequent occurrence of quartz veins. The more widespread areas of regional metamorphism offer more difficulties. They usually resemble to a certain extent the (weaker) rocks from which they are derived. The' intense tectonic activity which occurs in those areas produces distinct schistosity or foliation. If the metamorphics are of sedimentary origin steeply dipping and vertical beds are predominant. The bedding is coarser and less distinct than in corresponding sedimentaries. Allum (1962) states that if numerous and rather short close spaced ridges occur, those usually result from schistocity, whereas longer and more continuous ridges indicate the original bedding. The schistosity according to Allum is often approximately parallel to the bedding. Actually the strike direction can often be established photographically, but the determination of dip is only possible in rare cases. As every rock type has within a certain area its own photo characteristics, their regional distribution usually can well be delineated, but field work is essential to establish the lithology.

Gneiss, in moderate climates is not always easily distinguishable from granite, although the shapes of hills are elongated and schistosity may be reflected in the landforms. In the humid tropics gneisses are mostly less resistant thin granite and form somewhat lower zones.

This is explained by the fact that gneissosity renders the rocks more susceptible to the intense surficial runoff; where as in the warm climates with a prolonged dry season gneisses are more resistant. However, steep and narrow valleys are formed by the rapid vertical erosion, but the slope development under the influence of various weathering processes proceeds slowly because of the dryness and steepness of the slopes. Such rugged forms also seem to be characteristic of arid areas. SABET mentions, noticeable increase in the relief and the drainage pattern in coarse textured. Schists have stronger impact on the drainage and on the direction of the elongated ridges. The rocks crumble easily along these planes and large scree fans develop, especially if the content of mica is high. The mineral is strongly affected by temperature changes and frost action.

Quartzite schists are harder than mica schists and are more coarsely dissected and ridge forming. The gray tone is lighter and the drainage pattern is more influenced by the bedding than in the case of weaker rocks where a dendritic drainage pattern is often observed~ The dissection is most intricate in arid and semi-arid areas, particularly in phyllites. Wind work deflation tends to increase the effects of differential erosion. More rounded forms occur in humid climates, particularly in resistant metamorphic rocks e.g. crystalline limestone and quartzites. Quartizites tend to form a particularly rugged and coarsely dissected topography. Serpentine is characterized by smooth surface, steep slopes and often cellular structure. In the humid tropics if these are surrounded by more resistant rocks they tend to form poorly vegetated depressions, whereas subdued ridges occur where they are surrounded by weaker rocks particularly in dry areas.

Landforms related to sedimentary rocks

The interpretation of sedimentaries is somewhat more advanced than that of crystalline rocks. This is however, due to the importance of structural interpretations and its bearing on the lithological aspects. Grey tone criteria used in non-vegetated areas are influenced by humidity and

Sandstones/Conglomerates are characterised by the boldness and the regularity of their relief is mainly due to permeability and coarse drainage pattern. River valleys without water channel develop in these areas. The slopes are steep and narrow gullies develop. Joints/faults have a distinct influence on the dissection. Springs often occur at the base of sandstone escarpments and effect the recession of these slopes resulting in scarp retreat due to which large blocks and boulders are often found rolled down on to the slopes. In arid areas quartizitic sandstone exhibits sharp forms. Porous sandstone tends to have more rounded forms, especially in humid climates. If weaker rocks underlie the sandstones, the boundary is indicated clearly by their more gentle slopes. These characteristics apply only to well cemented sandstone and not if thin sandstone beds alternate with shales, etc. The bedding is often clearly indicated by the alignment of vegetation in humid areas but in semiarid areas vegetation is scantier on the sandstones. Natural forest is frequently found on sandstones in humid countries.

Shales are soft rocks and have low permeability. Infiltration thus is limited and surficial runoff is more in shale. Rapid erosion by river work and susceptibility to mass movements (slumping) along the gentle slopes are characteristic features. The dense drainage pattern lacks angularity unless more resistant sandy shale alternate with more clayey ones. The influence of geology on the drainage pattern is limited due to the softness of the rocks; Fracturing in these rocks is of little importance. Vertical incision of river and gullying in humid climates proceeds by rock/soil colour but there is a tendency of fin~ grained material in humid climates (shales, etc.) to appear darker in tone than sandstone.

Differential erosion is most effective if finely bedded rocks of varying resistance occur together. In areas of massive bedding, the details that can be interpreted are less especially in humid climates. Shales are generally weak and form depressions occupied by rivers, whereas sandstones, conglomerates, etc. form ridges. Relief and drainage pattern thus are the main indications of lithology.

Dendritic patterns are best developed in more or less horizontal beds, whereas parallel patterns are formed where more steeply dipping beds occur. The angle of dip has a strong influence on the landforms and on the 'texture' developed. The stratification and resulting alignment of welt defined ridges are the best indication for identification of sedimentary rocks. Limestones are an exception to this rule as they are normally better characterized by their karst topography in humid climate. Alignment in metamorphics is always much more vague and "wavy"; further the ridges are more subdued except where slates are involved. The distinction between slates and finely bedded resistant sedimentaries is thus difficult quickly, but the slope development also is rapid due to water saturated rock and soil mass. The result is a low lying and intensely dissected rolling country with rounded hills. Broad, open valleys and ill-drained plains develop in the more advanced stages of erosion.

Gullying is intense in dry climates, where occasional rain showers rarely transport the dry particles which are insufficiently protected by vegetation. Extreme gullying may result in "bad land" formation. Since slumping in arid areas does not play a role, steeper slopes and sharper forms develop than in humid regions of the slopes. The steepest and sharpest forms occur, where clays and sands alternate and badland topography develops in such association.

Climatic influence on limestone landscape: The landforms in limestone area depend largely on the climate and are furthermore influenced by the lithological composition of the rock and by the dip of, the beds. Karst (solution) features are most characteristic in pure limestones, where internal drainage plays an important role. Biohermal limestones, are generally dry and porous and surficial drainage is completely absent in them. The number of sink holes is limited and infiltration evidently occurs throughout the area. Biostormal (stratified) limestones are often more massive and surface drainage may occur. Rivers are normally rather angular in outline, valley sides are steep and only a few tributaries occur. The location of sink holes etc. is largely governed by the fracture pattern. Limestone is particularly a resistant rock type in arid countries because the shortage of rainwater slows" down the solution activity to a considerable extent.

Massive limestones are ridge forming, even in humid climates and steep cliffs frequently occur. For this inclination (dip) of beds alone is the main factor. Generally sinkholes are aligned parallel to the strike direction of tilted beds.

The climatological factor is more important for the development of landforms in limestone than in any other rock type. The Karst (solution) forms like lapies, sinkholes, etc. are influenced by temperature, precipitation, content of C02 and humic acid. Karst formation is rather active in the humid moderate climate and results in the formation of sinkholes, uvalas and other hollow features. Apart from this, lapies and grottoes are also formed. The Karstification in cold climates is usually less intense and especially less deep, because of the freezing of the ground during a part of the year. Lapies are well developed and sink-holes, etc. occur in high mountainous areas. On the contrary, huge vertically developed grottoes are often formed under the snow line due to large quantities of water infiltrating when the snow cover melts in spring time. Warm, semi-arid and arid climates are not very favorable for Karstification, because of limited amount of rain water, which further more has only a low content of CO_2. Further due to the high temperature and the scanty vegetation, there is little humic acid. The rare but heavy rain showers result in a predominance of surficial runoff and there is little infiltration. Solution may occur at greater depth due to ground water, but this does not affect the surface features. Thermal disintegration has only little effect on the limestones.

The situation is completely different in the humid tropics where the lime content notwithstanding the high temperature reaches into open valleys and considerably greater concentrations of lapies are found. The solution of lime thus progresses rapidly due to the greater amount of rainfall and by the higher content of humic acid. The limestone is rapidly dissolved and a landscape of positive forms (hills) remains which are normally conical and have convex slopes. The depressions between the hills are star-shaped and not circular sinkholes. Where impure and more compact limestone occurs "normal" Karst topography forms (sinkholes etc.) and sometimes it occurs even in the humid topics.

STRUCTURAL LANDFORMS

The study of structural landforms is important as it forms the basic and prime criteria in unraveling the stratigraphy and structure of any terrain. Structural geomorphology is concerned with landforms which owe their character to properties of, or activity within, the earth's crust. Problems of the earth's major relief, such as the structure and origin of the continents and ocean basins, though of obvious interest to the geomorphologist, are primarily the concern of the tectonic geologist and the geophysicist. Twidale (1971) classified structural landforms into two principal types: (i) Tectonic (ii) Structural (*sensu stricto*).

Tectonic landforms

Tectonic landforms are ones that are due directly wholly, and only to activities within the earth's crust, without the intervention of the forces of denudation. The most common landforms related to faulting are escarpments, which occur in various patterns (thus giving rise to horsts and grabens) and which are of varied origins. The precise evolution of these fault-generated scarps is, however, commonly difficult and in many instances impossible to elucidate, for a detailed knowledge of the geologic and geomorphic history of the area is required to distinguish between the two major genetic types, the fault scarp, which is tectonic, and the fault-line scarp, which is structural, in origin. All agree that some scarps are of fault-line character, but some workers deny that fault scarps of any magnitude can long survive weathering and erosion.

This mild controversy has arisen very largely from the contrasted experience of workers from various tectonic environments. Those from tectonically active regions are well aware that minor scarps with which are associated cracks, scars, or cicatrices, develop during earthquakes as a result of fault dislocation. In the aerial photographs and images faults are identified by their (a) linear trend (b) occurrence of vegetation along the fault line, (c) abutting of beds along the fault line, (d) relative displacement, (e) offsetting of beds etc. The scarps due to faulting are considered as structural landforms, while the fault itself forms a structural element and not a landform. Kalva wall in the Cuddapah Basin can be considered as a fault scarp. Although such minor features are undoubtedly swiftly by external attack, it would seem that recurrent movements along fault planes cause these minor scarps to be extended and rejuvenated. Arid conditions particularly, with their slow rates of weathering and erosion, are conducive to the survival of such scarps. And, although the available data are sparse and scarcely sufficient as a basis for judgment, it may be that the present is not typical of the past faulting may have formerly been more active than it now apparently is. Howsoever this may be the preservation of bold linear escarpments which display distinct triangular facets hanging valleys and wineglass or bottle-shaped valleys surely argues that these scarps form as a result of recurrent faulting so marked that the constructional effects of tectonism outpace the destruction wrought by external agencies. The proponents of this view consider that the triangular facets represent virtually the exposed fault plane, very little modified by weathering and wash. The presence of hanging valleys is taken to indicate that stream erosion has been unable to keep pace with uplift along the fault, the development of wineglass or bottle-shaped valleys as representing rejuvenation, and the development of valley in-valley forms as a result of fault dislocation. The faults responsible for these scarps are commonly still active so that earthquake foci may be located near them, and small fresh scarplets are evident. Some active faults display small reverse scarp lets, which face upslope with respect to the major form and which are probably due to joggling and adjustment along the fault plane.

On fault scarps, the elevation of the fault scarp is approximately equal to the throw of the fault; where this varies, as with pivotal faults, the height of the scarp also varies. Gani-Kalva fault is a good example.

Though the sole criterion for a fault scarp is that the difference in elevation on either side is directly due to the faulting is a useful one, there are difficulties. Not only does the ability to identify a scarp as tectonic imply a considerable knowledge of the tectonic and geomorphic history, but also some of the minor features associated with such scarps can be produced in other circumstances. Thus triangular facets are formed by the differential erosion of rocks of strongly contrasted resistance. The two formations may be brought into juxtaposition by faulting, in which case the scarp is of fault-line character, but the two may be in normal stratigraphic sequence. Again, wineglass valleys may result from stream incision in rock types of contrasted resistance, the open upper section being evolved in weaker rocks, the lower narrow or gorge section in tougher bedrock. But the occurrence of linear scarps, with combination of the characteristic features described above, trending along or closely parallel with a known fault, is strongly suggestive of a fault scarp.

Thus the existence of fault-generated scarps of tectonic origin is urged by many and is indeed strongly supported by field evidence. Workers whose experience has been in the more stable areas of the earth (none is absolutely stable, but the orogenic regions are certainly more active than the cratons) have, on the other hand, doubted whether tectonism can outpace erosion and weathering. They accept that small scarps develop as a result of faulting, but view them as ephemeral. The great linear escarpments observed in the field are, in their view, of structural and not tectonic origin, being due to the differential erosion of dissimilar strata brought into proximity by faulting. The scarps are, in other words, fault-line scarps, the line of dislocation having been brought into relief by the work of streams. Such scarps developed in association with wrench faults are known, a typical example being the Gani-kalva fault in the Cuddapah Basin.

Structural landforms

Structural landforms (*sensu stricto*) which evolve as a result of the exploitation of weakness in the earth's crust by external agencies come under this category. Thus, outcrops of less resistant rocks or fractures such as faults, joints and cleavage may be preferentially weathered and subsequently eroded by running water, glaciers, waves or wind. The resultant forms thus bear a direct relation to the geological structure of the area.

In the geomorphological sense, the term structure embraces not only passive factors of rock type (lithology) and the arrangement of strata (stratigraphy and tectonics), but also active or continuing changes in these properties. Thus for the purposes of geomorphology, the geologists structure and tectonics are conveniently subsumed under the one heading of structure.

Landform assemblages due primarily to the occurrence at the earth's surface of a particular rock type, such as limestone, sandstone, and granite, are of this kind.

Another potent influence on landform evolution is the pattern of fractures. Rocks subjected to stress behave in different ways according to their inherent properties, their geological environment, and the nature of the stresses. Some rocks under given conditions are brittle and fracture easily, giving rise to joints and to faults. Other rocks in similar conditions, or the same rocks in different environments or under different conditions of stress, do not break but bend instead, creating folds. But by their very development, folds themselves generate stresses, which cause the further formation of joints and fault patterns. These three types of structures - joints, faults and folds are found in common association and have a widespread and significant effect on landform evolution~

The influence of jointing and of lithology is inherent parts of any discussion concerned with geomorphological landscapes evolved on folded beds. The two factors merge in distinctive fashion in granitic bedrock, a common and widespread component of the continental areas, and specific consideration is devoted of these forms.

Volcanic forms are a manifestation of activity in the earth's crust, and are constructional or tectonic features, though characteristic volcanic landscapes also arise from erosion of these primary forms. Karst forms owe their distinction to the particular lithology and fracture pattern of limestone, and are therefore structural features, *'sensu lato'*.

Structural groups of landmasses: Strahler and Strahler (1976) made a threefold grouping of structural landmasses and each of these in turn contains two or more distinctive types.

Group A: Undisturbed sedimentary strata. These are thick covers of sedimentary rocks overlying ancient shield rocks.

The strata are most commonly of marine origin, deposited on the floors of shallow continental shelves and inland seas; they have been brought above sea level by crustal rise and are now in the process of undergoing fluvial denudation. Because no significant amount of bending or faulting has affected these strata, their attitude is nearly horizontal over very large areas.

Group B: Landmasses due to disturbed structures of tectonic activity. These landmasses show strongly the effects of bending and breaking of the crust by mountain-building processes. Sedimentary strata showing folding and faulting are "included in this group. Metamorphic rocks produced in root zones of ancient mountain belts are another type.

Group C: Eroded igneous masses. Exposed plutons - large bodies of intruded igneous rock - are one important type of igneous mass. A quite different type includes, extinct composite and shield volcanoes undergoing erosion.

Plateau, mesa and butte assemblages [Group A]: Plateau assemblages are formed by stream dissection in several geological situations. Where flat-lying sedimentary sequences of contrasted resistance to weathering and erosion occur close to the land surface, soft strata exposed at the 'surface may be worn away, with the result, that the highest resistant member of the sequence is, revealed. The upper bedding plane of this hard stratum forms a structural bench or a structural plain (depending on its extent) and also a resistant capping which causes the bounding slopes to remain faceted and precipitous. The Kaimur plateau of the Vindhyan, the Srisailam plateau in the Cuddapah Basin and the mesa landforms with cappings of the Banganapalle and Paniam quartzites of the Kurnool Group are some typical examples.

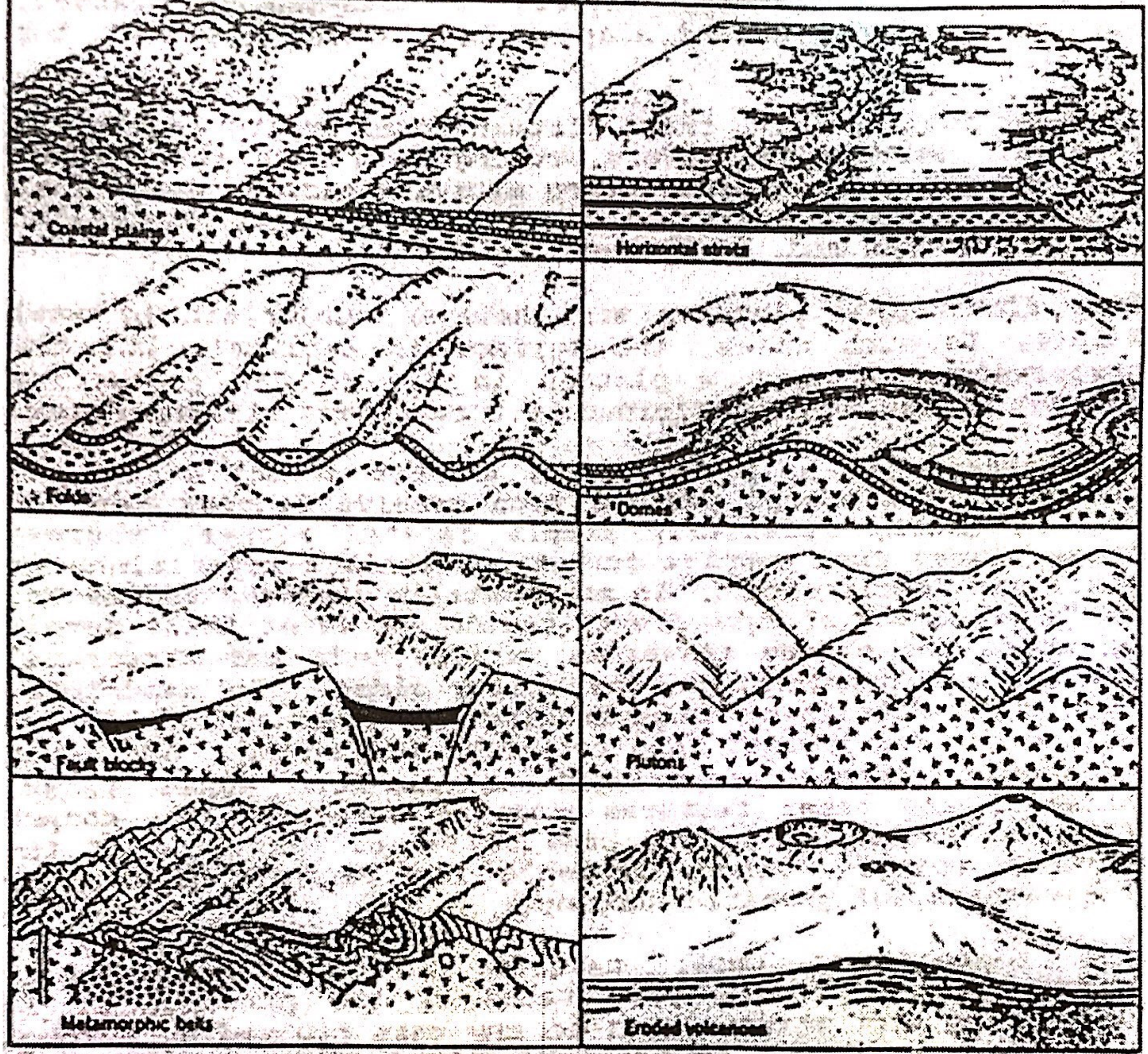

Fig.7 Several distinctive types of landmasses can be recognized on the basis of rock composition and structure.

(After Strahler & Strahler, 1976)

Where the local bedrock is massive, resistant and flat-lying, the bedrock itself is so resistant that stream dissection and weathering are slow. Steep and faceted slopes are evolved and high plains comprising many individual structural benches and plains are prominent.

In some areas a resistant duricrust (ferricrete, silcrete, clacrete, gibber) evolved through soil-forming processes on other geological formations, which may be tilted and folded, crystalline (e.g. granite), or inherently weak. Such duricrusts form caprock and afford the same degree of protection against weathering and erosion as do primary resistant formations. Thus, laterite cappings give rise to prominent plateau and mesa forms in the Eastern ghats and in Deccan plateaux. These can be easily identified in the aerial photos by their typical geomorphic expression.

Similarly, where flat-lying igneous veins, dykes, arid sills, or flows of lava, cap otherwise unresistant strata, plateau and mesa assemblages evolve.

In general, the more massive the local bedrock on which the plateau features are developed, the less intricate is the pattern of forms evolved, for, both in plan and in section, the assemblages are simpler than those resulting form the sculpture of complex sequences of strata, though in certain topographic situations and under particular climatic regimes, massive flat-lying formations may be intricately dissected resulting in a comparatively high scarp density.

However, they are rarely of a complexity comparable with that displayed by thin-bedded strata. Where a particularly hard still fairly resistant, bounded by steep faceted slopes, but lacking the flat top results. whatever their origin, these plateau forms evolve in similar fashion. Streams and rivers eroding to a base level lower than the caprock or hard outcrop excavate narrow, gorge-like valleys. Their planimetric pattern is strongly controlled by major joints and, if present, by faults. Some flat-topped plateaux are, however, underlain by weak strata. In such cases, the surface is cyclical; but the preservation of such a plateau is due to the protection against stream attack afforded by a resistant stratum below.

The streams and valley profiles exhibit strong structural control. The scarps molded from massive bedrock tend to be, in gross, relatively simple faceted slopes, whereas those shaped from complex formations exhibit repetitions of bluff and debris slope. In horizontally disposed sediments, or in sequences of lava flows, rapids and water falls develop where the stream traverses various beds and structural benches are prominent on the valley sides. In sandstone, even minor details of cross bedding and other structures are etched out and brought into relief by weathering. Odd, even grotesque, forms-some alleged to resemble human faces, animals, and other features such as beehives- are shaped from the rocks, as in the case of Paniam quartzite of the Kurnool Group. Others resemble the perched blocks, or loganstones, of granitic outcrops.

The caprock or upper massive stratum is gradually undermined, a process facilitated by the presence of an underlying soft stratum, but in any case proceeding through basal sapping. This is most characteristically manifested, as has long been appreciated (Jack, 1915), in the development of caverns or shelters. Many caverns are initiated at stream level by lateral corrasion, or by wetting of - the bedrock. Some are of structural origin, being coincident with the outcrop of a weak stratum. Most are developed at the junction of the bluff and the debris slope, as in the case of Auk Shale and Paniam Quartzite of the Kurnool Group - in the Cuddapah Basin. These caverns display inverse mamillation, negative exfoliation, and, in general, resemble the tafoni of granitic boulders.

The growth of such caverns causes the bluffs above them to be undermined and eventually to collapse; so the escarpment is made to retreat. The narrow gorges which initially pierced the cap rock and subdivided the uplifted stratum into a series of plateaux are thus widened; simultaneously, of course, the plateaux are reduced in area. Eventually, the plateaux are so small they are called mesas and these, in turn, are reduced to such an extent that their maximum diameter is less than the elevation above the adjacent valley or plain, when they are called buttes.

As described above, scarps eroded in sequences of flat-lying strata commonly display structural benches, but where the cap rock is a weathering profile or a capping such as basalt unrelated to the underlying sequence, the latter is, of course, not necessarily horizontally disposed and a wide range of detailed erosional forms are displayed within the overall context of the bluff-debris slope assemblage vertical and oblique ridges and clefts, for instance, may evolve in folded strata exposed by dissection beneath a lateritised weathering surface.

Folds and related forms [Group B]: The application of two sets of opposed stresses causes cross folding and the development of domes and basins as, for instance, in the folded Nallamalai belt of the Cuddapah Basin. Dome is a double plunging anticline, the length of which, in ground plan, is not more than three times its width. Similarly, a basin is a doubly plunging syncline, the length of which is ground plan is not more than three times its width. In a dome (also known as 'periclinal structure or 'pericline', though the terms seem superfluous) the strata dip from the centre of the structure outwards in all directions. This is known as quaquaversal dip.

Diapiric structures: Domes are also caused as a result of vertical uplift in the crust related either to magmatic intrusion or to the upwelling and injection of materials of lower specific gravity than the surrounding. Crustal structures of the latter category are gravity controlled and termed diapiric. Diapiric structures are deep seated and are caused by the upward migration of materials of lesser density than those which surround them. A salt dome is a typical diapir, examples of which have been described from many parts of the world.

Many domes contain cores of granitic material, whether the structures are diapiric or due to intrusion and consequent upthrust of country rocks known. Eg. Ipuru, Nakerakallu domes of the Cuddapah though actual is not Basin.

The sediments dip off the granite core, the dips being generally steeper on the east than on the west. The total uplift involved in the development of the dome which involves laccolithic intrusion has been estimated at about 3000 m. Because of the doming, major hogbacks and cuestas are developed in the resistant strata flanking the igneous mass.

Cuesta and hogback forms [Group B]: In a given climatic situation, a slope of a particular lithology tends toward a uniform morphology and inclination, being steeper only where subjected to very strong local attack, as for instance where rivers and streams impinge on the base of a cliff, and more gentle only at a stage when the slope has been worn down to such an extent that debris of appropriate volume and calibre to maintain slope morphology is no longer available.

In localities where resistant strata are inclined with respect to the horizontal, the ridges eroded from the strata are asymmetrical in cross-section. Their morphology varies according to the dip of the strata. Those eroded from beds of very low dip (say up to 5 °) and with very gentle dip slopes are called 'cuestas'. More steeply inclined strata (say, 10°-30°) give rise to ridges which, though still markedly asymmetrical in cross-section, display dip slopes which are far more steeply inclined than those occurring in cuestas (as seen in the western margin of the Cuddapah Basin). These are the 'crests' of French workers, the 'homoclinal ridges' of the English literature. Clearly there are many instances where the disposition of strata is such that it is not easy to determine into which of these two arbitrarily defined categories a particular asymmetric ridge should be placed. Moreover, many dip slopes consist not of a single exposed bedding plane, but rather of numerous such planes, each truncated, so that the inclination of the dip slope is less than the dip of the strata. Thus the precise disposition of the strata is by no means an infallible guide to the detailed morphology of the feature developed on them. But, in general, cuestas are obviously more common in sedimentary basins and in the platform areas than in orogenic belts, where, because of generally higher dips, homoclinal ridges are dominant.

The gentler dip or cataclinal (Powell, 1875, p.160), slope is, as mentioned above, a composite of many individual bedding planes and its inclination only in a general way approximates to the dip of the local strata. The steeper scarp, the anaclinal or anti dip slope, which faces up dip or toward the crest of an antiform and away from the trough in a synform, is faceted and commonly complex. The detailed morphology of this slope, which comprises the exposed ends of strata, is dominated by joints. But inequalities in the resistance of strata, and other zones of weakness, cause structural benches to be developed, so that many escarpments consist of repeated sequences of a bluff-debris slope assemblage.

As is the case with the scarps bounding plateaux, 'detailed sculpture varies greatly with the local bedrock sequence. Massive resistant strata form massive bluffs in the cataclinal slope, and in plan the cuesta (or homoclinal ridge) tends to be simple also. But where the sequence is complex, with numerous thin interbedded strata of contrasted resistance to erosion, the scarp is complex and the dissection intricate; in plan the line of ridge is much fretted.

In situations where the dip of the strata is 40°-45° or greater and exceeds the inclination of slope typical for the particular lithology and climate, weathering and erosion determine overall slope inclination, though these processes are in considerable measure controlled' by structure and lithology. Characteristic slope profiles develop on both sides of the ridge which is thus essentially symmetrical and is called a 'hogback'. In detail, structural contrasts are apparent, especially in the appearance of bluffs on the antidip side, but overall, the ridge is symmetrical.

Many cuestas, homoclines, and hogbacks are breached by streams, the valleys excavated by which are generally V shaped in cross-section, so that the cuestas are subdivided into a series of broadly triangular facets called flatirons, well exemplified in the alternating sequence of quartzite and phyllite of the Cumbum Formation of the Cuddapah Basin.

Eroded fold structures give rise to ridge and valley forms, but the details as well as the broad pattern of the topography vary according to the nature of the folding. Thus, long, essentially straight fold limbs give rise to long, parallel ridges and valleys. Pitching or plunging folds give rise to curved W or Z shaped outcrops and patterns of ridge and valley according to the rapidity or angularity of the change of strike.

Very steeply dipping sedimentary sequences, including those involved in isoclinal folds, give rise to numerous more or less parallel ridges and valleys. Not all ridges are simple, for where masses of resistant but varied beds are steeply dipping, broad complex ridges are developed; asymmetrical folds may display hogbacks on the steeper limb and cuestas on the other.

Exposed plutons- Eroded igneous masses [Group C]. The general trend of geomorphological thinking is that mineralogy is second only to the nature and closeness of the fracture pattern in determining the susceptibility of a given rock to weathering and, hence, to erosion. In particular, the biotite content is considered significant, though plagioclase is also the most susceptible of the rock-forming minerals commonly present in granitic rocks. However, one school of thought, believes that grain size is more important than either mineralogy or fracture pattern.

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Two of the most common and characteristic features evolved on and from granitic bedrock-isolated residual hills of particular morphologies, and rounded boulders-have not only been given different names in different parts of the English speaking world, but the same word, 'tor', has been used of both.

The term 'inselberg' encompasses a considerable range of morphological types. It was originally used for ridges, ranges, and isolated residuals in arid and semiarid regions. This climatic restriction is in practice difficult to maintain, for similar forms occur in other climatic regions and, leaving aside the associated problems of climatic change and inherited forms, the field evidence indicates that in some cases at least the forms, the field evidence indicates, are structural.

An inselberg is in the literal sense an island mountain, and its essential feature is its abrupt rise from the surrounding plains, whether the latter are of erosional or depositional type. Inselbergs of granitic composition may take the form of ridges and ranges. Inselberg comprise a number of major joint" blocks, each of which has been moulded into one of two basic shapes: the angular castellated type, also known as the' castle koppie', and the domed inselberg or 'bornhardt'. Though" they display many variations in detail, these are the basic forms.

The castellated forms are dominated by the orthogonal joint system. They comprise numerous little rounded joint blocks, or 'woolsacks', still *in situ*, and include host of the inselbergs. Domed inselbergs, on the other hard, are dominated by curvilinear joints, the geometry of which, together with the degree of exposure of the rock mass, determines the morphology of the residual forms which are high compared with horizontal diameter and the flanks of which are coincident with steeply plunging joints are culled 'sugar loaves'.