BHARATHIDASAN UNIVERSITY

Tiruchirappalli- 620024
Tamil Nadu, India

Programme : M.Tech., Geological Technology and Geoinformatics

Course Title : Geomorphology and Geodynamics
Course Code : MTIGT0506

Unit-1: Introduction to Geomorphology & Geodynamic & Denudational Geomorphology

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- Geomorphology is the study of the morphology or form of the Earth's surface
- The study of landforms on or near the Earth's surface and the processes working on them
- Geomorphology is the sub-discipline of geology that describes the physical changes of the surface of the earth over time
- Geomorphology is the science of landforms – their origin, evolution, form and spatial distribution of Continental and Submarine landforms

Geomorphology relates to all the other disciplines of geology in two directions:

Tectonics, petrology, geochemistry, stratigraphy, and climate determine the geomorphology of the earth and its regions by controlling the principal influences on landscape.

Therefore evidence from observations of the landscape in turn constrain the tectonic, petrologic, geochemical, stratigraphic, and climatic history of the earth and its regions

Landform Controls

Driving forces

- solar radiation
- gravity
- earth's internal heat

Resisting forces

- lithology
- geologic structure

Processes: interaction of driving and resisting forces

Keith – First person to use the term Geomorphology in 1894

Earlier, it was called as Physiography

But Physiography includes climatology, meterology, Oceanography, mathematical geography and landforms

The term “Geomorphology has come as a result of dissatisfaction with the term of Physiography

Geomorphology is primarily geology.

Development of Geomorphology

In the 17th & early 18th century, surface features of the earth were commonly attributed to catastrophic, often biblical-like events; (Flood, Earthquake, Eruption, Tsunamis, Meteors)

- a school of thought referred to as "catastrophism"

During the late 18th & 19th century, the works of Hutton, Playfair, & Lyell introduced the concept of "uniformitarianism" (Mountain building, Erosion, deposition, glaciers)

"The present is the Key to the Past"

By the late 19th century, Gilbert postulated that landforms reflect an adjustment between geomorphic processes and geology

Uniformitarianism, in the philosophy of naturalism, assumes that the same natural laws and processes that operate in the universe now, have always operated in the universe in the past and apply everywhere in the universe.

It is frequently summarized as "the present is the key to the past," because it holds that all things continue as they were from the beginning of the world.

The concept of uniformity in geological processes can be traced back to the Persian geologist, Avicenna (Ibn Sina), in *The Book of Healing*, published in 1027.

Modern uniformitarianism was formulated by Scottish naturalists in the late 18th century, starting with the work of the geologist James Hutton, which was refined by John Playfair and popularised by Charles Lyell's *Principles of Geology* in 1830.

The term *uniformitarianism* was coined by William Whewell, who also coined the term catastrophism for the idea that the Earth was shaped by a series of sudden, short-lived, violent events.

C. Paradigms Of Landscape Formation And Change

Paradigm: dominant worldview; the way in which most scientists think about and understand the world

Catastrophism

- recurrent cataclysmic events occurring over a limited time (earth is young)

Uniformitarianism

- the present is the key to the past
- laws of physics, chemistry, and biology don't change over time
- change is slow and gradual (earth is old)

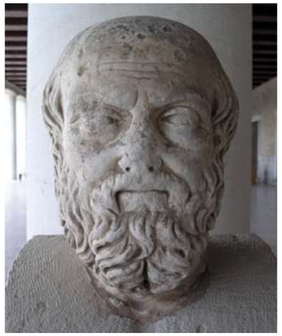
Davis' Geographical Cycle

- cycle of linear, unidirectional landscape change
- youth, mature, old age stages followed by rejuvenation

Process geomorphology

- driving and resisting forces
- thresholds and equilibrium

Early contributions to geomorphology



Herodotus (485-425 BC) – Father of history

He has made some geological observations

He observed the yearly increment of sand and silt in the Nile river and stated that "Egypt as Gift of Nile"

He noted shells in the hills of Egypt and concluded that the palaeo sea up to lower Egypt

Aristotile (384-322 BC) – He made some observation on origin of Spring

He believe that the source of spring water is from the percolation of rainwater and water formed within the earth by condensation of air

Dry land can be submerged.
Land can be raised from beneath the ocean.
Described erosion by rivers, and deposition in deltas

Strabo (54BC – 25AD) – He traveled widely in Itlay and observed sinking and rising lands

He inferred that the summit of mount Vesuvius was of volcanic origin

He also observed that the size of the delta of river varied to the regions to regions

Seneca (…– 65AD) – He recognized that the valleys are developed due to stream erosion

THE DAWN OF MODERN GEOMORPHIC IDEAS

Avicenna (980-1037 AD) – He opined that the mountains are formed due to uplifting of ground or removing of soft rocks by erosion of stream

Leonardo da Vinci (1452-1519) studied the topography of the Arno River basin, drew the first contour map of a whole river basin, and believed that rivers carved their valleys and shaped topography.

Early contributions: Nicolas Steno 1638 -1686

Nicolas Steno wrote *Preliminary discourse to a dissertation on a solid body naturally contained within a solid* . He was the first person to hypothesize that the sea shells found at mountain tops were actually fossils and not spirits trapped within the rock, as was the current theory. He also introduced the ideas of original horizontality and superposition, and is recognized as one of the founding fathers of geology.

Italian and French hydraulic engineers developed the study of rivers in the late 17th century to address flooding problems along rivers draining the Alps.

Della Natura de' Fiumi
"The Nature of Rivers"

First Book on Rivers was published by Domenico Gugleilmini in 1697.

The book discusses the nature of rivers and their parts, the motion of water, confluents and estuaries, banks, and materials and application.

Targioni-Tozetti (1712 – 1984)

- Italian who recognized differential stream erosion
- He was the first person to say that age of the earth is not in terms of 1000's of years

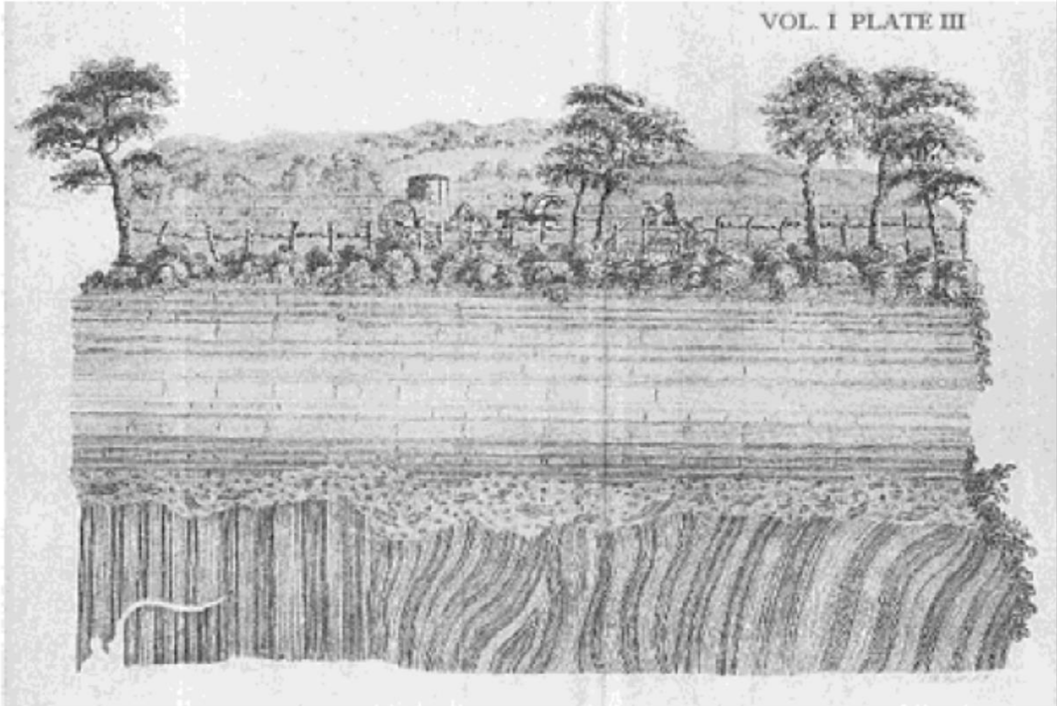
Frenchman Guetthard (1715-1786) (Geologist)

- First to recognize the gradation of mountains
- He say that the materials removed from hills not simply deposited in ocean, but develop the flood plains
- He was the first to argue that sea is a powerful destroyer than the rivers (Massive destruction of chalk hills, N France)
- Evolve the fundamental principles of Denudation and first to recognize the volcanic landforms

Hutton's Era (1726 – 1797) Basically Physician interested in Geology from Edinburgh, Scot land

Wrote *Theory of the Earth* in 1795 where he laid the foundation of many of the fundamental principles of Geology. He included chapters on uplift, erosion, and consolidation of rock.

Unfortunately, he did not communicate his ideas very effectively, so they didn't catch on!



See for yourself:
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Book 2 of 4 at http://www.gutenberg.org/files/14179/14179-h/14179-h.htm

Hutton’s Era (1726 – 1797) Geologist from Scot land

Propounded the Granite was igneous origin

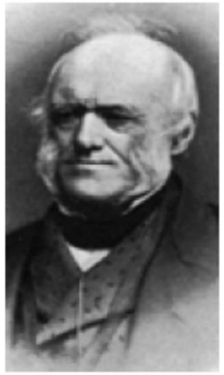
Evolve the concept of “Present is the Key to the Past”

Established the doctrine of “uniformitarianism” in opposition to that of catasotrophism

His first book “Theory of Earth” and 2nd one “Theory of Earth with proofs and illustrations”

Werner (1749-1817) theorized that all mountains formed under water, and were ultimately sculpted by rapidly receding oceans.

Early contributions: Sir Charles Lyell



Advocate of doctrine of ***uniformitarianism***: theory that slow geological processes have occurred throughout the Earth's history and are still occurring today. 'The present is the key to the past.'

The idea contrasted ***catastrophism***: theory that Earth's features formed in single, catastrophic events and remained unchanged thereafter.

The debate continues in some form today where geomorphologists are still piecing together the history of various landscapes across the earth.

Two geomorphic principles arise from Hutton and Lyell's works:

1) Landforms and the landscape evolve (*very Darwinian!*).

2) Frequency and magnitude in the landscape.

Contributions: *Principles of Geology, first published in three volumes in 1830-33*

Frequency and magnitude of geomorphic processes

The most frequent events do not do the greatest amount of work (not surprising)

The largest events do the most work, but they are infrequent.

Moderately sized transport events do the most geomorphic work in the landscape as a consequence of the frequency of moderate sized events

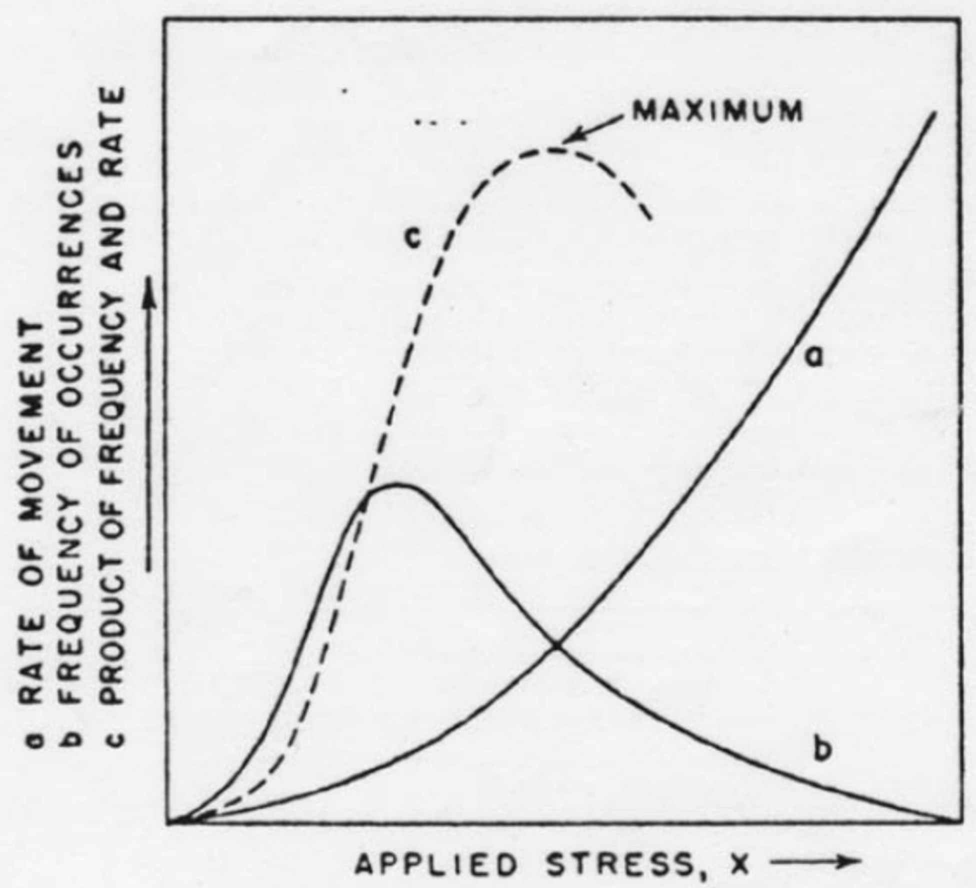
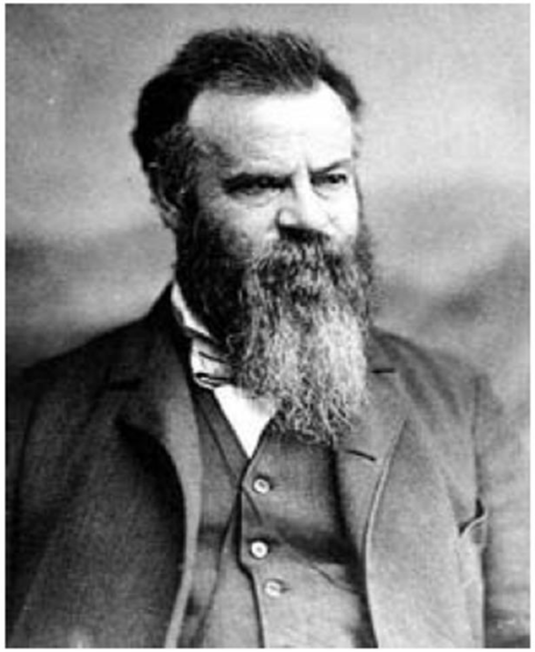


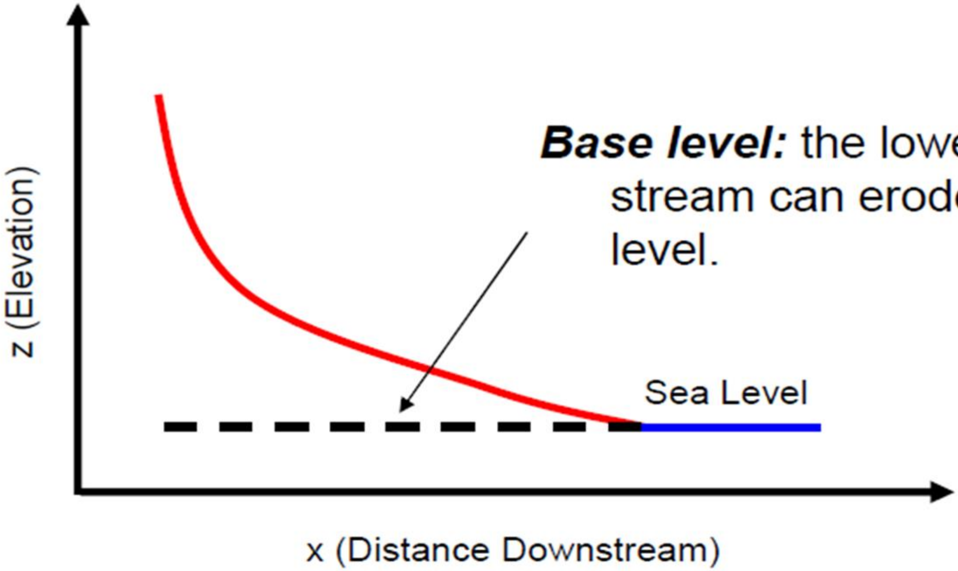
FIG. 1.—Relations between rate of transport, applied stress, and frequency of stress application.

From: Wolman, M. G. & Miller, J. P. (1960). Magnitude and frequency of forces in geomorphic processes. *Journal of Geology*, 68, 54-74.

John Wesley Powell



Early director of USGS who first explored the Grand Canyon and who introduced the idea of ***base level.***



Base level: the lowest elevation to which a stream can erode. Usually coincident with sea level.

Contributions: *Exploration of Colorado River*, 1869. Wrote *Canyons of the Colorado, 1895.*

Grove Karl Gilbert

Powell's assistant in the Grand Canyon expeditions.

He is acknowledged as being the father of modern geomorphology.

Gilbert's was the first work to systematically discuss weathering and bedrock erosion (debris production mechanisms) as well as erosion and transport of sediments in the landscape.

He also stated the fundamental relations between slope, energy available for erosion, and stream discharge.

Gilbert's View of *Dynamic Adjustment*

• Landforms reflect a unique accommodation between dominant processes and local geology.

Contributions: *Report on the Geology of the Henry Mountains (1877), The Transportation of Debris by Running Water (1914), Hydraulic-Mining Debris in the Sierra Nevada (1917).*

Agassiz : Recognized glacial landforms in Europe - introduced the concept of Ice Ages (1837)

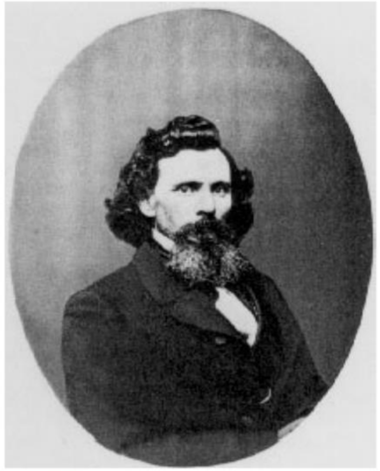
Davis (1850-1934) – "The great definer and analyst"

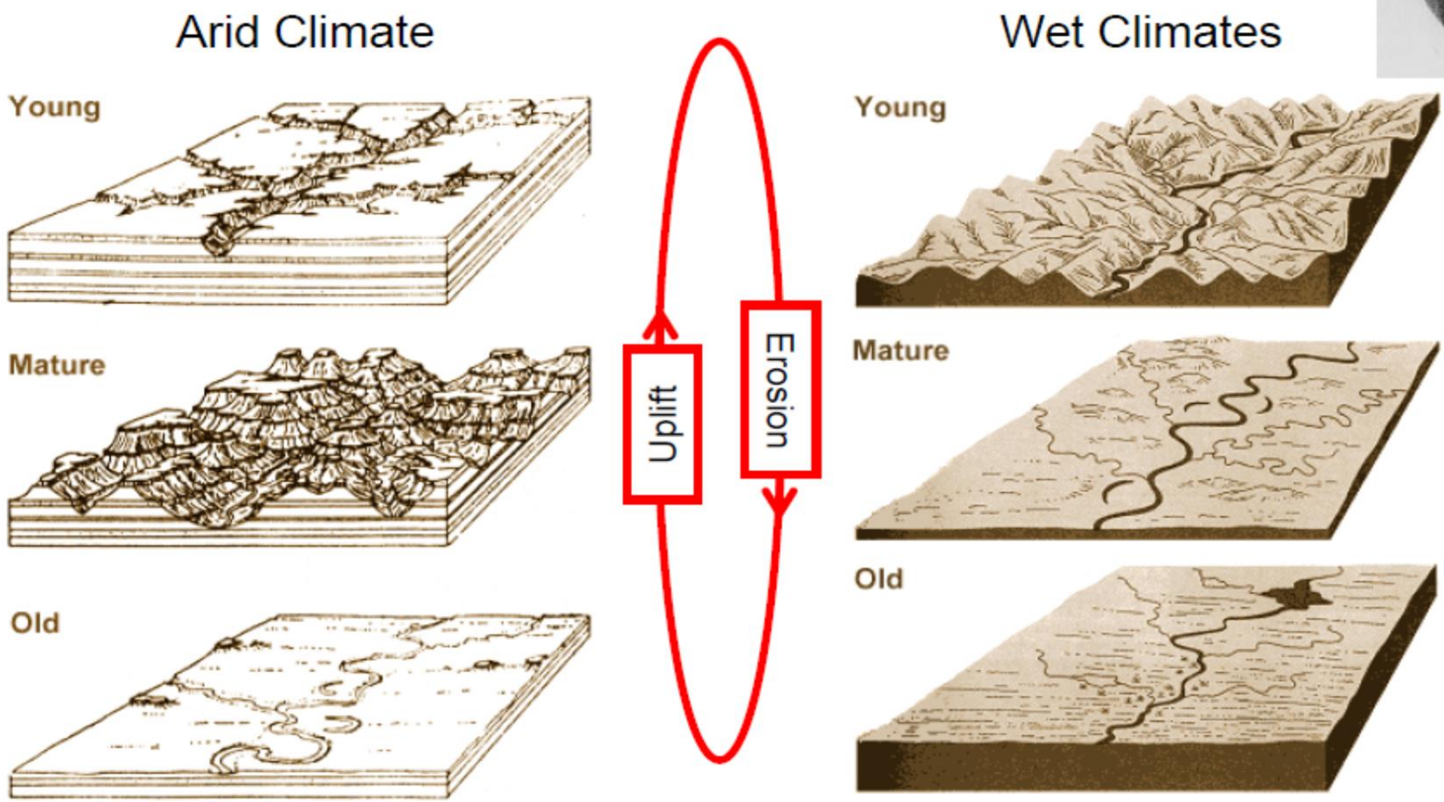
He gave a new life to geomorphology. He introduced the genetic methods of landform description

Propounded the concept of geomorphic cycle and there from evolution of landforms

He explained differences in landforms to differences in geological structures, geological processes and stages of development

William Morris Davis: Geographical Cycle (AKA: Cycle of Erosion)



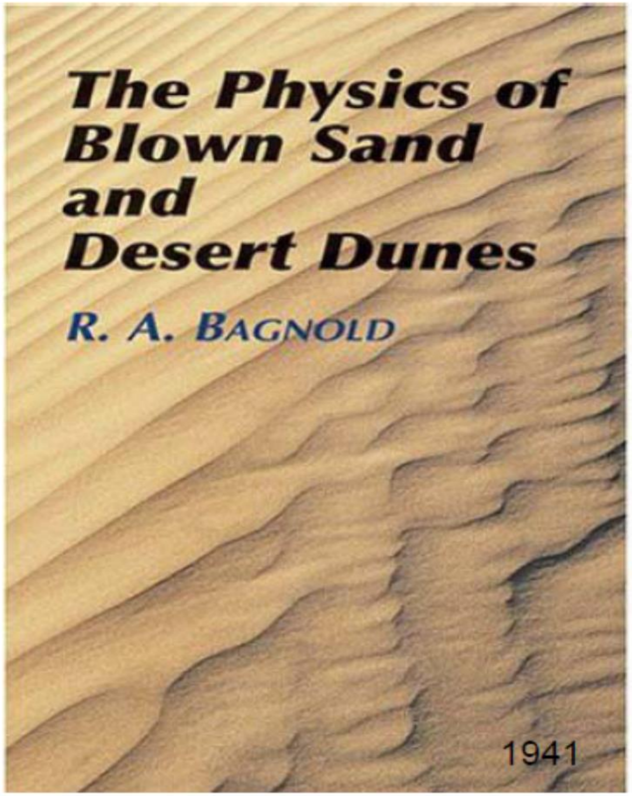


THE MODERN ERA

The modern era has refocused geomorphology as a predictive science, making G.K. Gilbert the most important early thinker in the discipline.

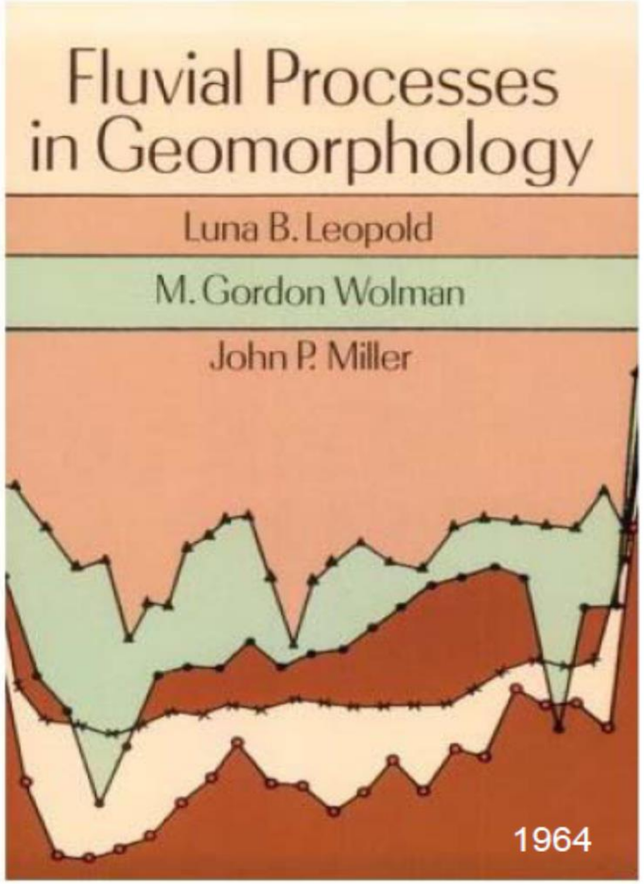
There were many leaders in the 20th century, but at least 2 stand out - Bagnold and Leopold.

R.A. Bagnold



Bagnold was one of the first to use fundamental physics to explain landscape features. His book remains the standard reference in the field today.

Luna Leopold

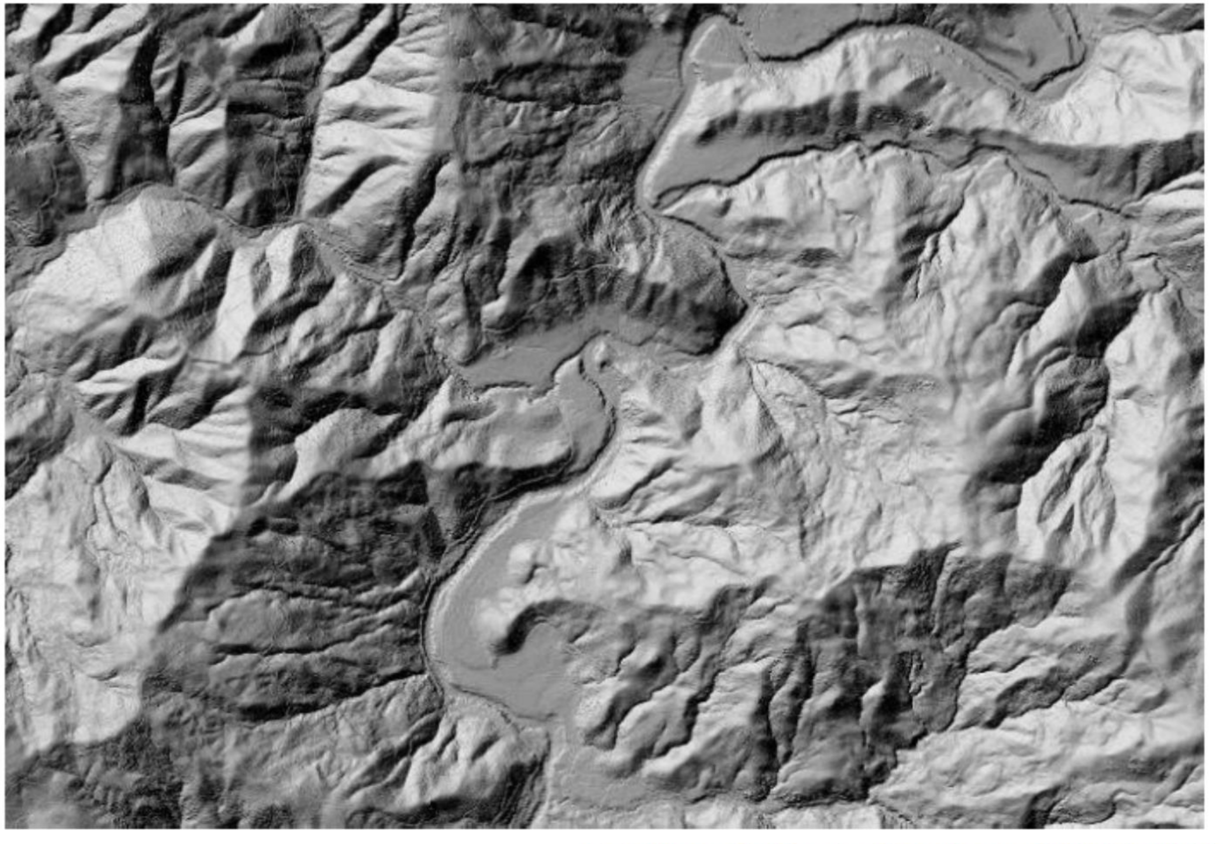


Leopold served as Chief of the Hydrology Section of the USGS in the late 1950s and 1960s where he and several colleagues revolutionized geomorphology by placing it on a firm quantitative and theoretical base.

http://eps.berkeley.edu/people/lunaleopold/

Current trends

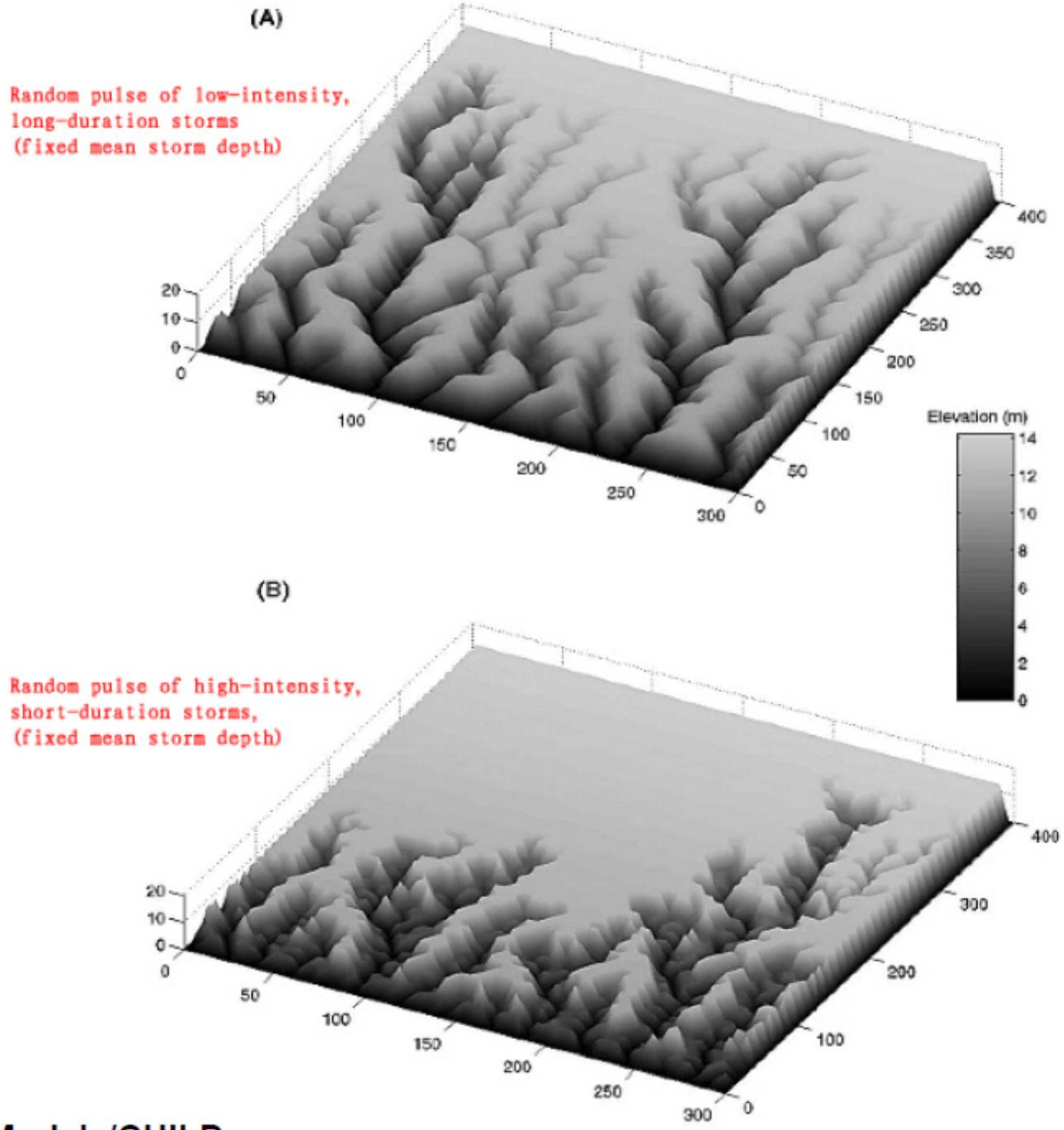
1. Quantitative analysis of topographic relief



Eel River, California (Courtesy of Bill Dietrich)

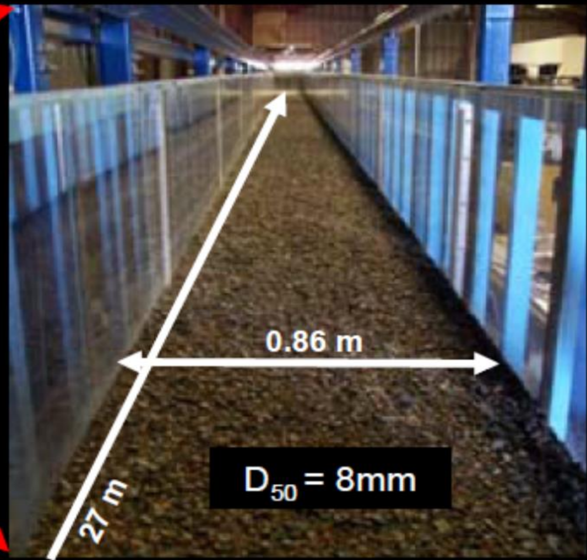
2. Computer-generated models of landscape evolution

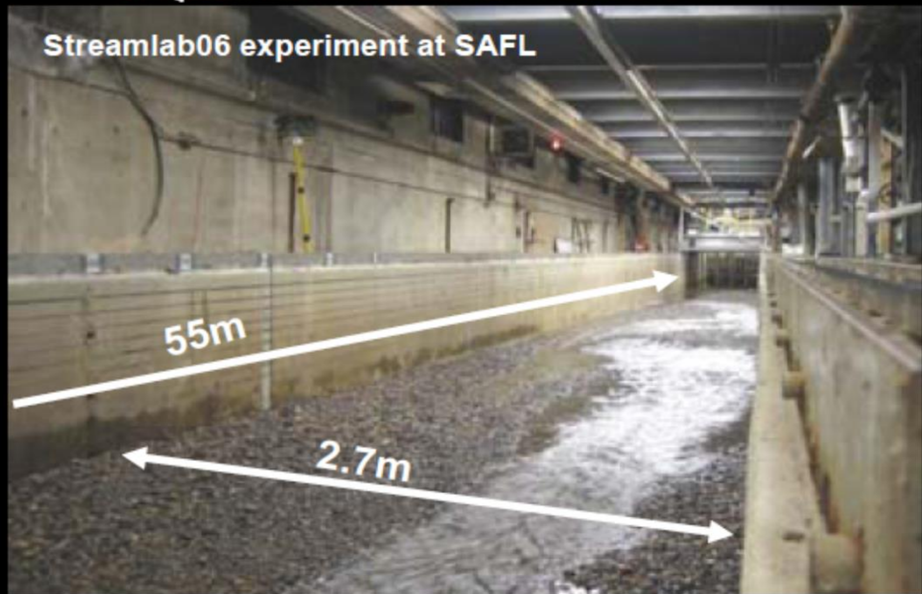
Output from CHILDS
(**C**hannel-**H**illslope **I**ntegrated **L**andscape **D**evelopment)



http://hydrology.mit.edu/index.php/Models/CHILD

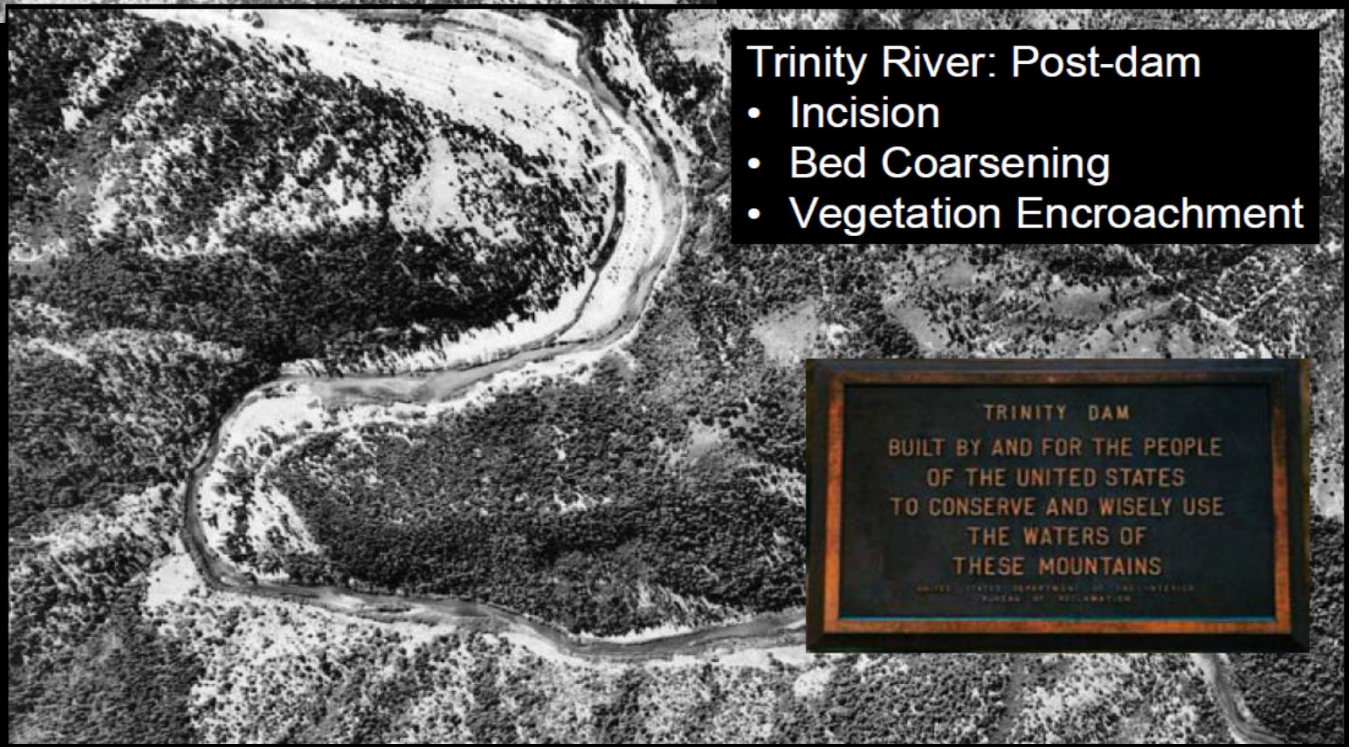
3. Application and testing of models of landscape processes





4. Using geomorphology as a tool to understanding ecologic processes and landuse impacts

Effects of Dam Construction on River Channels



RECENT TRENDS IN GEOMORPHOLOGY

A tendency for geomorphology to become more strictly geological than geographical as a result of an increasing application to geomorphic studies of other phases of geology

- Mineralogy in the study of weathering
- Stratigraphic and paleontology methods in palaeogeomorphology

The development of regional geomorphology, which attempt to divide the continents into areas of similar geomorphic features and history

Application of geomorphic principles in groundwater, soil science, engineering geology,

FUNDAMENTAL CONCEPT OF GEOMORPHOLOGY

1. **The same physical processes and laws that operate today operated through out geologic time, although not necessarily always with same intensity as now.**

This is based on the important principle of modern geology and is known as the principles of uniformitarianism

It was first by Hutton in 1785, beautifully restated by Playfair in 1802 and popularized by Lyell with lot of editions

Hutton taught that the "The present is key to the past", but he applied this principles very rigidly and argue that the geological processes operated through out the geological time with same intensity. We know now this not true

Glaciers were more significant during Pleistocene and during the other periods than now

Climates have not always distributed as now

Some regions that are now humid have been desert. The areas now deserts have been humid

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

W.M. Davis stated earlier that the major control factor in the development of landforms are structures, process and stage

Today there are some geologists who doubt the validity of stage as a major control factor. But no geologists doubts the important of process and structures

In general, structural features such as fold, fault, joint, etc. of rocks are much older than the geomorphic forms developed upon them

3. To a large degree the earth's surface possess relief because the geomorphic processes operates at different rates.

Different gradation of the earth surface due to the variation in lithology and structure from place to place of earth crust

Hence they behave with varying degrees of resistance to the gradational processes

Differences in rock composition and structures are not only reflected in regional geomorphic variability but in the local topography as well

The local intensity of particular processes may change notably in response to differences in such factors such as temperature, moisture, altitude, topographic configuration and the vegetal cover

4. **Geomorphic processes leave their distinct imprint upon landforms and each geomorphic process develops its own characteristics assemblage of landforms.**

Just as species of plants and animals have their diagnostic characteristics, same way landforms have their distinguishing features depending upon the geomorphic process responsible for their development

Floodplains, alluvial plains and deltas are by the stream action

Sinkholes and caverns are by groundwater

Morains and drumblins by glaciers

Sand dunes by aeolian actions

5. **As the different erosional agents act upon the earth surface there is produced an orderly sequence of landforms.**

The landforms possess distinctive characteristics depending upon the stage of their developments

It is probably true that most geomorphologists believe that landforms have an orderly and sequential development in youthful, mature and old stage as postulated by Davis

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

Usually, most of the topographic features have been developed in current cycle of erosion, but there may exist within an area remnants of features produced prior cycles

It is a rare thing to find landscape assemblages which can be attributed solely to one geomorphic processes, even though we can recognize the dominant one

Horberg (1952) classify the landforms into 1) simple, 2) compound, 3) monocyclic, 4) multicyclic, 5) exhumed or resurrected landscapes

Simple landscapes – by a single dominant processes

Compound landscapes – by two or more geomorphic processes

Monocyclic landscapes –the imprint of only one cyclic of erosion

Multicyclic landscapes – by the more than one cyclic of erosion

Exhumed or resurrected landscapes – formed during the geological past, then buried and now exposed for erosion

7. Little of the earth's topography is older than Tertiary and most of it no older than Pleistocene

The age of the topographic features with erosion surfaces dating back to Cretaceous or even as far as the Precambrian.

These are very rare, they are exhumed forms (buried and exposed)

Most of the present topographic features are Pleistocene and only some of the topographic features are date back to Tertiary

Ashley (1931) believed that the most of the world scenery like mountains, valleys, shores, lakes, etc. are Post-Miocene

He estimated that the 90% of the present topography belonging to Post-Tertiary age

But geological structures very old compare to topographic features developed upon them

Himalayas were probably first folded in Cretaceous and latter in Eocene and Miocene, but its present elevation was attained only in Pleistocene

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

Climatic changes during the Pleistocene have had far-reaching effects upon present day topography

Glaciations directly affected many million sq km

Many stream courses were altered as a result of ice invasions for example: Ohio, Missouri, Mississippi

World sea level were affected. Withdrawal of sea water and form the huge ice sheets lead to lowering of sea level to 300 – 500 ft

During the interglacial ages, sea level again raised

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

The climatic factors such as temperature and precipitation influence the operation of geomorphic features

Some detailed studies indicate that the climatic factors influence the topographic details

Climatic factures controls the vegetal covers, precipitation, evaporation

Differences in climatic conditions as related to slopes facing the sun and those are not exposed

10. **Geomorphology, although concerned primarily with present day landscapes, attains its maximum usefulness by historical extension.**

Geomorphology concerns itself primarily with the origin of the present landscapes, but in most landscape, there are present form that date back to previous geologic epochs or period

So geomorphologist must adopt historical approach to identify the geomorphic history

Palaeogeomorphology deals with the ancient topography and paleolandforms

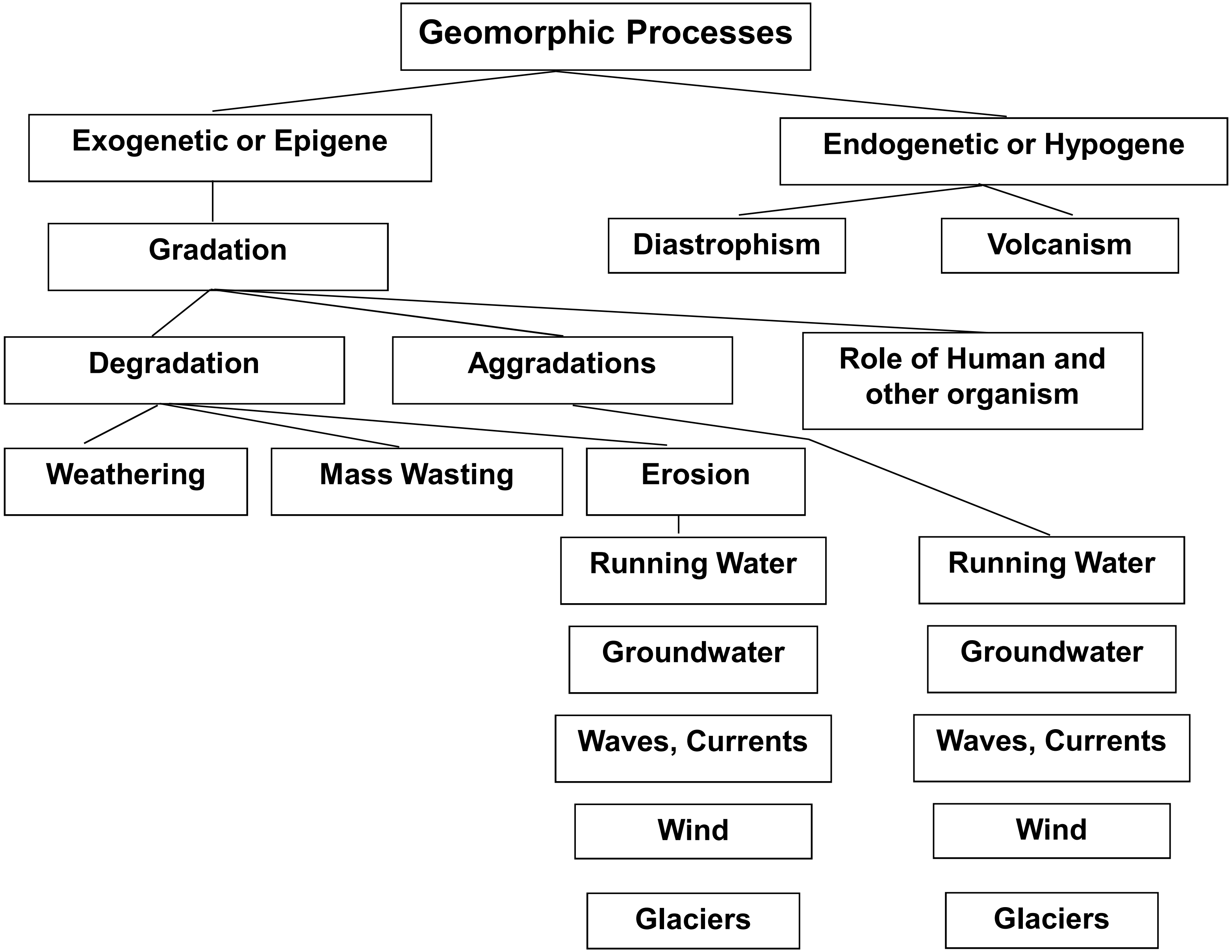
GEOMORPHIC PROCESSES

➔**Depending upon their individual nature and mode of operation, the natural agencies may be classified broadly into two categories**

➔**Earthmovements, earthquakes and volcanic necessarily have their origin underneath the surface of the earth. Therefore, they may be classified as endogenous or hypogene processes**

➔**That is the geological processes originating and operating within the earth are called endogenous or hypogene processes**

➔**The blowing wind, running and underground water, waves and currents of water bodies (Lakes, sea, oceans), glaciers, blowing sand, etc. are originating and operating on the surface of the earth are called as the exogenous or epigene processes.**


Geomorphic Processes
Exogenetic or Epigene
Endogenetic or Hypogene
Gradation
Diastrophism
Volcanism
Degradation
Aggradations
Role of Human and other organism
Weathering
Mass Wasting
Erosion
Running Water
Groundwater
Waves, Currents
Wind
Glaciers
Running Water
Groundwater
Waves, Currents
Wind
Glaciers

➔**<u>Endogenous or hypogene processes</u> are generally develop the irregularities upon the earth surface. For example:- accumulation of lava due to volcanic eruption causes the formation of volcanic mountain or plateau in vast plain surface and the severe earthquakes create the lot of irregularities in the surface of the earth**

➔**<u>Endogenic processes</u> expansion of oceanic crust and continual drifting of continental crust**

➔**<u>Diastrophism:</u>** ***is a general term for all crustal movements produced by endogenic Earth forces that produce ocean basins, continents, plateaus and mountains***

➔**<u>Diastrophism:</u> involves orogenic processes marked by the deformation of the Earth's crust and epiorogenic processes which result in regional uplift and subsidence of the crust without large scale deformation**

➔**Orogenesis, or mountain building, tends to be a localized process that distorts pre-existing strata**

➔**<u>Volcanism:</u> There are nearly 60,000 volcanoes on the earth and about 50,000 occur as seamounts in the Pacific Ocean floor. Accordingly, it is obvious that the volcanoes have an important role in modifying the Earth's surface**

- ➔**Upwelling of magma through the vent and fissure type volcanoes naturally modifies the topography**

- ➔**Extensive flow of magma creates the vast plateaus like Deccan plateau in western India**

- ➔**The crustal rocks may also be deformed by the intrusion of magma producing domal structures**

➔The exogenous or epigene processes always tend to reduce the surface of the earth to a continuous and gradual slope with out any irregularities

➔The process of development of a continuous and gradual slope of the land-mass may be defined as the gradation

➔The mechanism of reducing the altitude of a highlands due to its wear and tear processes may be described as the degradation

➔The materials or sediments result from the degradation are deposited in the low lying lands like river, lake basins, surface depression are called aggradation

➔ The aggradations and degradation occur simultaneously upon the earth surface to reduce the same to continuous and gradual slope

The natural processes which are play in grading the surface of the globe in four different stages as follows

1. Mechanical breaking down of the rock masses
2. Decomposition of the rock due to chemical reactions
3. Transportation of broken rock debris, sand, silt, etc.
4. Deposition of the transported materials under favourable condition

Weathering: Weathering which is responsible for disintegration and decomposition of rocks. Through various processes reduce the great mountains into fine particles (sand, clay)

The factors which are influence the weathering are structure of the rock, the topography, vegetation of the terrain, climate, etc.

Weathering may be classified into Physical and Chemical weathering

Physical weathering: also called mechanical weathering due to

- ➔Rocks expand due to unloading of rock masses
- ➔Repeated heating and cooling arising out of fluctuations in temperature
- ➔Activities of organisms

Chemical Weathering: Due to chemical processes, disintegration of rock will take place. The following are the some of important chemical weathering processes such as

- ➔Hydration
- ➔Hydrolysis
- ➔Oxidation
- ➔Carbonation
- ➔Solution

Erosion and Transportation of Materials: Erosion encompasses acquisition of loose materials, grinding and wearing down of the bedrock by the material, mutual attrition of particles and transportation of the debris and also taken the materials by solution

The following are the important agents of erosion

- Running water
- Groundwater
- Waves & currents
- Wind and
- Glaciers

Human Activity: is also recognized to modify the Earth's surface, large quarries, rock cut and fills and other excavations are some examples

Geomorphic Equilibrium

- A balance exists between landforms and processes;

- This balance is dependent on the interaction of energy, force and resistance;

- When thresholds are exceeded, a temporary disequilibrium will trigger a response to meet a new equilibrium condition;

- One process may affect others;

- Equilibrium conditions are more obvious over extended timeframes.

DENUDATIONAL GEOMORPHOLOGY

(2.1) Definition

Landforms and Land features caused by physical process and chemical process of disintegration.

2.2 NEED FOR STUDYING DENUDATIONAL - GEOMORPHOLOGY

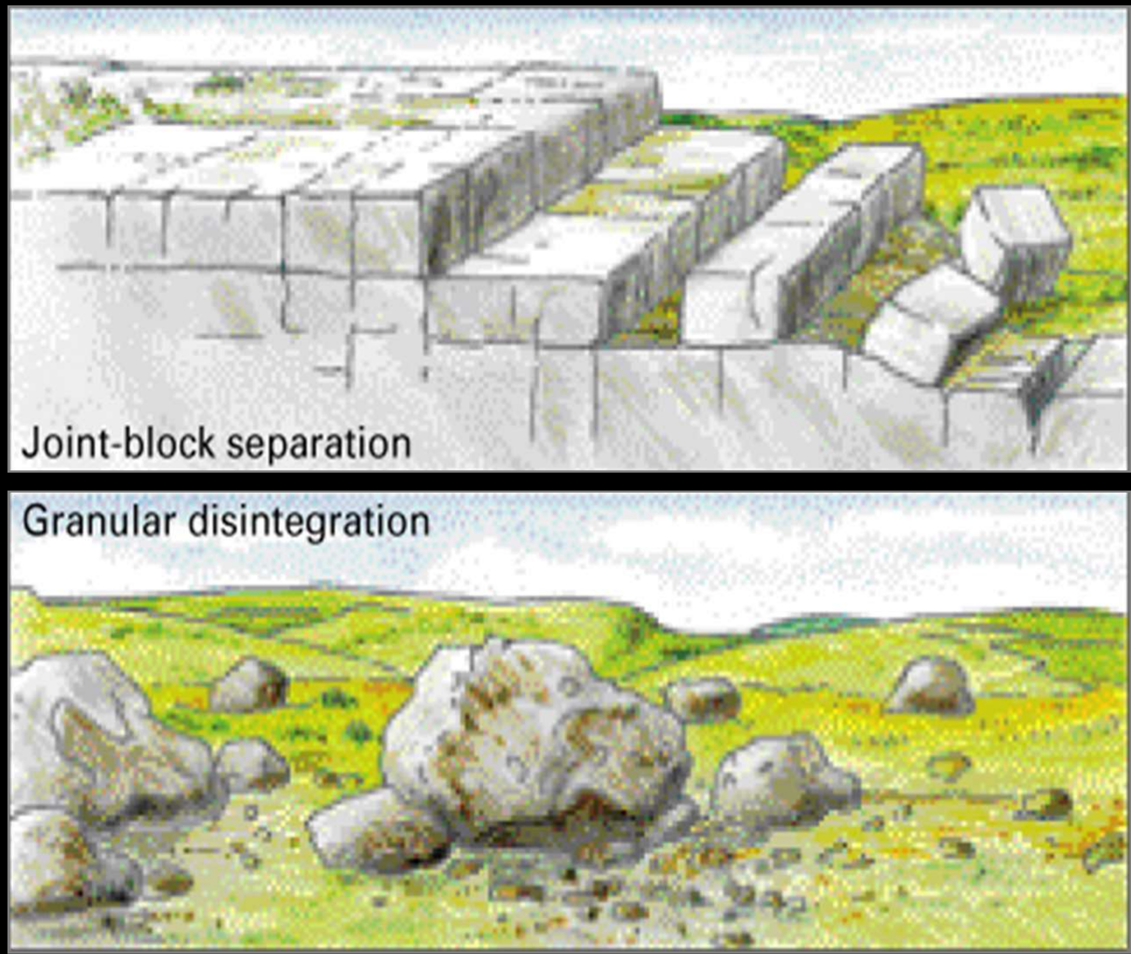
- **Discrimination of Rock types**
- **Mapping and understanding of planation surfaces**
- **Detection of active tectonism by dating Planation surfaces occurring at different levels**
- **Mineral targetting in Talus cone, fan etc.,**

- **Depth and degree of weathering and there from erosion vulnerability**
- **Groundwater targetting**
- **Soil profile - Palaeo climatology and**
- **Landslide hazard zonation**

Denudational Processes

Weathering

weathering is the combined action of physical weathering, in which rocks are fractured and broken, and chemical weathering, in which rock minerals are transformed to softer or more soluble forms



Physical Weathering

Physical weathering produces regolith from massive rock by the action of forces strong enough to fracture the rock (frost action, salt-crystal growth, unloading, and wedging by plant roots)

in chemical weathering, the minerals that make up rocks are chemically altered or dissolved (the end products are often softer and bulkier forms that are more susceptible to erosion and mass movement)

(2.3) DENUDATIONAL PROCESSES

Weathering: breakdown of rock and mineral material by physical and chemical means, without transportation; i.e. in situ

Physical Weathering

Chemical Weathering

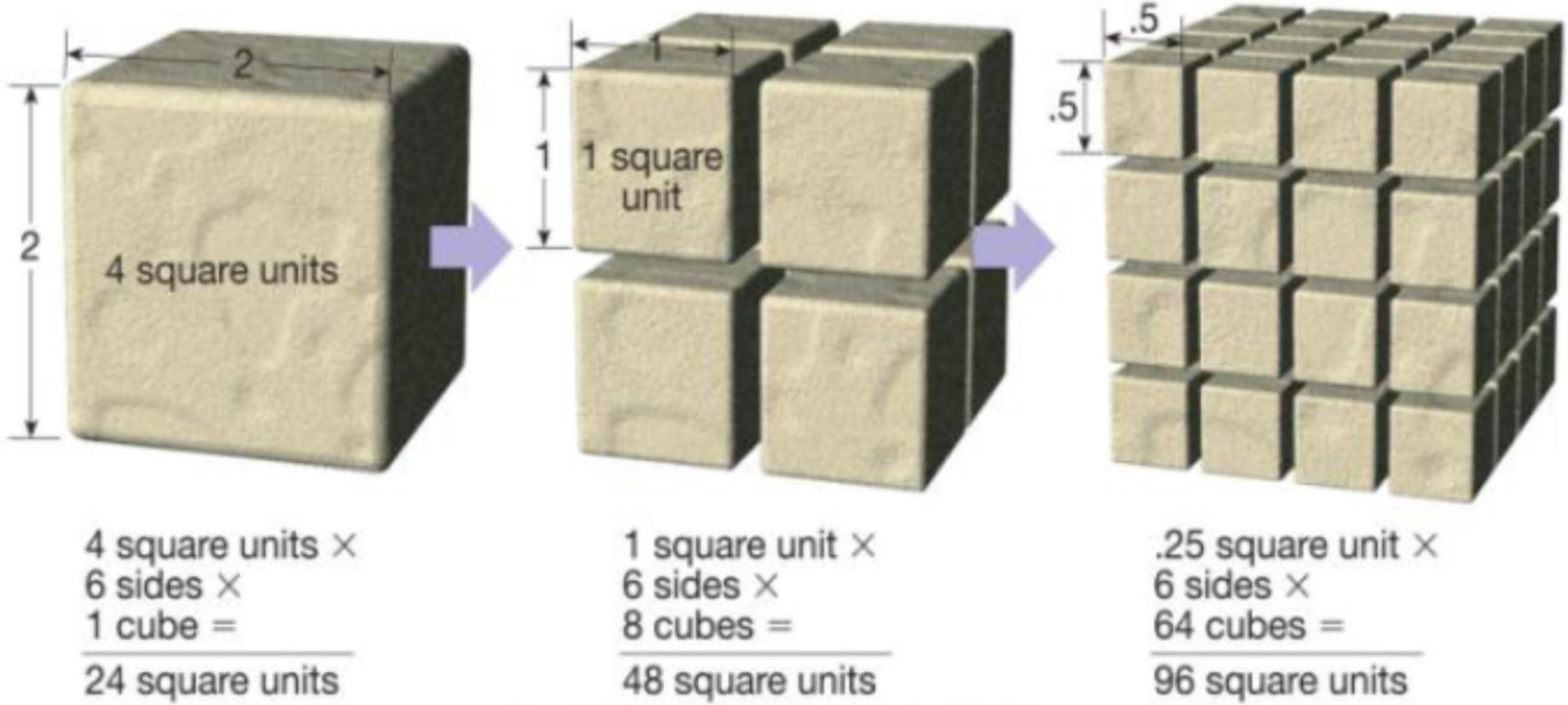
Physical weathering due to

- **pressure release**
- **water: freeze - thaw cycles**
- **crystallization of salt in cracks**
- **thermal expansion and contraction**

All this increases the total surface area exposed to weathering processes.

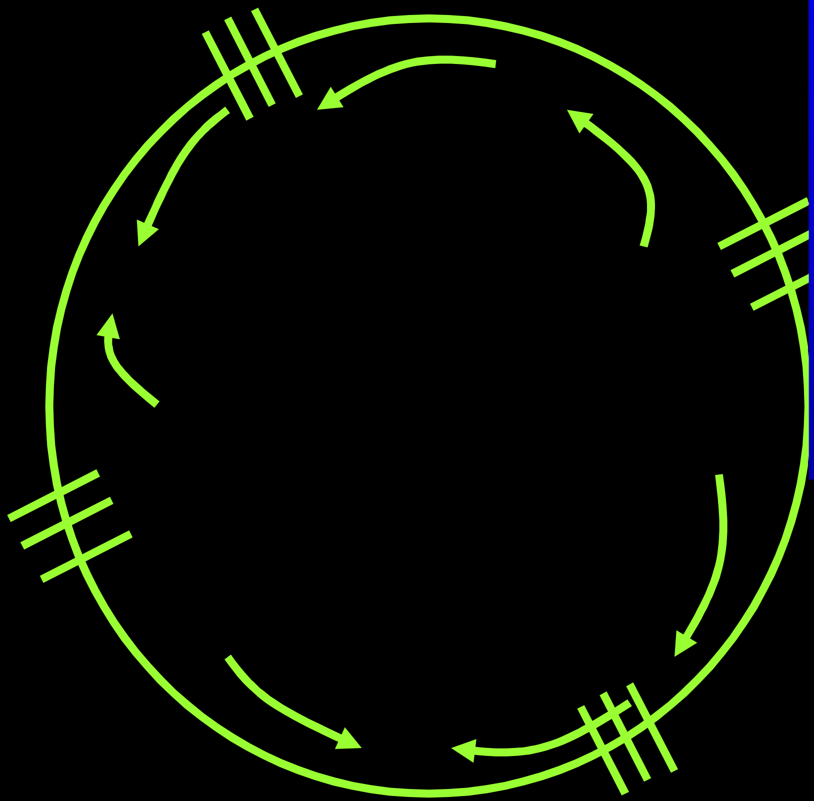
In mechanical or Physical weathering, a rock is broken down into smaller pieces without changing its mineral composition

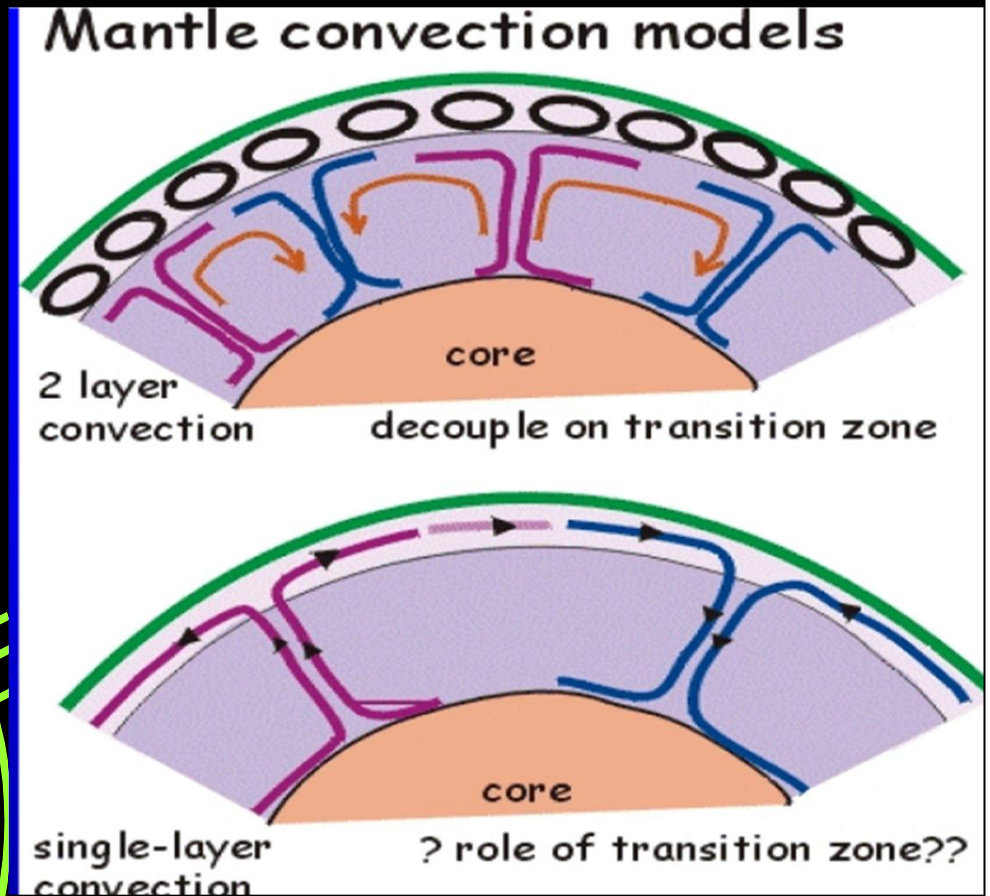
Increase in surface area by mechanical weathering



PHYSICAL WEATHERING

Due to compression and ratification of the earth crust





mountain building / Upwarping, downwarping, grabening, etc

Temperature Variations

Day time - 70^0 - 80^0

Night time - -10^0

Such repeated and alternate fluctuations cause physical disintegration. It is also called as thermal weathering.

(e.g) Exfoliation domes

Thermal expansion due to the extreme range of temperatures can shatter rocks in desert environments.

Repeated swelling and shrinking of minerals with different expansion rates will also shatter rocks.

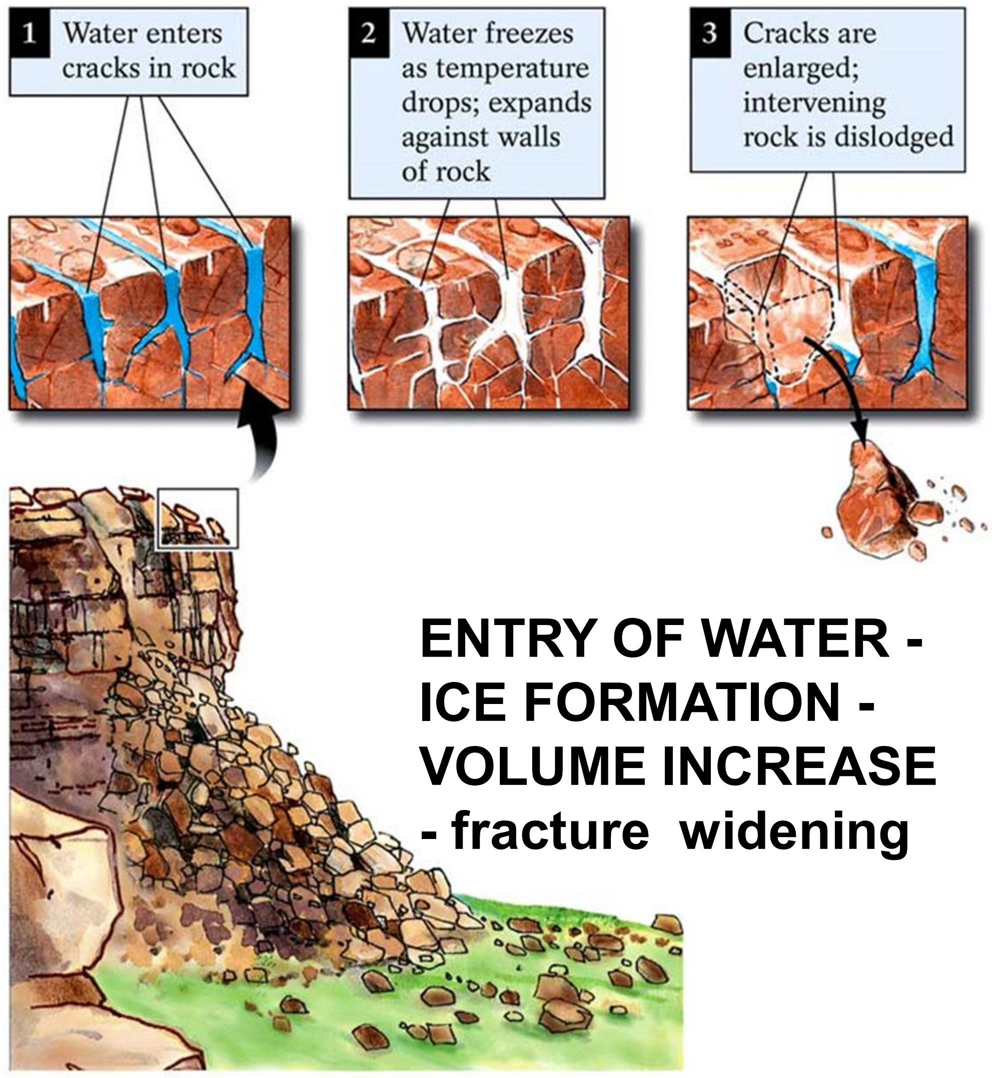
Thermal Expansion and Contraction

Source: Tom Bean

FREEZING / FROST ACTION

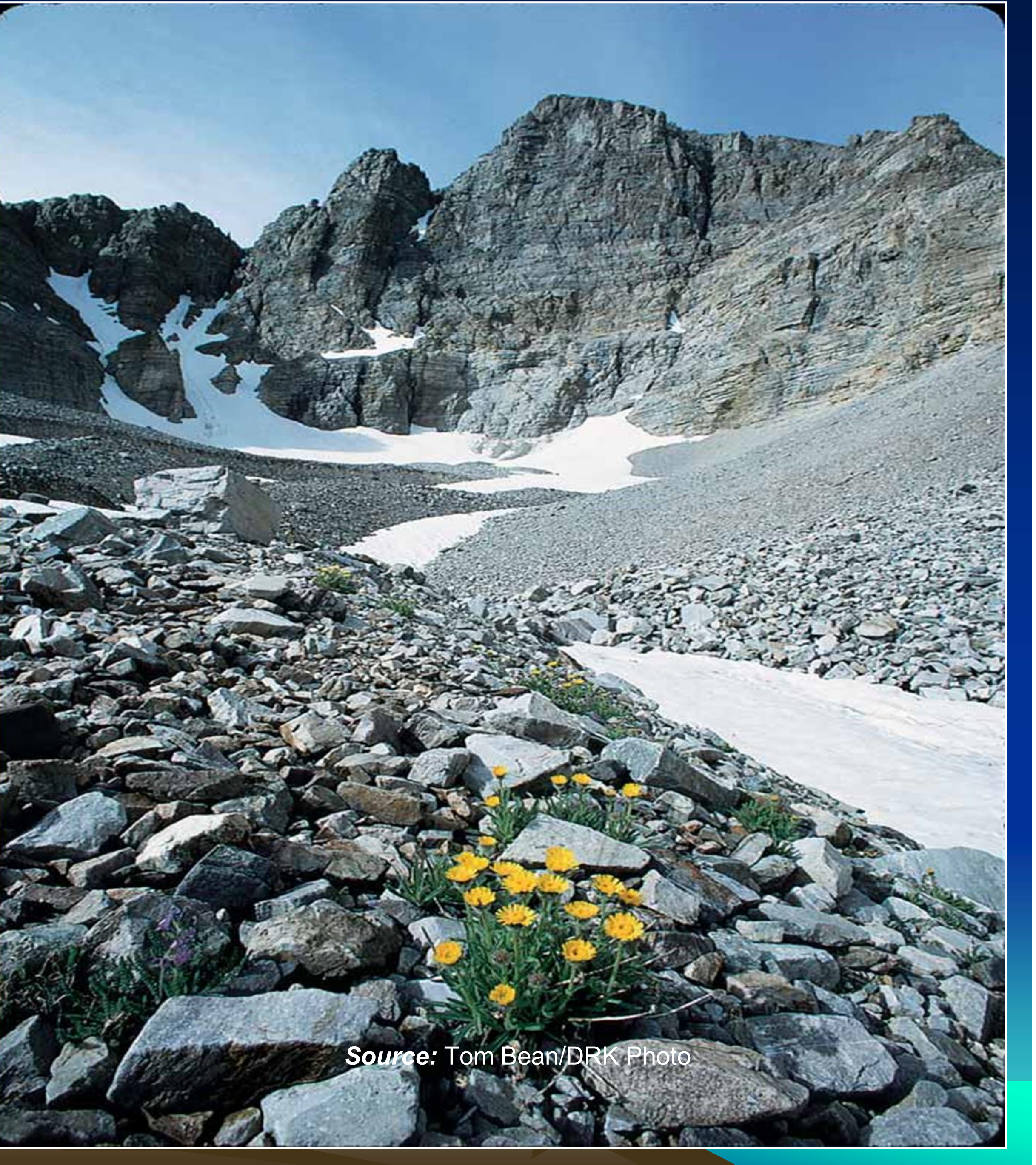
one of the most important physical weathering processes in cold climates is frost action, the repeated growth and melting of ice crystals in the pore spaces of soil and in rock fractures

when water freezes in bedrock joints and bedding planes, it expands and can split rocks apart



ENTRY OF WATER - ICE FORMATION - VOLUME INCREASE - fracture widening

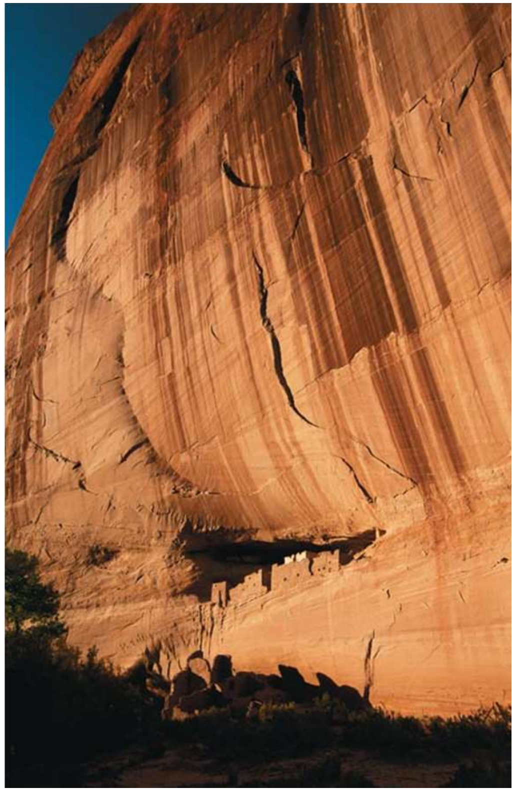
Evidence of Frost Wedging in Wheeler Park, Nevada

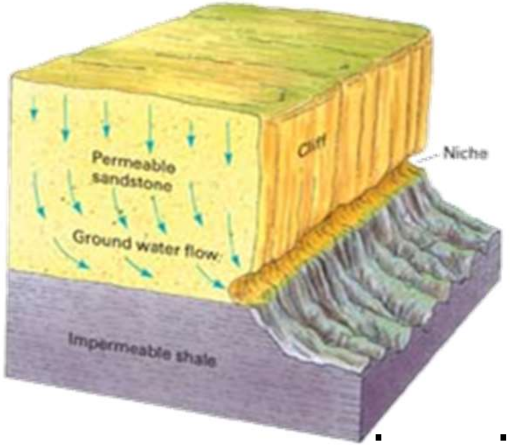


Source: Tom Bean/DRK Photo

Salt-crystal growth: Water evaporates from sandstone pores, leaving salt crystals behind. Crystals grow and disintegrate rock.

- Occurs in arid and semiarid regions

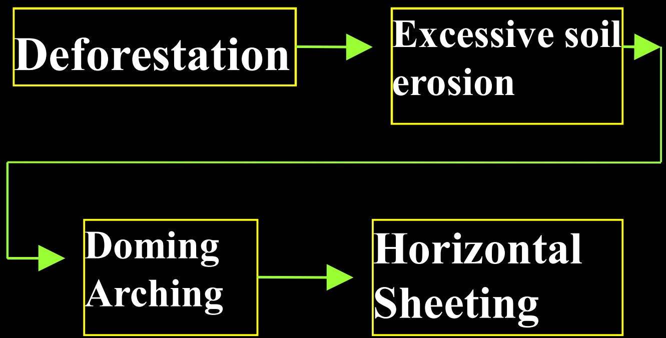


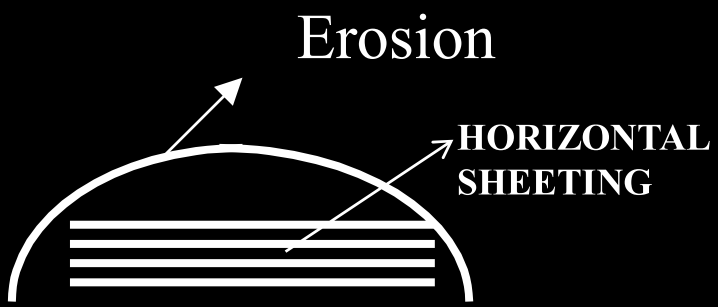


in arid climates, slow evaporation of ground water from outcropping sandstone surfaces causes the growth of salt crystals

crystal growth breaks the rock apart grain by grain, producing niches, shallow caves, and rock arches

SOIL EROSION – Exfoliation Sheeting





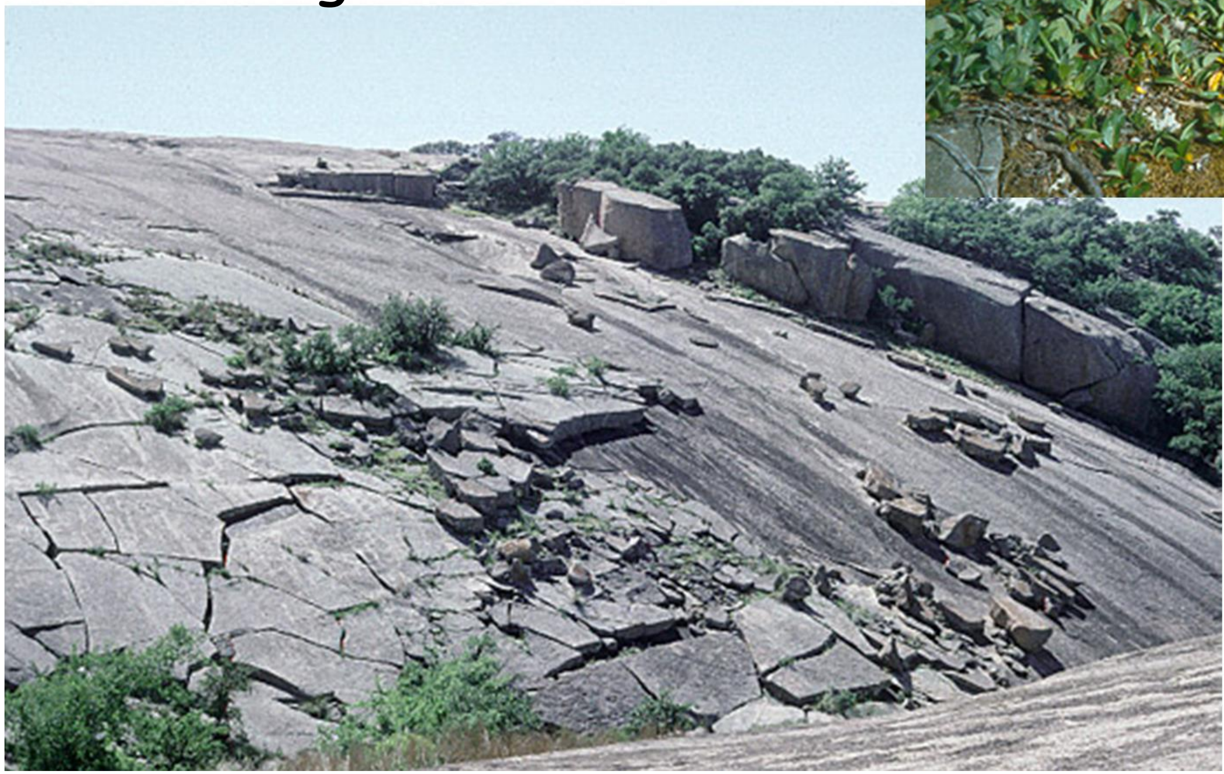
unloading occurs as rock is brought near the surface by erosion of overlying layers

as the rock above is slowly worn away, the pressure is reduced, and the rock expands slightly in volume

this causes the rock to crack in layers that are more or less parallel to the surface, creating a type of jointing called
sheeting structure

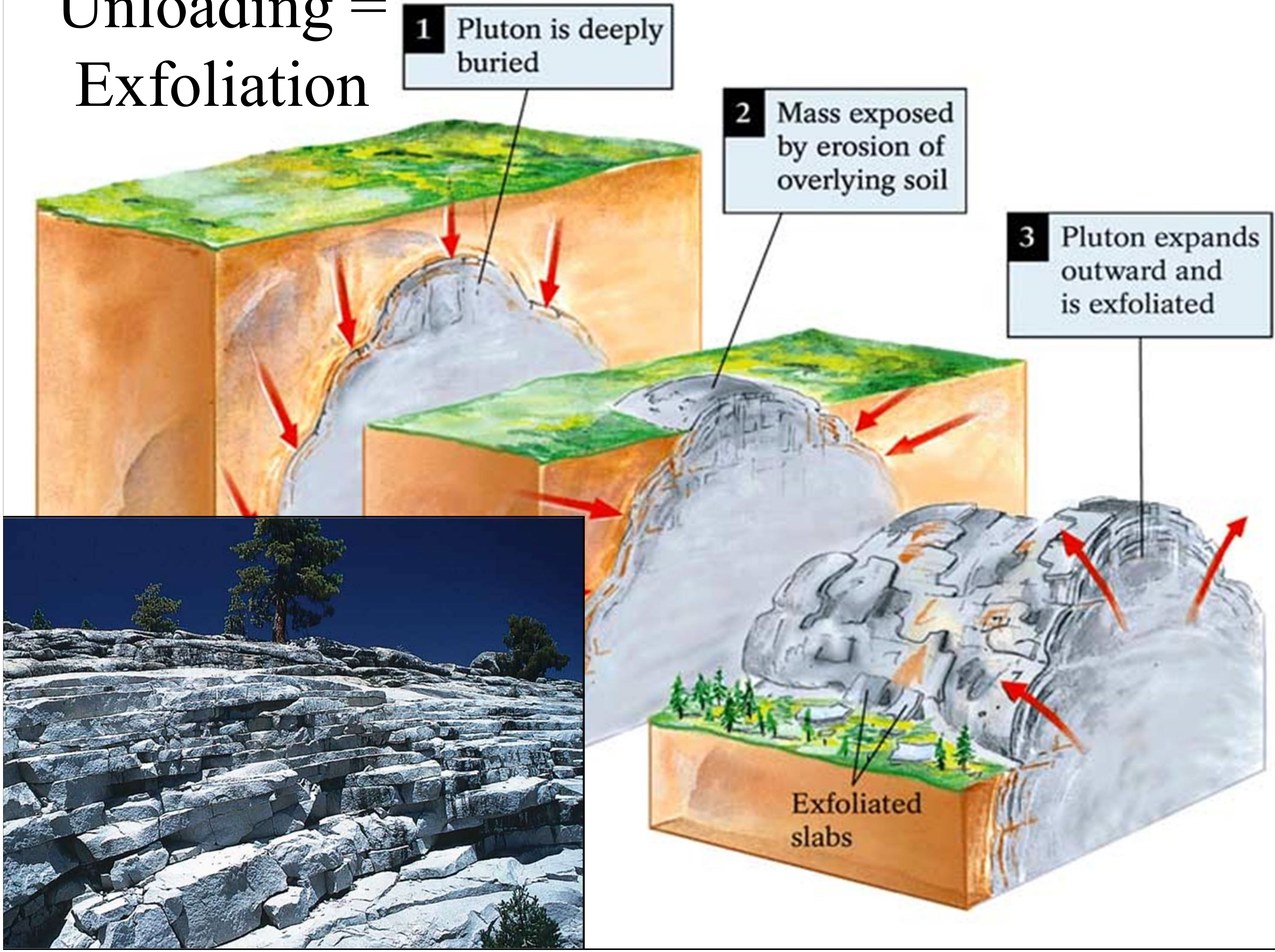
Exfoliation:
Rock breaks apart in layers that are parallel to the earth's surface; as rock is uncovered, it expands (due to the lower confining pressure) resulting in exfoliation.

Exfoliation of a small pluton

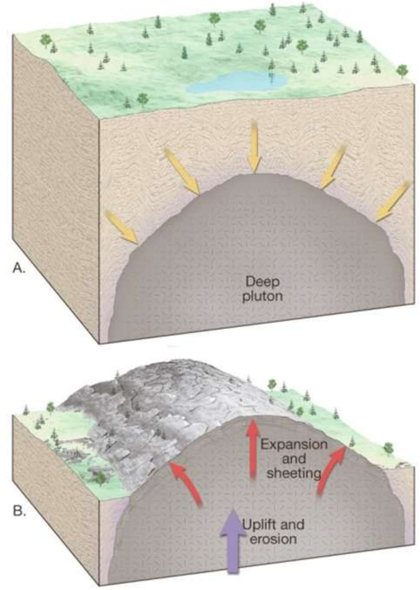


Exfoliation of Granite

Unloading = Exfoliation



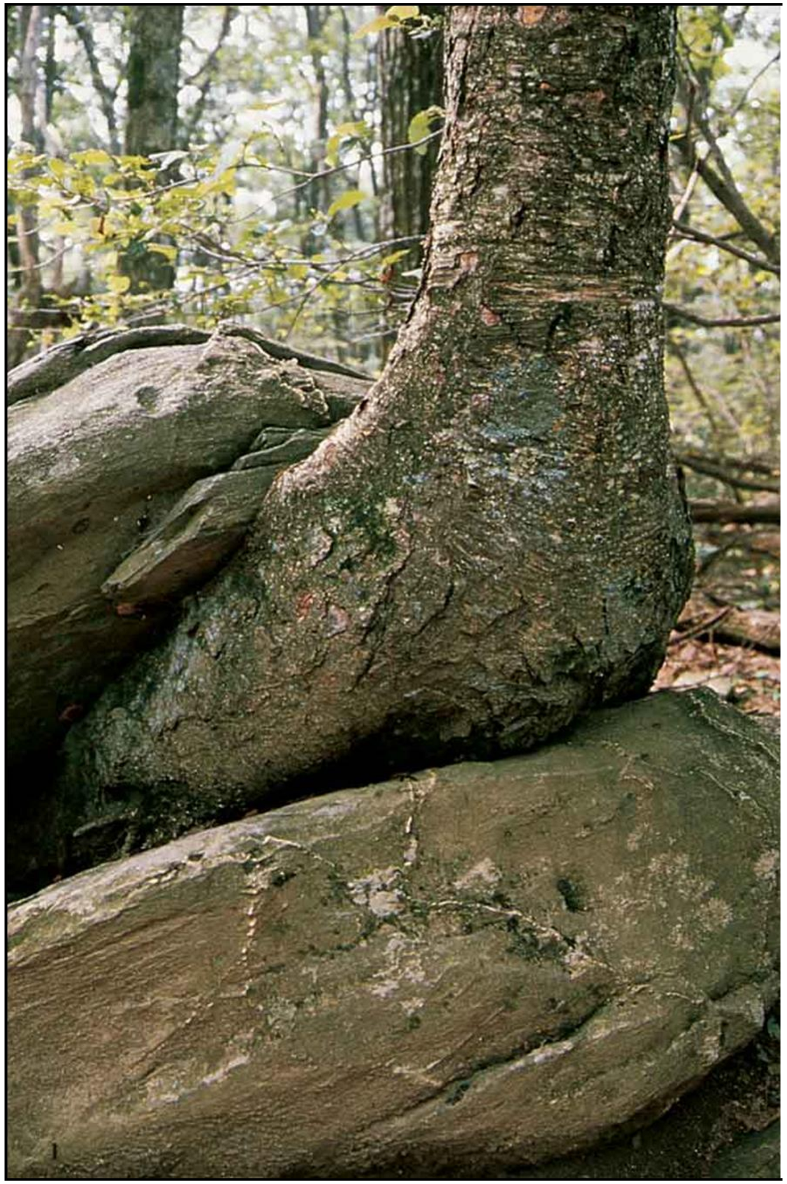
Sheet Joints (Exfoliation)



PRYING ACTION OF PLANTS

ROOT WEDGING

Tree Roots Growing
in Rock Fractures
Animal Burrows



Source: Runk/Schoenberger/Grant Heilman

Hydraulic weathering by tree roots, Angkor Wat temple complex, Cambodia

Photo courtesy of Reece Rehm; GEOG111 - Fall, 2000

PRYING ACTION OF ANIMALS

ANIMALS AND INSECTS LIKE ANTS MAKE DEEP HOLES IN THE CRUST AND ILNITIATE PROCESS OF DENUDATION INTIATE THE

- ***BURROWING***

burrowing

(2.3.7) HUMAN ACTION

➔ ***Quarrying and blasting***

Mass Wasting

- Mass wasting is the downslope movement of regolith and masses of rock under the pull of gravity.
- Mass wasting is a basic part of the rock cycle.
  - Weathering, mass-wasting, and other aspects of erosion constitute a continuum of interacting processes.

GRAVITATIONAL GLIDING or MASS WASTING

Gravitational Gliding

doming and fracturing in upper reaches

Rock flowage / soil creep solifluction

LANDSLIDE BLOCK - VENEZULA

EXFOLIATION SHEETING DUE TO GRAVITATIONAL GLIDING

Mass Wasting

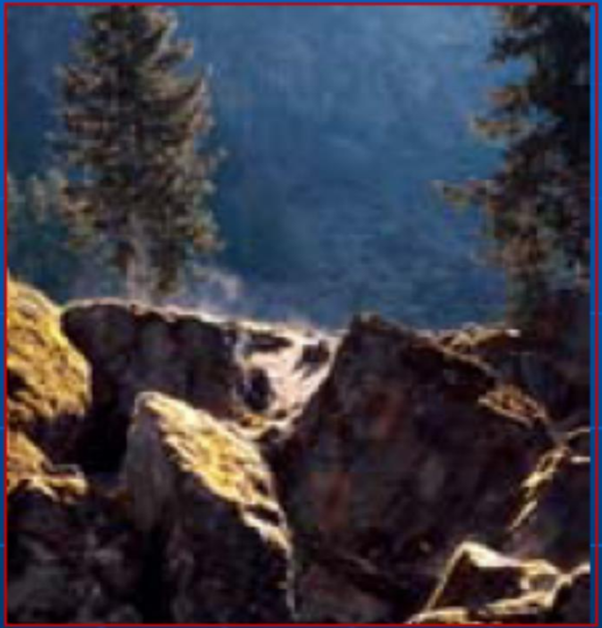
Mass Wasting: spontaneous downhill movement of soil, regolith, and bedrock under the influence of gravity

What Are the Different Types of Mass Wasting?

- Classified on the basis of:
  - Rate of movement - fast or slow
  - Type of movement - falling, sliding, or flowing
  - Type of material - rock, soil, and debris
- Rapid movements involve visible movements of material
- Slow movements are imperceptible except from their effects such as cracked walls and tilted trees or power poles

What Are the Different Types of Mass Wasting?

- Falls
  - Rockfalls are a common type of rapid mass wasting
  - May occur along steep canyons, cliffs, and road cuts



  - Talus builds up at the base, where fallen material collects
  - Failure along joints or bedding planes may be caused by undercutting, earthquakes, or frost wedging

What Are the Different Types of Mass Wasting?

- Slides - slumps and block
  - Move along one or more surfaces of failure
  - May consist of soil, rock, or both
  - May move rapidly or slowly
  - Slumps involve movement along a curved surface
  - Rock or block slides move along a planar surface, often where dip is the same as slope direction

What Are the Different Types of Mass Wasting?

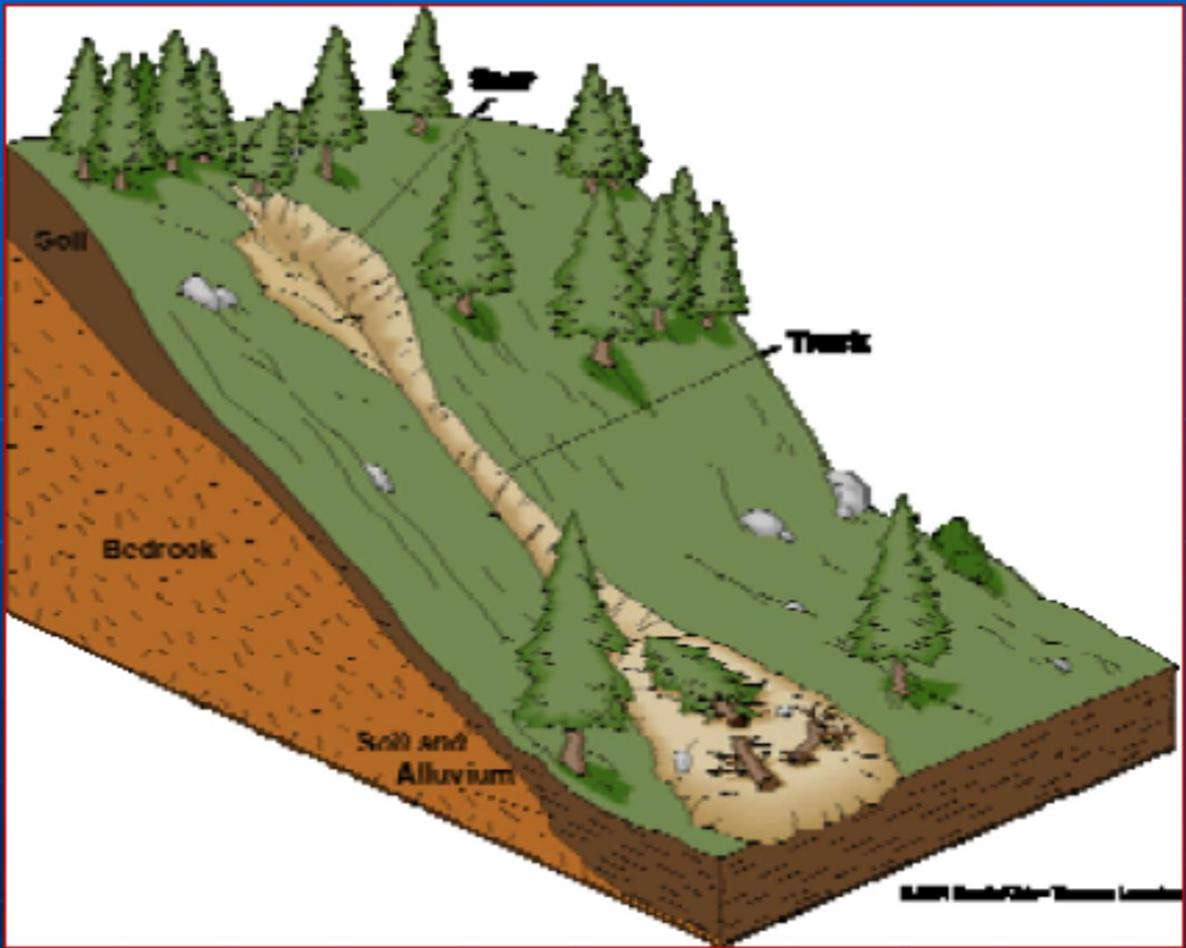
Flows move as a viscous fluid or show plastic movement

*mudflows are fluid and move fastest, common in arid or mountainous regions

*debris flows are more viscous

*earthflows move as thick, viscous masses of wet regolith

Mudflows



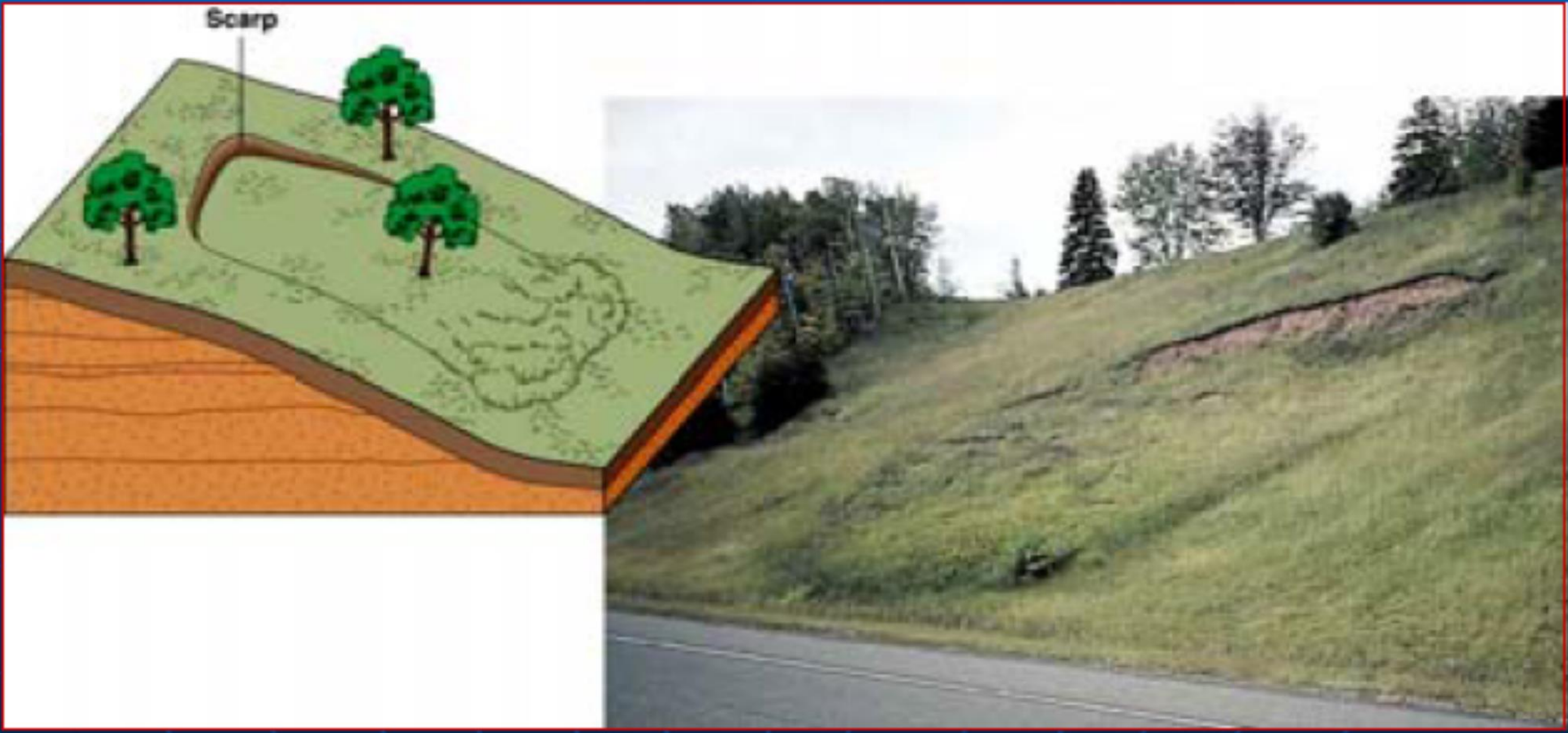
- Consist of at least 50% silt and clay sized particles, at least 30% water
- Usually follow pre-existing channels until the slope decreases, then fan out

Debris flows

- Composed of larger sized particles than mudflows
- Don't contain as much water as mudflows
- Rarely confined to pre-existing channels

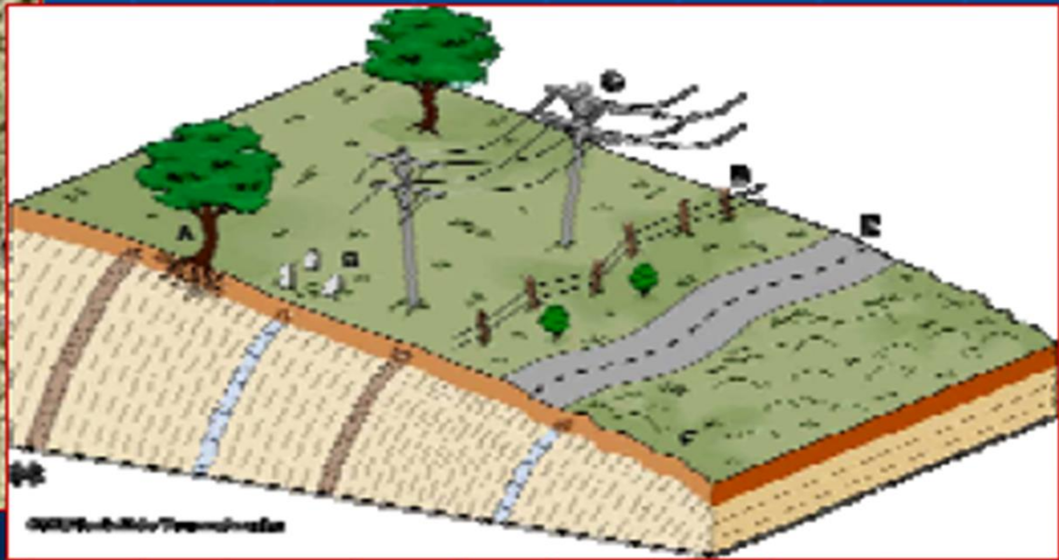
Earthflows

- Slumps from the upper part of a hillside
- Occur most commonly in humid climates



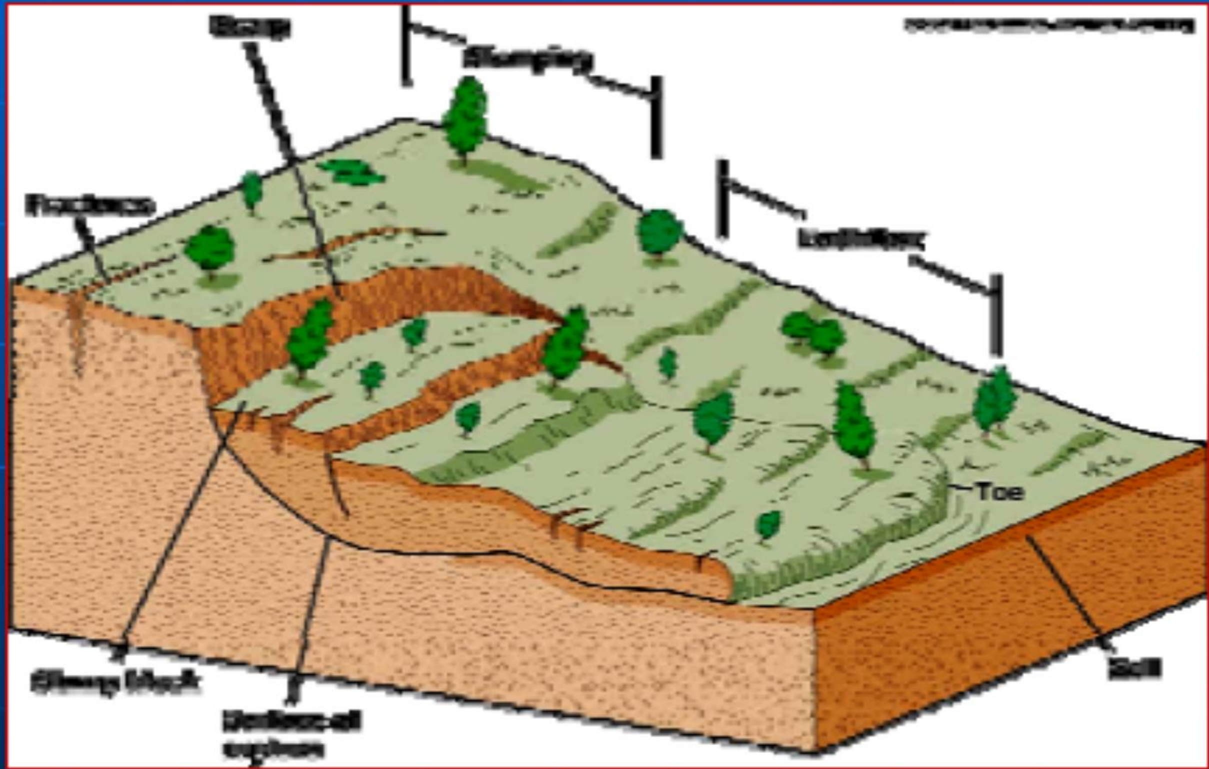
Creep

- Slowest type of flow, most common in humid climates such as the southeastern US
- Extremely destructive over time; difficult to recognize or control



Complex Movements

- Occurs when several of the recognized types are involved in a mass movement
  - slide-flow
  - debris avalanche



TYPES OF MASS WASTINGF (Modified after Varnes 1978

Type of movement			Type of material		
			Rocks	Predominantly coarse - debris	Predominantly fine - soil
Falls			Rock fall	Debris fall	Earth fall
Topples			Rock topple	Debris topple	Earth topple
Slides	Rotational		Rock slump	Debris slump	Earth slump
	Translational	Few units	Rock block slide	Debris block slide	Earth block slide
		Many units	Rock slide	Debris slide	Earth slide
Lateral spreads			Rock spread	Debris spread	Earth spread
Flows			Rock flow	Debris flow	Earth flow
			Rock avalanche	Debris avalanche	
			Deep creep	Soil creep	
Complex and compound			Combination in time and/or space of two or more principal types of movement		

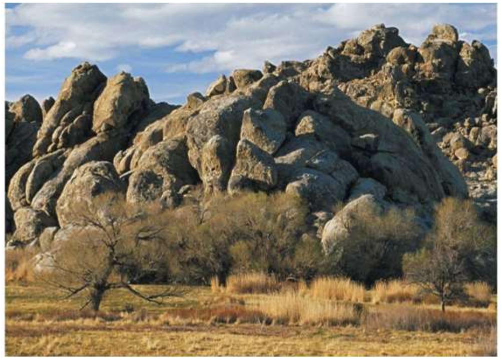
In chemical weathering, a rock is broken down by chemical reactions that change its mineral composition and physical and chemical properties

Weathering

Chemical Weathering

Chemical Weathering: chemical change in rock minerals through exposure to the atmosphere and water

- Most effective in warm, moist climates
- Hydrolysis
- Oxidation
- Carbonic acid action
  - Dissolves limestone, creating caverns
  - Weathers buildings, tombstones
- Soil acids weather basalt



Chemical Weathering and its Landforms

the dominant processes of chemical change affecting silicate minerals are oxidation, hydrolysis, and carbonic acid action

oxidation and hydrolysis change the chemical structure of minerals, turning them into new minerals that are typically softer and bulkier and therefore more susceptible to erosion and mass movement

carbonic acid action dissolves minerals, washing them away in runoff

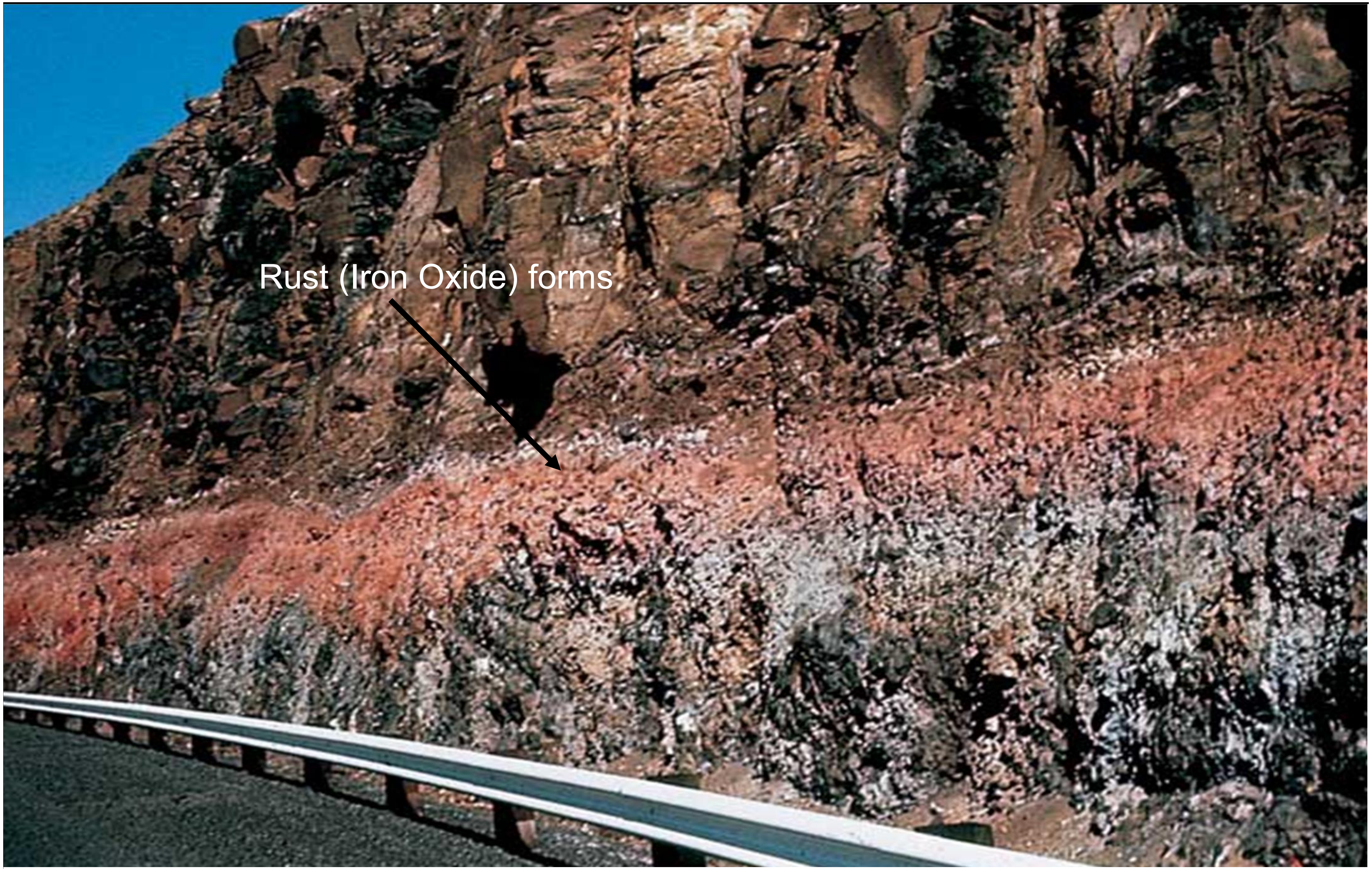
Oxidation

Oxygen dissolved in water promotes oxidation of sulfides, ferrous oxides, native metals

ADDITION OF OXYGEN → CONVERSION OF SILICATES INTO OXIDES CAUSE PHYSICAL DISTINTEGRATION

$$4\,Fe + 3\,O_2 \rightarrow 2Fe_2O_3$$

Oxidation of Basalt



(2.4.2) REDUCTION

REMOVAL OF OXYGEN OR ADDITION OF HYDROGEN DESTRUCT ROCKS

FE+++ -- O → FE++

(red) (black)

Ferric to Ferrous

Hydration: attachment of water molecules to crystalline structure of a rock, causing expansion and weakness

ADDITION OF WATER MOLECULES IN IT MINERAL LATTICE CAUSE WEATHERING

Ca So4 + 2 H2O → CASO4.2H20

KAL SI3 O8 + H → HALSI3O8 + K

1. Hydrolysis and 2. Carbonation

1. $H_2O \rightleftharpoons H^+ + OH^-$ (ionization)
2. $H_2O + CO_2 = H_2CO_3$ (carbonic acid)

Interactions with minerals, e.g.:

olivine $MgSiO_4 + H_2CO_3 = Mg(HCO_3)_2 + H_4SiO_4$

- entirely dissolves

felspar $KAlSi_3O_8 + [H^+/OH^-] = HAlSi_3O_8 + KOH + Al_2O_3 .3H_2O + H_2SiO_3$

- produces "clay" minerals

quartz $SiO_2 + [H^+/OH^-] = H_4SiO_4 + SiO_2$

- partially dissolves (leaving 'quartz sand')

2.4.4. CARBONATION

Addition Of Co 2 Into Rock Elements And the resultant Decay of Rocks Called **Carbonation.**

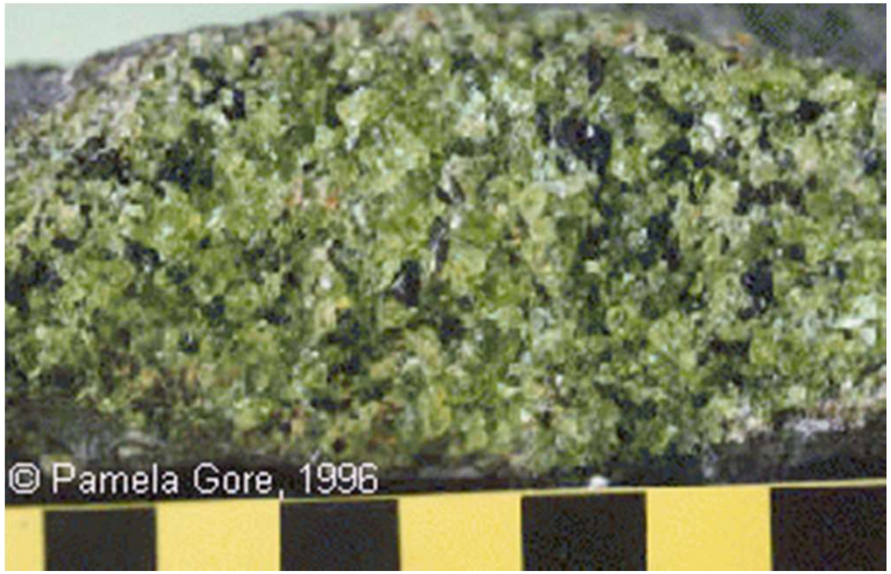
Co2 is Added into the Elements Like Calcium, Magnesium , Sodium or Potassium Form Carbonates,

k2O Al2O3 6siO2 + H2 Co3 + Water = K2 Co3 + (A2O3 2SiO2 2H2O3) + 4SiO2

(orthoclase) (carbonic acid) (potassium carbonate) (kaolinite)

- Similarly (Na2 O3 Al2O3 6SiO2) changes to clay **(Albite)**
- gabbro and pyroxene also changes to clay.

Olivine/pyroxene to clay



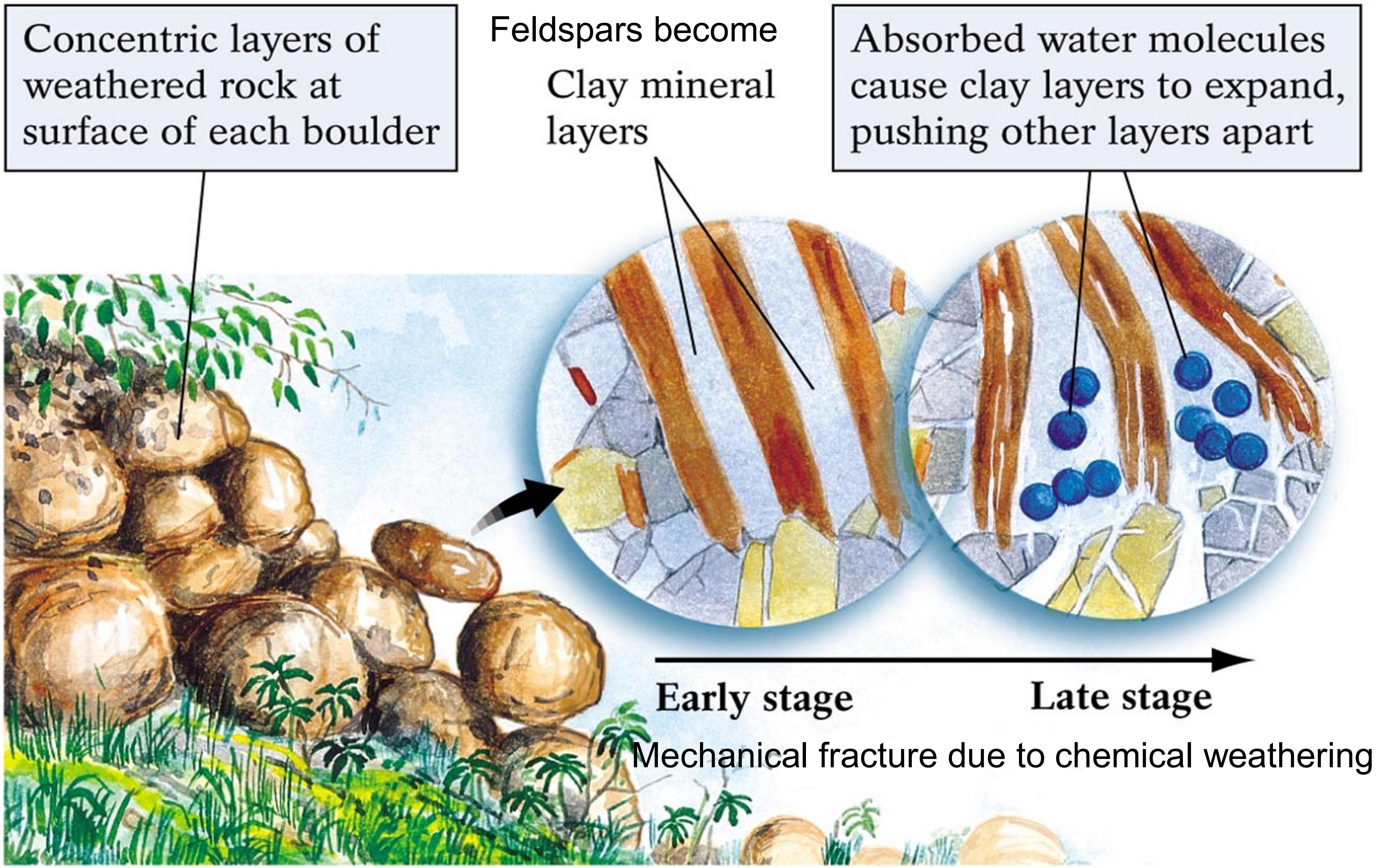
+ H_2CO_3 (acid)

↓

Feldspars to clay

+ H_2CO_3 (acid)

Hydrolysis – Feldspar to Clay



Water is the main operator:

Dissolution: Many ionic and organic compounds dissolve in water Silica, K, Na, Mg, Ca, Cl, CO3, SO4

Acid Reactions

Water + carbon dioxide <---> carbonic acid

Water + sulfur <---> sulfuric acid

H+ effective at breaking down minerals

Precipation and resolification:

During the Course of transport such solution get resolidified as secondary crystals.

(E.g)

Silicious solutions → Secondary silica like Amythist, Amorphous Qtz, Geoid, plasma etc., *Solution*: process by which rock is dissolved in water

- Is strongly influenced by pH and temperature
- When water becomes saturated, chemicals may precipitate out forming *evaporite* deposits.
- Calcium carbonate (calcite, limestone), sodium chloride (salt), and calcium sulfate (gypsum) are particularly vulnerable to solution weathering.

Dissolution

$H_2O + CO_2 + CaCO_3$ --> $Ca^{+2} + 2HCO_3^-$

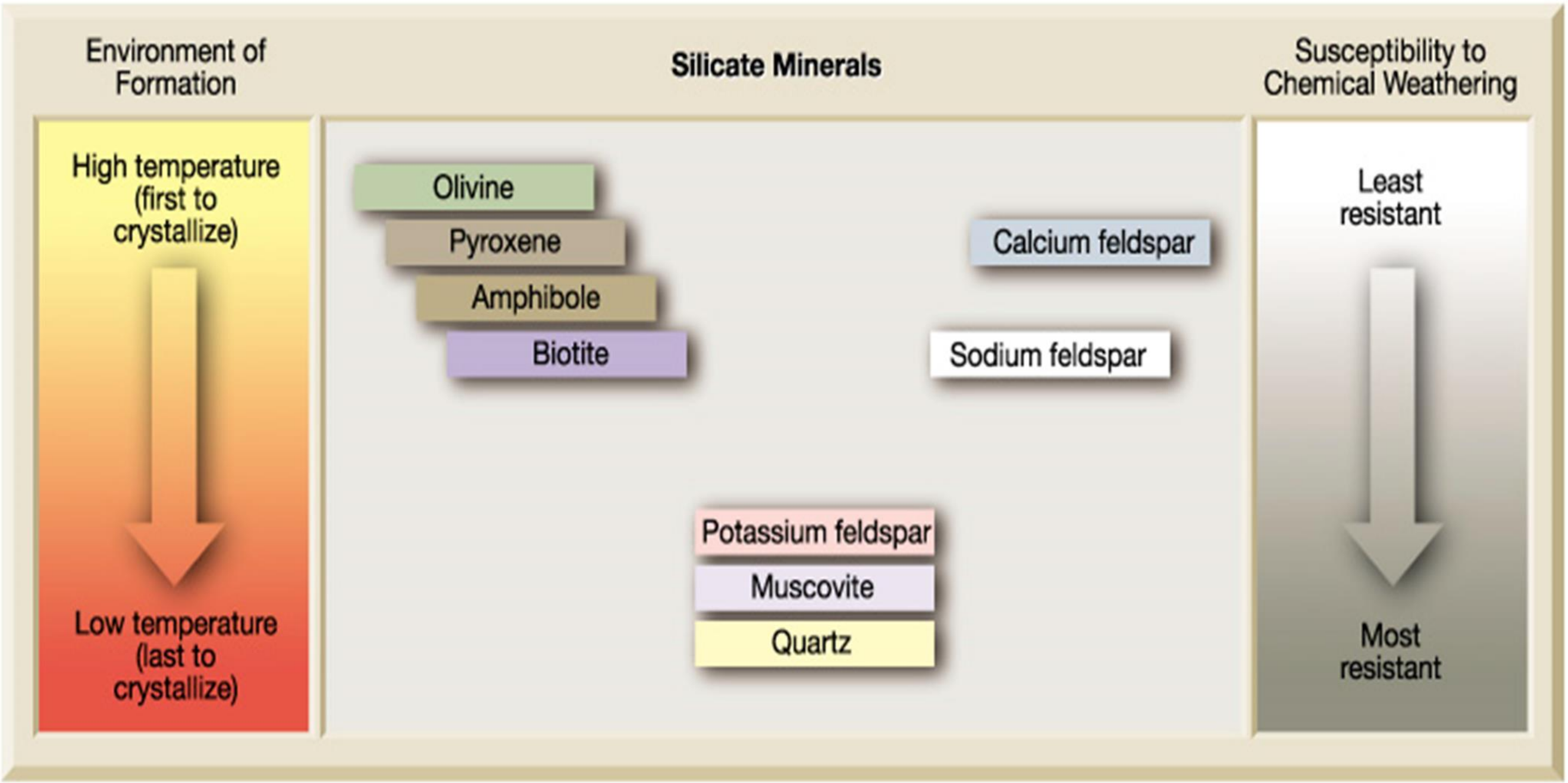
water + carbon dioxide + calcite dissolve into calcium ion and bicarbonate ion

Biological activity in soils generates substantial CO_2

Bicarbonate is the dominant ion in surface runoff.

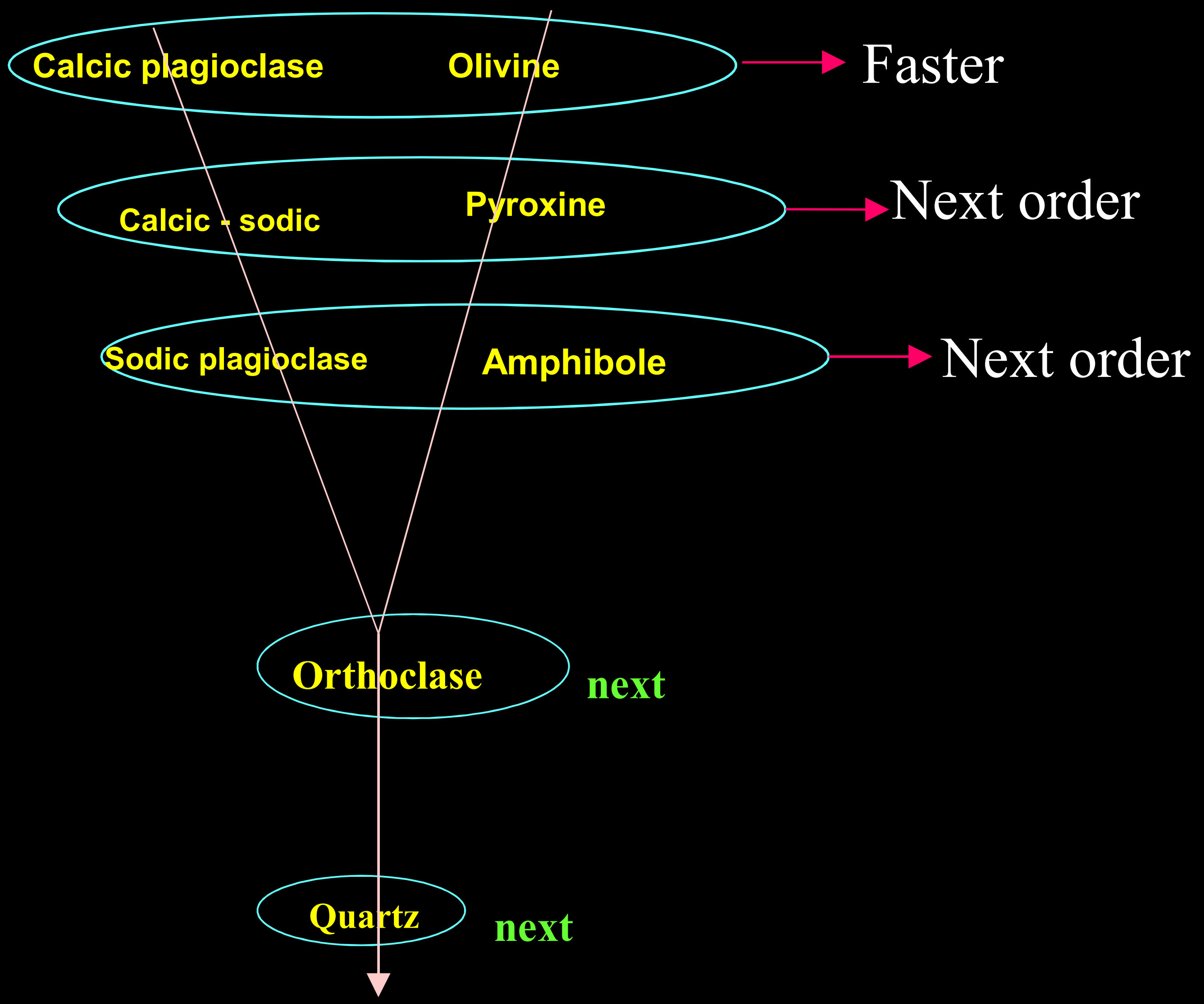
Bowens Reaction Series and Weathering

$Mg_2SiO_4 + 4CO_2 + 4H_2O \Rightarrow 2Mg+ = 4HCO_3^- + H_4SiO_4\,(aq)$



$2KAlSi_3O_8 + 2H_2CO_3 + 9H_2O \Rightarrow Al_2Si_2O_5(OH)_4 + 4\ H_4SiO4\,(aq) + 2K^+ + 2HCO_3^-$

(2.4.5) Solution acitivity



DENUDATIONAL

LAND FORMS

1. Summit Zone Features

Summit Zone Features

- Denudational Hills
  - Highly Dissected
  - Moderately Dissected
  - Poorly Dissected
- Erosional Plateau
  - Highly Dissected
  - Moderately Dissected
  - Poorly Dissected
- Erosional Mesa / Butte
  - Highly Dissected
  - Moderately Dissected
  - Poorly Dissected
- Tors
- Exfoliation Domes / Born Horte
- Residual Hills
- Arched hills
- Inselberg
- Intermontanane Valley

Slope Zone Features

Debris Slope / Scree Slope

Barren Slope

Midslope Mounds

Rock Slump

Debris Avalanche

Rock Creep / Rock Slide

Foot Hill Zone

Talus Cone / Fan

Debris Wash Plain

Plain Zone

Pediment

- **Rocky Pediment**
- **Weathered Pediment Shallow**
- **Weathered Pediment Moderate**
- **Weathered Pediment Deep**

Pediplain

- **Deeply Weathered**
- **Moderatly Weathered**
- **Poorly Weathered**

Lateritic upland

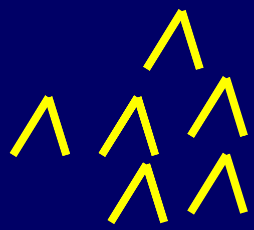
- **Dissected**
- **Undissected**

2.5 DENUDATIONAL LANDFORMS

I SUMMIT ZONE

Dendudational hill or Hill complexes

hills of irregular X, Y, Z

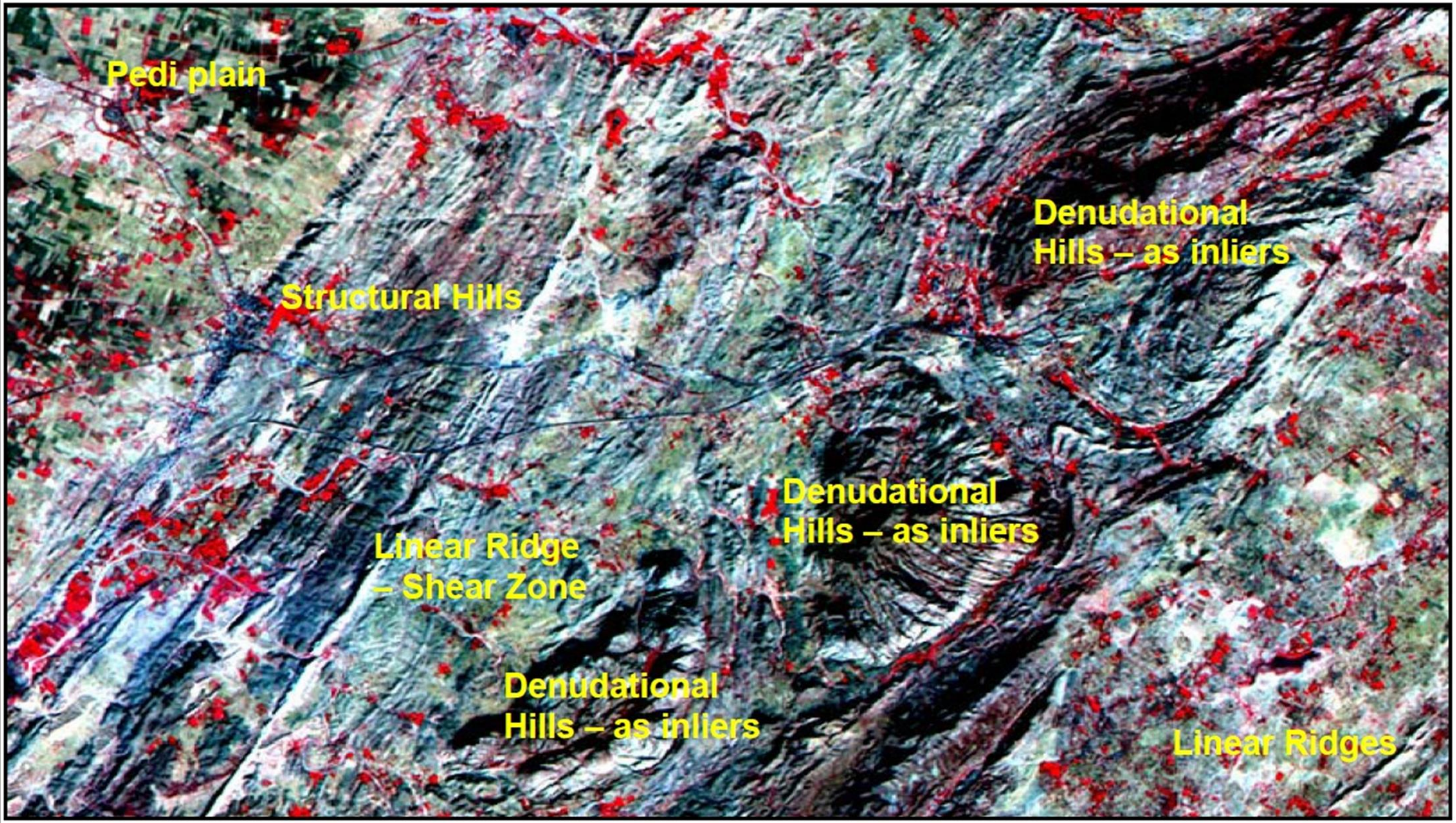


Hill complexes

Size less, shapeless, pattern less & relief less hills

Sizeless, shapeless, patternless & reliefless hills

Fig. 4.20: Satellite image of Aravali region showing the Structural landforms



DENUDATIONAL HILL COMPLEXES

DENUDED CLIFFED HILLS

(PICTURE PEAK, JOHN MUIR, WILDERNESS)

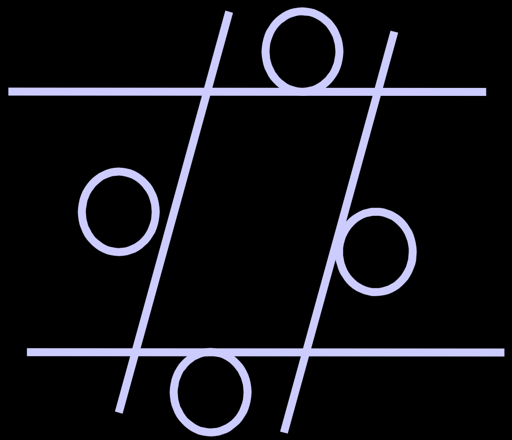
DENUDED MOUNTAINS

(GREAT SAND DUNES, NATIONAL MONUMENTS)

DENUDED MOUNTAINS

(GREAT SAND DUNES, NATIONAL MONUMENTS)

Dissected Hills



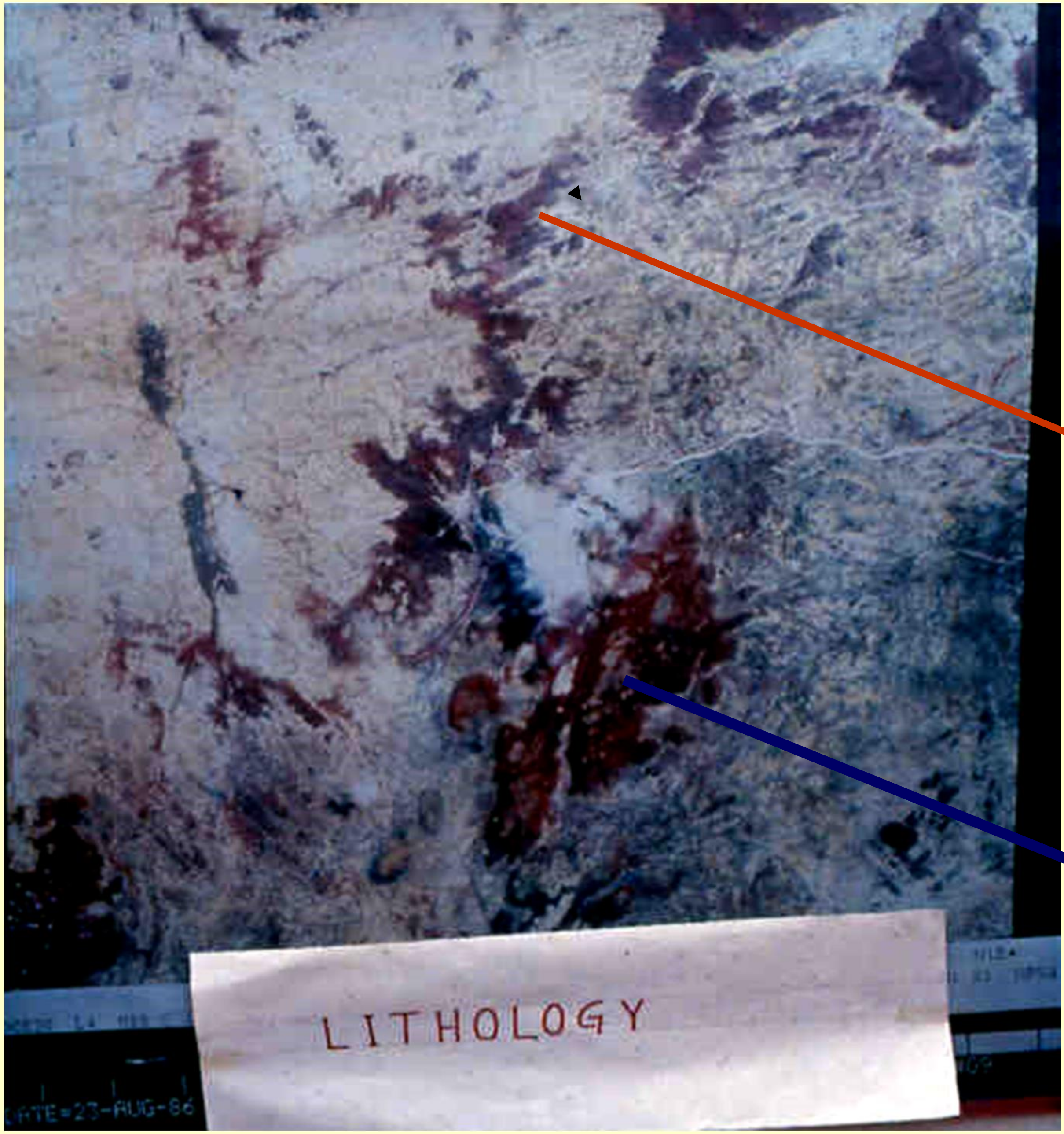
Expression

- ⇨ Hills dissected by criss crossing fractures
- ⇨ With cliffs, peaks and serrations

Environment

- ⇨ better Groundwater possibility
- ⇨ prone for land slides / subsidences
- ⇨ streams down below expected to carry more silt.

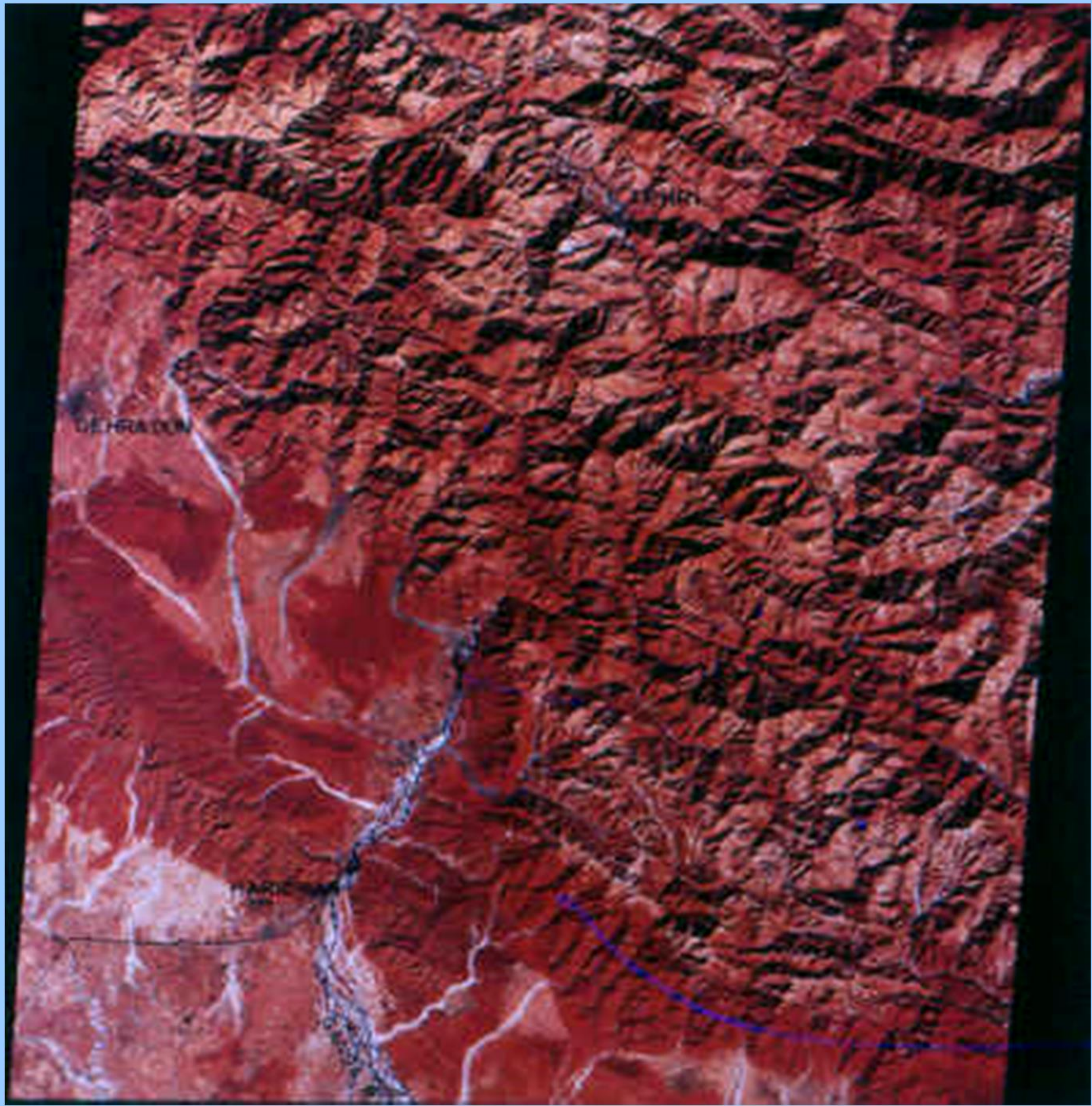
DISSECTED HILLS

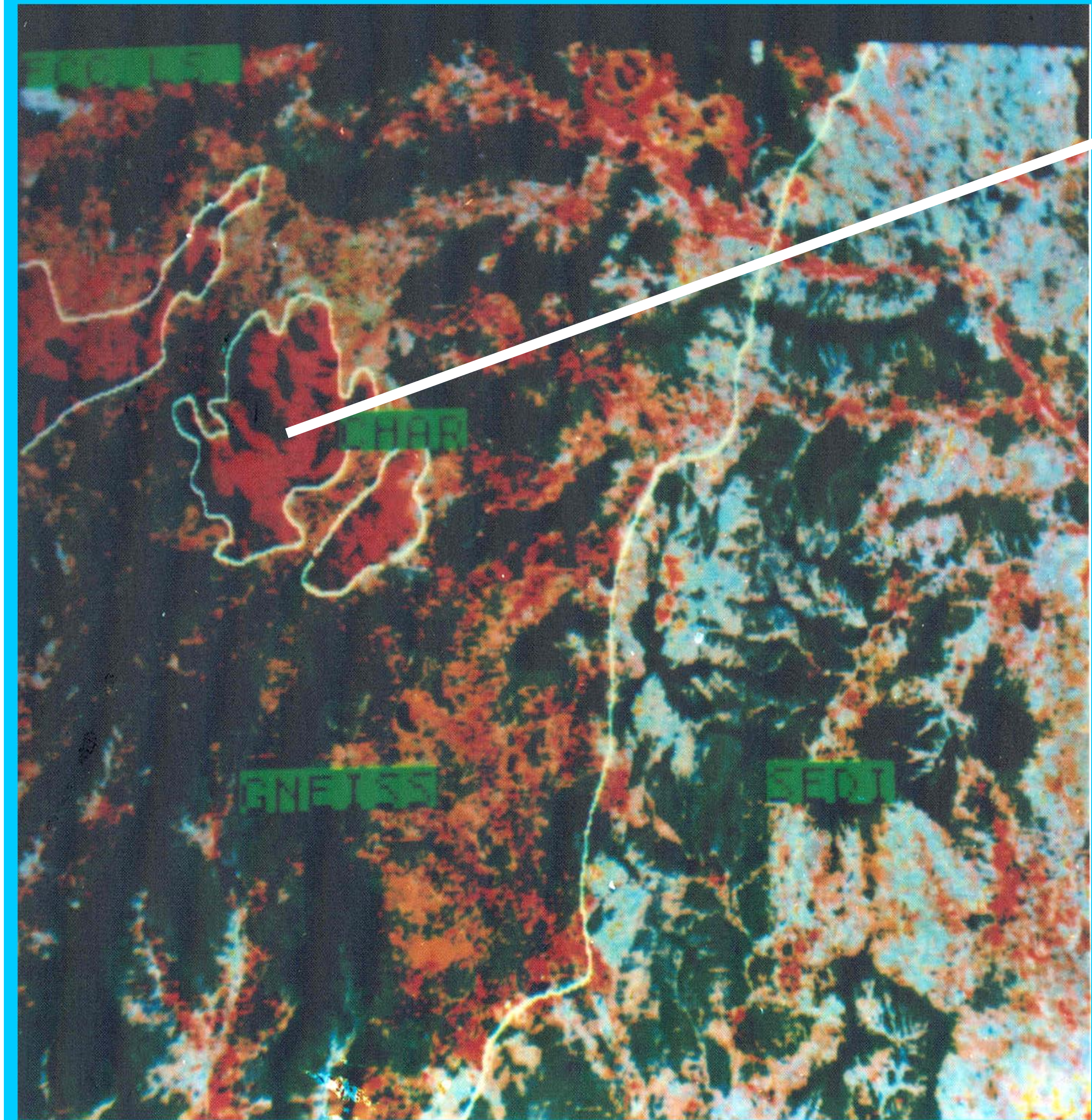


MORE DISSECTED

POORLY DISSECTED

DISSECTED HILLS





UNDISSECTED DENUDATIONAL HILLS

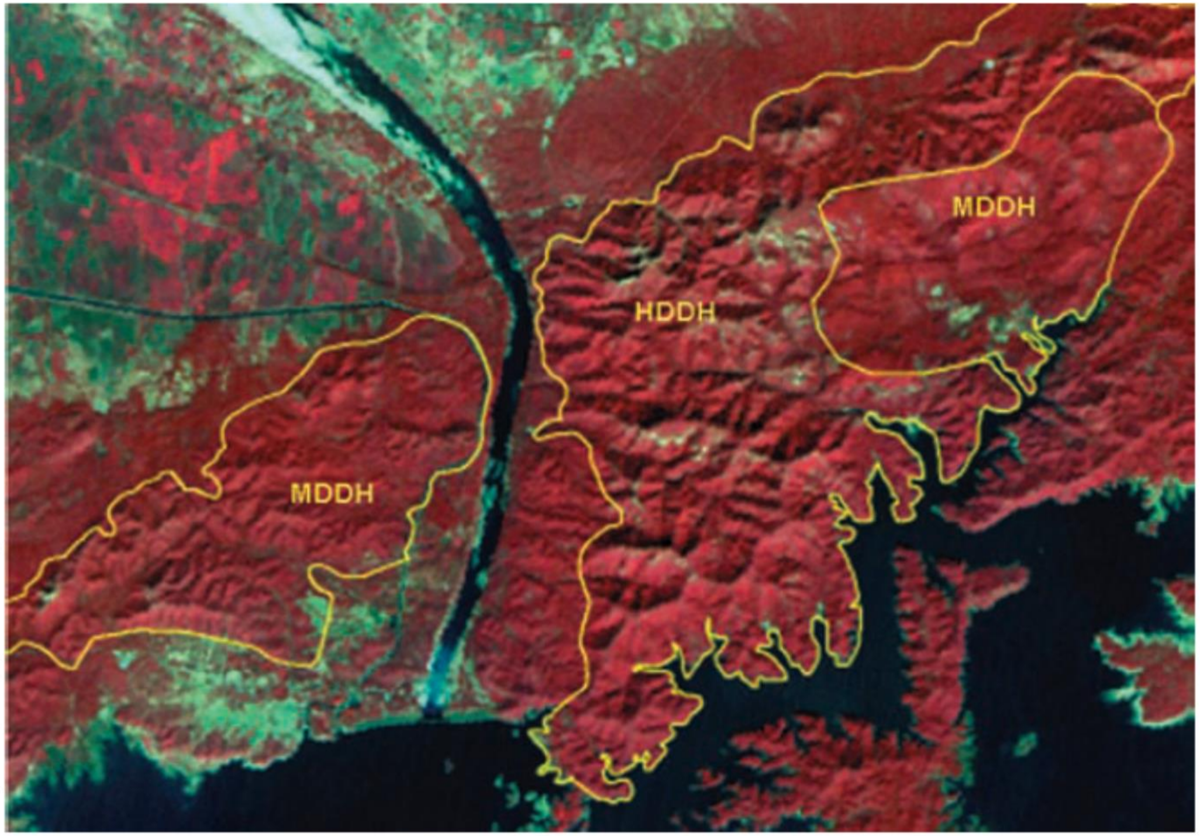


Fig. 2.17 Highly dissected denudational hills (HDDH) and Moderately dissected denudational hills (MDDH) within the Plateau-Ridge-Valley Complex of Hoshangabad district, Madhya Pradesh state. The density of drainage lines is relatively moderate and therefore moderate dissection in case of MDDH, whereas, the density of drainage lines is relatively high and therefore high dissection in case of HDDH.

Plateau: Vast horizontal plate like landforms covering several hundred sq km Surrounded by vertical wall like escarpments are developed due to tectonic processes

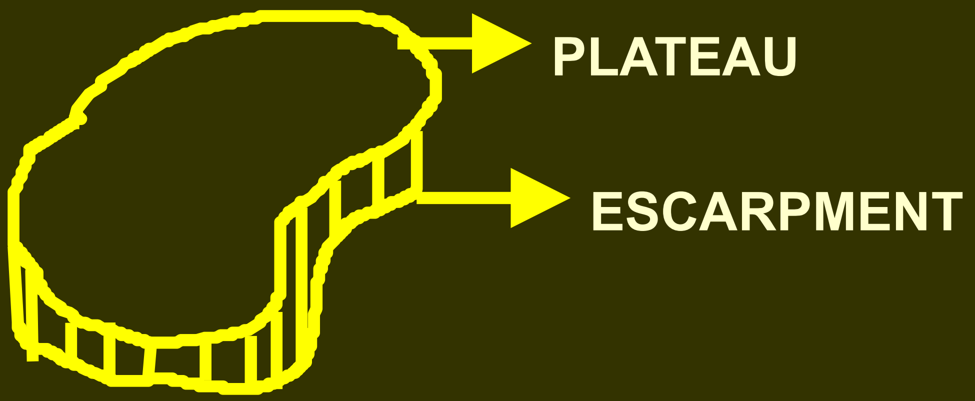
E-g

i) Plateau in Sst - Vindhyans

ii) Plateau in Cuddapah

iii) All Deccan trap plateau

iv) Plateau in metamorphites (charnockite)

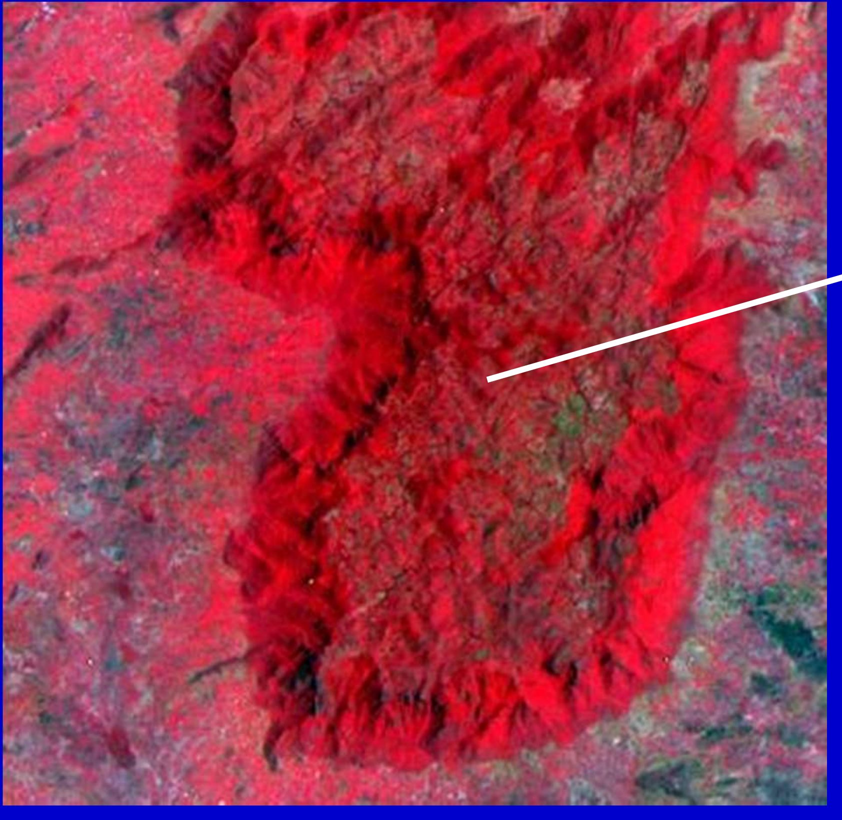


b) Signatures

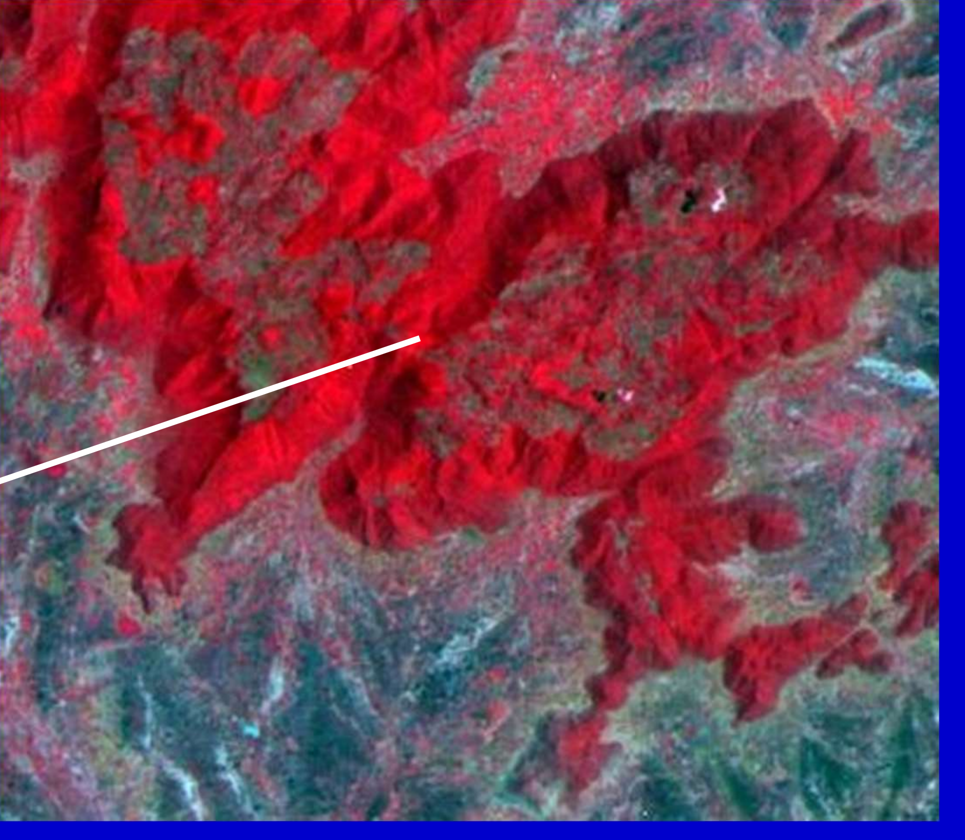
- normally boat like
- rims / slopes prolific with vegetation

Plateau : Broadly, any comparatively flat area of great extent and elevation and extensive land region considerably elevated (more than 150-300m in altitude) above the adjacent country or above sea level and dissected by deep valleys or canyons. A plateau is usually higher and has more noticeable relief than a plain (it often represents an elevated plain).

EROSIONAL PLATEAU

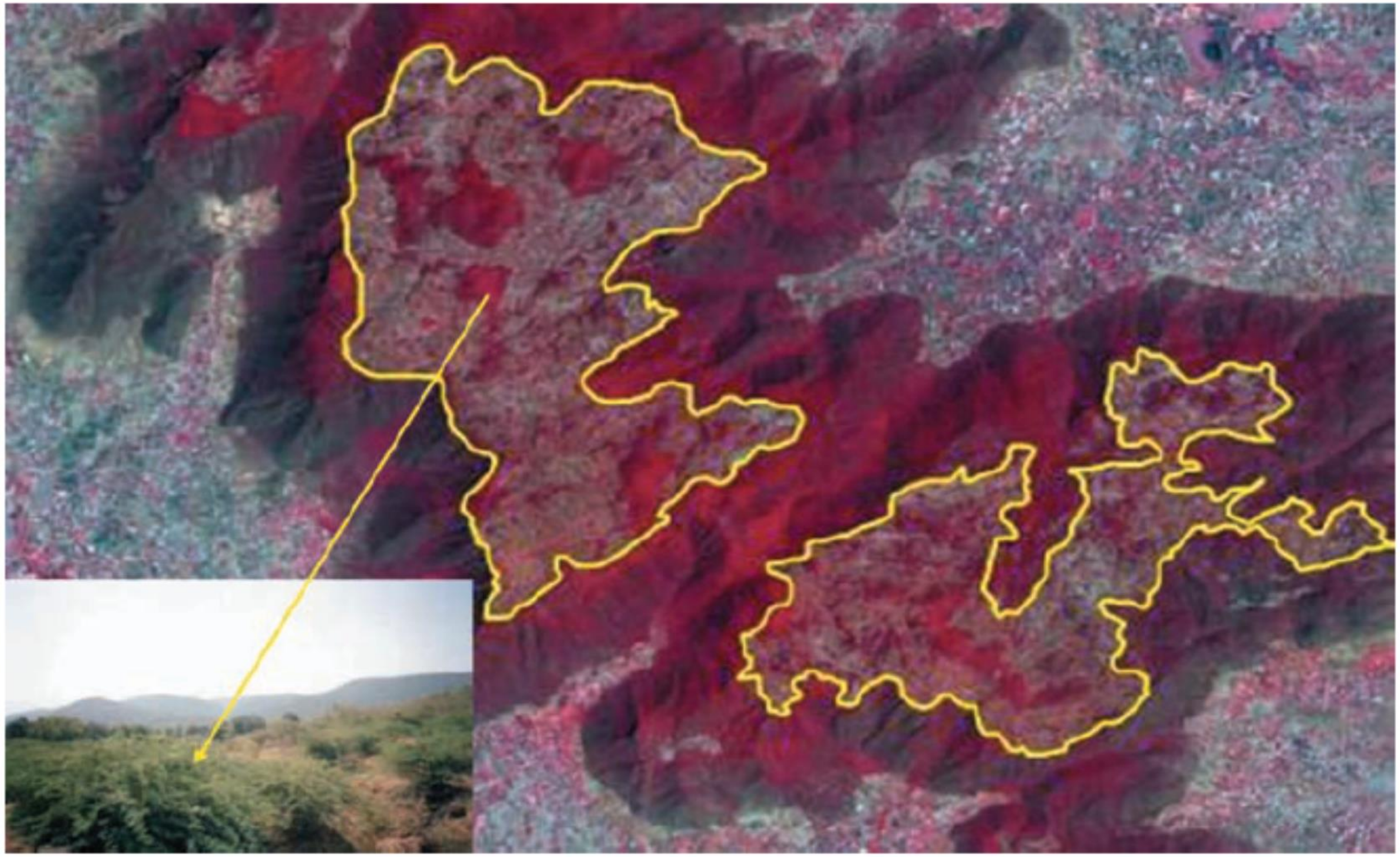


POORLY DISSECTED



HIGHLY DISSECTED

Fig. 2.23 Plateau Top in the low dissected upper plateau in Pachamalai hills consisting of charnockites in Tiruchirappalli district, Tamil Nadu. There is an elevation difference of 1000m (approx.) between the plateau top and foot hills. The top is undulated.



Erosional Mesa / Butte

Mesa: An isolated nearly level land mass standing distinctly above the surrounding country bounded by abrupt or steeply sloping erosion scarps on all sides, and capped by layers of resistant, nearly horizontal rocks (usually lavas). Less strictly, a very broad, flattopped, usually isolated hill or mountain of moderate height bounded on at least one side by a steep cliff or slope and representing an erosion remnant.

Butte: A conspicuous, usually isolated generally flat-topped hill or small mountain with relatively steep slopes or precipitous cliffs, often capped with a resistant layer of rock and bordered by talus, and representing an erosion remnant carved from flat-lying rocks; the summit is smaller in extent than that of a mesa.

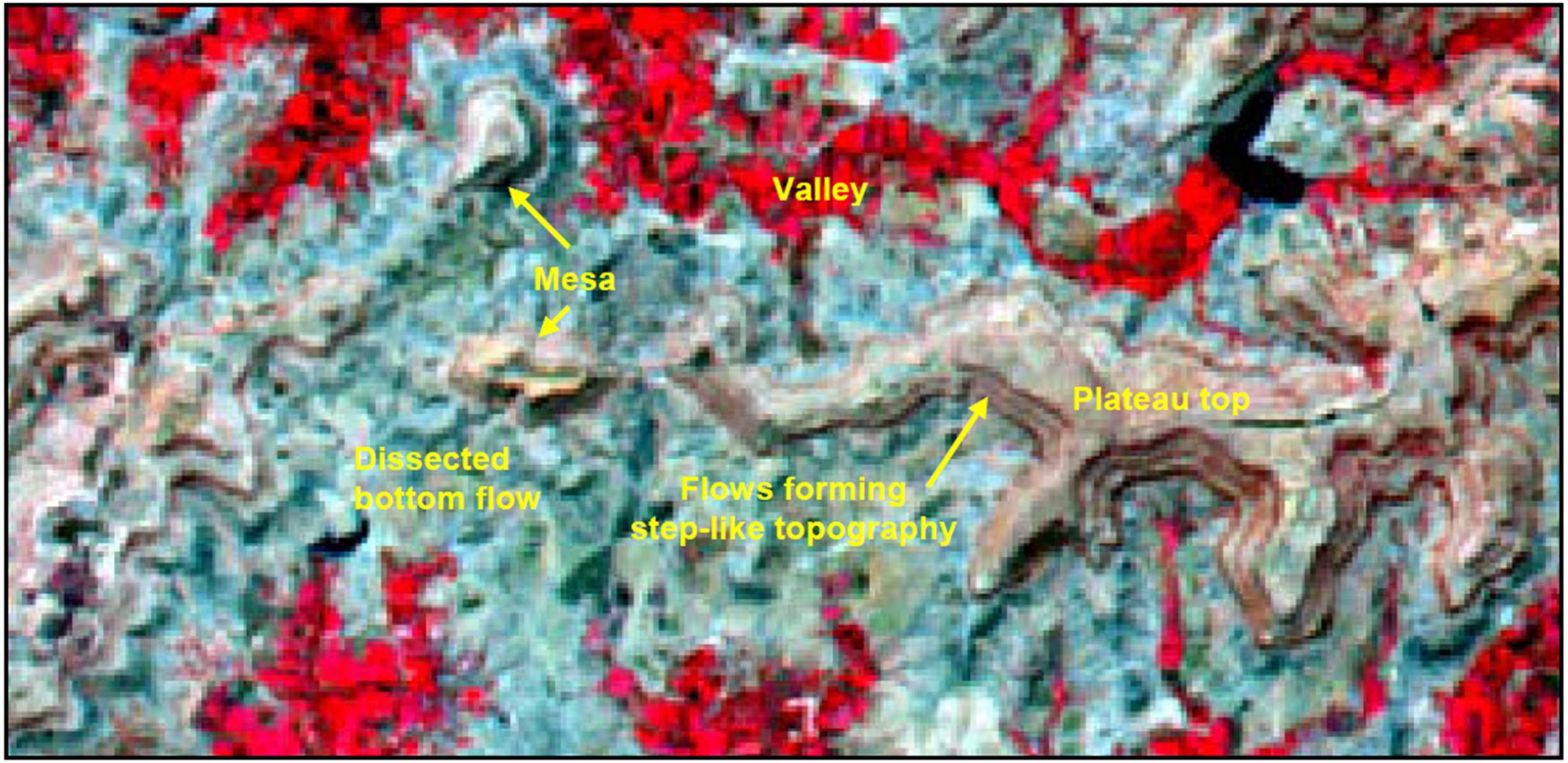


Fig. 4.7: Satellite image of Deccan trap area
showing a pile of basalt flows forming step like topography

Fig. 4.18: Satellite image of Peninsular India showing the Denudational landforms.

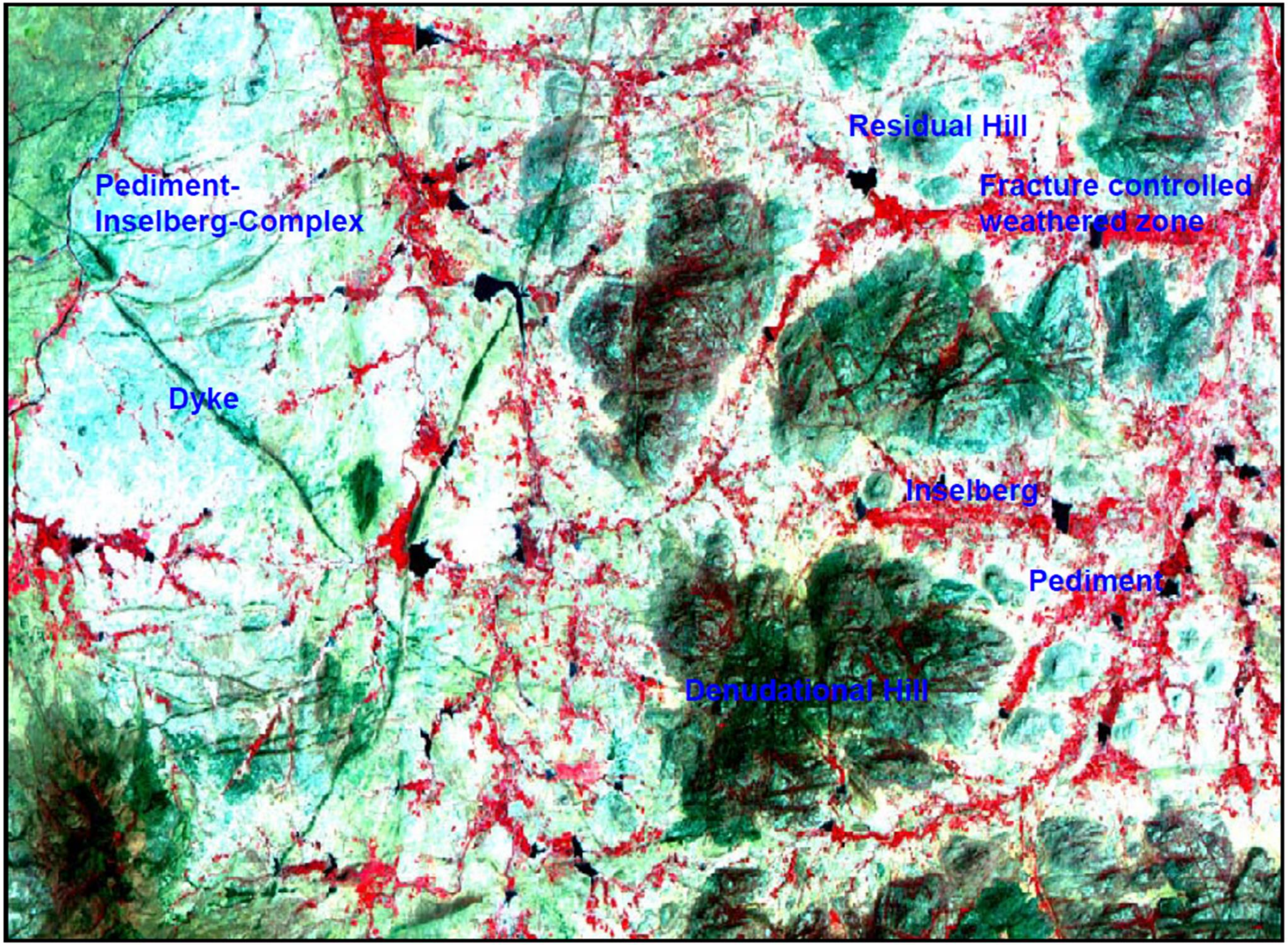
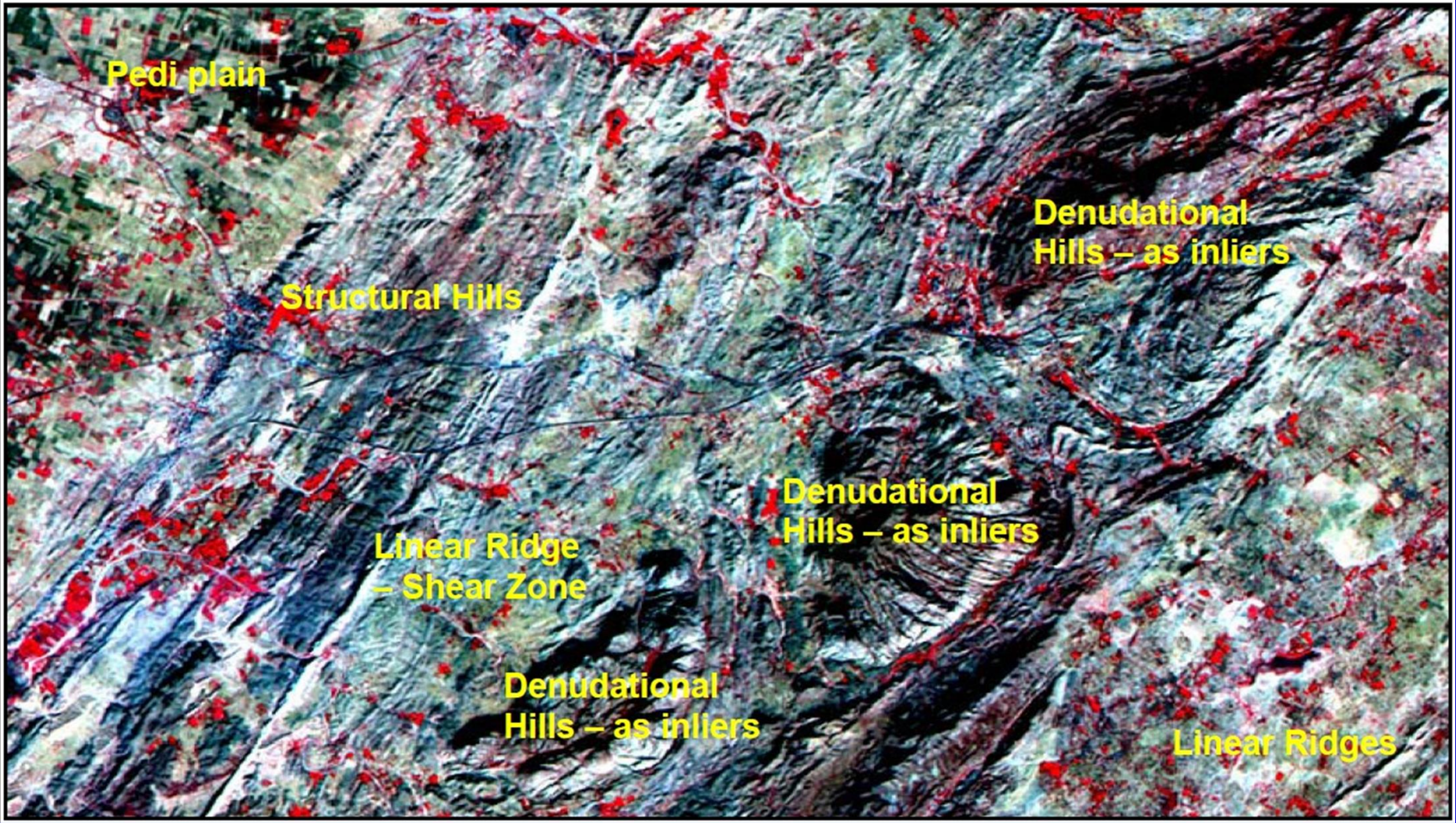


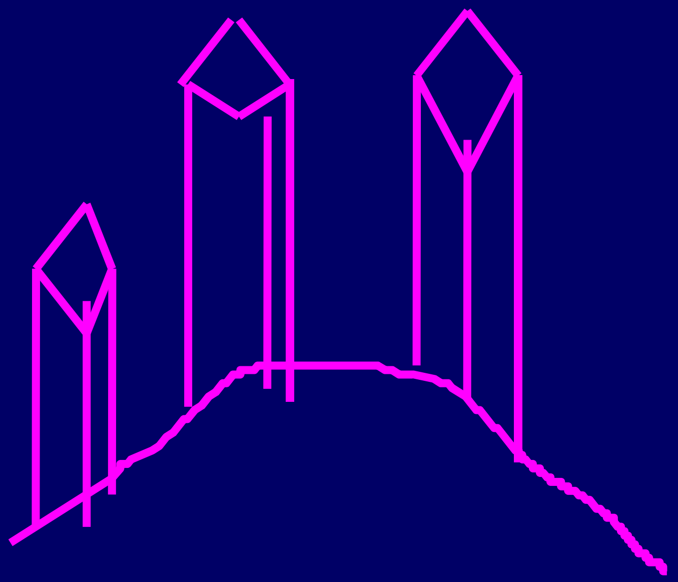
Fig. 4.20: Satellite image of Aravali region showing the Structural landforms



TORS

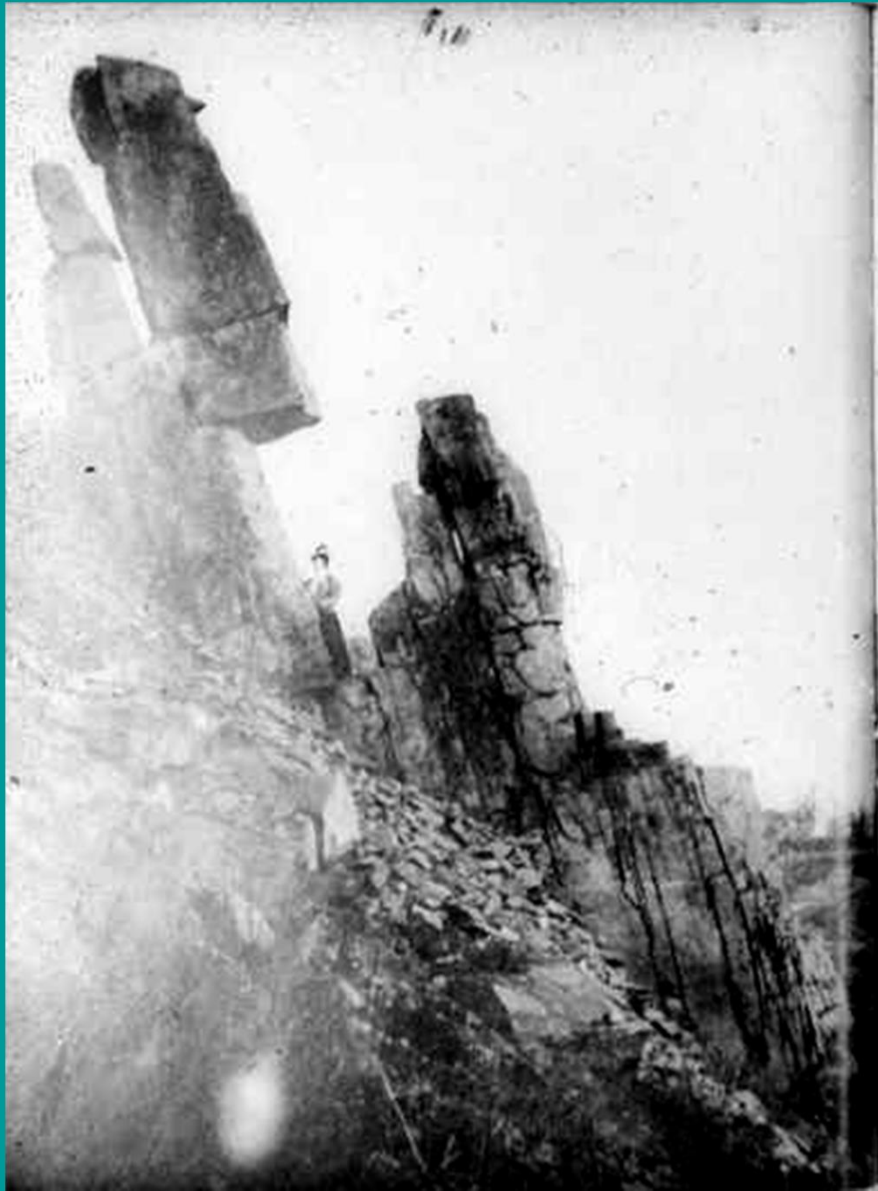
Tor is a complexly jointed blocked hills

(a) Tor complex



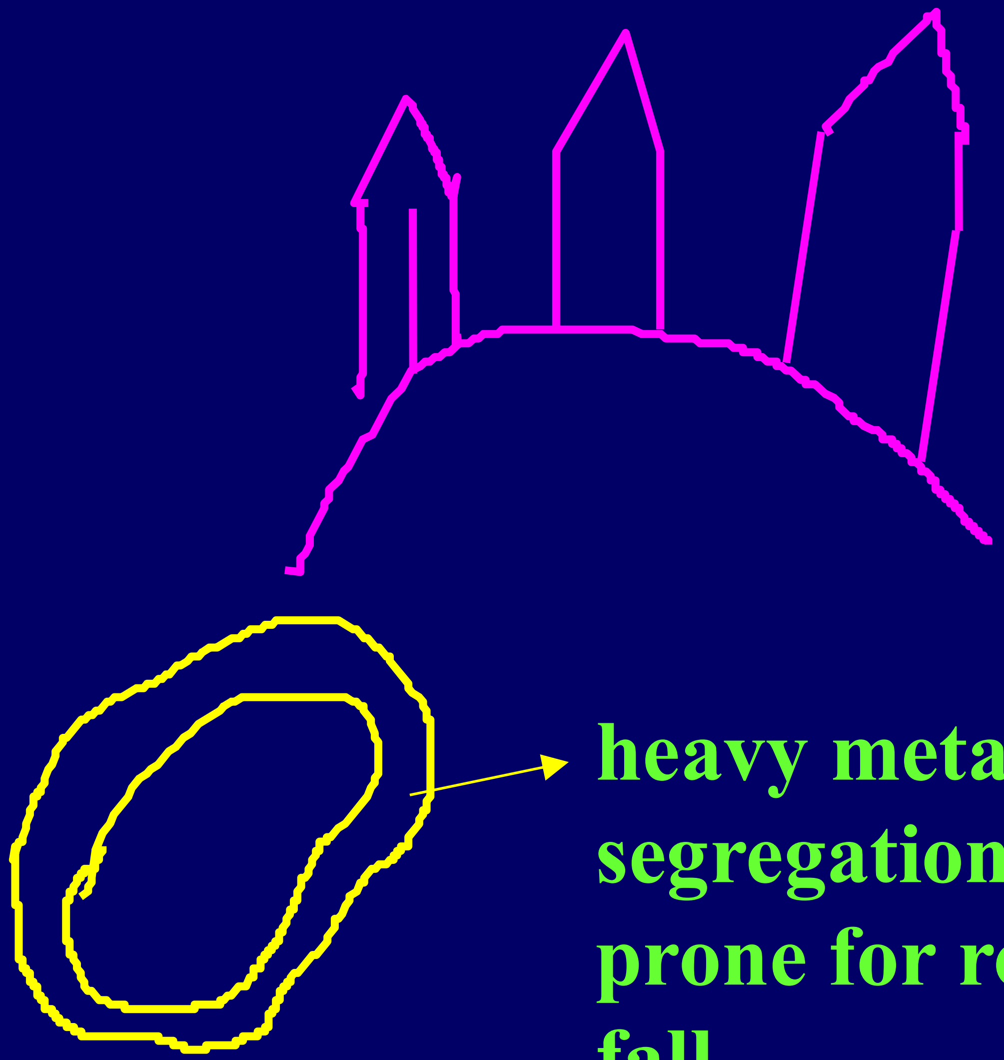
Tor: A high, isolated, craggy hill, pinnacle, or rocky peak; or a pile of rocks, much-jointed and usually granitic, exposed to considerable weathering, and often assuming peculiar or fantastic shapes.

- **No heavy metal seggregate in the foot.**
- **Less reservoir siltation in the foot hill reservoirs**

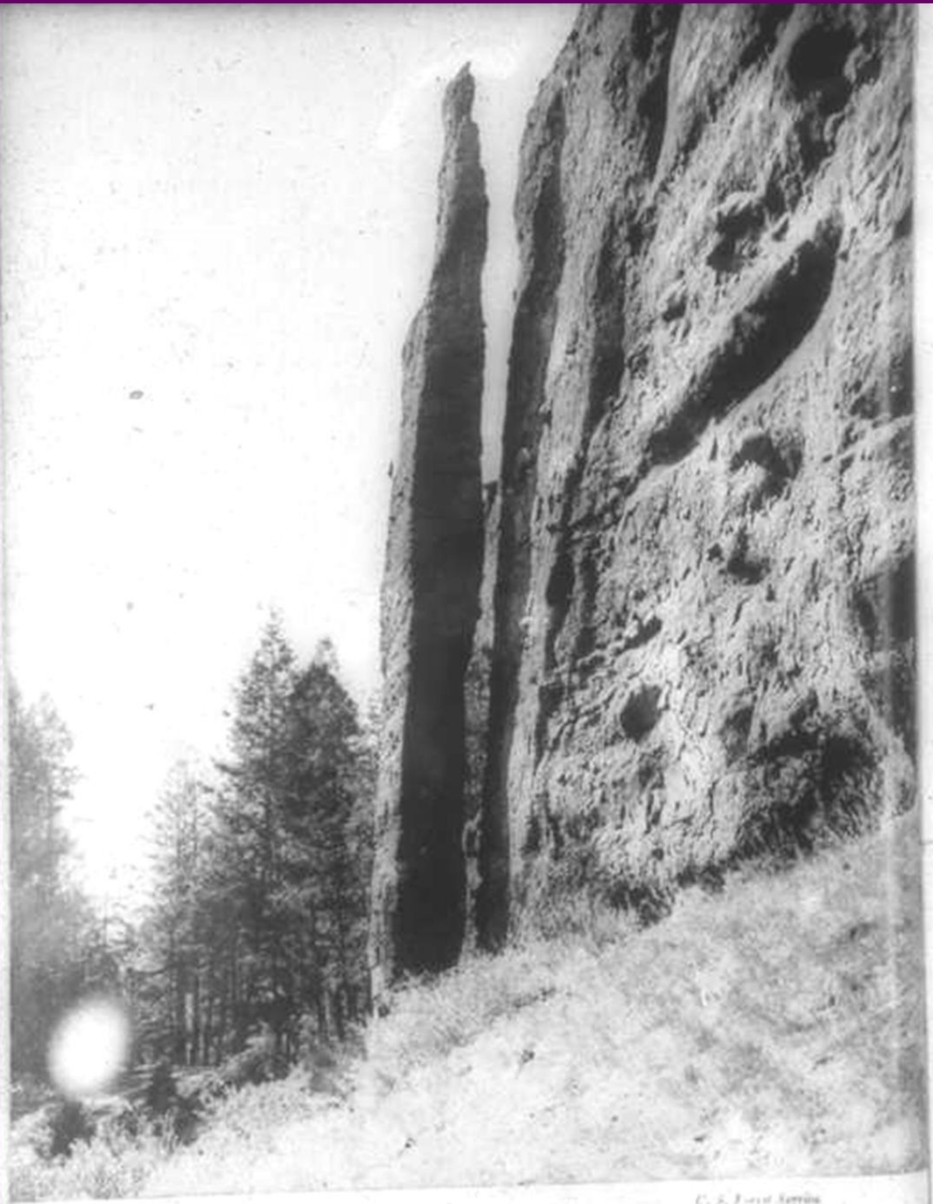



Courtesy of William Allen
HEAD, FORT LEE
of weathering
joints, except for the

(b) Tor cliffs



heavy metal segregation and prone for rock fall



U. S. Forest Service

CHIMNEY ROCK ALONG THE HIGHWAY BETWEEN CODY AND YELLOWSTONE PARK

Vertical joints in horizontal beds of volcanic tuff and agglomerate.

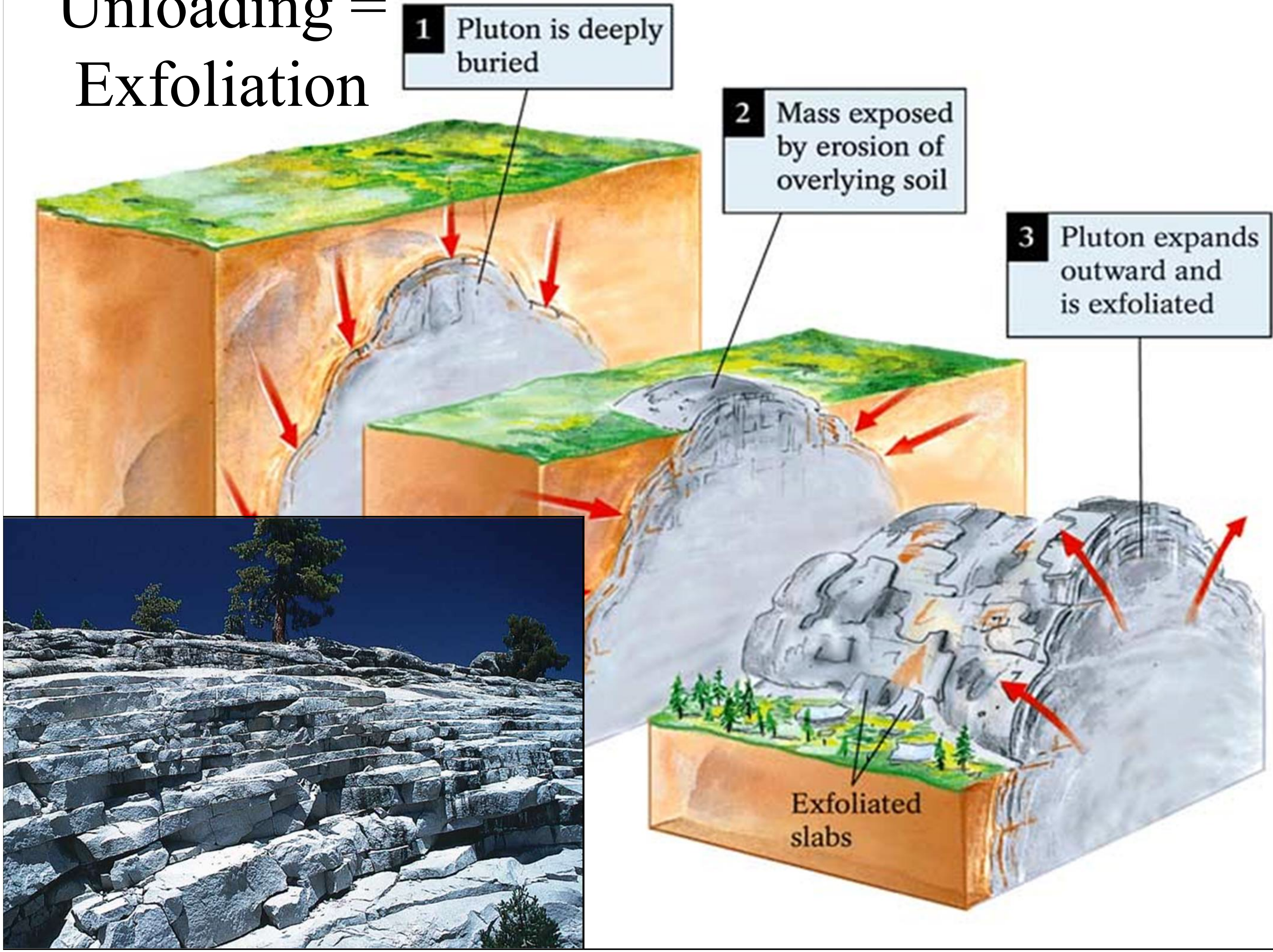
RELICT TOR CLIFF (TORRES DEL PAINE, PANTAGONIA)

TOR CLIFF (ALPENGLOW, NEPAL)

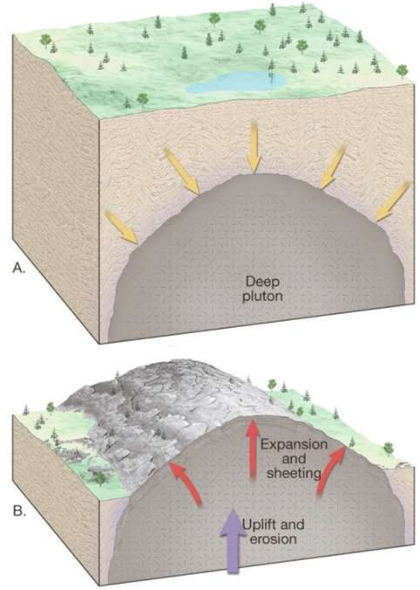
Exfoliation domes

- solid rocks occur at the core with shells of different layers outside.
- mostly occur in semi arid and arid tracts.

Unloading = Exfoliation

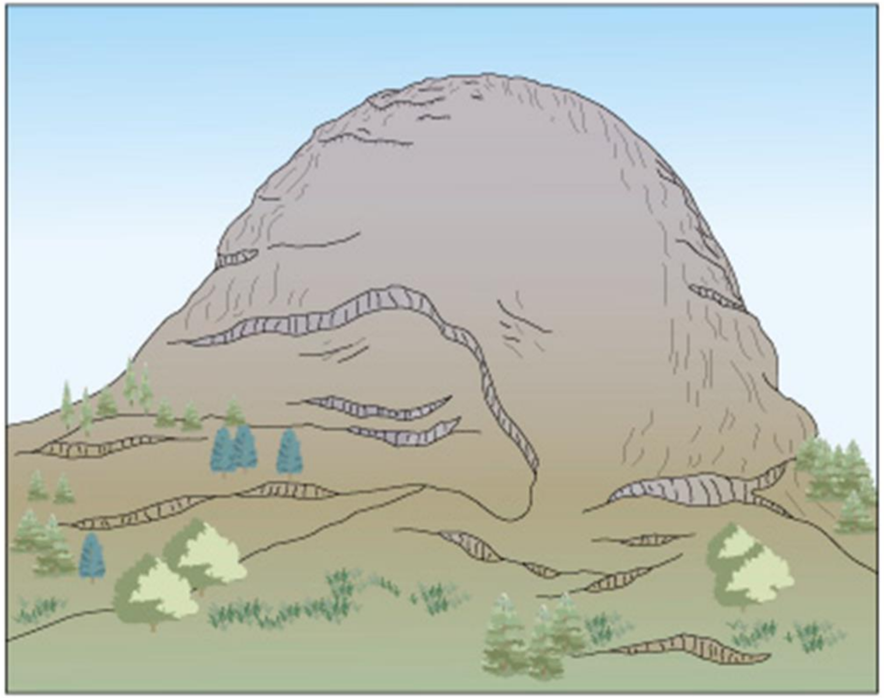


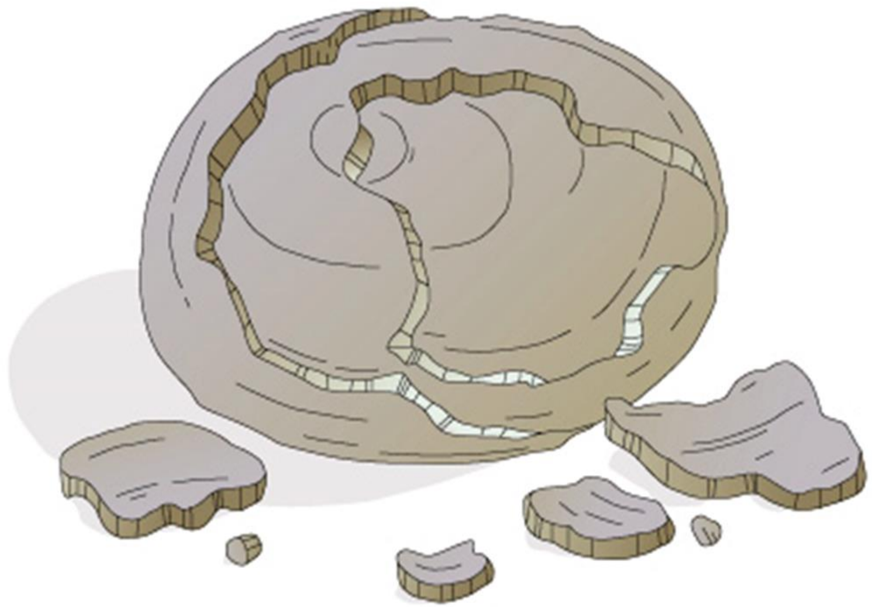
Sheet Joints (Exfoliation)



SPHEROIDAL WEATHERING

Example of Exfoliation domes-





ONION SHELL WEATHERING

EXFOLIATION DOMES

ESCARPMENTS

A steep slope or long cliff that results from erosion or faulting and separates two relatively level areas of differing elevations

A steep slope or long cliff formed by erosion or by vertical movement of the Earth's crust along a fault. Escarpments separate two relatively level areas of land.

Residual hills

Suggest maturity of weathering process
debris slope with scattered material

(e.g) hills in Bangalore area

RESOURCE:

Foot hills will have metal, mineral and concentrates

ENVIRONMENT:

- Erosion prone
- Downward reservoirs siltation prone.

<u>Residual hills:</u> **A small remnant hill, which has witnessed all forms of denudation.**

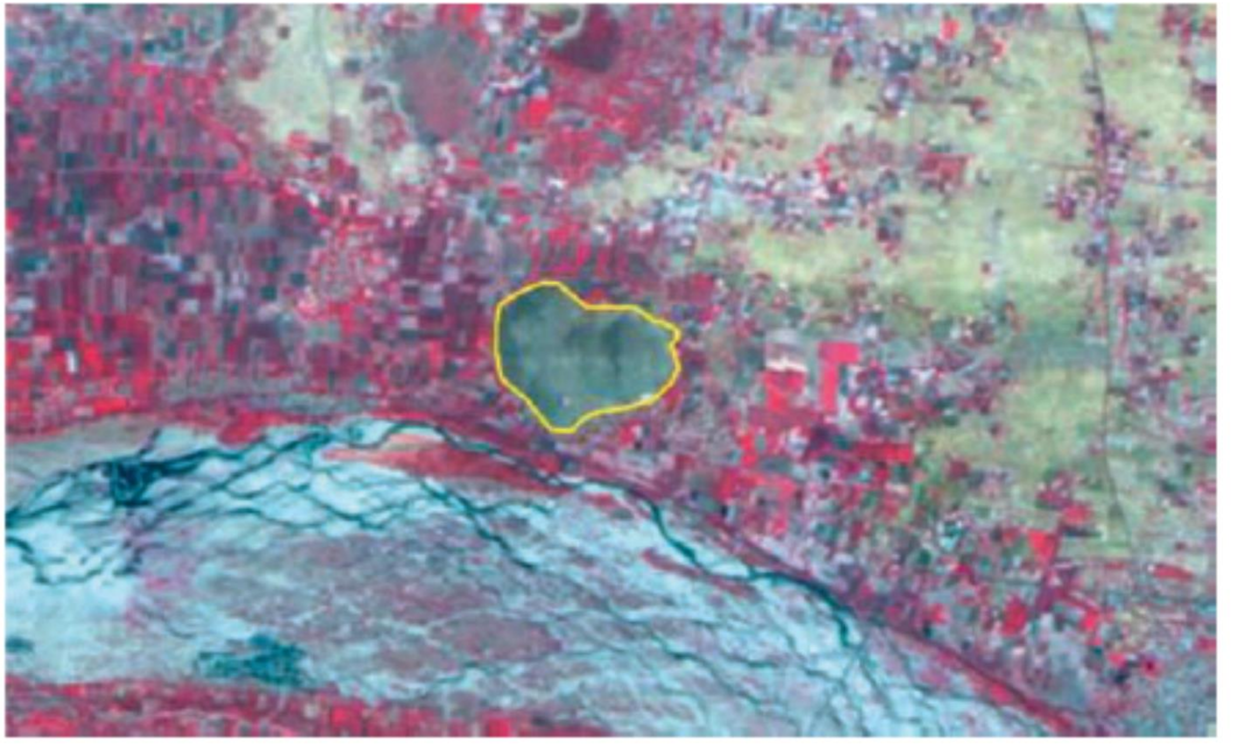
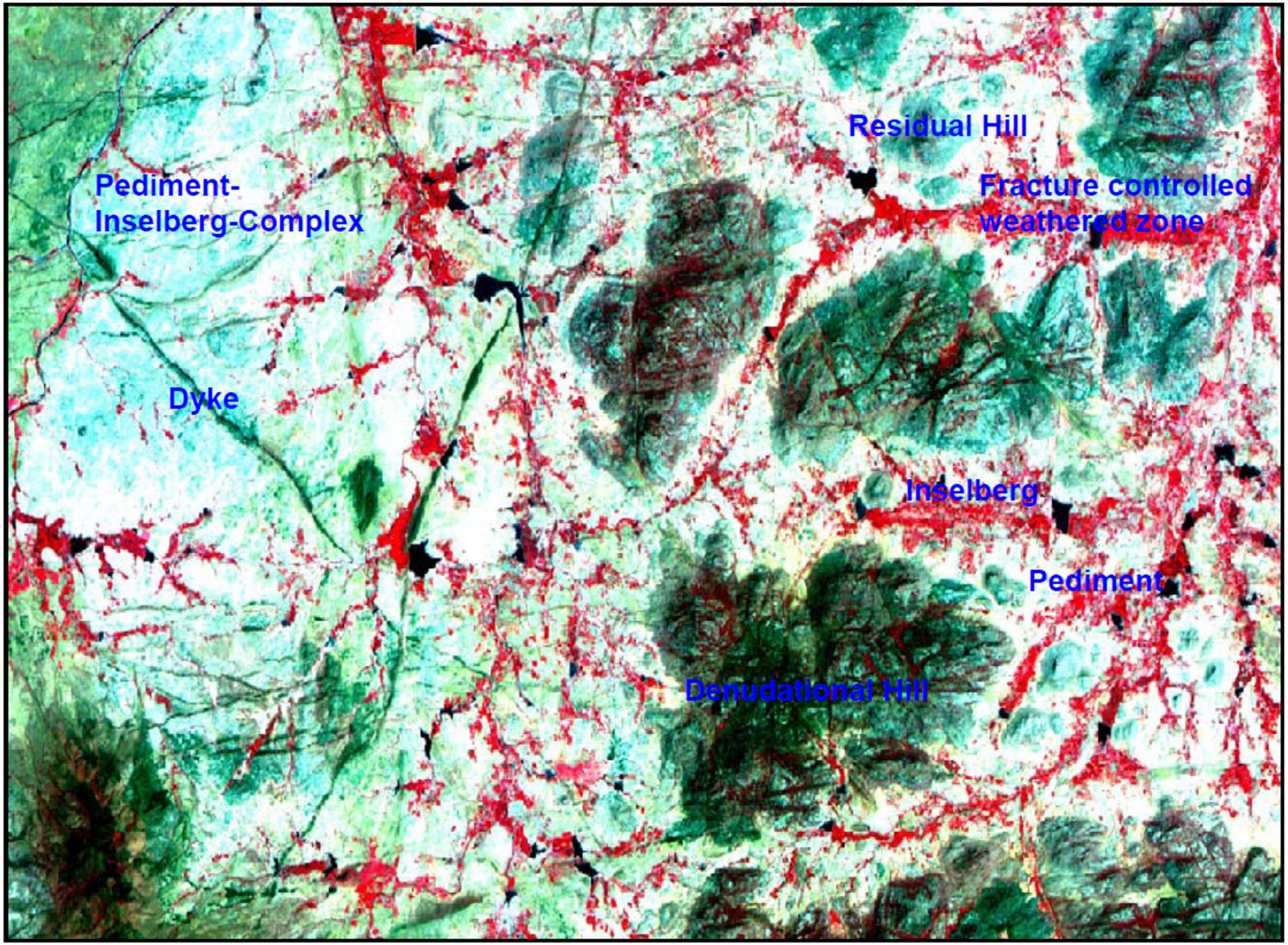


Fig. 2.27 A Residual hill, which is locally called as Tiruvengimalai adjacent to Cauvery river in Tiruchirappalli district, Tamil Nadu.

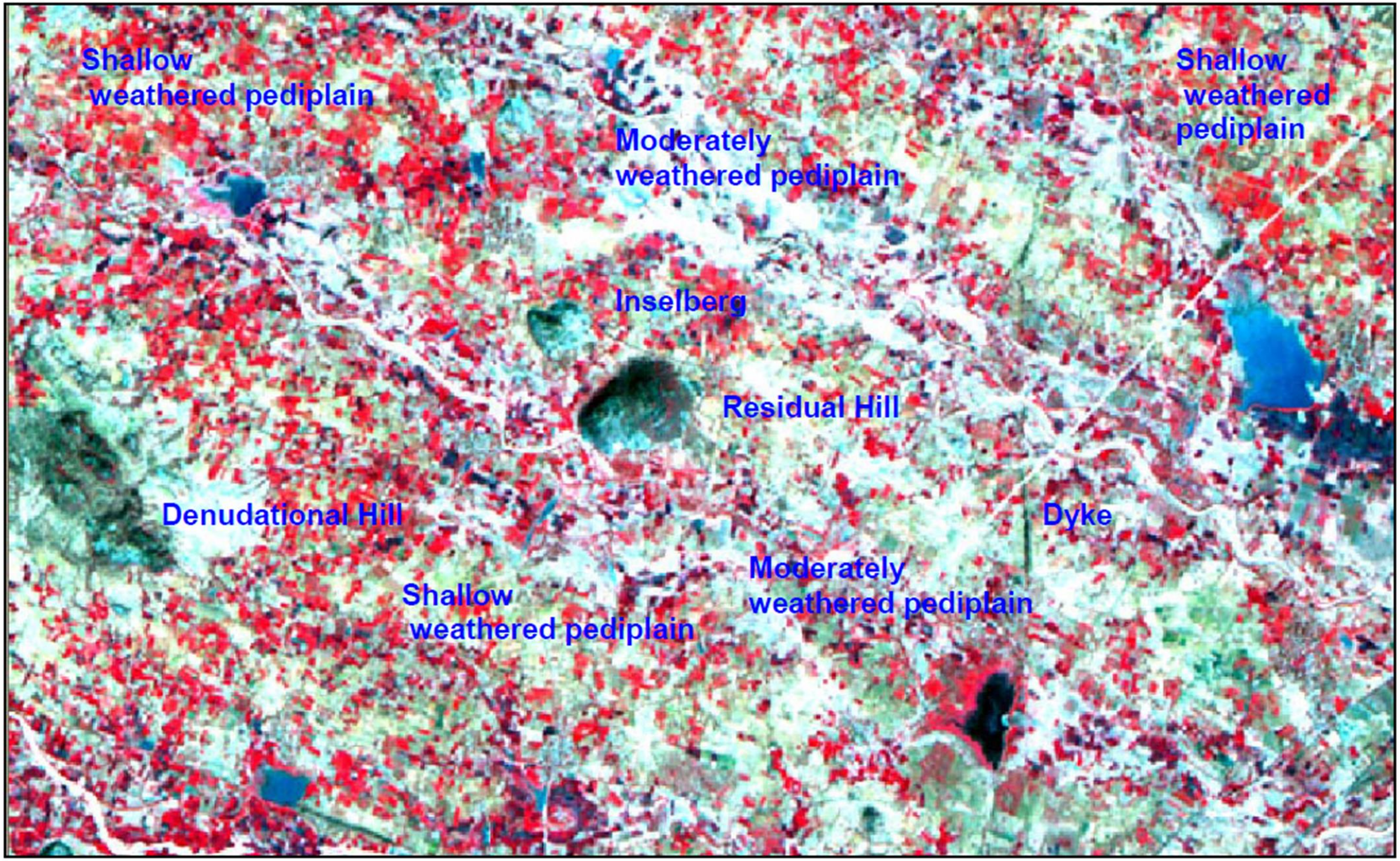
Fig. 4.18: Satellite image of Peninsular India showing the Denudational landforms.



INSELBERG

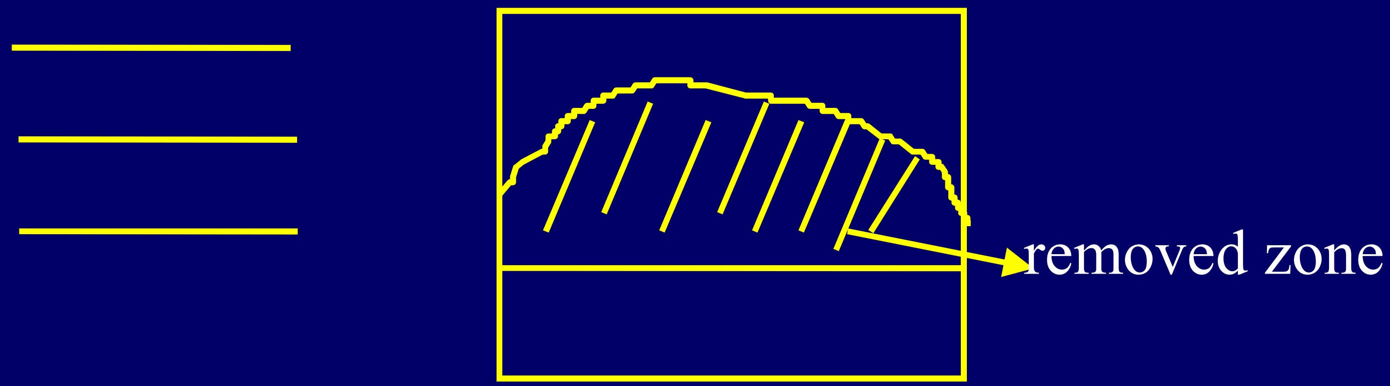
Fig. 2.22 Inselberg along Manapparai – Turaiyur main road in Tiruchirappalli district, Tamil Nadu. The rock here is used for floors in the houses after it is polished.

Fig. 4.19: Satellite image of Peninsular Gneissic Complex showing weathered zones



(2.5.4) Arched hills

Due to differential resistance, bottom portion scooped out leaving the top layer.



unstable area for heavy structures.

E.g:

- **Granitic areas**
- **S.st areas**
- **Cuddapah**

Landscape Arch, Arches, N.P. Utah

ARCHID HILL

(DELICATE ARCH, ARCHES NATIONAL PARK, UTAH)

Inselberg

- ***isolated conical hills***

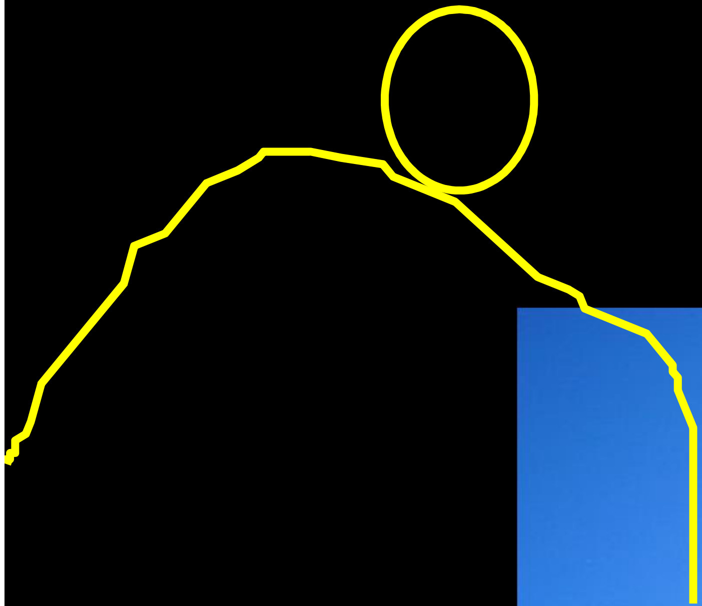
- No mineral resources in foot hills.

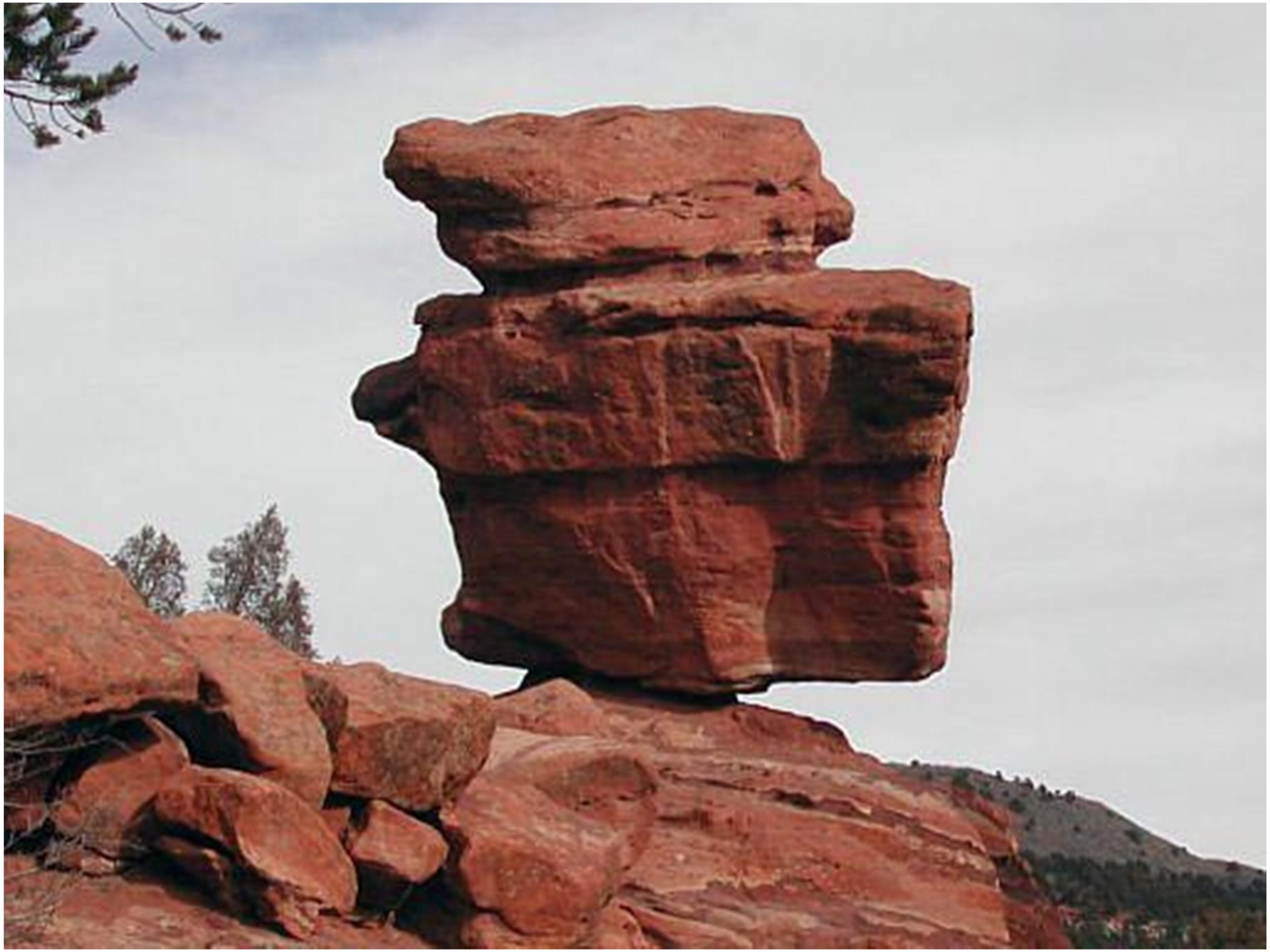
- No siltation in downward reservoirs.

Inselberg A prominent, isolated, steep-sided, usually smoothed and rounded, residual knob, hill or small mountain of circumdenudation rising abruptly form and surrounded by an extensive and nearly level

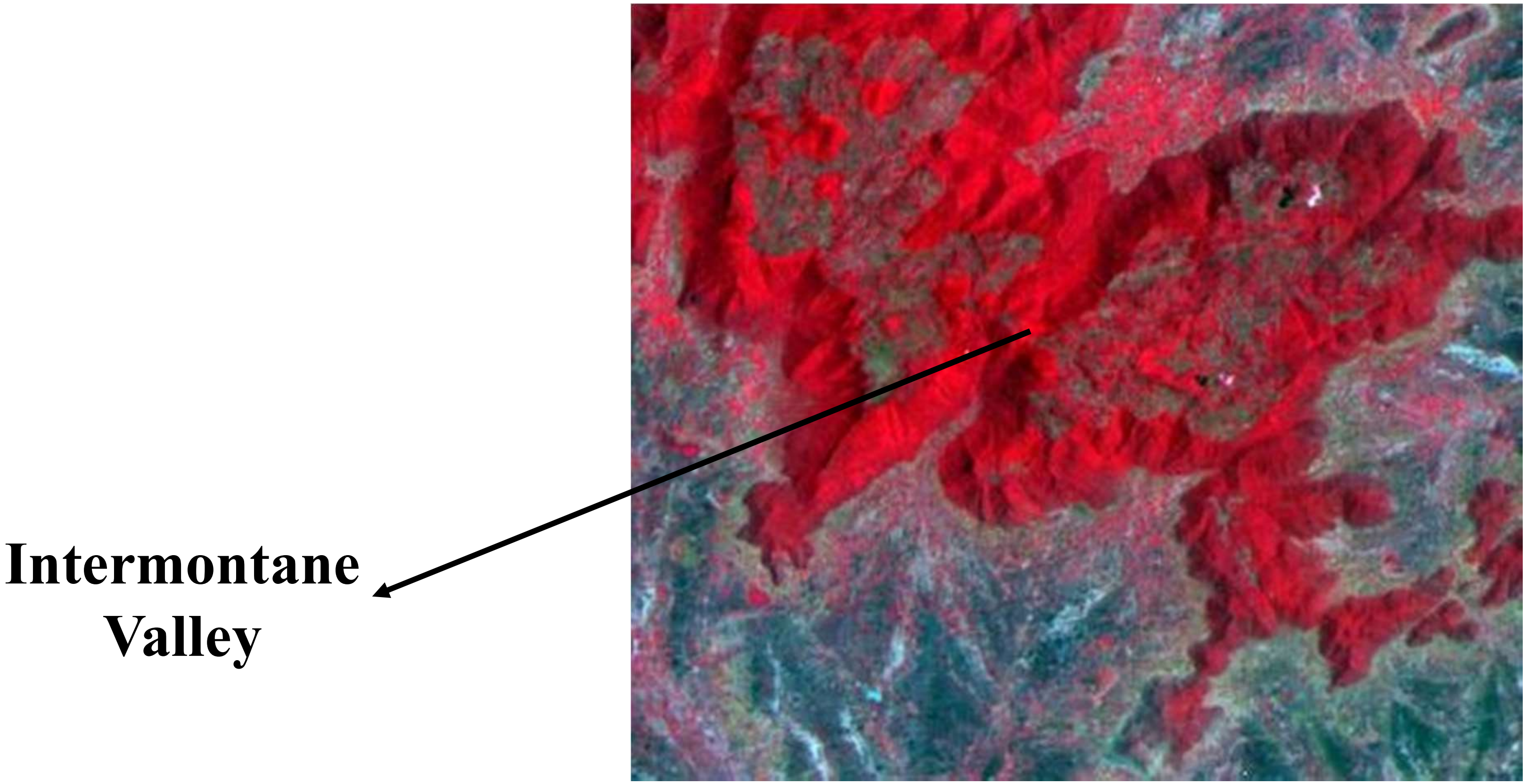
Balanced rocks

Balanced Rock is one of the most popular features of Arches National Park, situated in Grand County, Utah, United States. Balanced Rock is located next to the park's main road, at about 9 miles (14.5 km) from the park entrance.





Intermontane Valley: The valley between the mountains.



SLOPE RELATED LAND FORMS

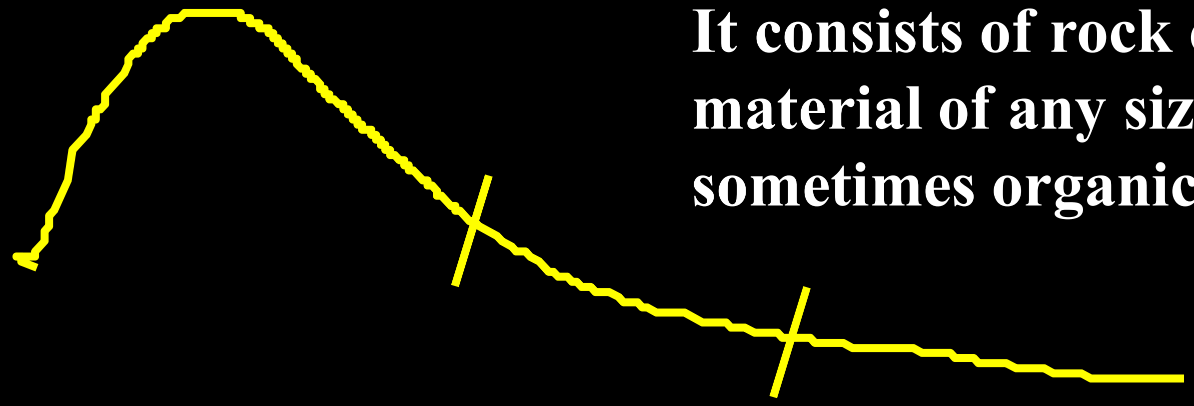
Slope Zone Features

- Debris Slope / Scree Slope
  - Steep
  - Moderate
  - Shallow
- Barren Slope
- Midslope Mounds
- Rock Slump
- Debris Avalanche
- Rock Creep

(II) SLOPE ZONE

(2.5.14) Debris slope:

debris - Any surficial accumulation of loose material detached from rock masses by chemical and mechanical means, as by decay and disintegration. It consists of rock clastic material of any size and sometimes organic matter



Zone between summit zone and pediment

CONICAL HILL WITH DEBRIS SLOPE

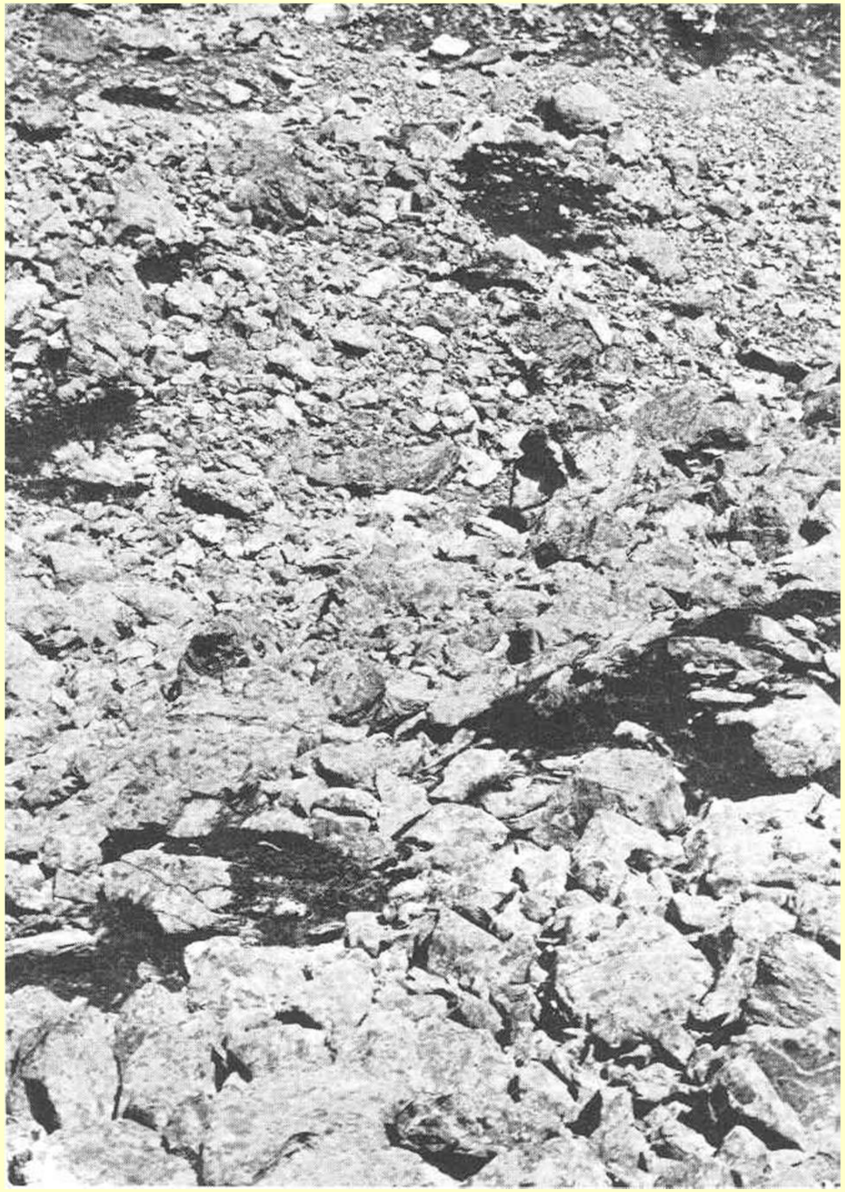
(SUNRISE, RIO)

DEBRIS SLOPE

DEBRIS SLOPE

TEAR SCAR - AUSTRIA

SCREE SLOPE - SWITZERLAND



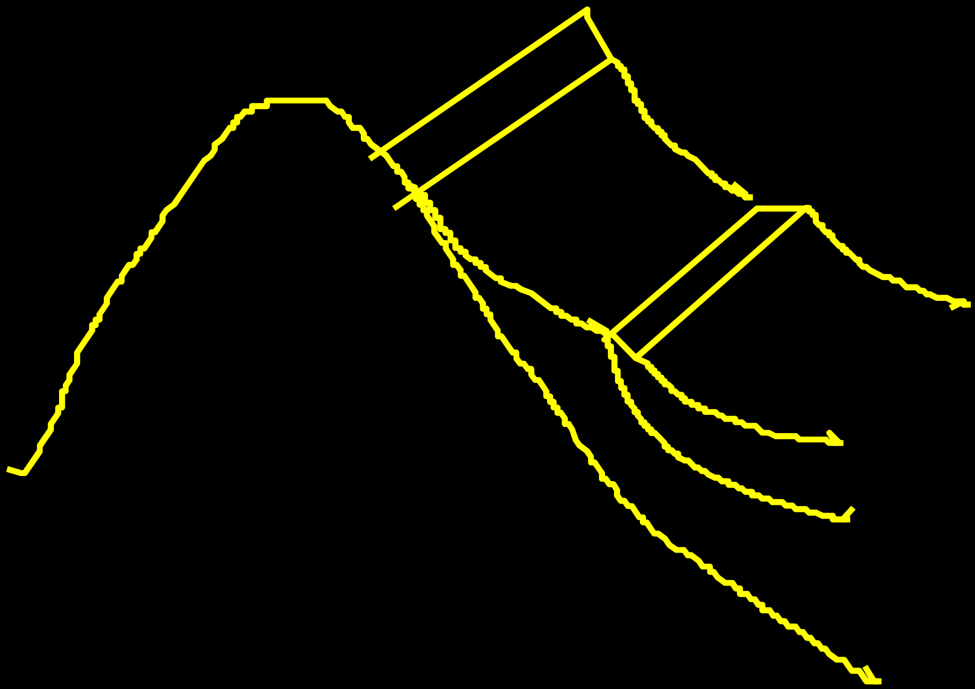
scree slope – A portion of a hillside or mountainslope mantled by scree and lacking an up-slope rockfall source (i.e. cliff). Compare – talus slope, scree, talus

SCREE SLOPE - LADAKH

(2.5.8) Rock slumb

→ Slope 60^0 to 30^0

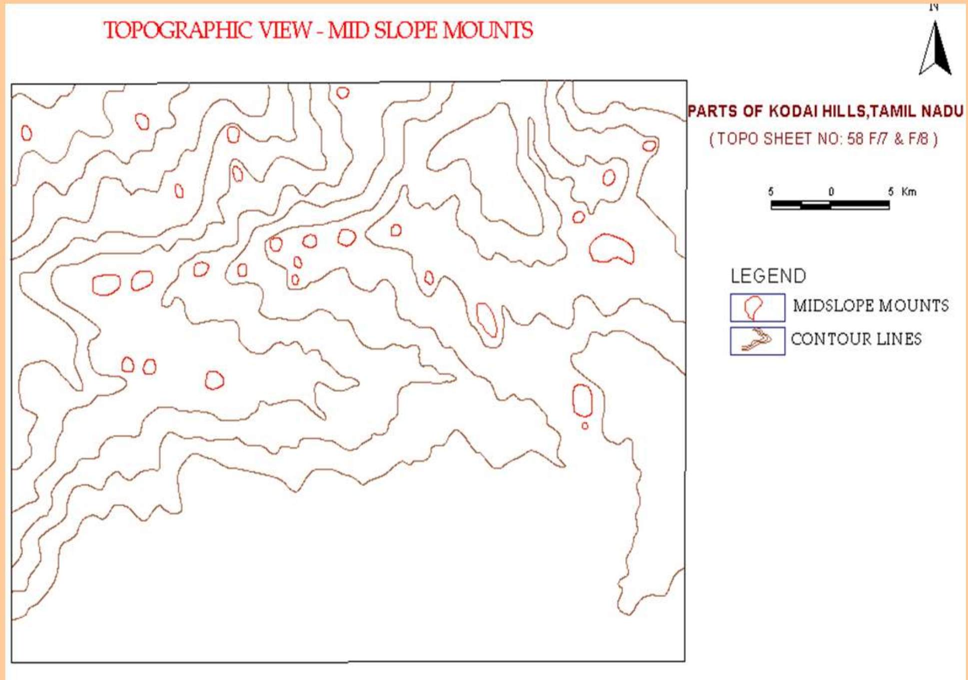
→ Along debris slope there will be a series of parallel to sub parallel slips will be there.



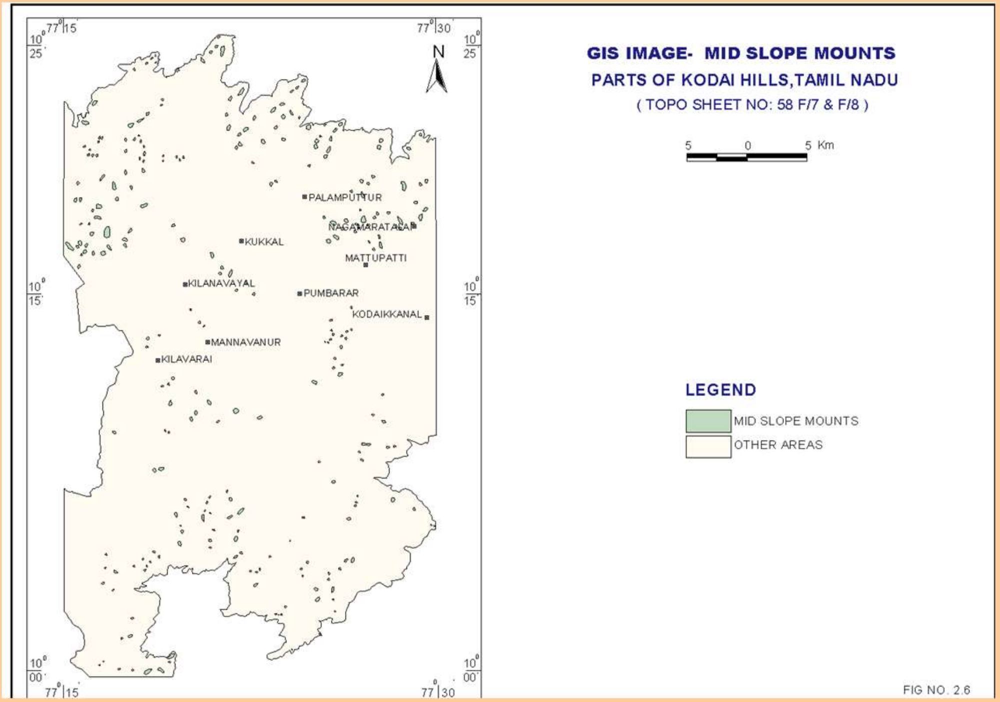
ROCK SLUMP

SLUMP

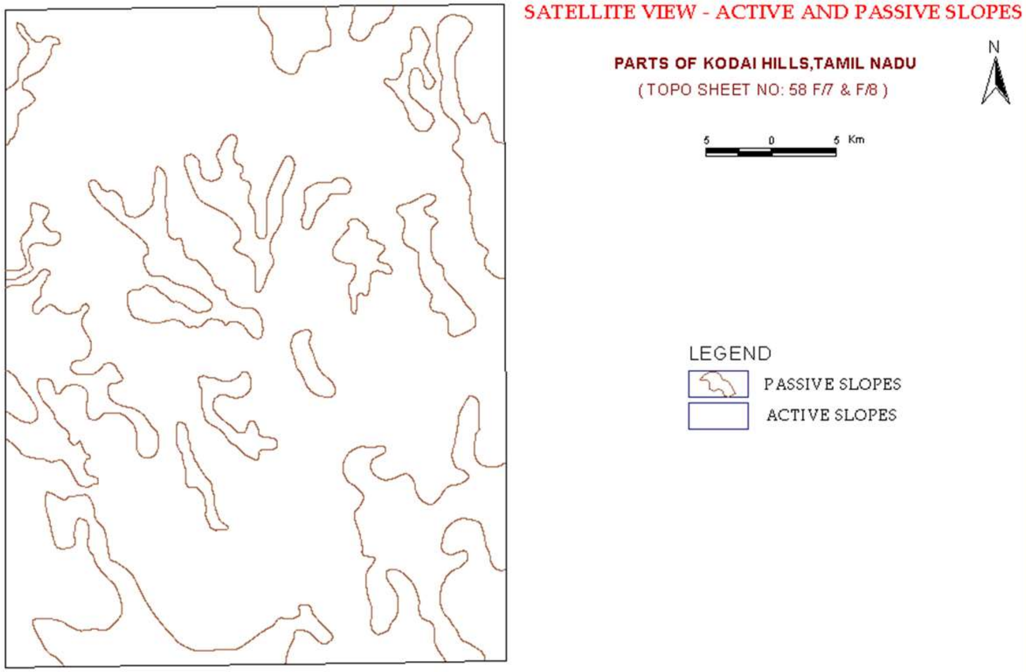
DEBRIS SPLAY (VALLEY OF FIRE, NEVEDA)



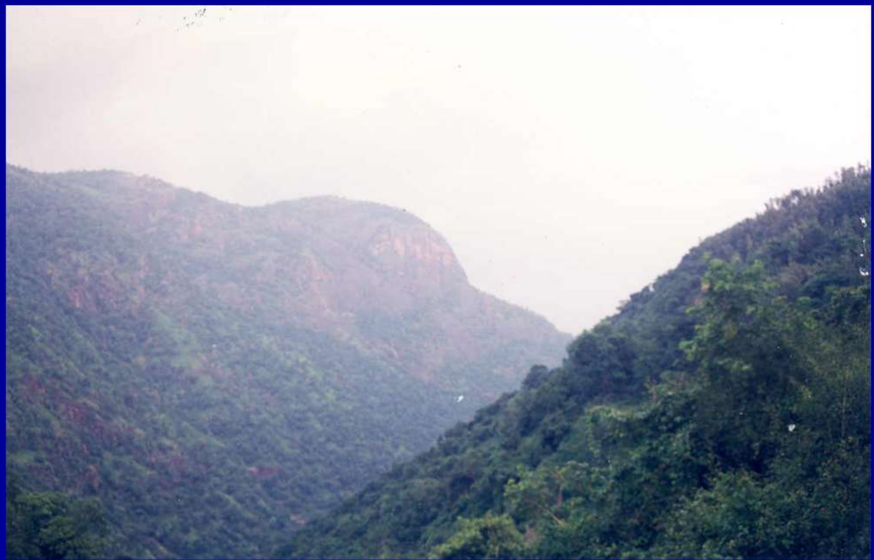
MID SLOPE MOUNTS

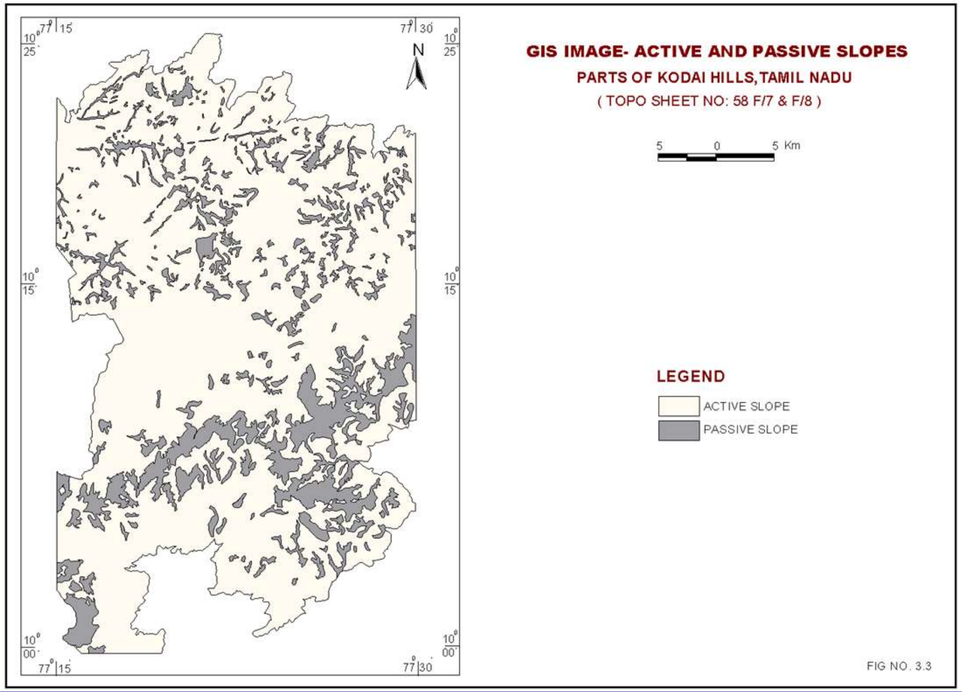


MIDDILE SLOPE MOUNT



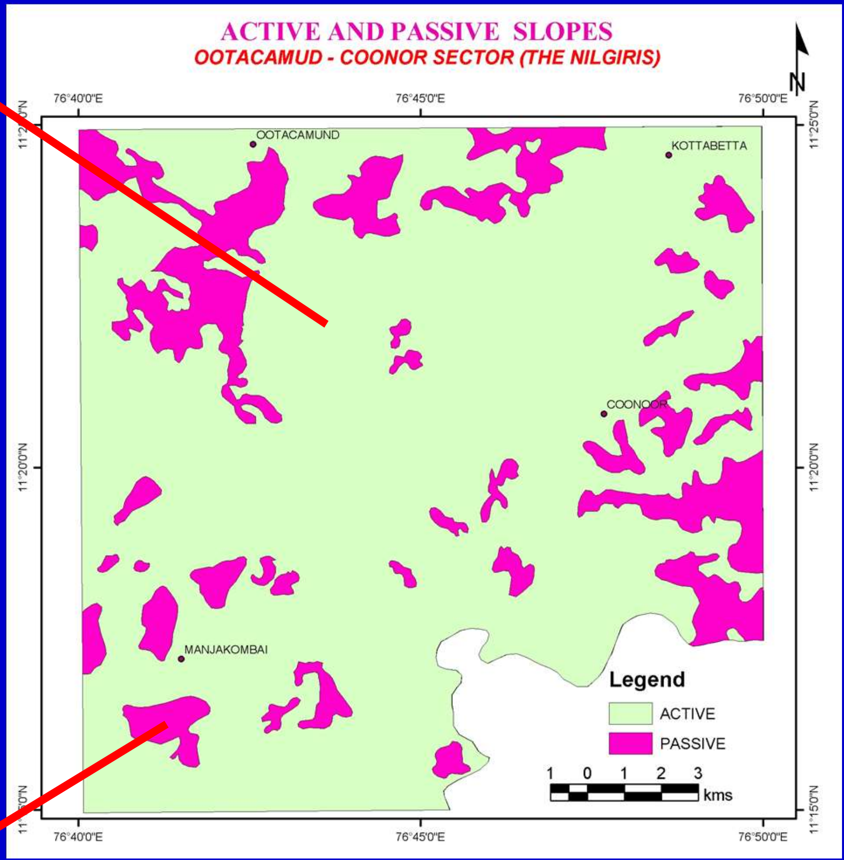
ACTIVE – PASSIVE SLOPES





ACTIVE – PASSIVE SLOPES

ACTIVE SLOPE



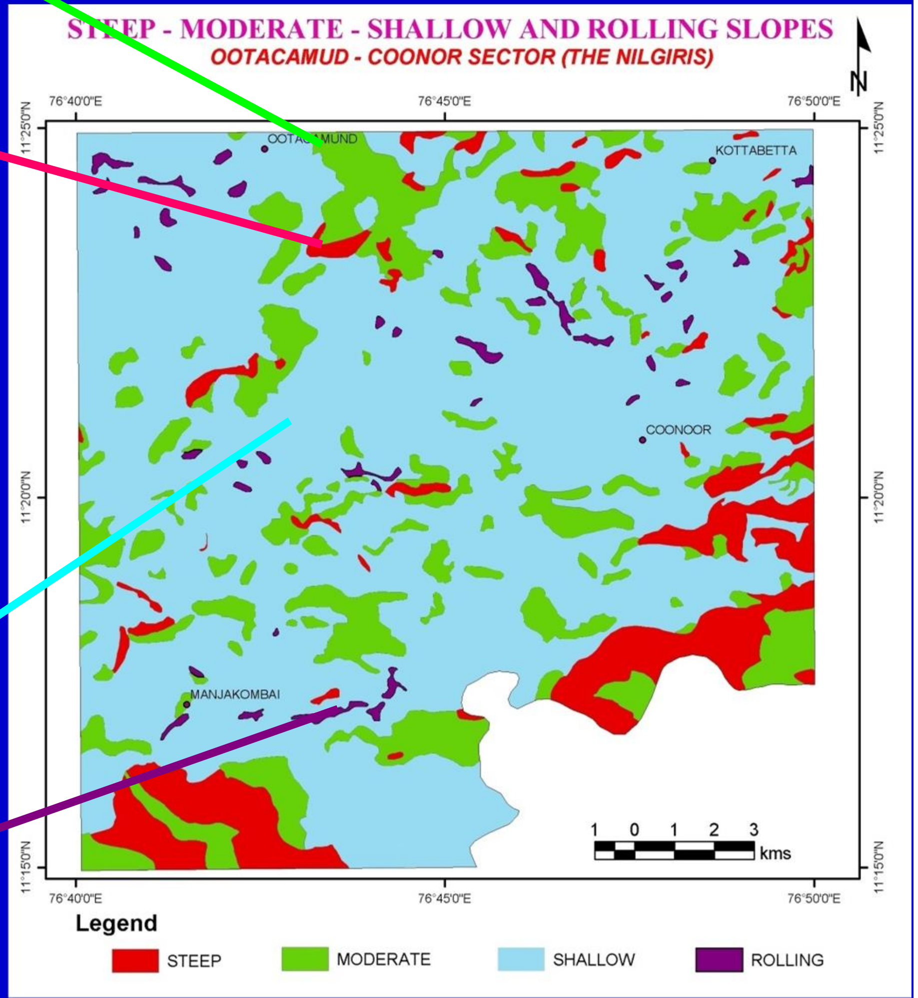
PASSIVE SLOPE

(VEGETATIVE COVER)

STEEP – MODERATE – SHALLOW - ROLLING SLOPES

MODERATE SLOPE

STEEP SLOPE



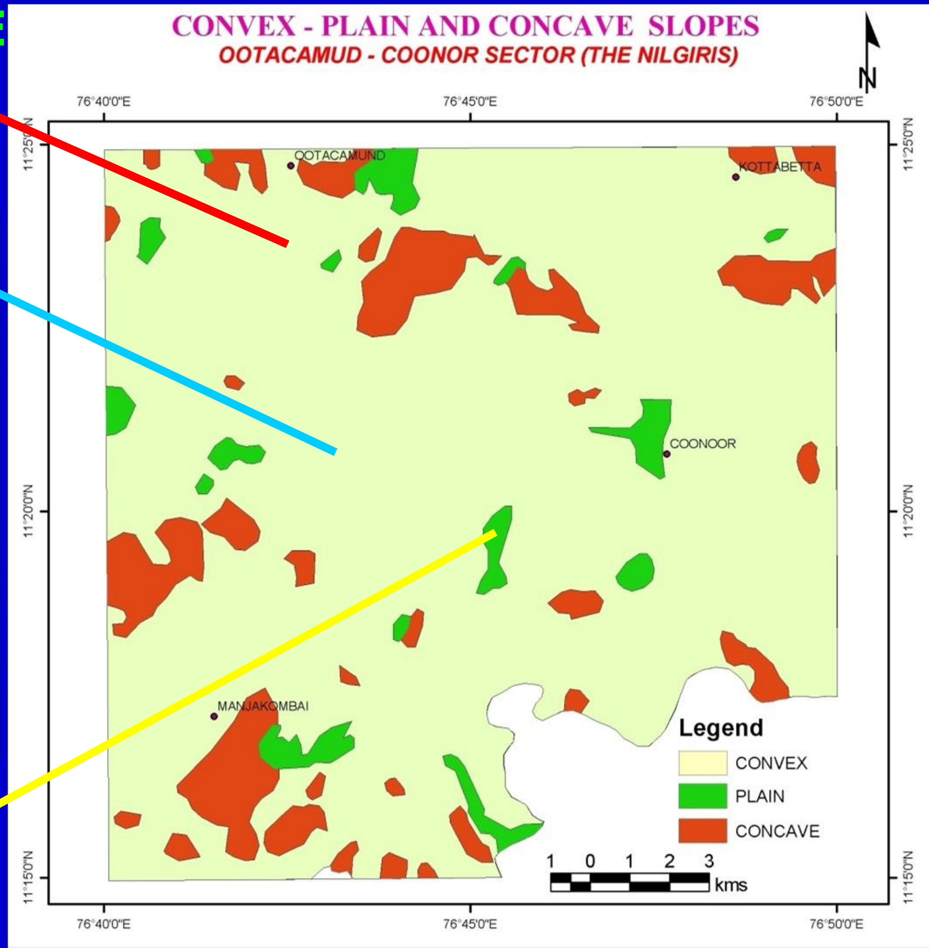
SHALLOW SLOPE

ROLLOING SLOPE

CONVEX – PLAIN - CONCAVE SLOPES

CONCAVE SLOPE

CONVEX SLOPE



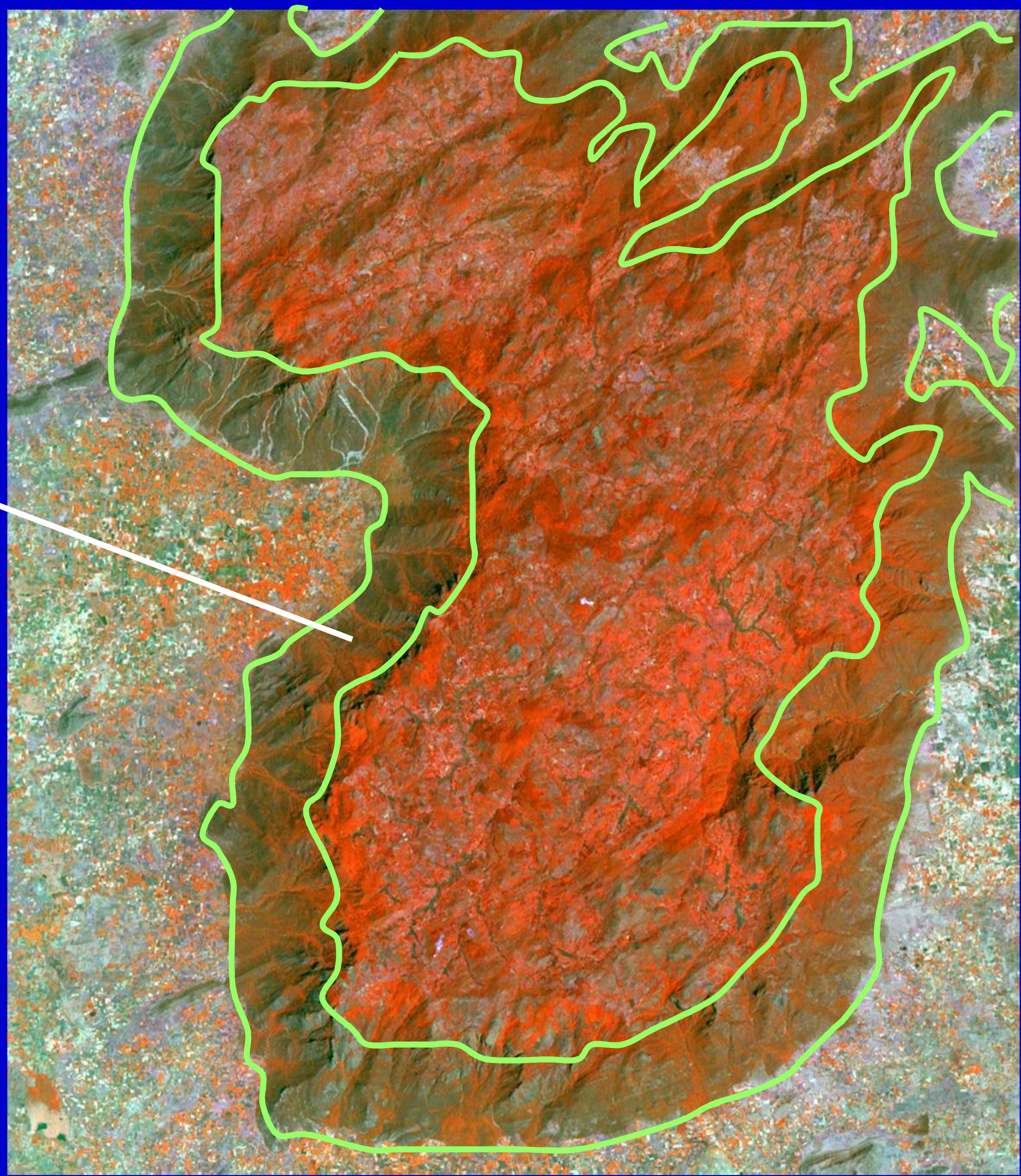
PLAIN

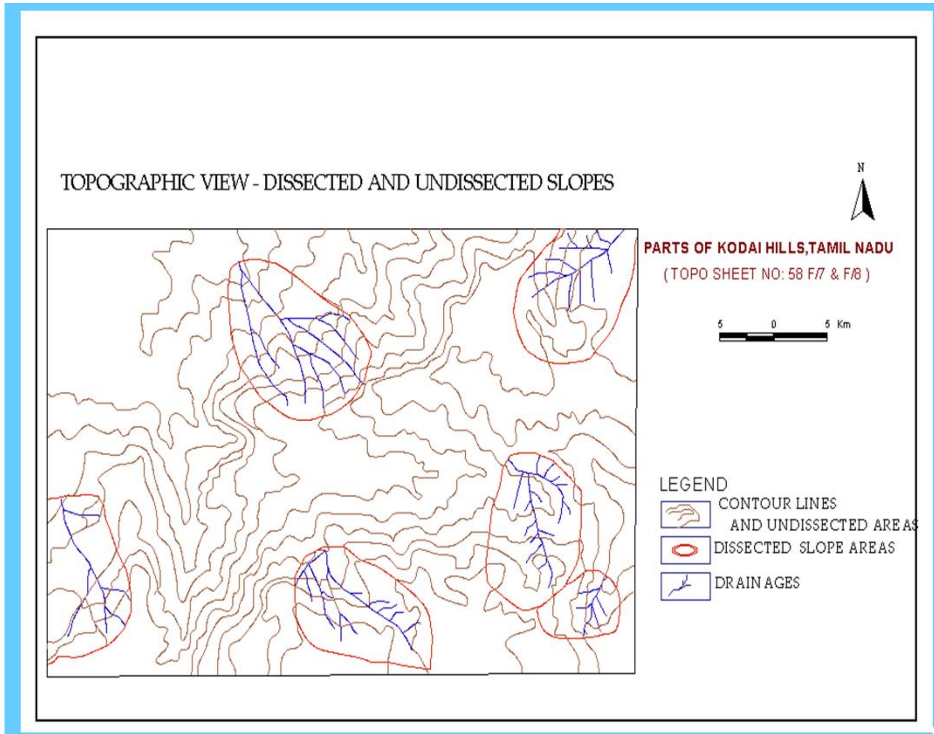
CONVEX / PLAIN SLOPE

COMPOSITE SLOPE

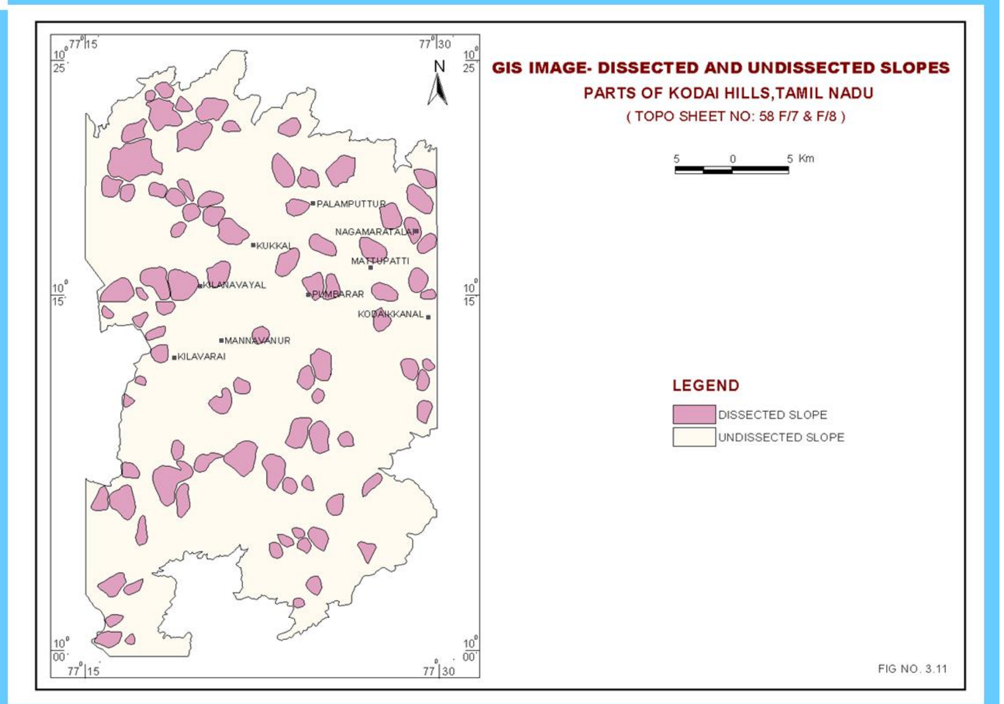
COMPOSITE SLOPE

COMPOSITE SLOPE

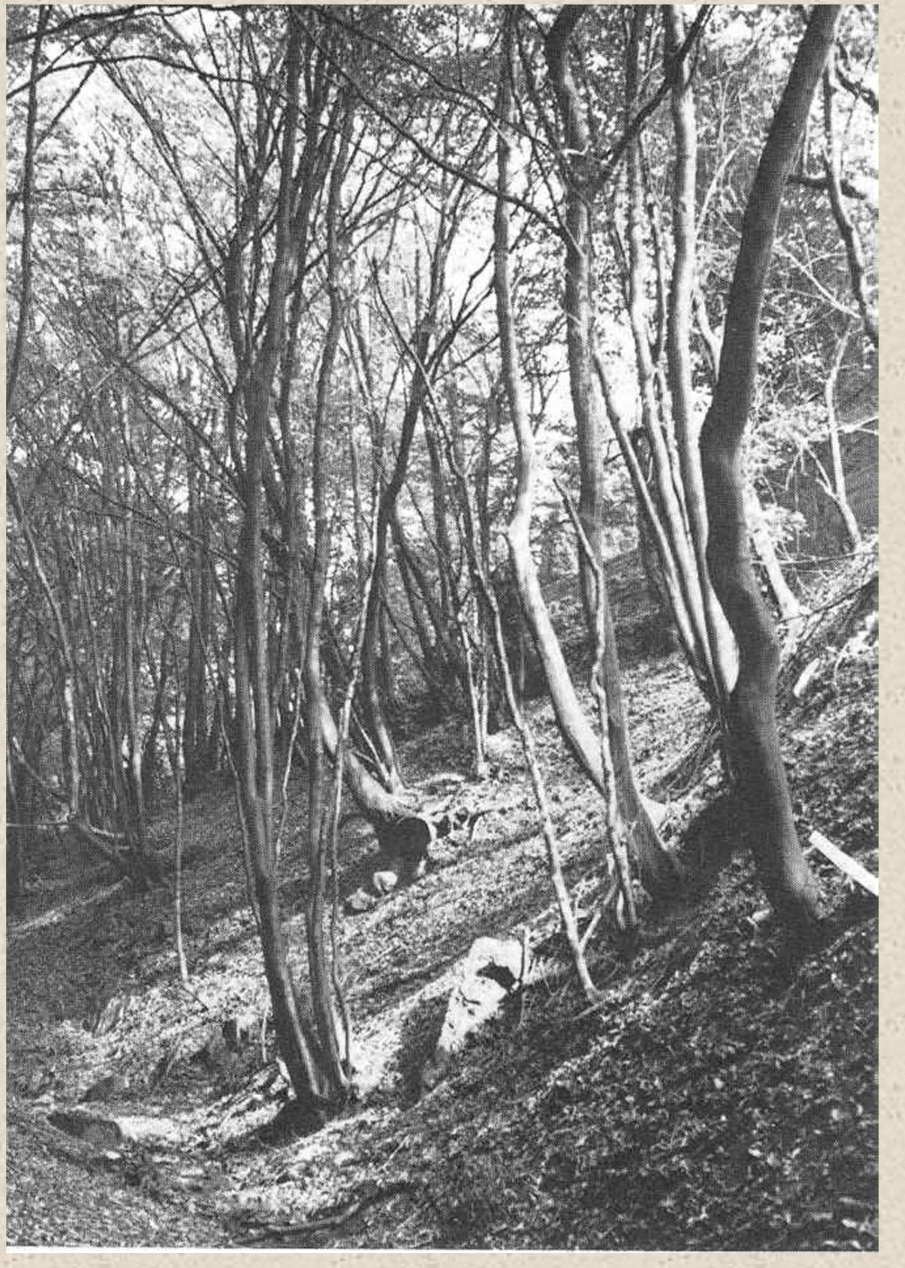




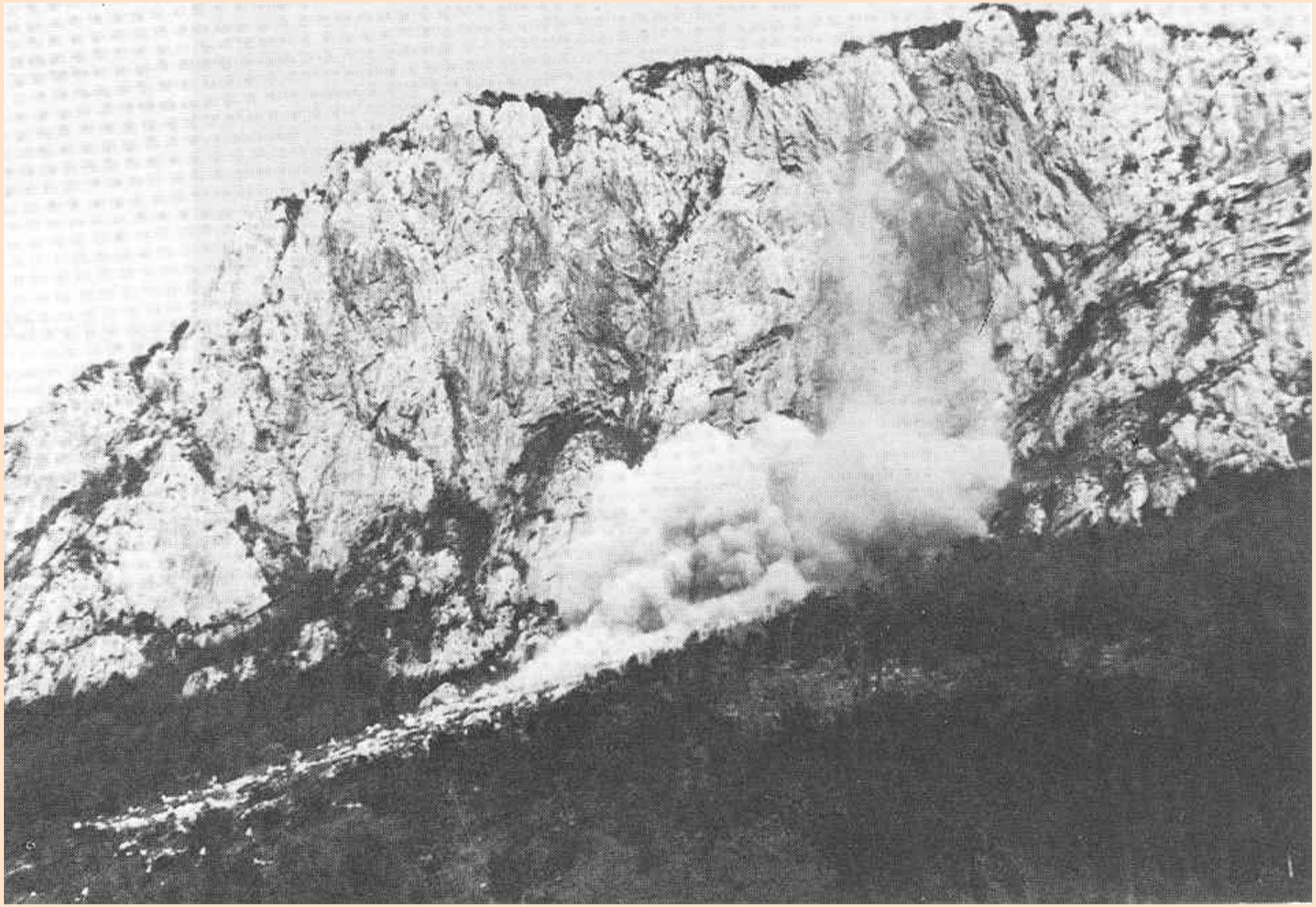
DISSECTED AND UNDISSECTED



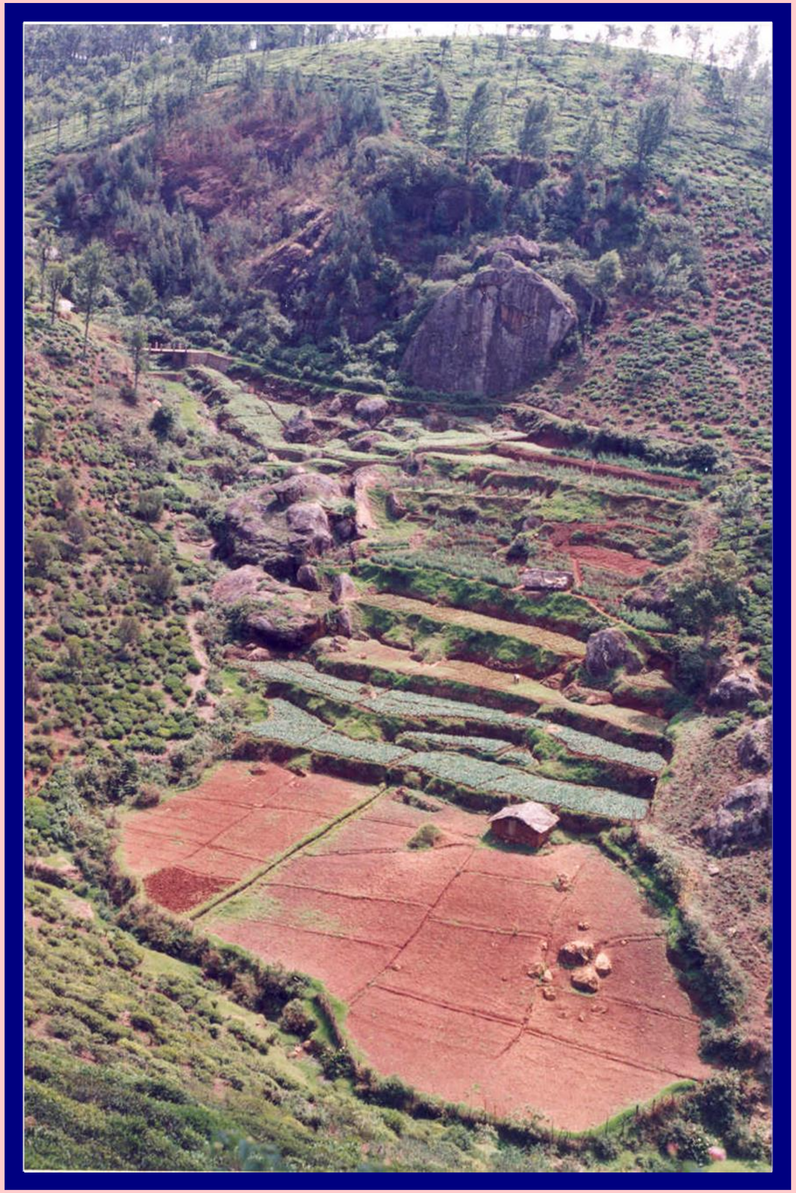
CREEP, SLOPE BENT - AUSTRIA



ROCK FALL - ITALY



ROCK SLIDE



FOOT HILL FEATURES

Foot Hill Zone

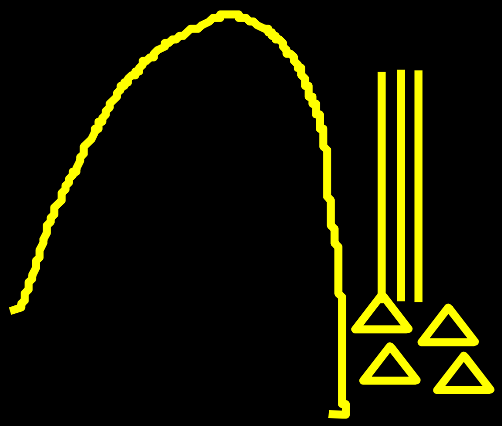
Rockfall zone

Talus Cone / Fan

Debris Wash Plain

(2.5.15) Composite slope

(III) FOOT HILL ZONE:

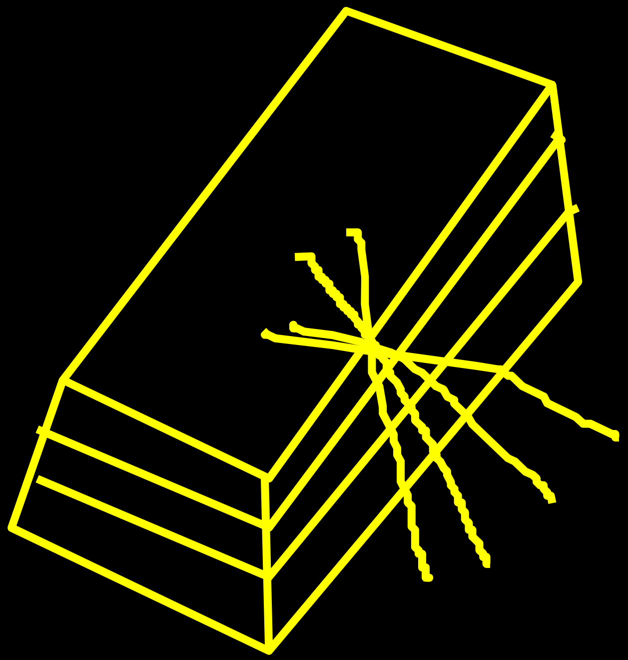


2.5.16 Rock fall

→ if the slope is steeper then rocks will fall like a water fall

→ as result the foot hills have heaps of angular and assorted materials

(2.5.17) Talus cone/ Fan



➔ **eroded materials from the hills getting dumped at the foot hills with coning effect**

> 15 ^{0}- cone

< 15^0 - fan

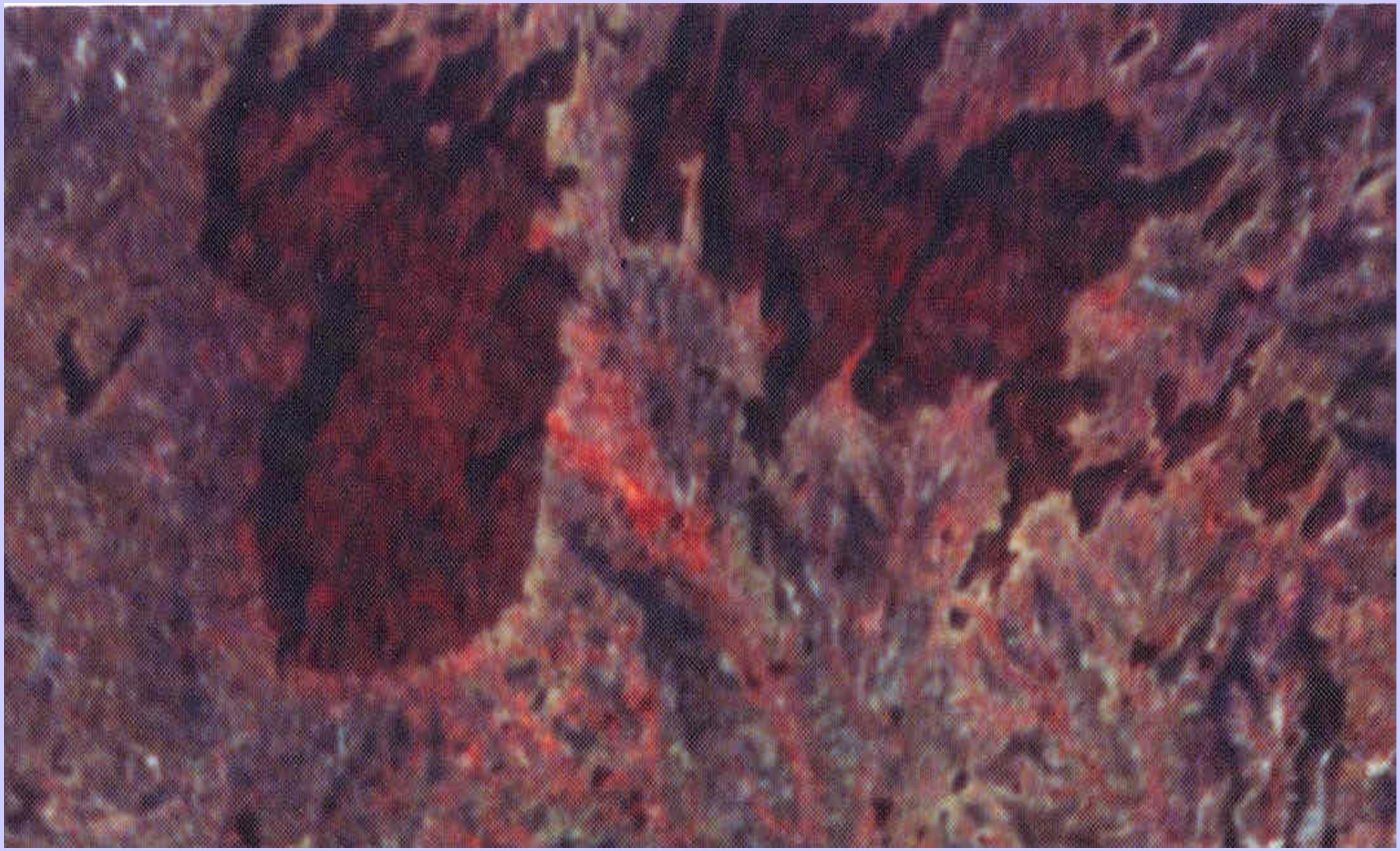
TALUS FAN/SCREE

SCREE CONE - AUSTRIA

scree - A collective term for an accumulation of coarse rock debris or a sheet of coarse debris mantling a slope.

Scree is not a synonym of talus, as scree includes loose, coarse fragment material on slopes without cliffs. Compare - talus, colluvium, mass movement.

TALUS FAN / DEBRISH WASH PLAIN



PLAIN RELATED FEATURES

Plain Zone

Pediment
- Rocky Pediment
- Weathered Pediment Shallow
- Weathered Pediment Moderate
- Weathered Pediment Deep

Pediplain
- Deeply Weathered
- Moderatly Weathered
- Poorly Weathered

Lateritic upland
- Dissected
- Undissected

Pediment:

A broad, flat or gently sloping, rock floored erosion surface or plain of low relief, typically developed by sub aerial agents (including running water) in an arid or semiarid region at the base of an abrupt and receeding mountain front or plateau escarpment, and underlain by bedrock (occasionally by older alluvial deposits) that may be bare but more often partly mantled with a and discontinuous veneer of alluvium derived form the upland masses and in transit across the surface.

PEDIMENT (THE LONG WINDING ROAD)

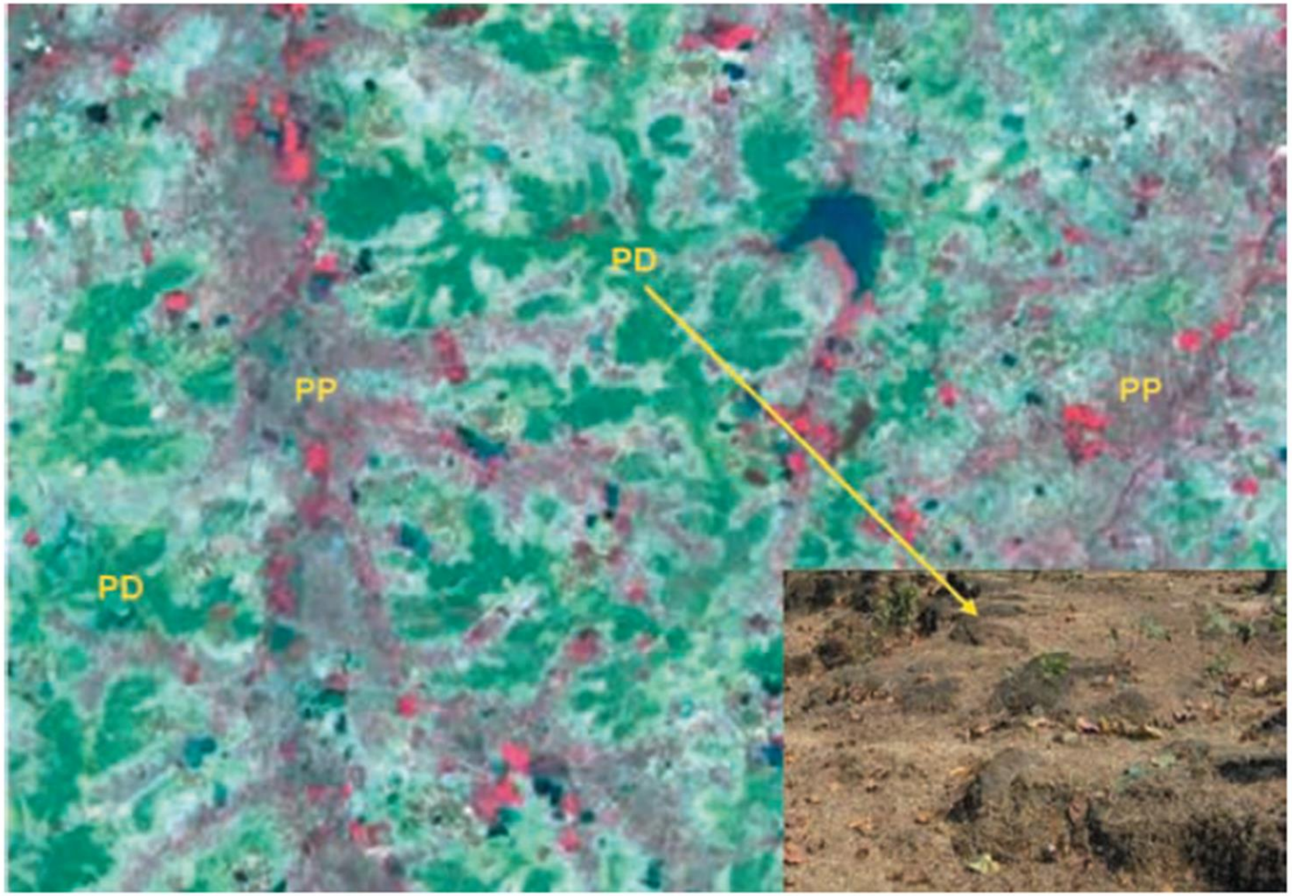
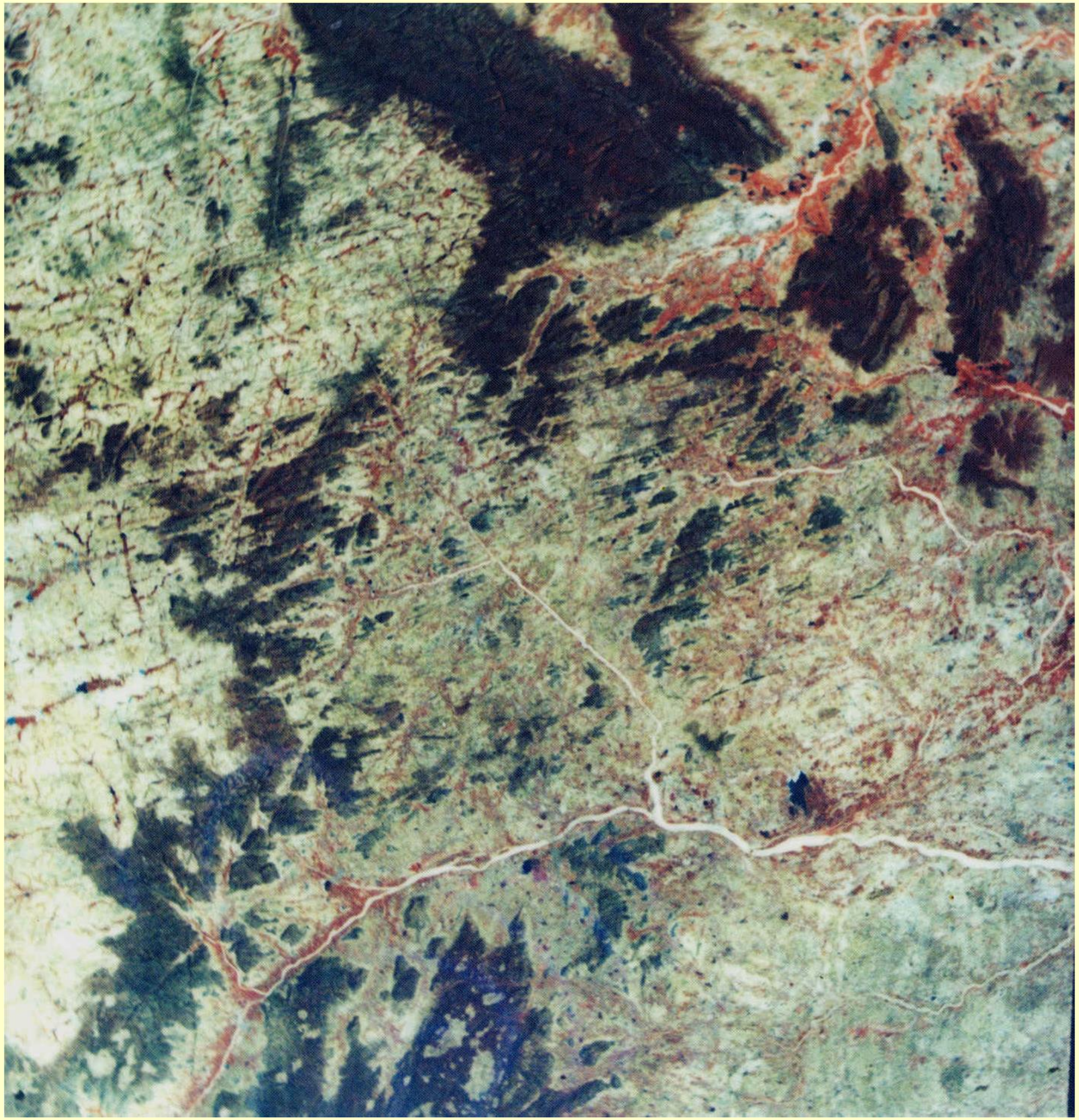
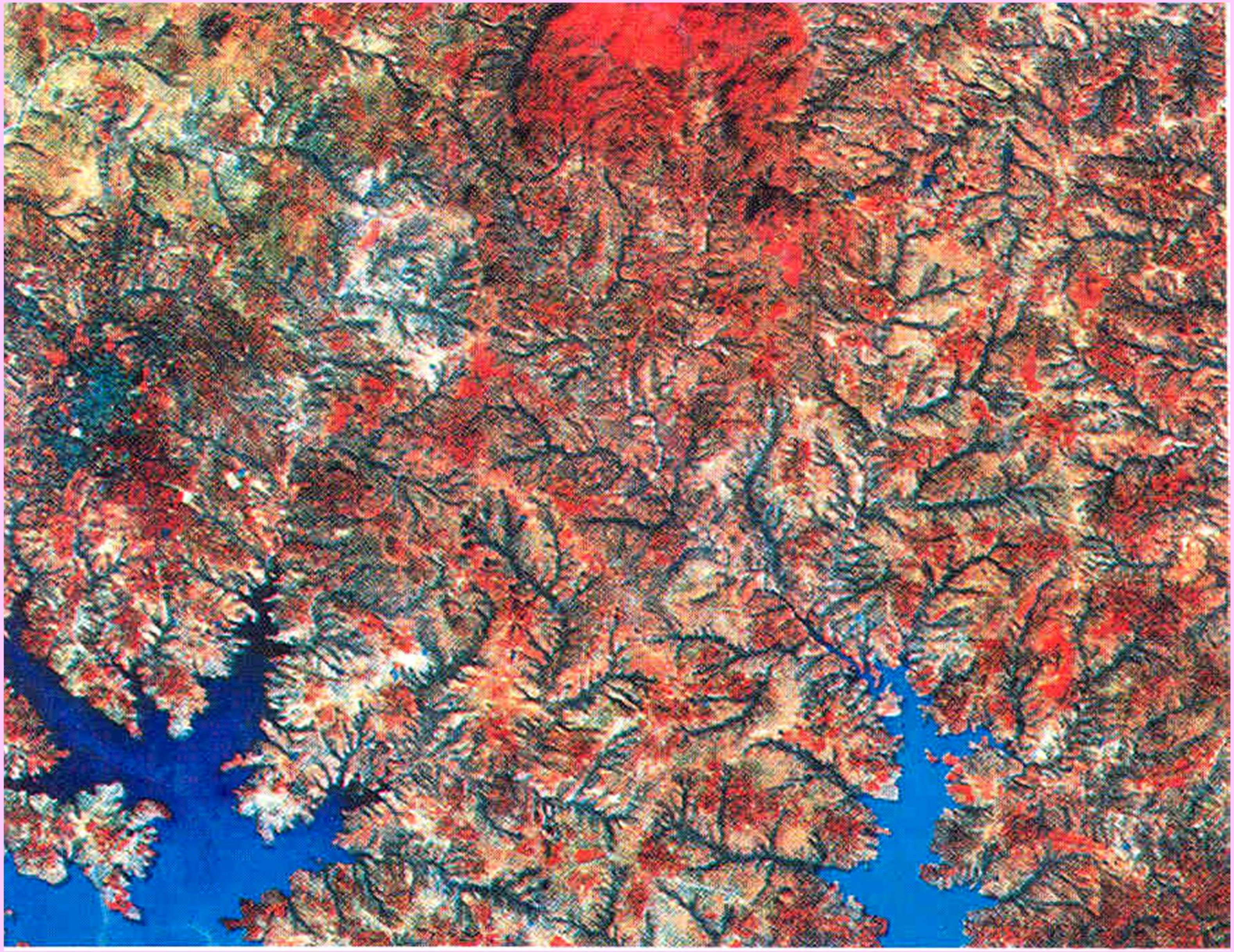


Figure 2.31 Pediments (PD) and pediplains (PP) occurring in Raipur district, Chhattisgarh state as seen from the IRS LISS-III rabi season satellite image. The green tone of the pediment areas is because of the laterite lithounit, which brings a good contrast between the pediplains and pediment areas.

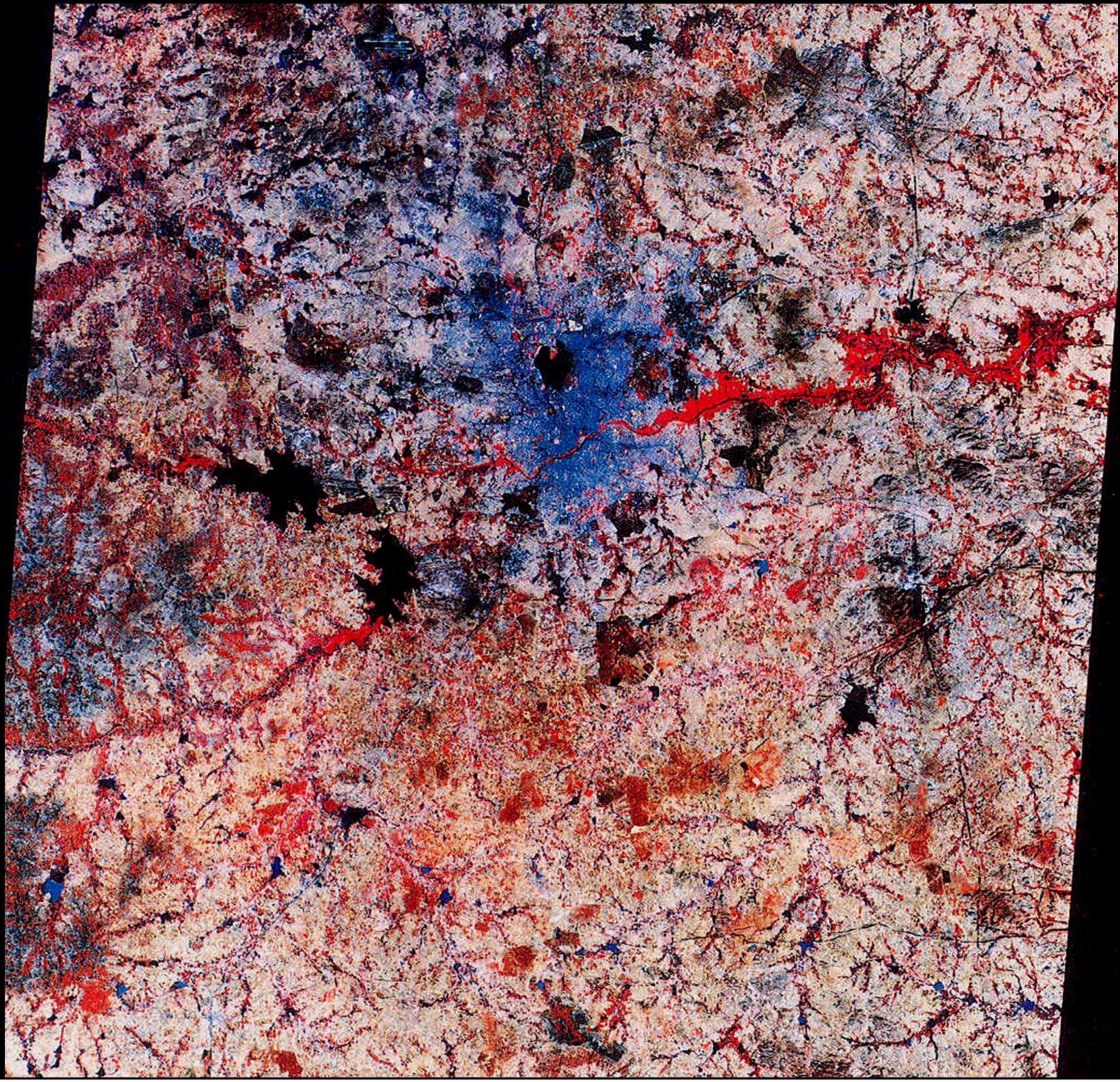


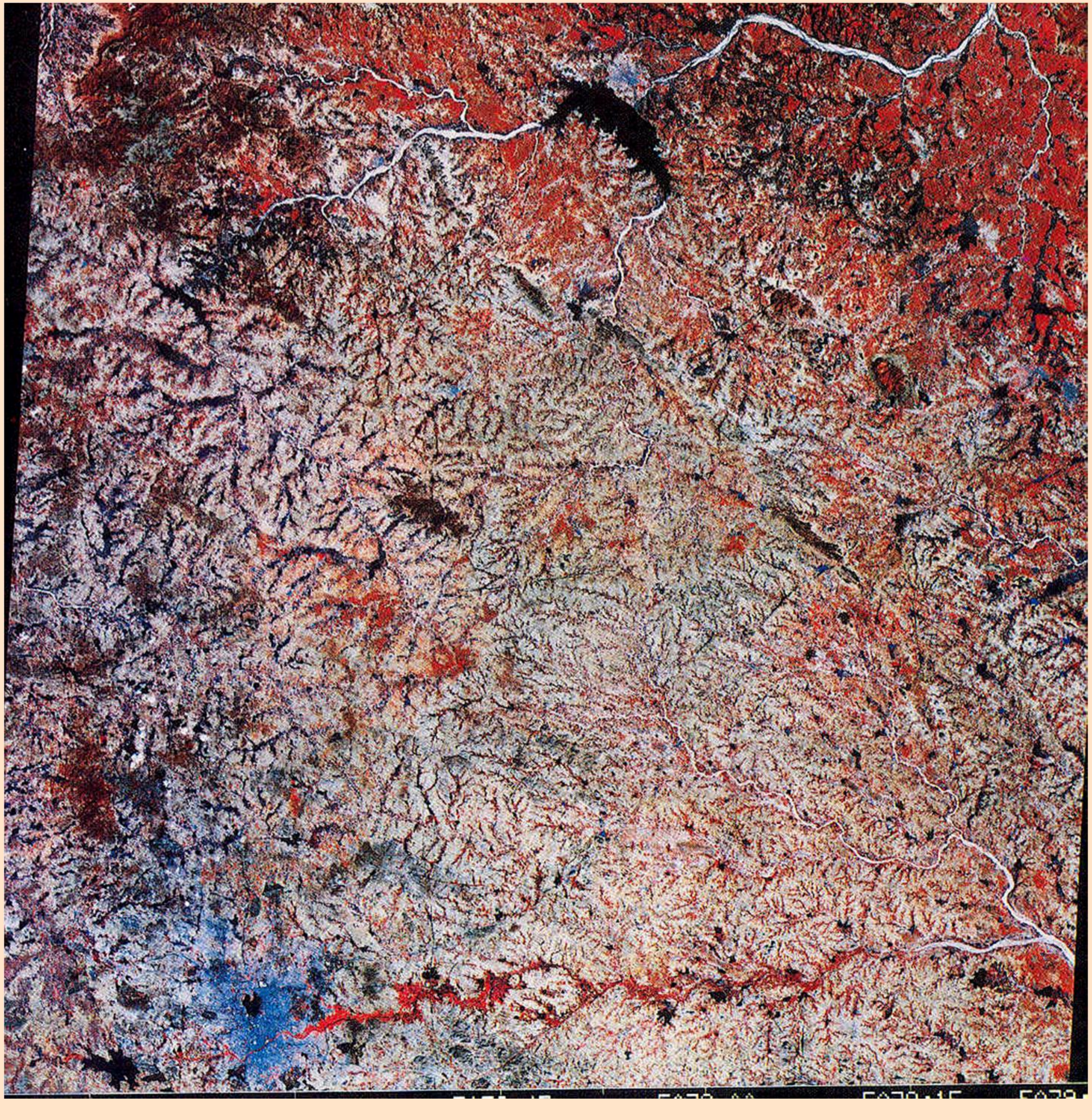
Dissected Pediment

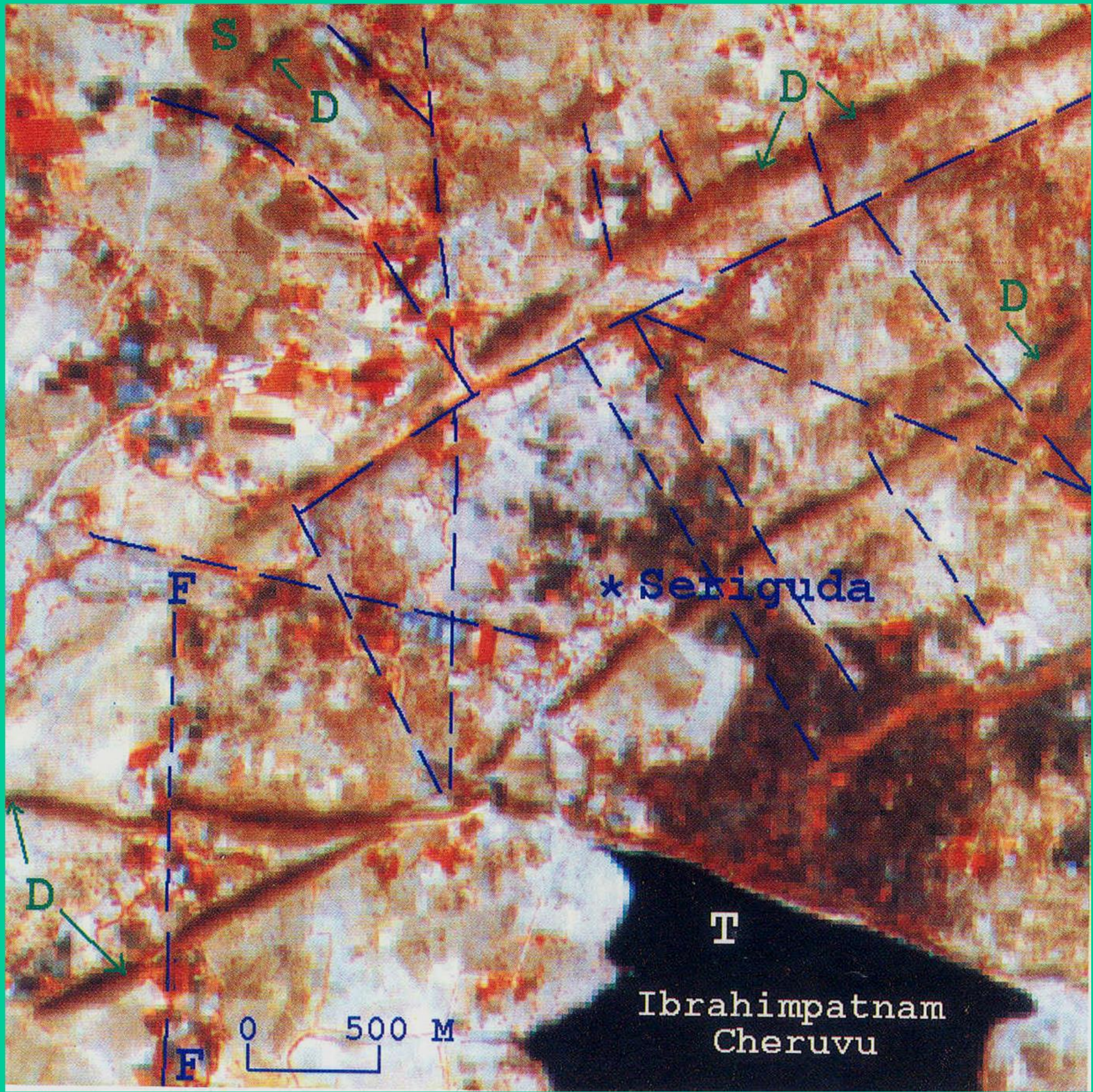
Dissected Pediment



Dissected Pediment



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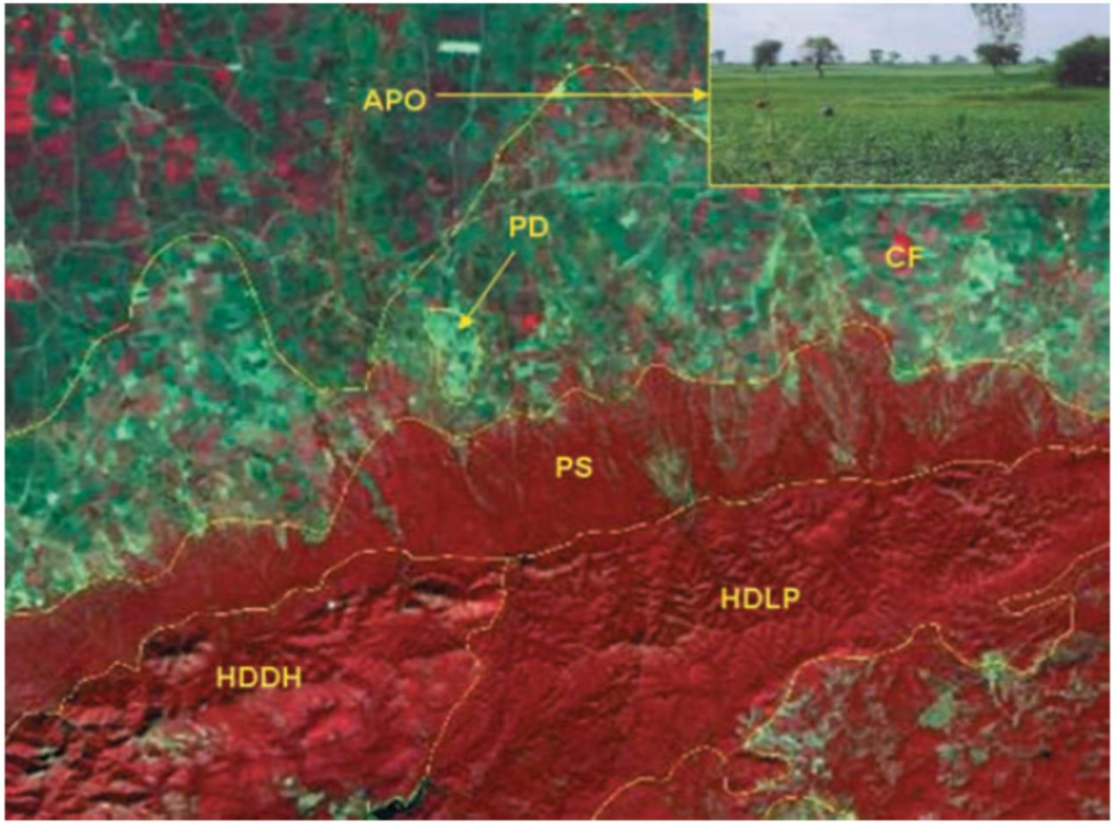
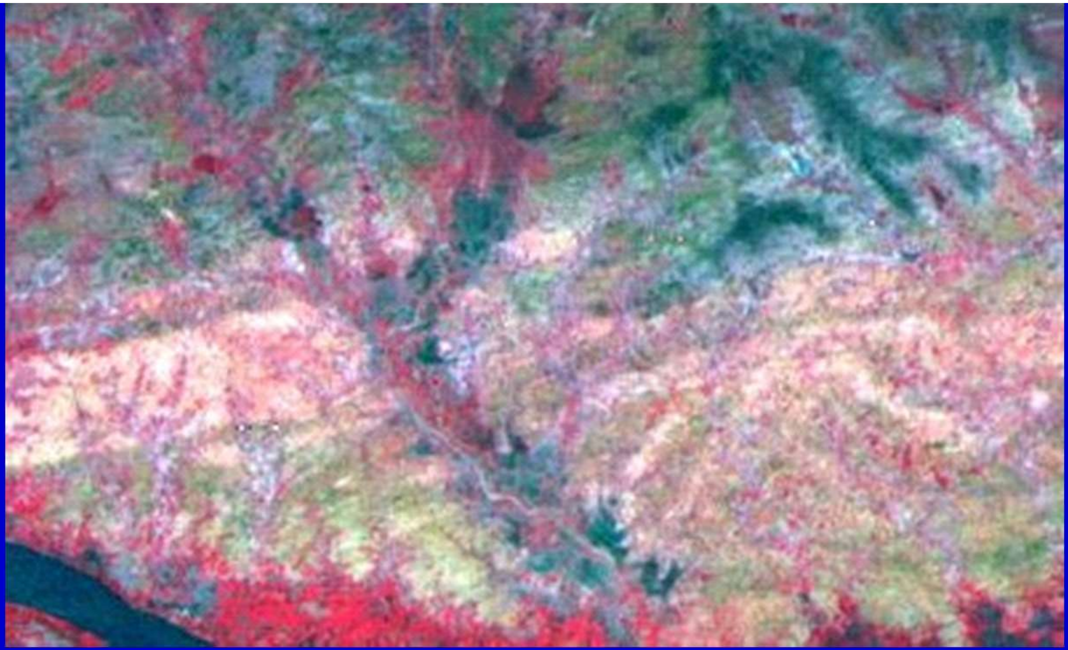


Fig. 2.18 Highly dissected denudational hills (HDDH), highly dissected lower plateaus (HDLP), Piedmont slope (PS), colluvial fans (CF), pediment (PD) and older alluvial plains (APO) in Hoshangabad district.

Pediment-Inselberg Complex:

The pediments dotted by numerous inselberg of small sizes, which makes it difficult to distinguish from the pediments. Hence it is called as a complex of pediment and inselberg.

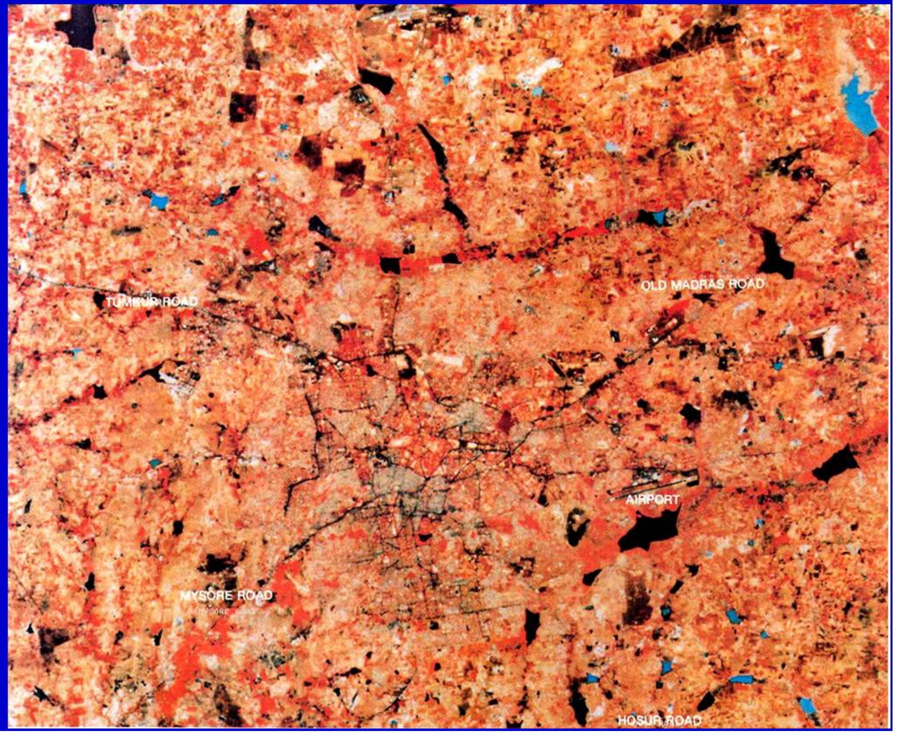
Fig. 2.28 Pediment Inselberg Complex southeast of Tataayyagarpettai in Tiruchirappalli district, Tamil Nadu. It is difficult to separate inselberg and pediment here. Pediment dotted with inselbergs (appearing as dark spots in the image) is seen here.



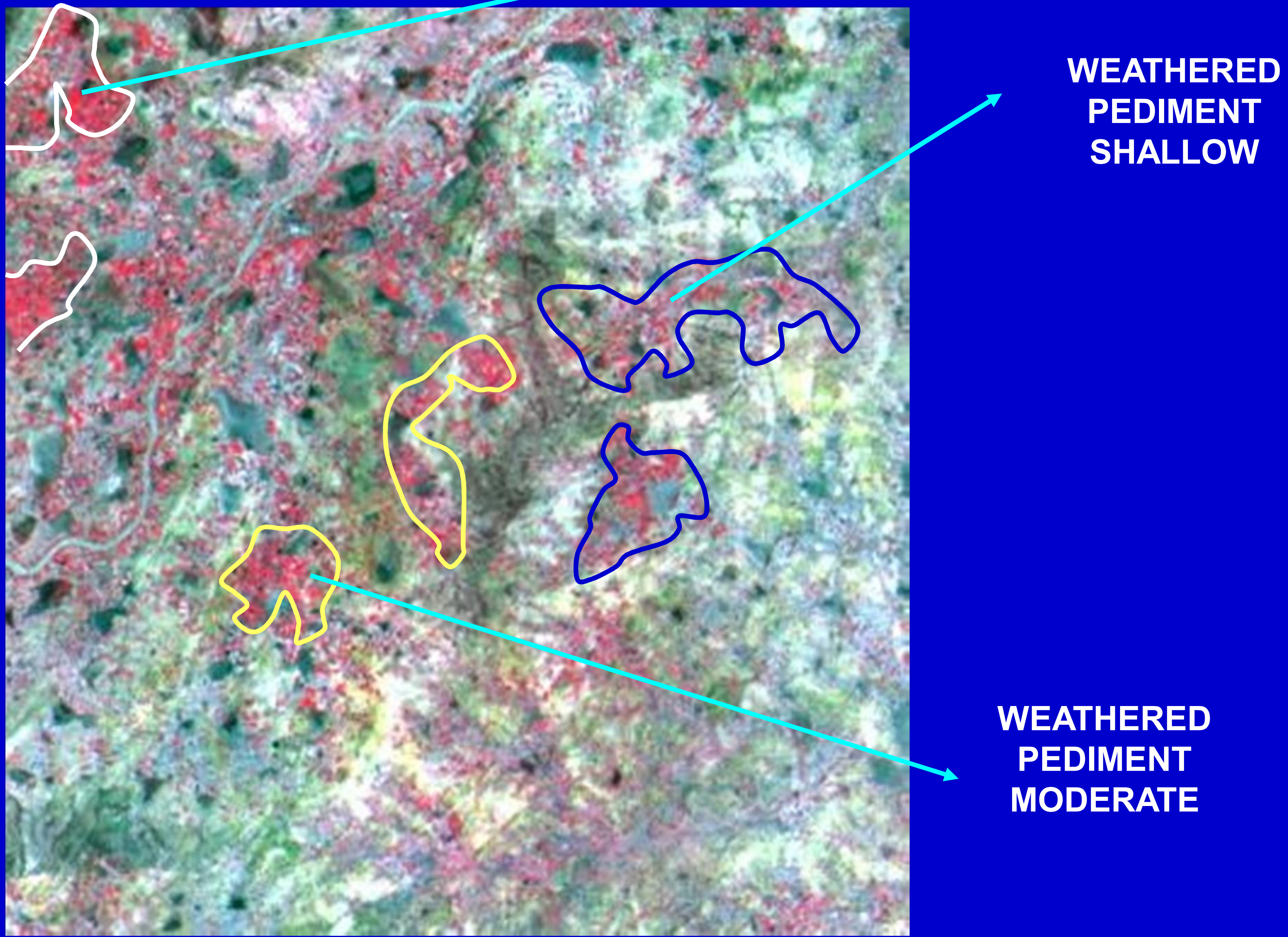
ROCKY PEDIMENT

WEATHERED

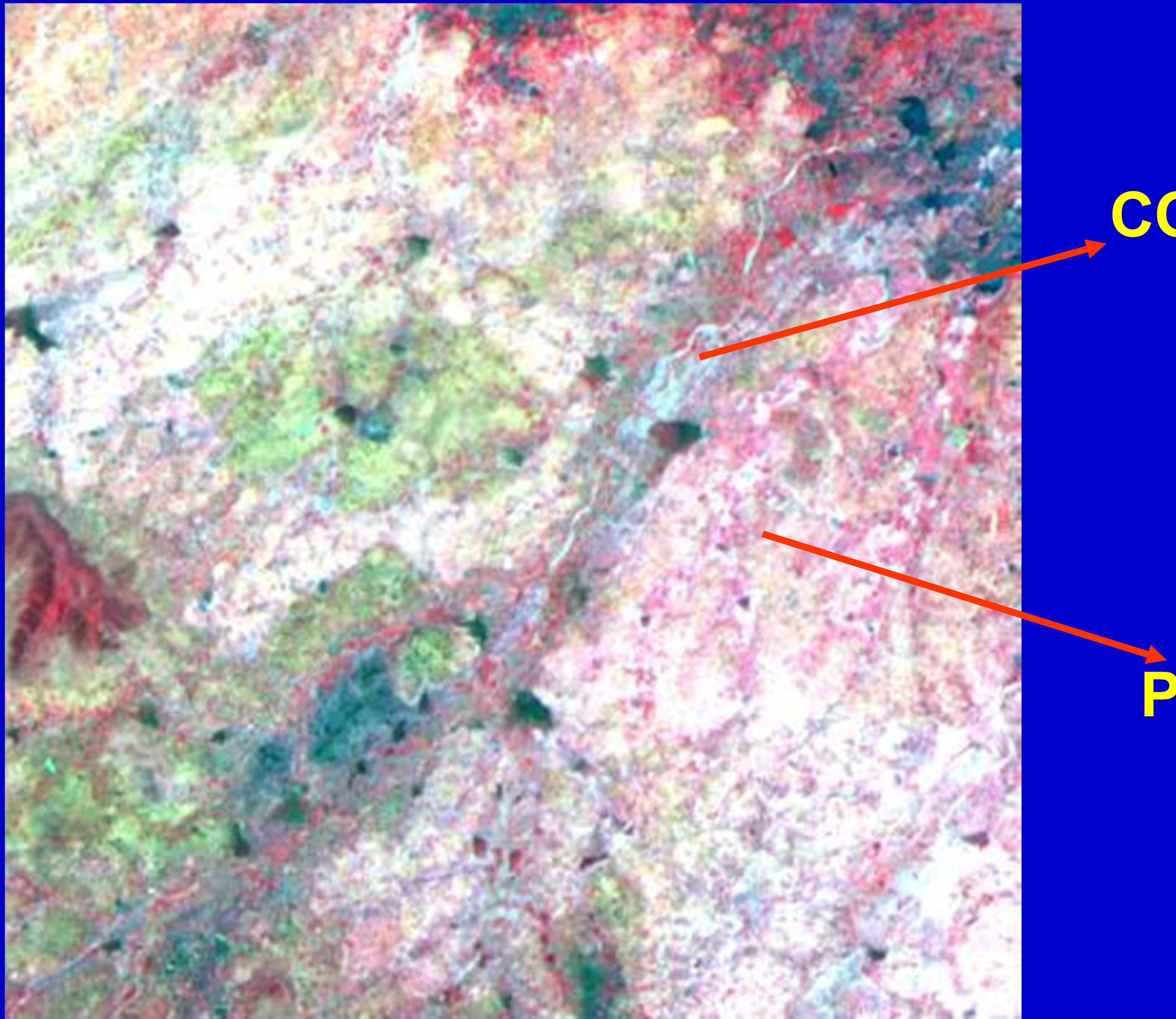
PEDIMENT MODERATE



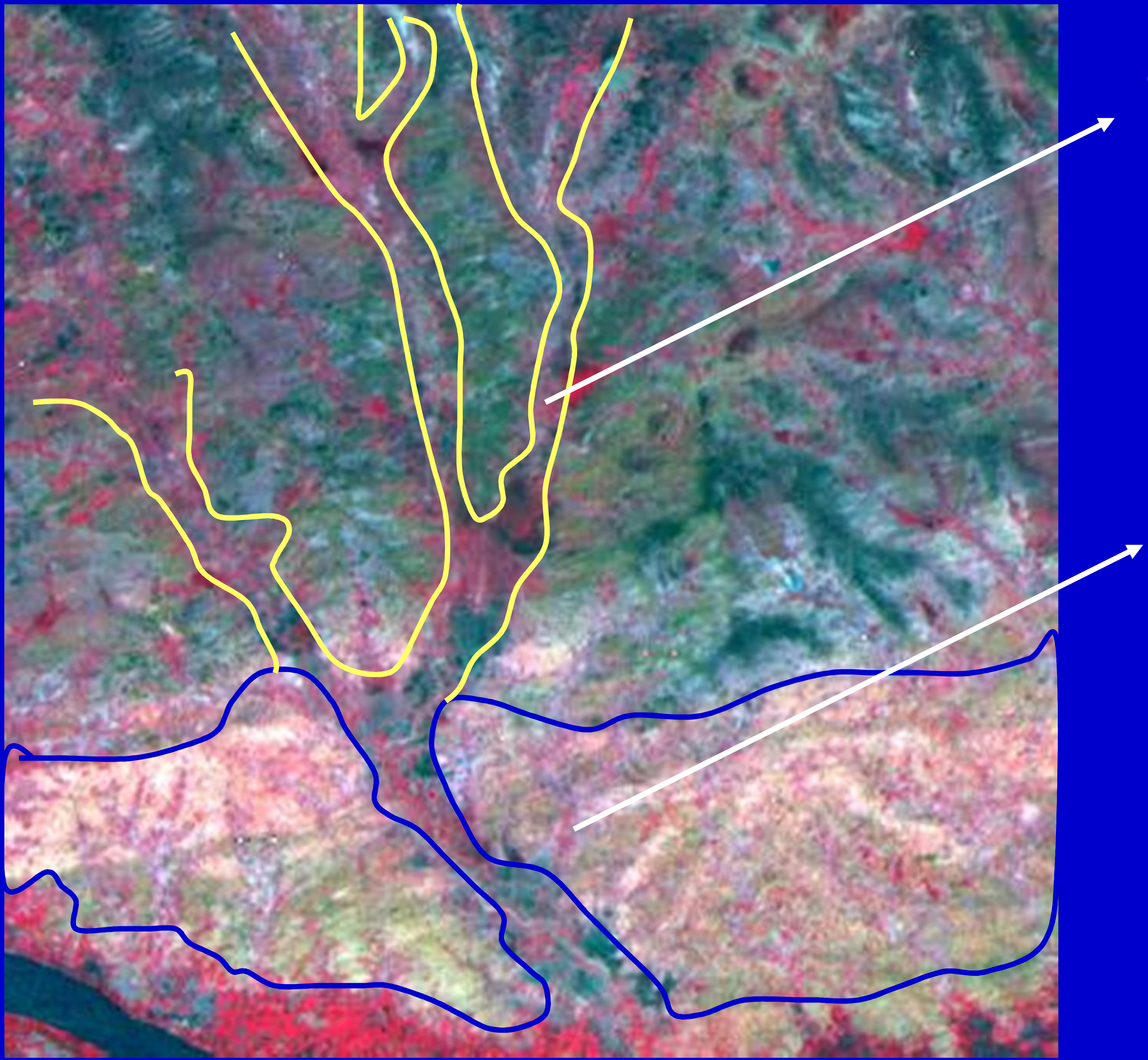
PEDIMENTS



WEATHERED PEDIMENT DEEP
WEATHERED PEDIMENT SHALLOW
WEATHERED PEDIMENT MODERATE



COLLUVIAL
FILL
PEDIPLAIN



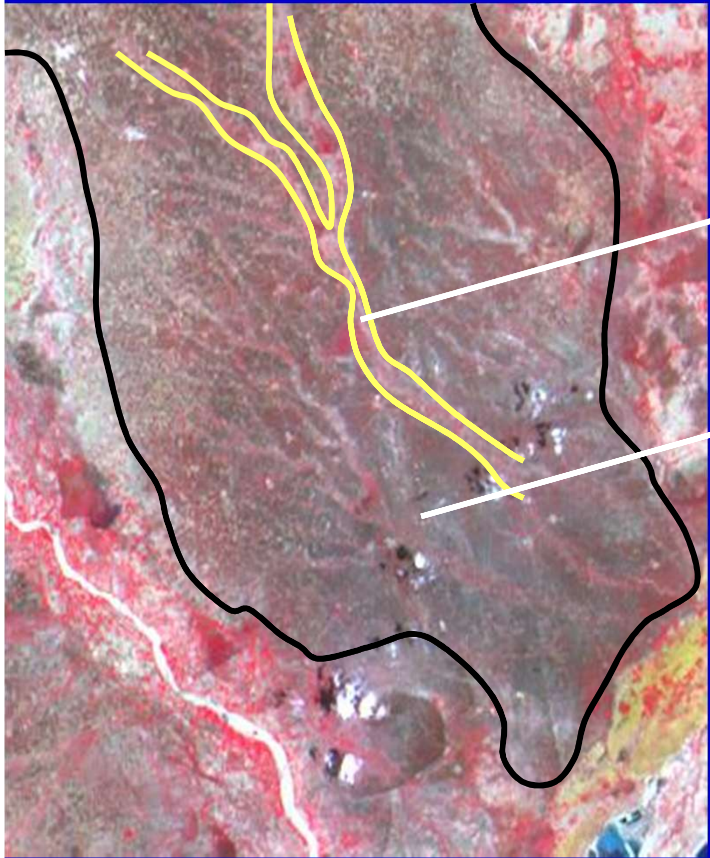
COLLUVIAL FILL
MODERATE

ROCKY
PEDIMENTS

Pediplain:

An extensive, multi-concave, thinly alluviate rockcut erosion surface formed by the coalescence of two or more adjacent pediments and occasional desert domes, and representing the end result (the "peneplain") of the mature stage of the erosion cycle.

PEDIPLAIN



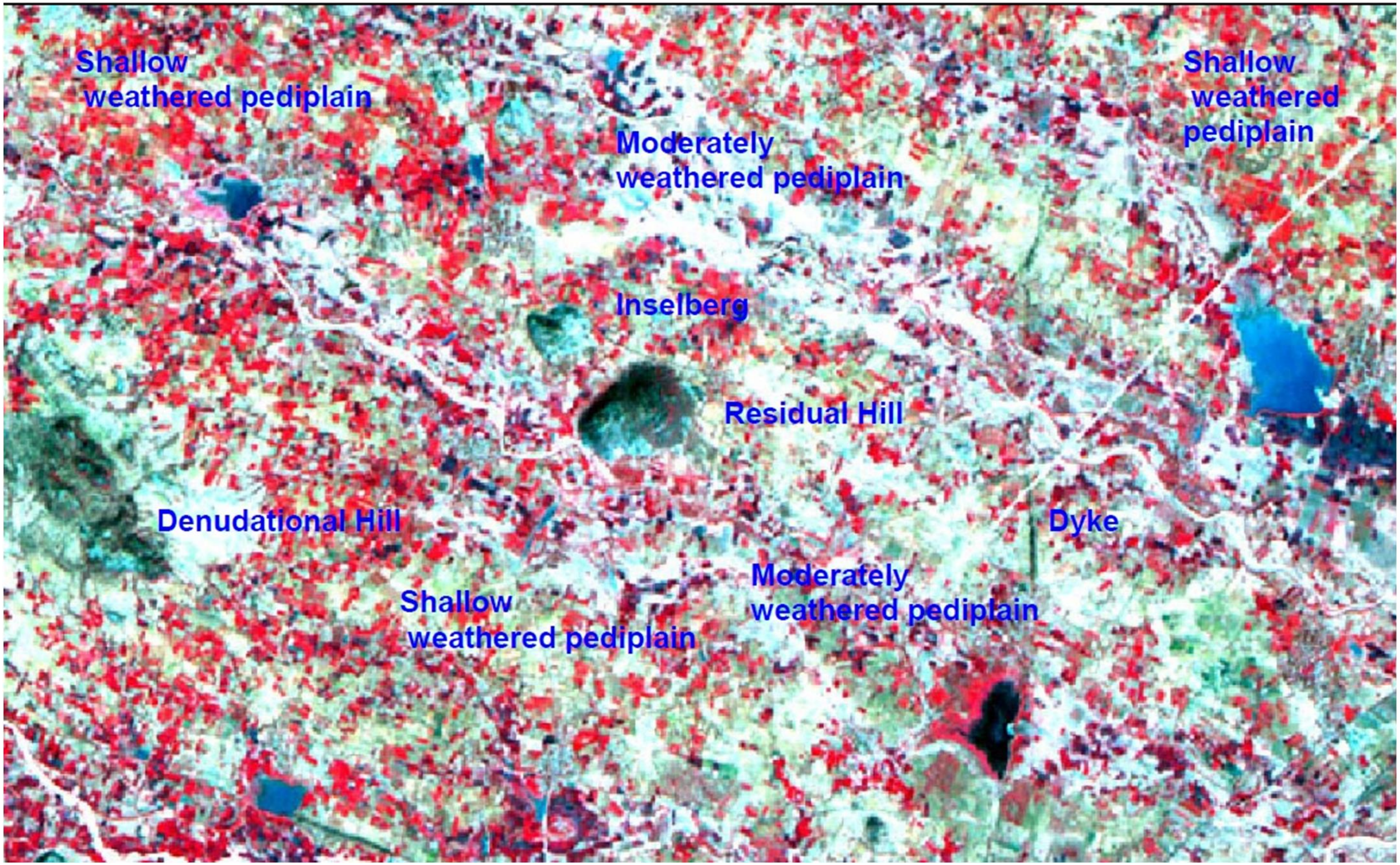
COLLUVIAL FILL SHALLOW

PEDIPLAIN - POORLY WEATHERED

PEDIPLAIN MODERATELY WEATHERED

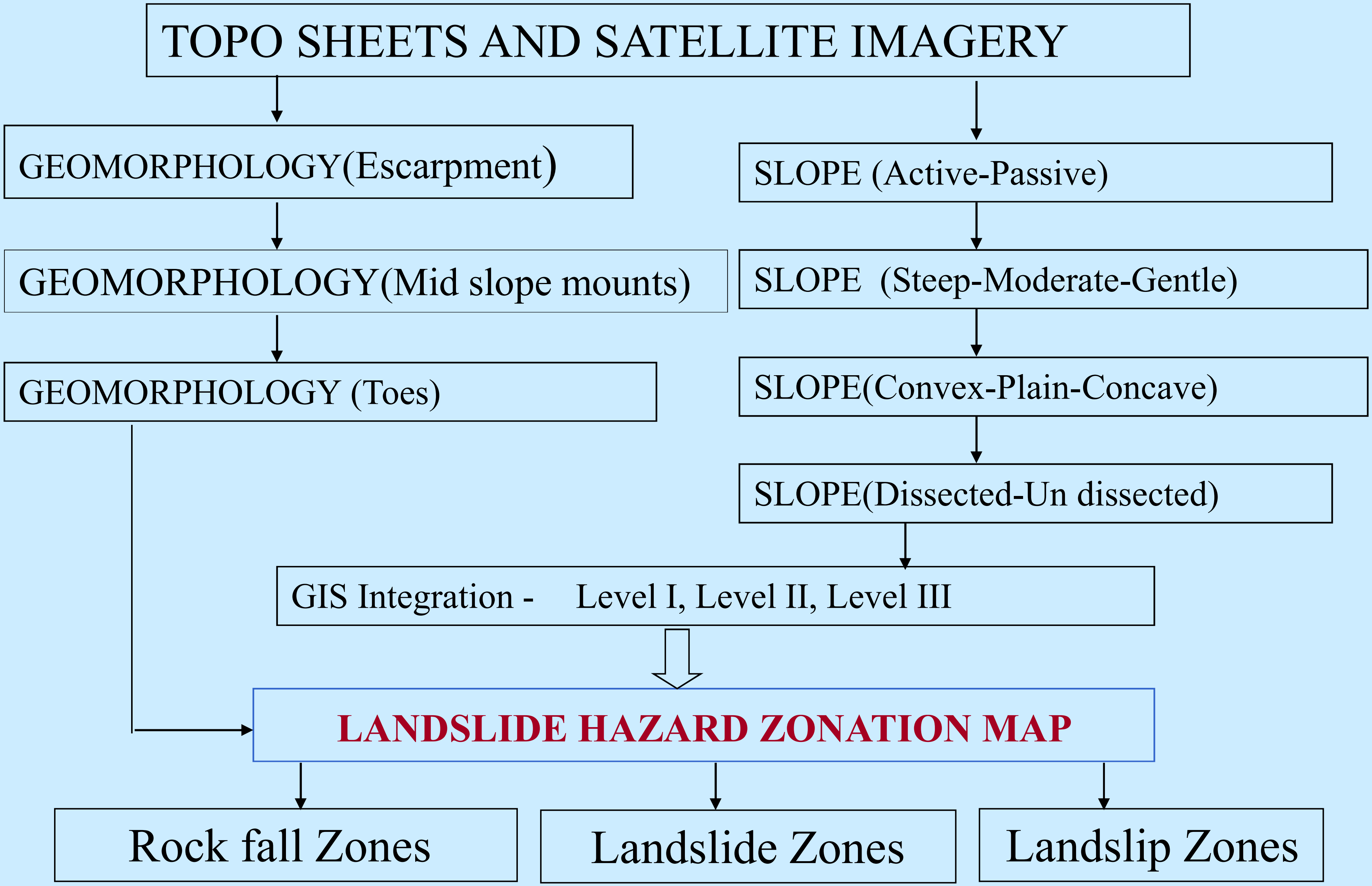
PEDIPLAIN DEEPLY WEATHERED

Fig. 4.19: Satellite image of Peninsular Gneissic Complex showing weathered zones

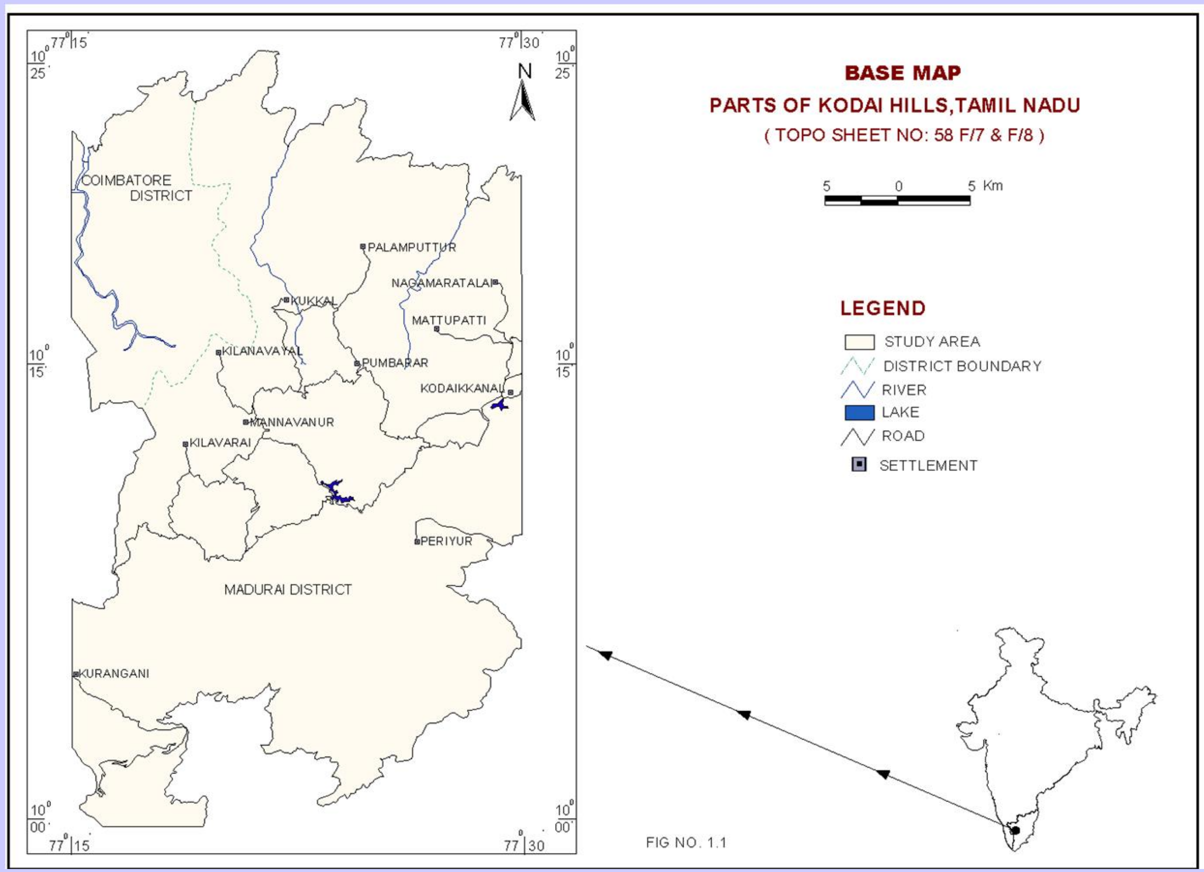


GEOMORPHOLOGY WITH SPECIAL REFERENCE TO LANDSLIDES

METHODOLOGY



STUDY AREA



Toposheets 58F/7 and 58F/8.

Includes parts of Kodaikanal, Coimbatore and Madurai Districts of Tamil Nadu.

GIS BASED SLOPE MAPPING

- Active – Passive Slopes
- Convex – Plain – Concave Slopes
- Steep – Moderate – Gentle Slopes
- Dissected And Undissected Slopes

LEVEL - I INTEGRATION

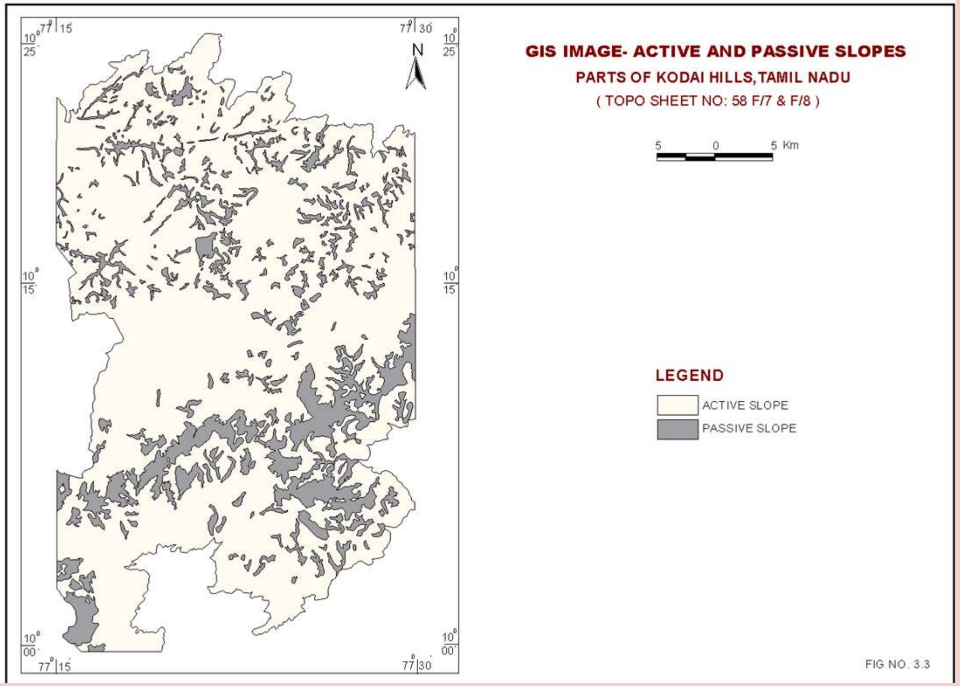
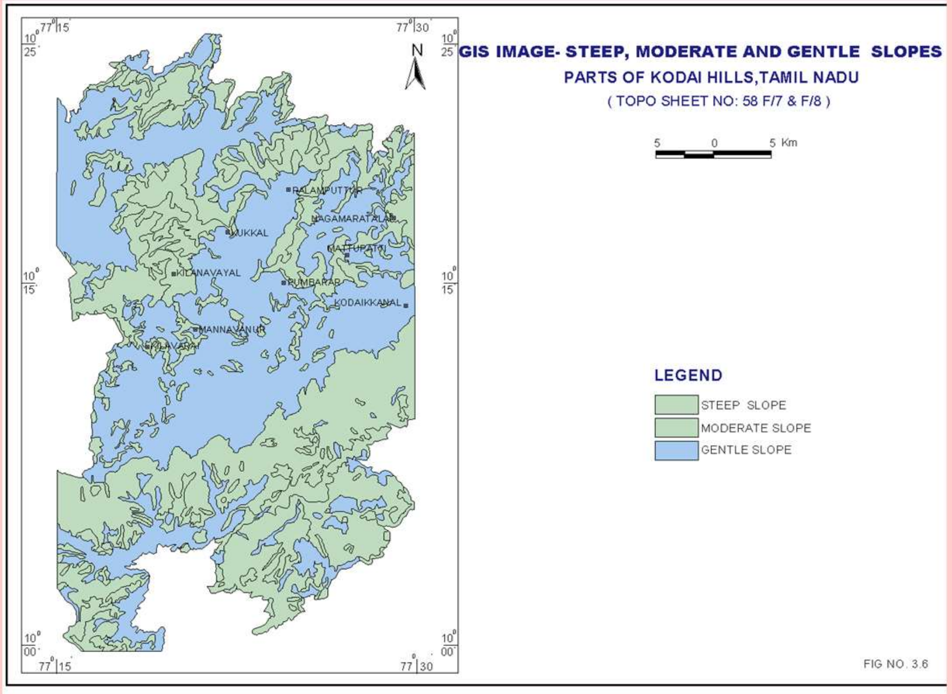


IMAGE - A

IMAGE - B

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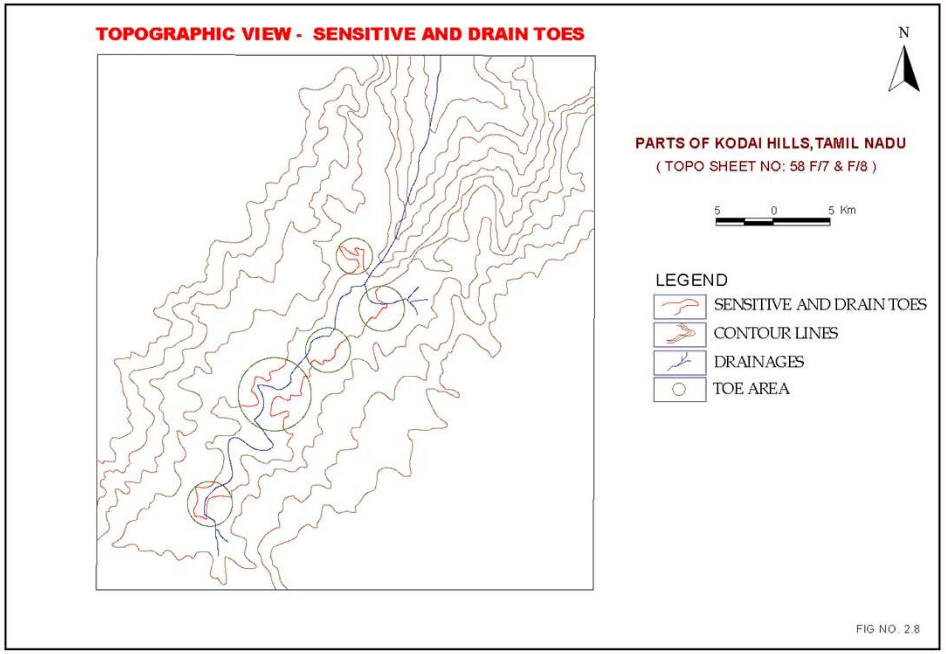


FIG NO. 2.8

TOES

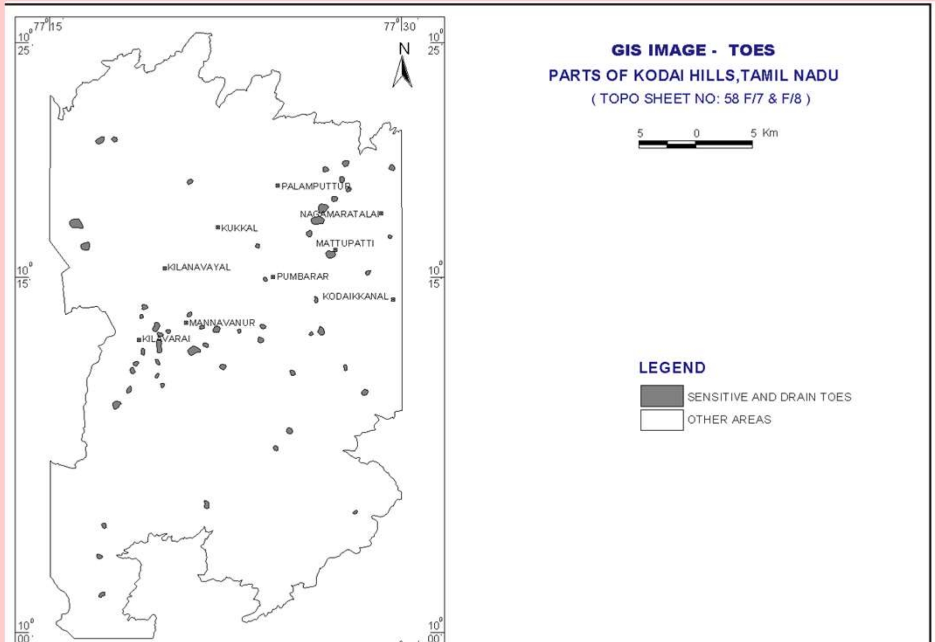
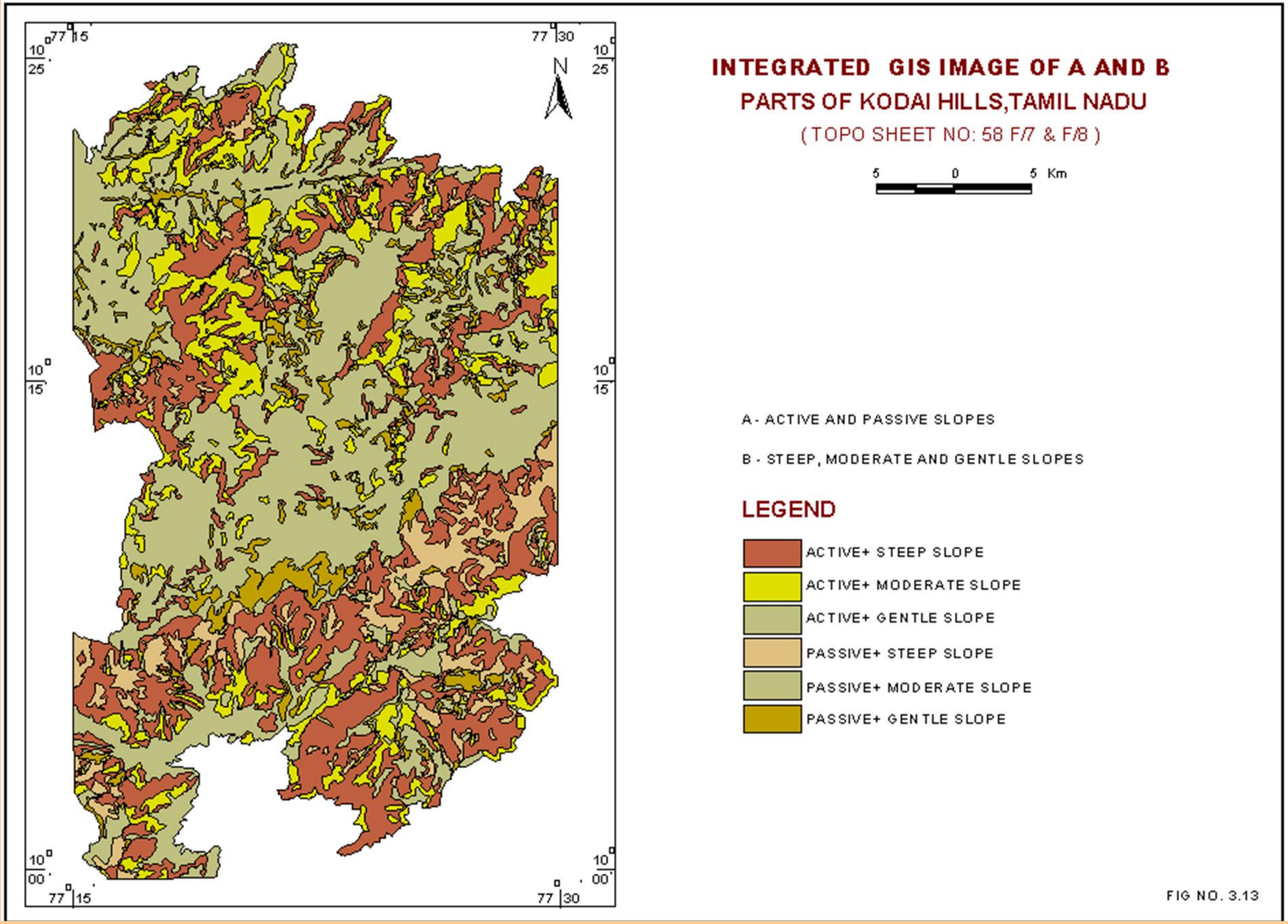


FIG NO. 2.9

INTEGRATION OF IMAGE A & IMAGE B



LEVEL – II INTEGRATION

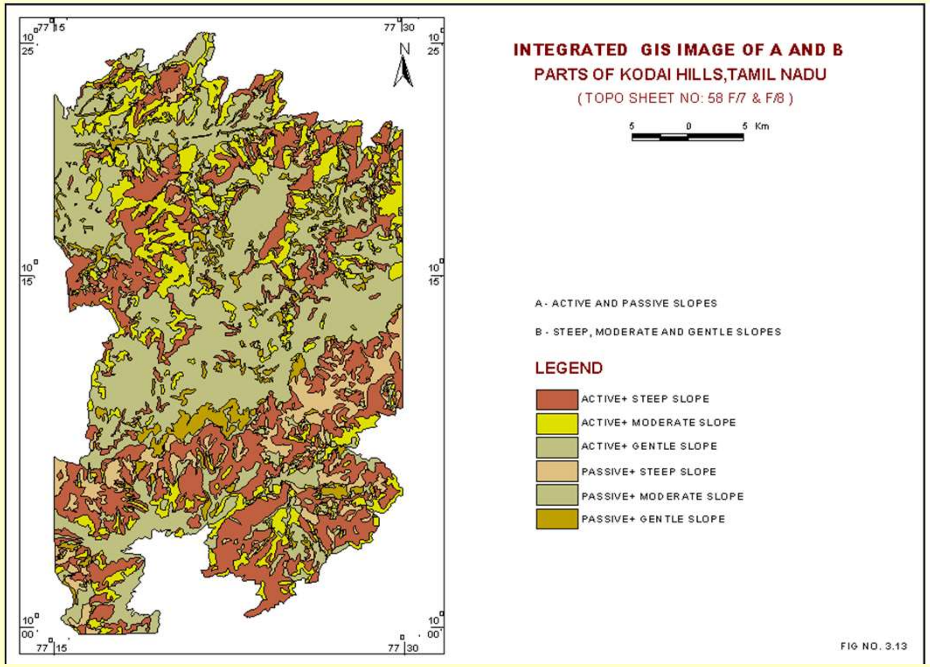
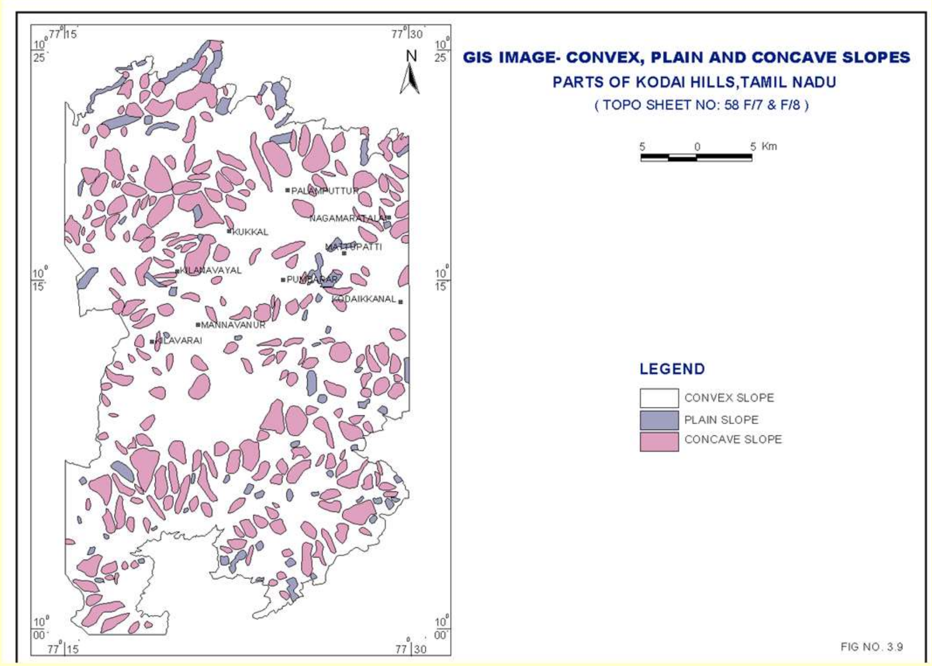


IMAGE A & B

IMAGE - C



INTEGRATION OF IMAGES A AND B + C

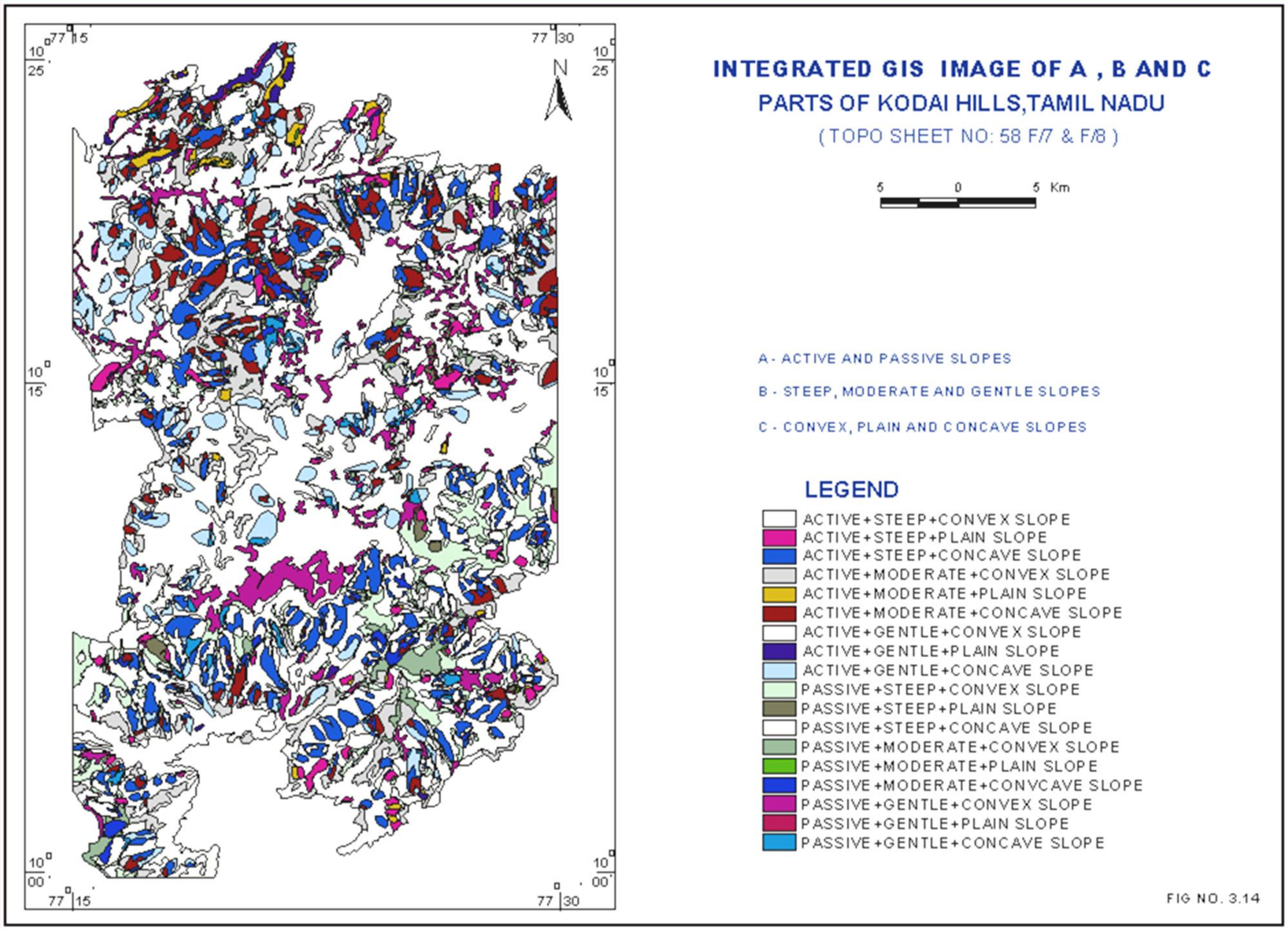
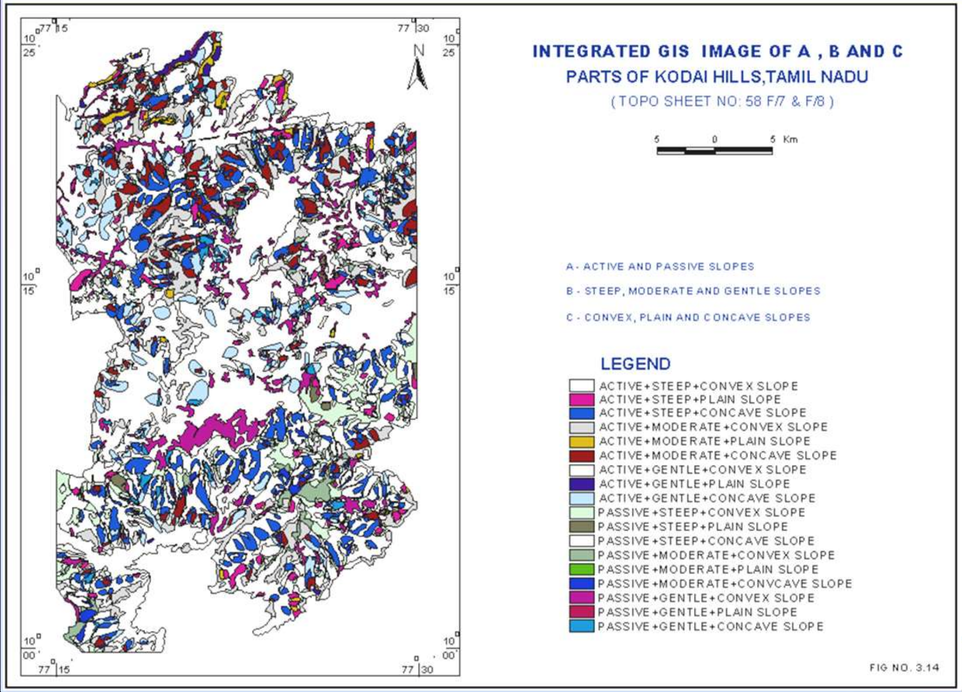


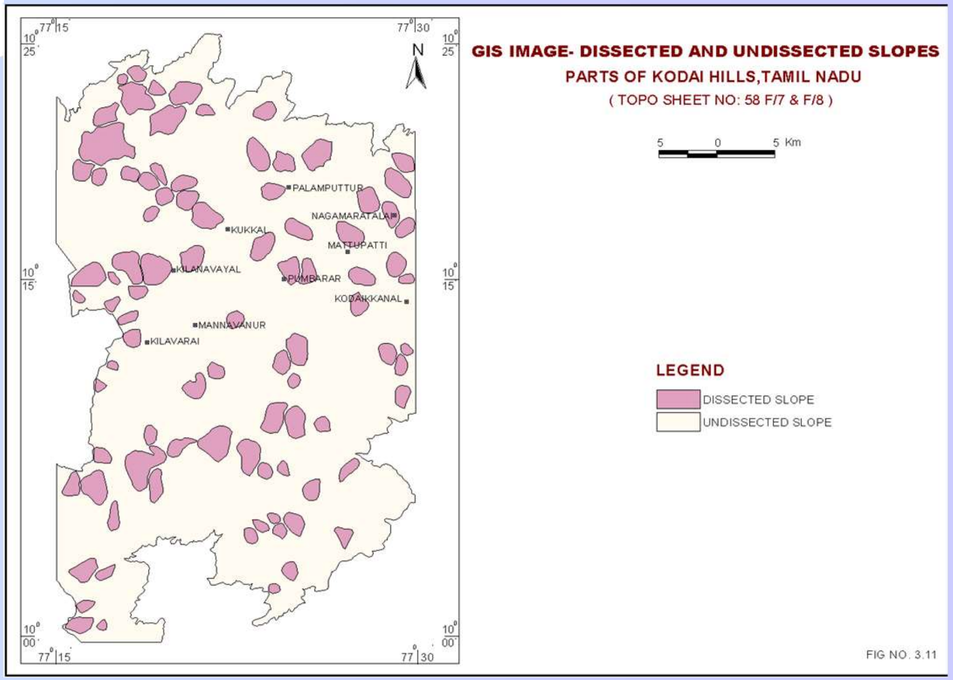
FIG NO. 3.14

LEVEL - III INTEGRATION



IMAGES A, B AND C

IMAGE - D



INTEGRATION OF IMAGES A, B, AND C + D

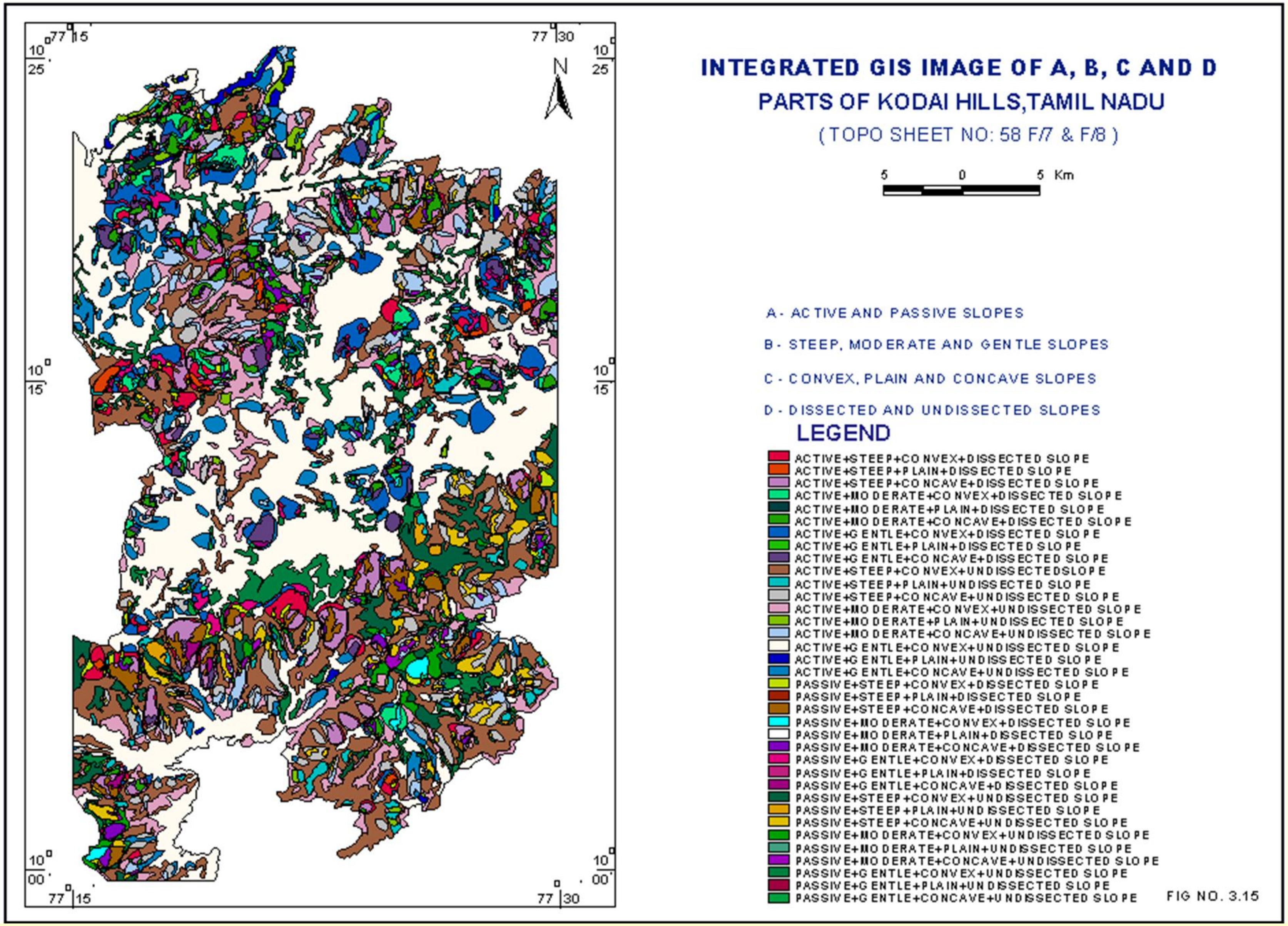
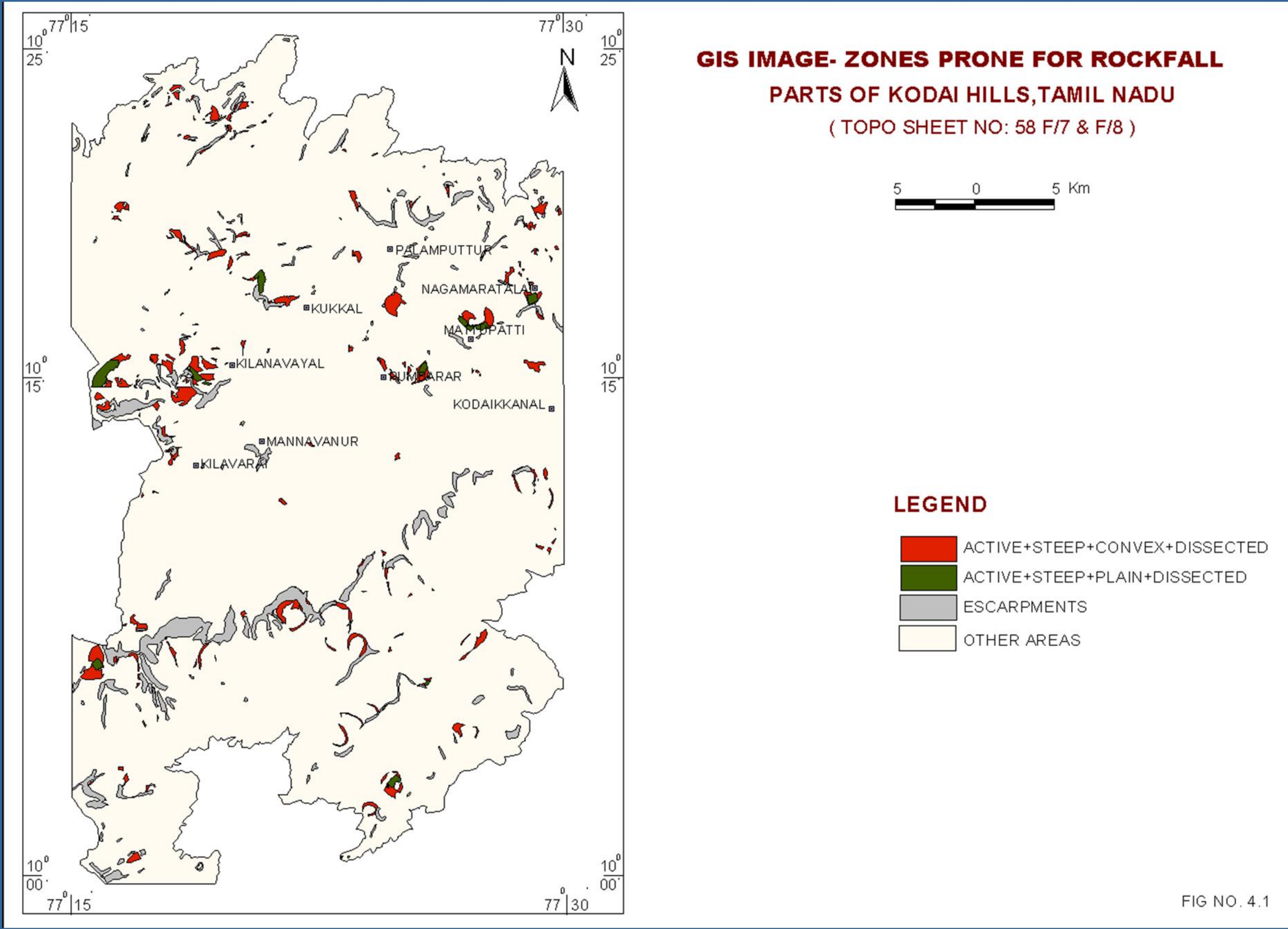
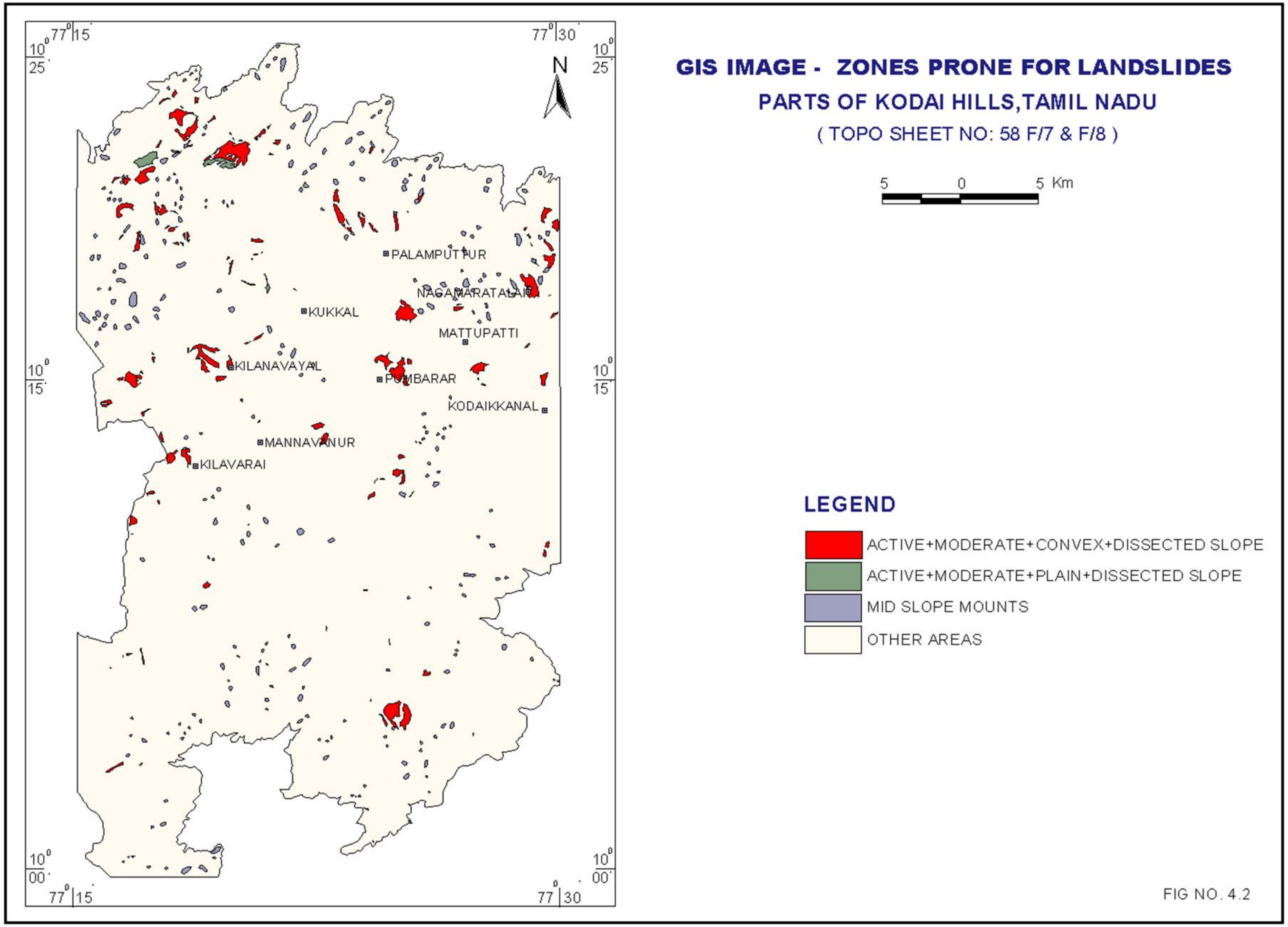


FIG NO. 3.15

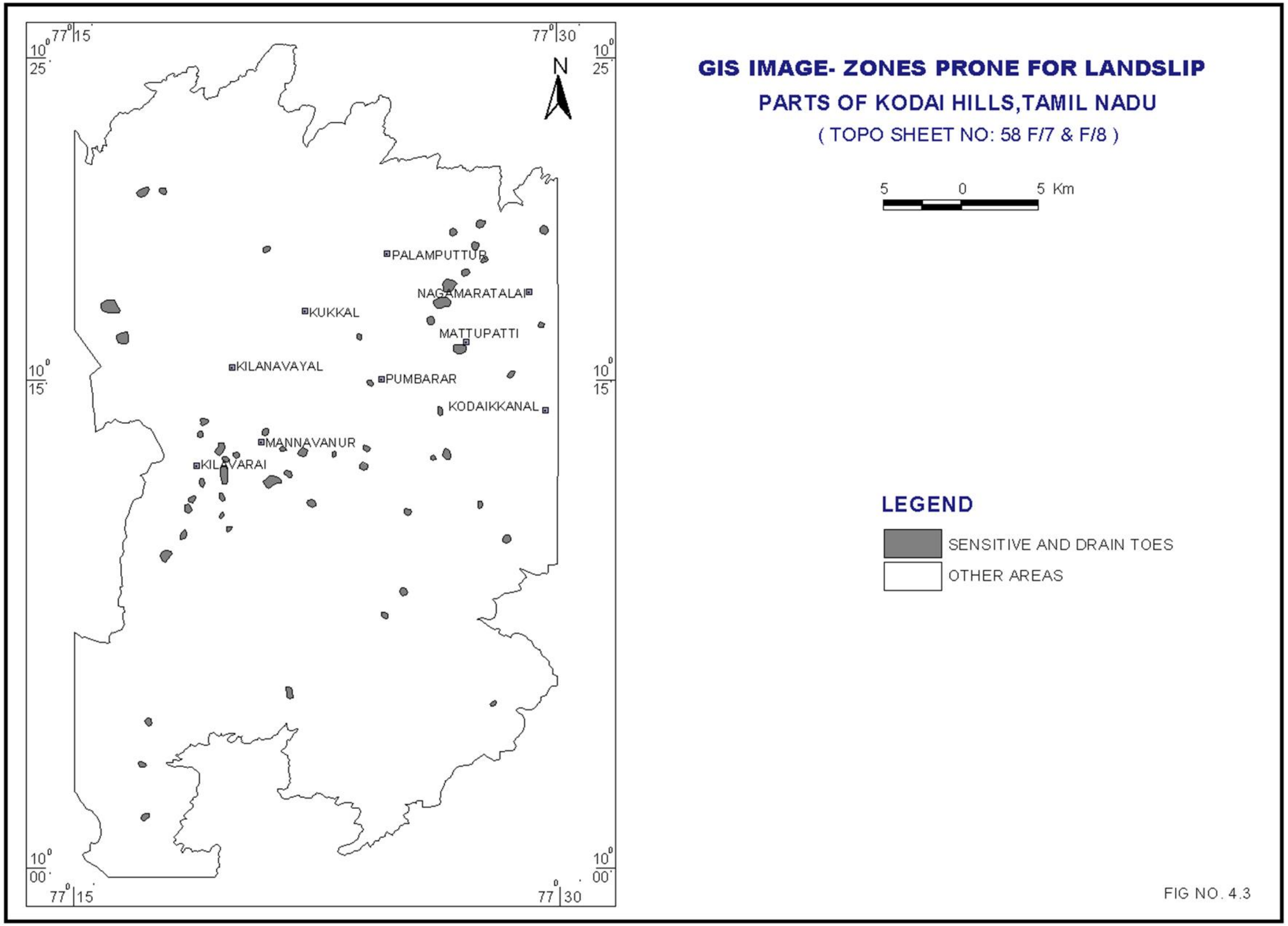
ROCKFALL ZONES



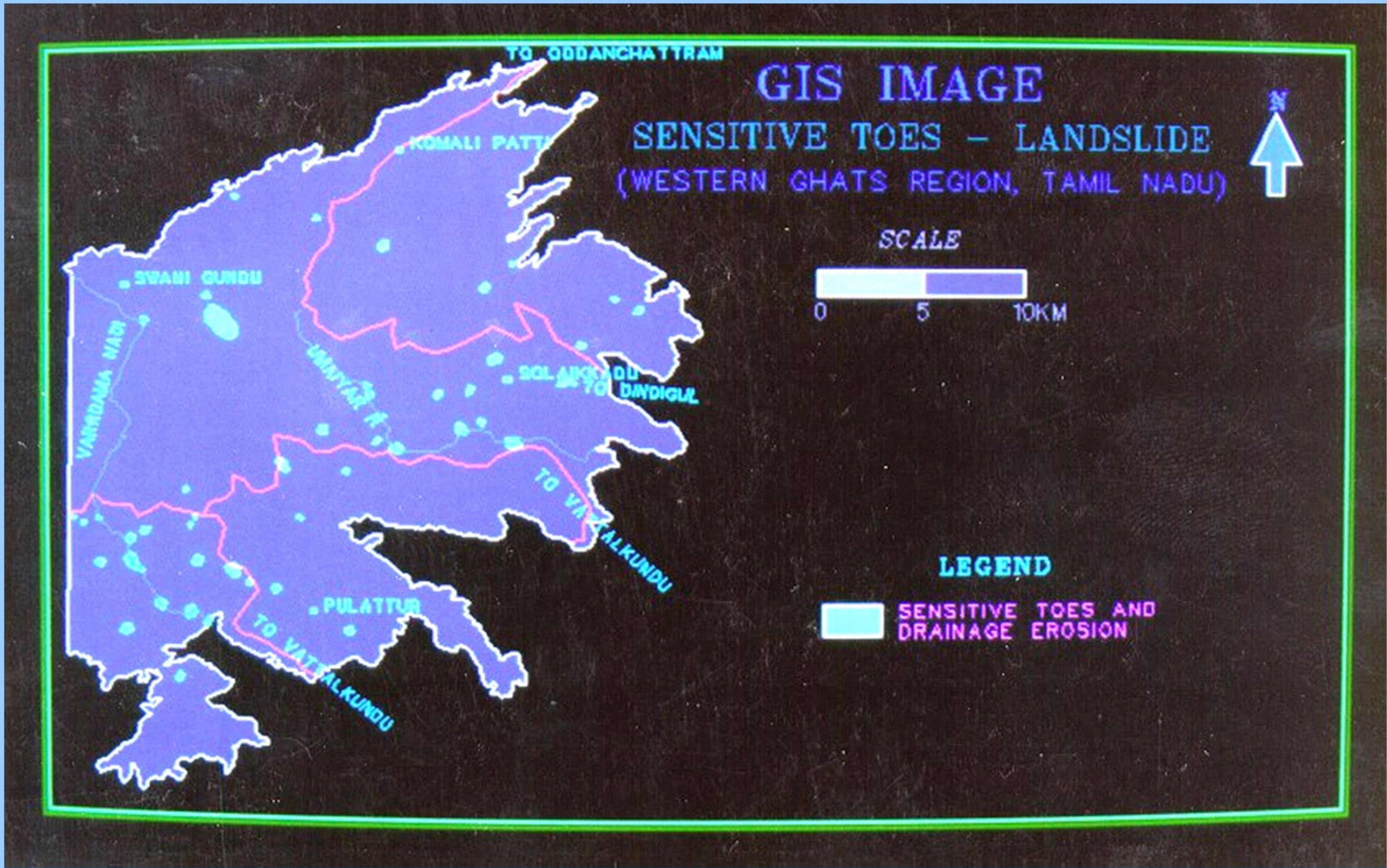
LANDSLIDES ZONES



LANDSLIP ZONES



SENSITIVE TOES AND LANDSLIDES



STUDIES - RESULTS
&
RECOMMENDATIONS

FROM THE GIS ANALYSIS…………..

ZONES PRONE FOR

- ROCKFALL
- LANDSLIDE and
- LANDSLIP

Were identified and demarcated.

IN ROCK FALL ZONES

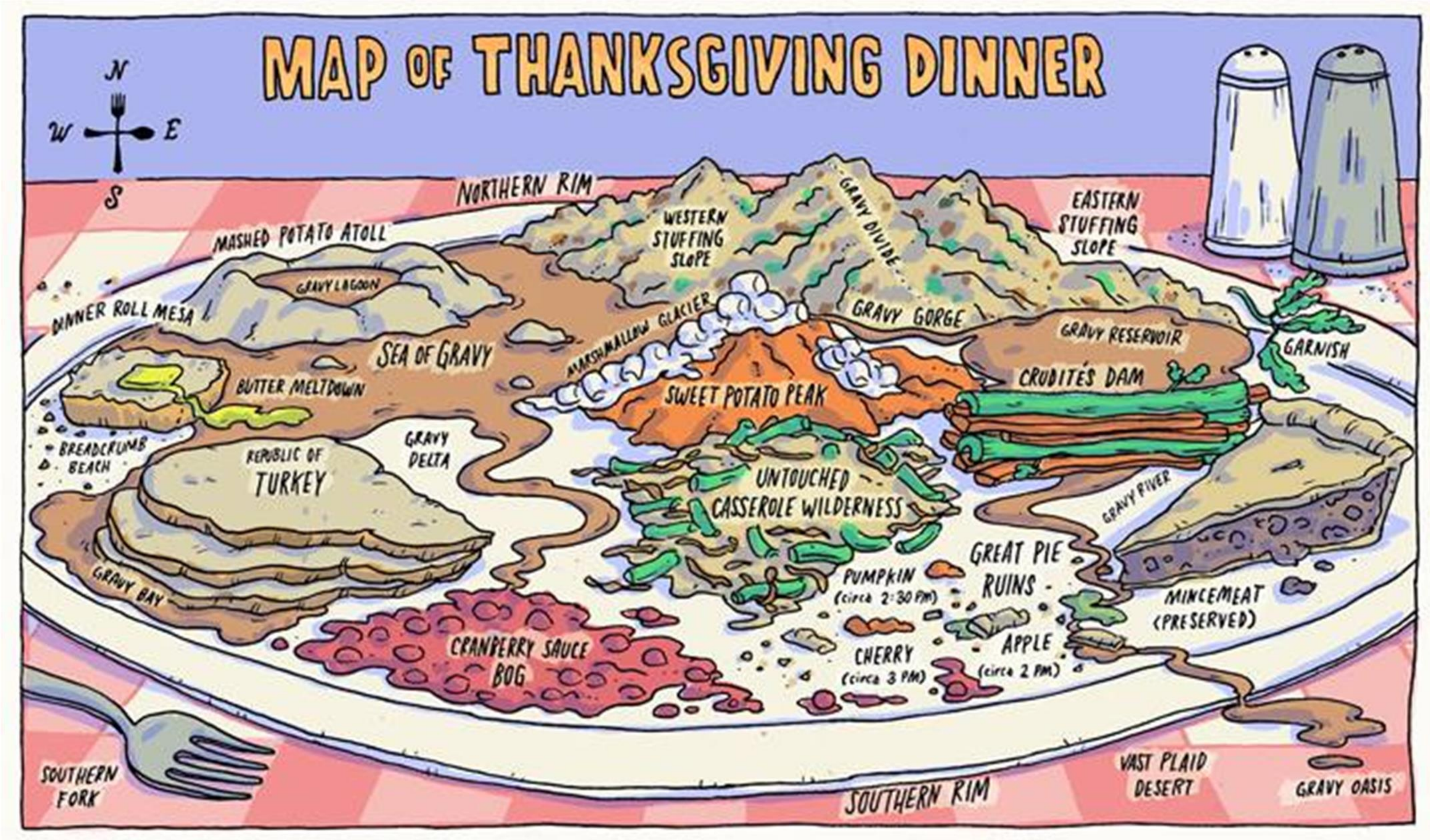
- PROTECTION WALLS
- NAILING
- GEOTEXTILING Were Recommended.

IN LAND SLIDE ZONES

- GULLY PLUGGING
- GULLY FILLED VEGETATION and
- AFFORESTATION Were Suggested.

IN LAND SLIP ZONES

- CONSTRUCTION OF PROTECTION WALLS
- FLATTENING OF TOES and
- GARLAND DRAINAGES Were Suggested.


MAP OF THANKSGIVING DINNER
N
W
E
S
NORTHERN RIM
MASHED POTATO ATOLL
GRAVY LAGOON
DINNER ROLL MESA
WESTERN STUFFING SLOPE
GRAVY DIVIDE
EASTERN STUFFING SLOPE
GRAVY GORGE
MARSHMALLOW GLACIER
SEA OF GRAVY
BUTTER MELTDOWN
GRAVY RESERVOIR
GARNISH
CRUDITÉS DAM
SWEET POTATO PEAK
BREADCRUMB BEACH
REPUBLIC OF TURKEY
GRAVY DELTA
UNTOUCHED CASSEROLE WILDERNESS
GRAVY RIVER
GREAT PIE RUINS
PUMPKIN (circa 2:30 PM)
GRAVY BAY
MINCEMEAT (PRESERVED)
CRANBERRY SAUCE BOG
CHERRY (circa 3 PM)
APPLE (circa 2 PM)
SOUTHERN FORK
VAST PLAID DESERT
SOUTHERN RIM
GRAVY OASIS