Bharathidasan University

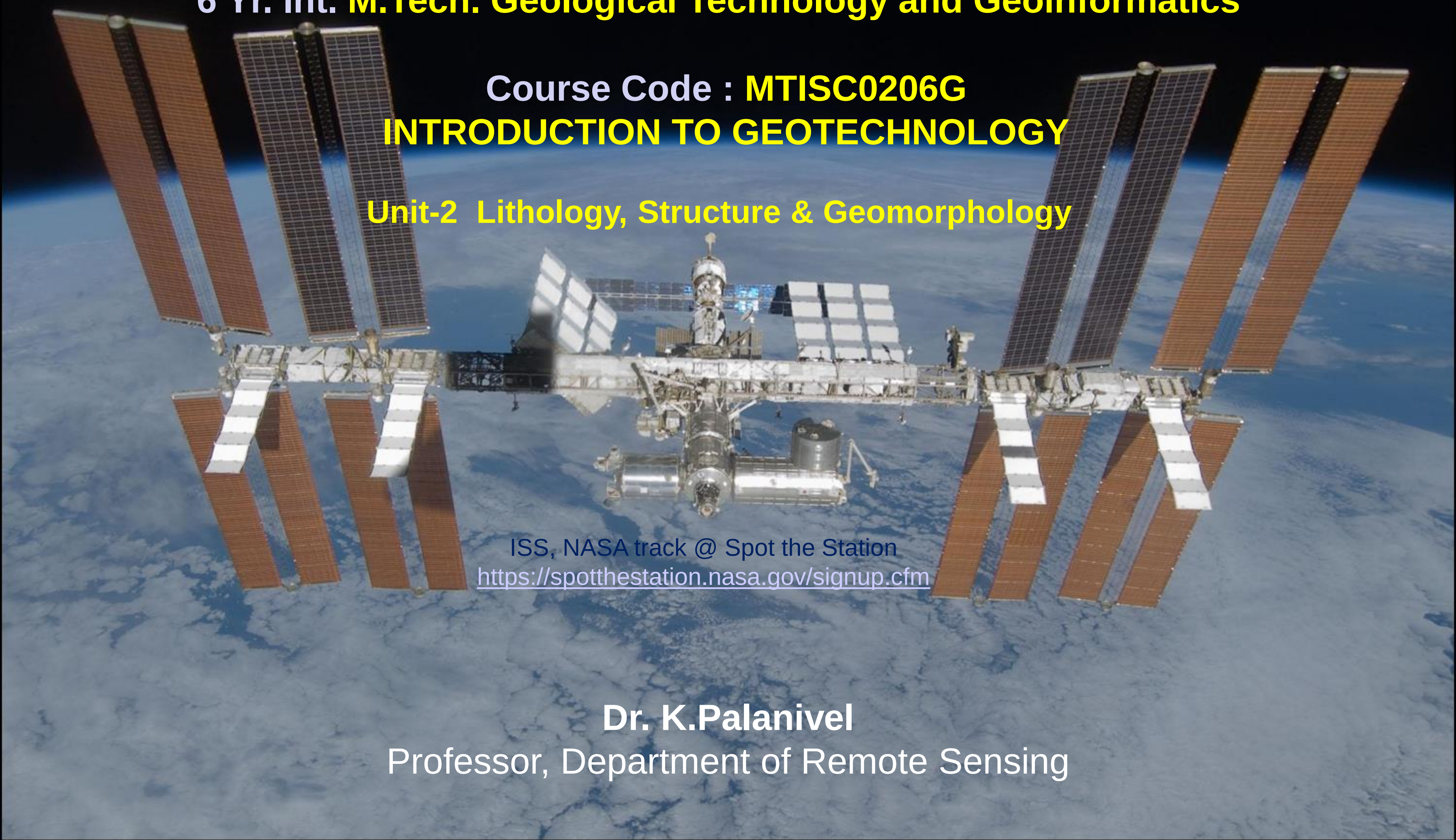
Tiruchirappalli – 620 023, Tamil Nadu

6 Yr. Int. M.Tech. Geological Technology and Geoinformatics

Course Code : MTISC0206G

INTRODUCTION TO GEOTECHNOLOGY

Unit-2 Lithology, Structure & Geomorphology



ISS, NASA track @ Spot the Station
https://spotthestation.nasa.gov/signup.cfm

Dr. K.Palanivel
Professor, Department of Remote Sensing

Course Objectives

- To know the content and familiarize the courses of this entire programme
- To study the basics and concepts of major disciplines in Geological Technology
- To understand the importance of Geoinformatics and its applications
- To learn the application of Geological Technology and Geoinformatics in natural resources mapping
- To learn the application of Geoinformatics in natural disaster mitigation.

MTISC-0206G - INTRODUCTION TO GEOTECHNOLOGY ---- 3 credits

1. Earth System Processes: 6hrs

Earth Sciences: Definition, Branches of Earth Sciences, Scope and importance of Earth Sciences

Earth System Processes: Origin, interior & age of the Earth – Plate tectonics – Formation of Continents & Oceans – Mountain building activities – origin of rivers – Physiography of the Earth.

2. Lithology, Structure, Geomorphology: 12hrs

Lithology: Rock forming minerals – Igneous, Sedimentary & Metamorphic Rocks – Stratigraphy.

Structure: Folds, faults, geotectonics and their significance.

Geomorphology: Various Geomorphic Processes – Regional Geomorphology of India – Geological Ecosystems.

3. Natural Resources and Disasters: 12hrs

Natural Resources: Mineral Provinces of India and exploration strategies – Hydrocarbon provinces of India and exploration strategies–Water Resources and exploration strategies. Soil, Forest & Biomass and Marine resources.

Natural Disasters: Geodynamic Processes and Natural Disasters (Seismicities – Landslides – Floods – Tsunami – Other Natural Disasters).

4. Remote Sensing Based Mapping: 12hrs

Aerial Remote Sensing – Satellite Remote Sensing Principles – Digital Image Processing concepts – GPS based mobile mapping principles – Image interpretation principles for Geotechnology.

5. Geoinformatics: 6hrs

Definition & Concepts – Input Sources (Satellite, Aerial & Ground based) - Computer based Geospatial data base generation – data modeling on Natural Resources, Eco Systems & Natural Disasters – Information Systems.

Course Outcomes

After the successful completion of this course, the students are able to:

- Create subject interest amongst the students joined in this programme and gain knowledge on variety of sub disciplines that they can choose for their future.
- Understand the scope and importance of the Geological Technology and Geoinformatics subjects.
- Provide a brief exposure to the course works of entire 6 year programme.
- Brief exposure to the advanced and computerized tools in Geoinformatics and their applications to Geology, Natural Resources and Natural Disasters.
- Understand the concepts of mapping using Remote Sensing Satellites, Aerial Photography and Digital Image Processing.
- Know the concepts of Geospatial / Geoinformatics Technology based database generation, modeling and information systems.

INTRODUCTION TO GEOTECHNOLOGY
UNIT – II LITHOLOGY, STRUCTURE, GEOMORPHOLOGY

2. Lithology, Structure, Geomorphology: 12 hrs.

Lithology: Rock forming minerals – Igneous, Sedimentary & Metamorphic Rocks – Stratigraphy.

Structure: Folds, faults, geotectonics and their significance.

Geomorphology: Various Geomorphic Processes – Regional Geomorphology of India – Geological Ecosystems.

LITHOLOGY

- Study of rock types exposed as outcrops on the surface of the Earth, their physical and chemical characters and represent their spatial distribution horizontally in a map or vertically in a graph is known as lithology.

- Rocks are composed of one or several rock forming minerals / crystals – mostly of Silicates of Aluminium, Sodium, Calcium, Potassium, etc.

- Other rock forming minerals are: Oxides, Sulphides, Carbonates, etc.

Minerals:

- Mineral is a naturally occurring inorganic solid substance that is characterized with a definite chemical composition and very often with a definite atomic structure.

- In nature more than two thousand minerals are known to occur.

- These minerals generally occur in group and form a rock.

How does the crystals/minerals formed?

Igneous

Evaporites

Sublimates / Fumeroles

- **Crystals** are formed either from magma, solution or vapour saturated with a chemical compound at slow decreasing of temperature and pressure conditions.

- **Crystalline rock** masses have consolidated from aqueous solution or from molten magma.

- The vast majority of igneous rocks belong to this group and the degree of crystallization depends primarily on the conditions under which they solidified.

Rock forming minerals :

- The common minerals that constitute the main composition of the rock are called rock forming minerals.

- Though there are thousands of minerals only few minerals form the great bulk of the rocks of the crust of the earth.

- Even among this only 25% or so make up almost 99.5% of common rocks.

- There are three groups which covers most of the common rock forming minerals.
  - Silicates
  - Oxides
  - Carbonates

SILICATE MINERALS

- FELDSPAR GROUP
- PYROXENE GROUP
- AMPHIBOLE GROUP
- MICA GROUP …

Common Elements in Earth's Crust

ELEMENT	SYMBOL	PERCENTAGE OF CRUST (by weight)	PERCENTAGE OF CRUST (by atoms)
Oxygen	O	46.6%	62.6%
Silicon	Si	27.7	21.2
Aluminum	Al	8.1	6.5
Iron	Fe	5.0	1.9
Calcium	Ca	3.6	1.9
Sodium	Na	2.8	2.6
Potassium	K	2.6	1.4
Magnesium	Mg	2.1	1.8
All others		1.5	0.1

OXIDE MINERALS – Magnetite, Haematite…

CARBONATE MINERALS – Magnesite, Calcite…

MINERALS of SULFATES, SULPHIDES, PHOSPHATES, HALIDES, etc.,

Rock-Forming Minerals

MINERAL	COMPOSITION	PRIMARY OCCURRENCE
Ferromagnesian silicates		
Olivine	$(Mg,Fe)_2SiO_4$	Igneous, metamorphic rocks
Pyroxene group		
Augite most common	Ca, Mg, Fe, Al silicate	Igneous, metamorphic rocks
Amphibole group		
Hornblende most common	Hydrous* Na, Ca, Mg, Fe, Al silicate	Igneous, metamorphic rocks
Biotite	Hydrous K, Mg, Fe silicate	All rock types
Nonferromagnesian silicates		
Quartz	SiO_2	All rock types
Potassium feldspar group		
Orthoclase, microcline	$KAlSi_3O_8$	All rock types
Plagioclase feldspar group	Varies from $CaAl_2Si_2O_8$ to $NaAlSi_3O_3$	All rock types
Muscovite	Hydrous K, Al silicate	All rock types
Clay mineral group	Varies	Soils and sedimentary rocks
Carbonates		
Calcite	$CaCO_3$	Sedimentary rocks
Dolomite	$CaMg(CO_3)_2$	Sedimentary rocks
Sulfates		
Anhydrite	$CaSO_4$	Sedimentary rocks
Gypsum	$CaSO_4 \cdot 2H_2O$	Sedimentary rocks
Halides		
Halite	NaCl	Sedimentary rocks

*Contains elements of water in some kind of union.

SILICATE GROUP:

- About 92% of the earth crust is made up of silicates

- Most common silicate minerals are made up of chiefly a few of the following nine elements (Na, K, AL, Ca, Mg, Fe, Li, Si and O) ----- SiO_4 Tetrahedron

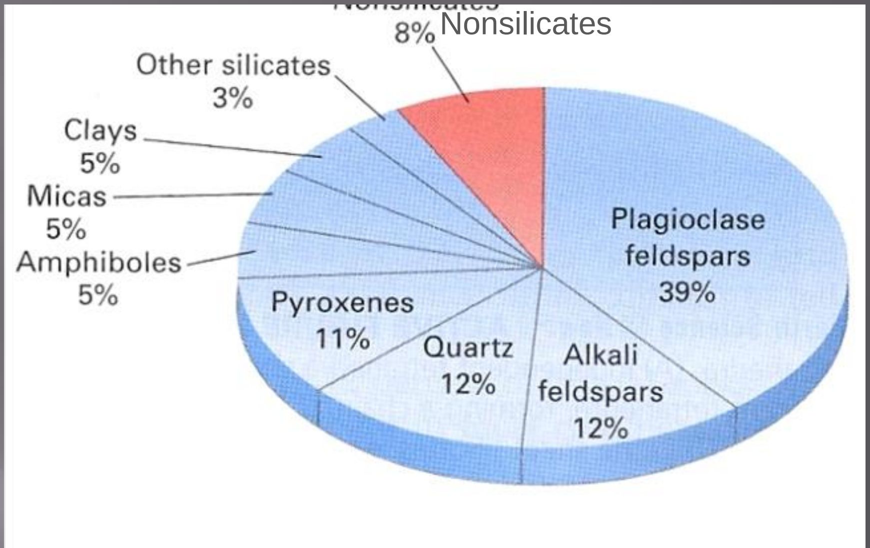


Figure 2.16 The silicate minerals compose 92 percent of the Earth's crust. Feldspar alone makes up about 50 percent of the crust, and pyroxene and quartz constitute another 23 percent. *Source:* Modified from Klein, *Manual of Mineral Science*, 22nd ed., John Wiley & Sons, Inc, 2002

- It can be an independent tetrahedron or doubly linked tetrahedron and complex-linked tetrahedron. ----- Chain structures, sheet structures and network structures

Table 2–5 Common rock-forming silicate minerals

Silicate mineral	Composition	Physical properties
Quartz	Silicon dioxide (silica, SiO_2)	Hardness of 7 (on scale of 1 to 10); will not cleave (fractures unevenly); specific gravity: 2.65
Potassium feldspar group	Aluminosilicates of potassium	Hardness of 6.0–6.5; cleaves well in two directions; pink or white; specific gravity: 2.5–2.6
Plagioclase feldspar group	Aluminosilicates of sodium and calcium	Hardness of 6.0–6.5; cleaves well in two directions; white or gray; may show striations on cleavage planes; specific gravity: 2.6–2.7
Muscovite mica	Aluminosilicates of potassium with water	Hardness of 2–3; cleaves perfectly in one direction, yielding flexible thin plates; colorless; transparent in thin sheets; specific gravity: 2.8–3.0
Biotite mica	Aluminosilicates of magnesium, iron, potassium, with water	Hardness of 2.5–3.0; cleaves perfectly in one direction, yielding flexible thin plates; black to dark brown; specific gravity: 2.7–3.2
Pyroxene group	Silicates of aluminum, calcium, magnesium, and iron	Hardness of 5–6; cleaves in two directions at 90°; black to dark green; specific gravity: 3.1–3.5
Amphibole group	Silicates of aluminum, calcium, magnesium, and iron	Hardness of 5–6; cleaves in two directions at 56° and 124°; black to dark green; specific gravity: 3.0 3.3
Olivine	Silicate of magnesium and iron	Hardness of 6.5–7.0; light green; transparent to translucent; specific gravity: 3.2–3.6
Garnet group	Aluminosilicates of iron, calcium, magnesium, and manganese	Hardness of 6.5–7.5; uneven fracture, red, brown, or yellow; specific gravity: 3.5–4.3

CLASSIFICATION OF ROCK TYPES

Rocks

Igneous ***Sedimentary*** ***Metamorphic***

IGNEOUS ROCKS

Definition:

"These are the rocks formed by the solidification of Magma either underneath the surface or above it"

"All the rocks that have formed from an originally hot molten material (Magma) through the process of cooling and crystallization".

Magma - Hot molten material occurring naturally below the earth surface.

Lava - Erupted hot molten material (Magma)

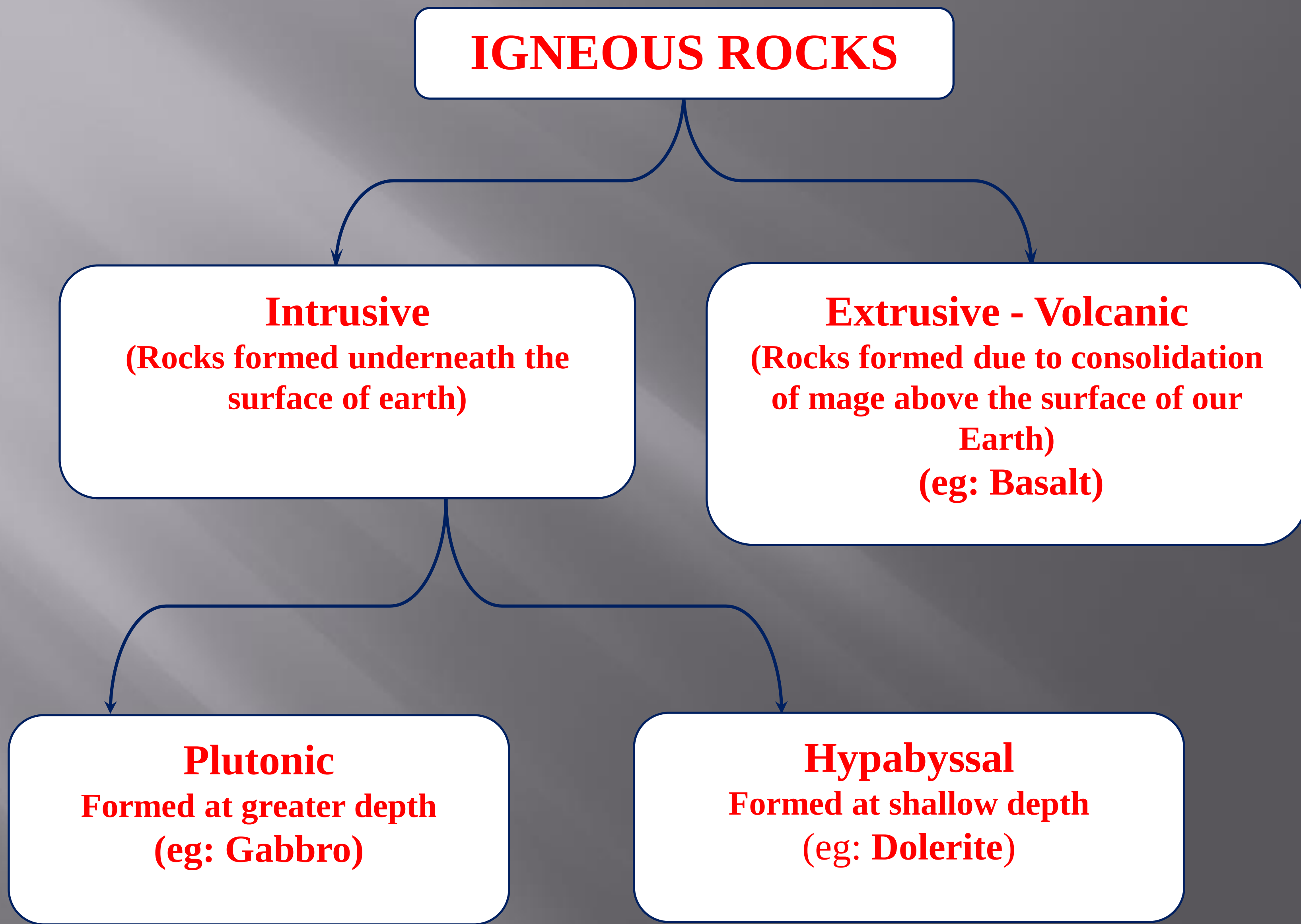
- Magma can exist as a melt as long as physical and chemical environment surrounding it remains unchanged.

- If there is a change in temperature and pressure due to its upward movement – cooling and crystallization takes place.

- Both Magma and Lava become igneous rock on cooling.

Magma Characteristics:

- Rocks are in hot molten stage
- Formed at greater depth
- Formed due to high temperature
  - Due to rise in temperature with depth
  - Radioactive material and related temperature
- Dominantly of melt with little crystalline or solid fraction and gaseous fraction
- Magma is a mobile melt so it is able to move upward and get consolidated.


IGNEOUS ROCKS
Intrusive
(Rocks formed underneath the surface of earth)
Extrusive - Volcanic
(Rocks formed due to consolidation of mage above the surface of our Earth)
(eg: Basalt)
Plutonic
Formed at greater depth
(eg: Gabbro)
Hypabyssal
Formed at shallow depth
(eg: Dolerite)

Plutonic rocks:

- Formed at considerable depths – generally 7 – 10 kms below the surface
- Very slow rate of cooling
- So coarse grained
- Exposed at the surface due to erosion of the overlying strata and Plate Tectonic upliftments.

Photograph of Quartz porphyry from the island of Alnö, Sweden. Phenocrysts of clear glassy rounded quartz and white orthoclase feldspar are set in a fine-grained matrix. Sample is just over 10 cm long – Source: Wikipedia

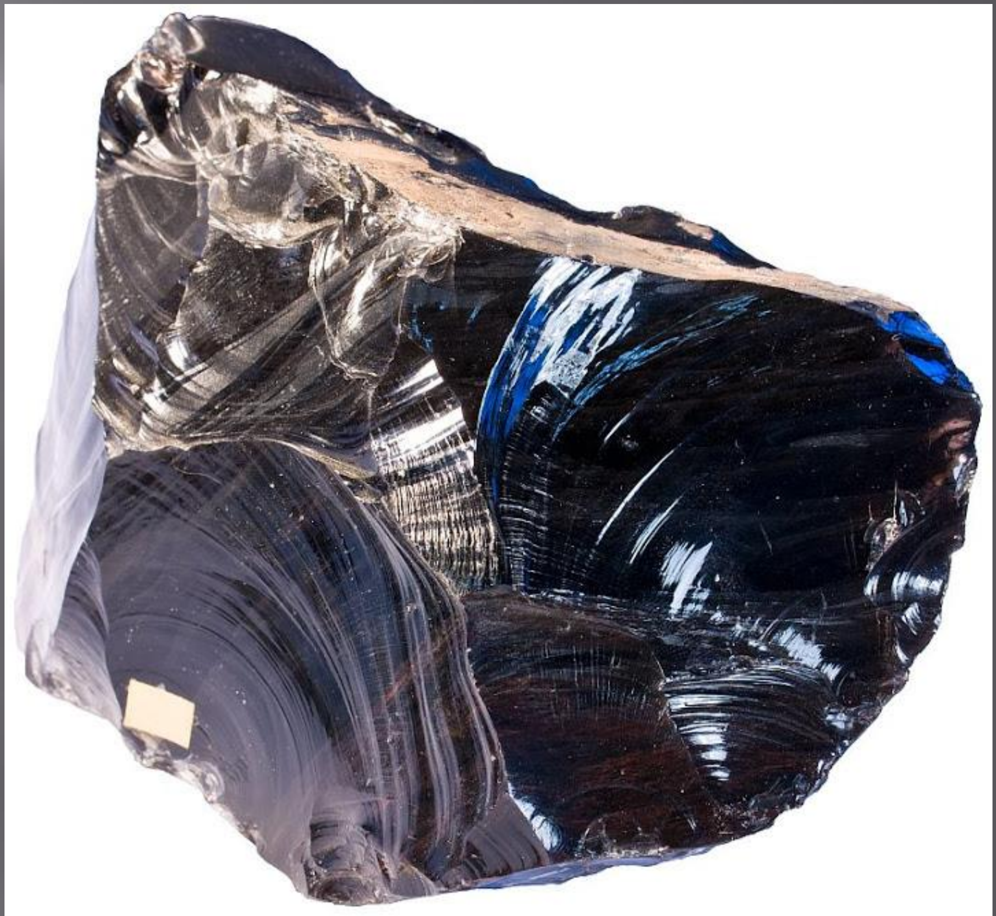
Volcanic rocks:

- Formed at surface of the earth

- Very fast cooling rate because of atmosphere and water contact. (sudden chilling)

- So very fine grained or even glassy

Obsidian



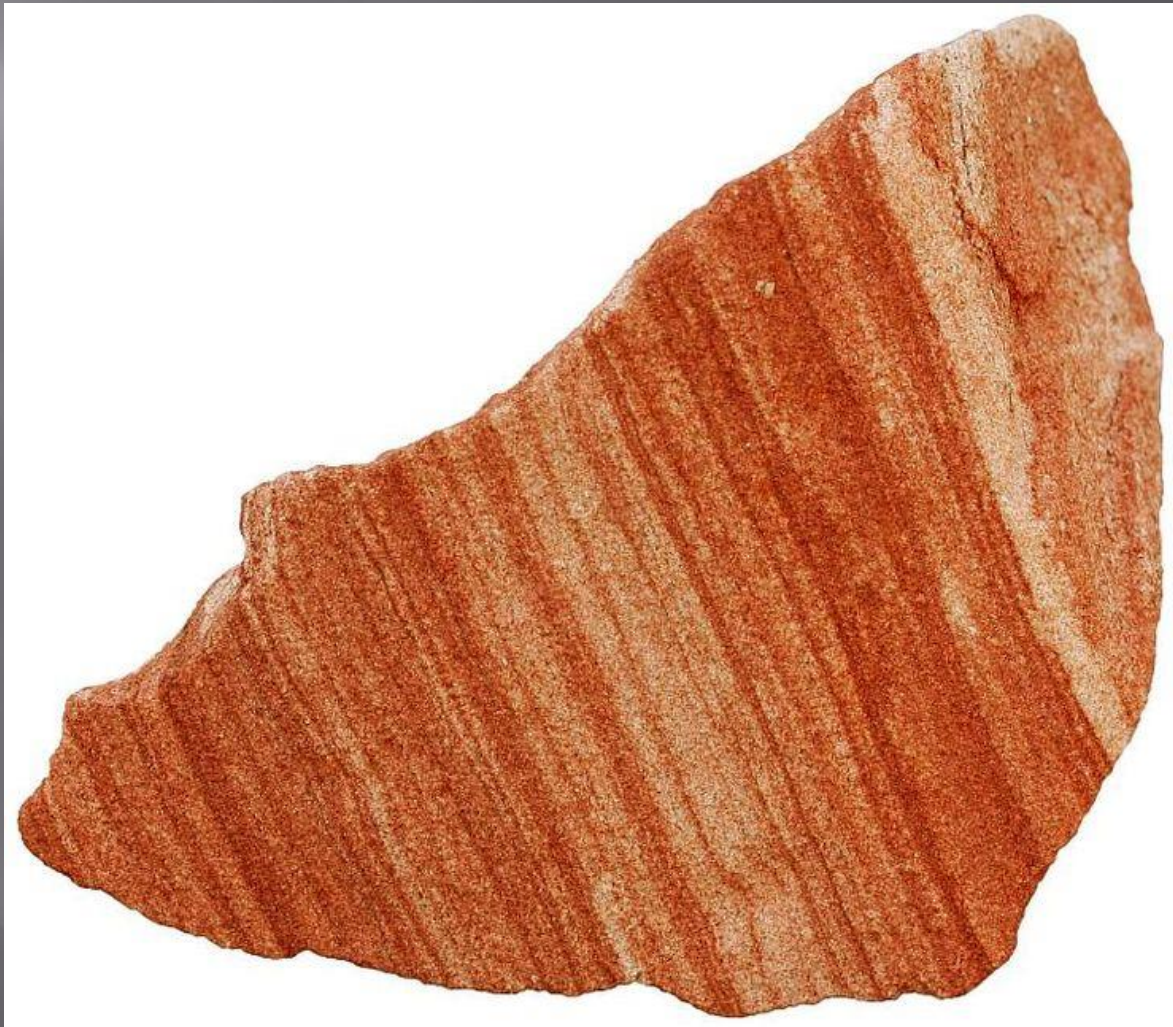
SEDIMENTARY ROCKS

Rocks formed from the consolidation of sediments due to pressure.

Classified as clastic and non-clastic rocks.

These rocks will depict layering, sedimentary structures and textures

Sandstone



METAMORPHIC ROCKS

Hornfels

Rocks that are formed due to deformation of preexisting rocks or sediments under high pressure and temperature conditions.

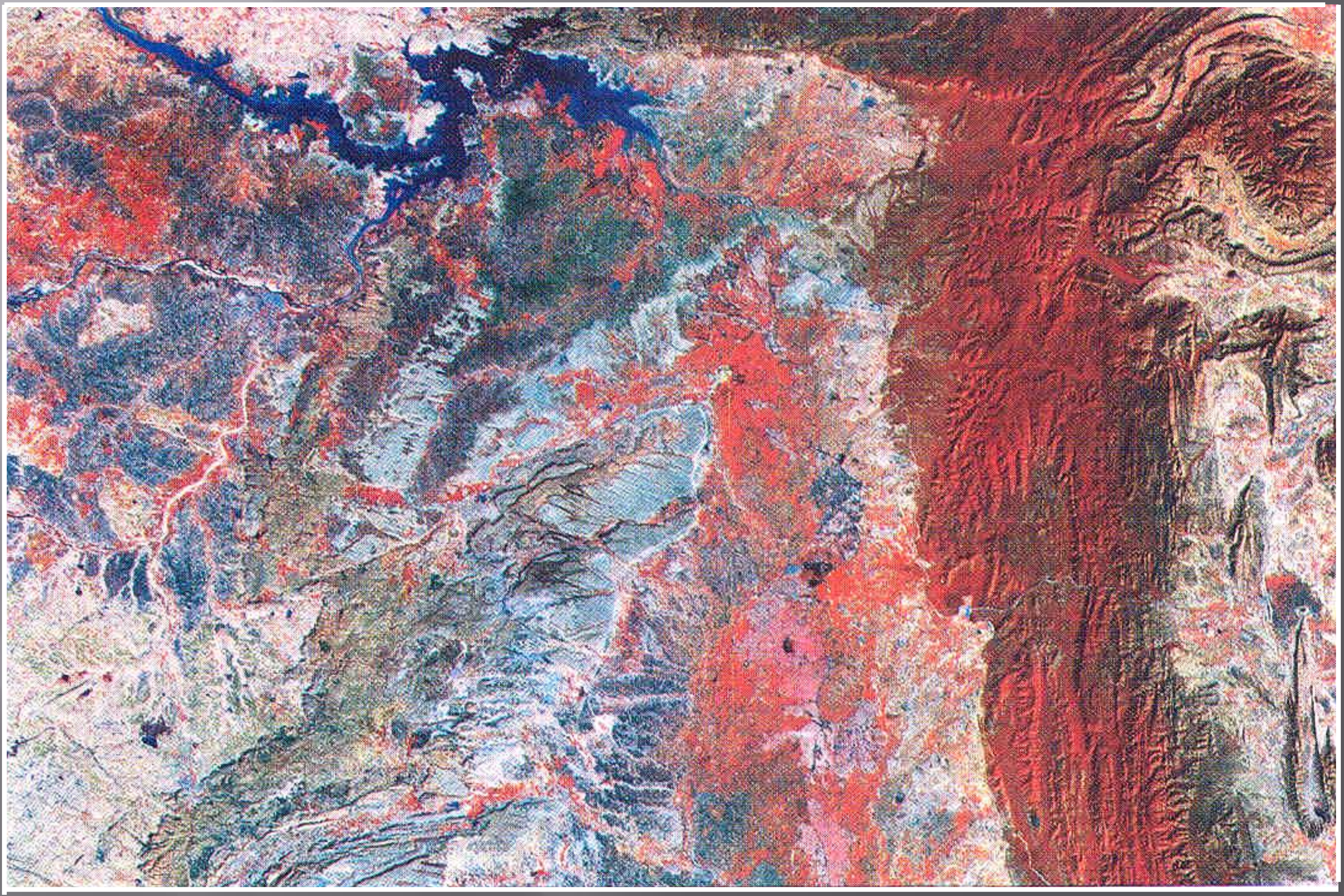
Melting / partial melting with recrystallization of minerals and ultimately deformed rocks will be formed.

Generally these rocks will depict gneissose or schistose structures with alteration rims.

LITHOLOGICAL STUDIES

GINGEE GRANITE

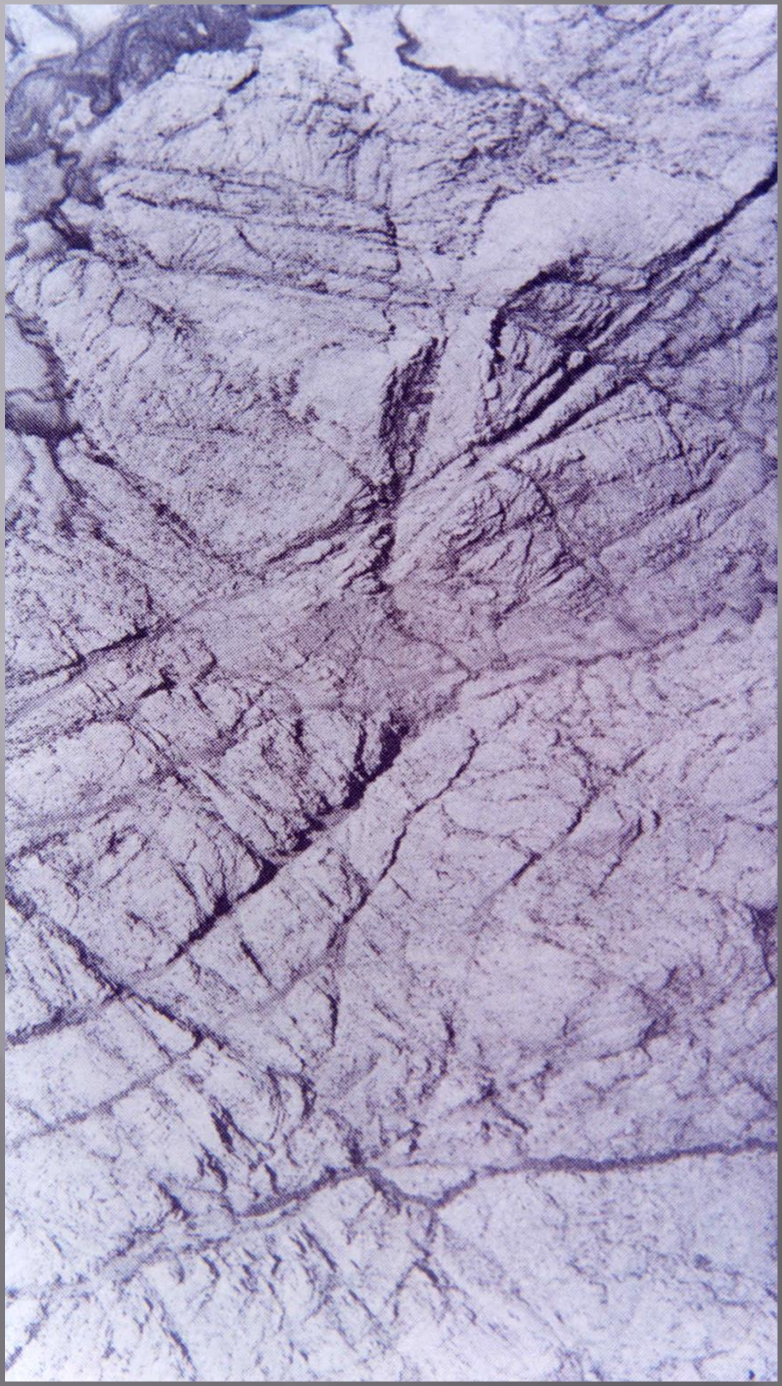
LISS III – CUDDAPAH BASIN



METAMORPHIC TERRAIN

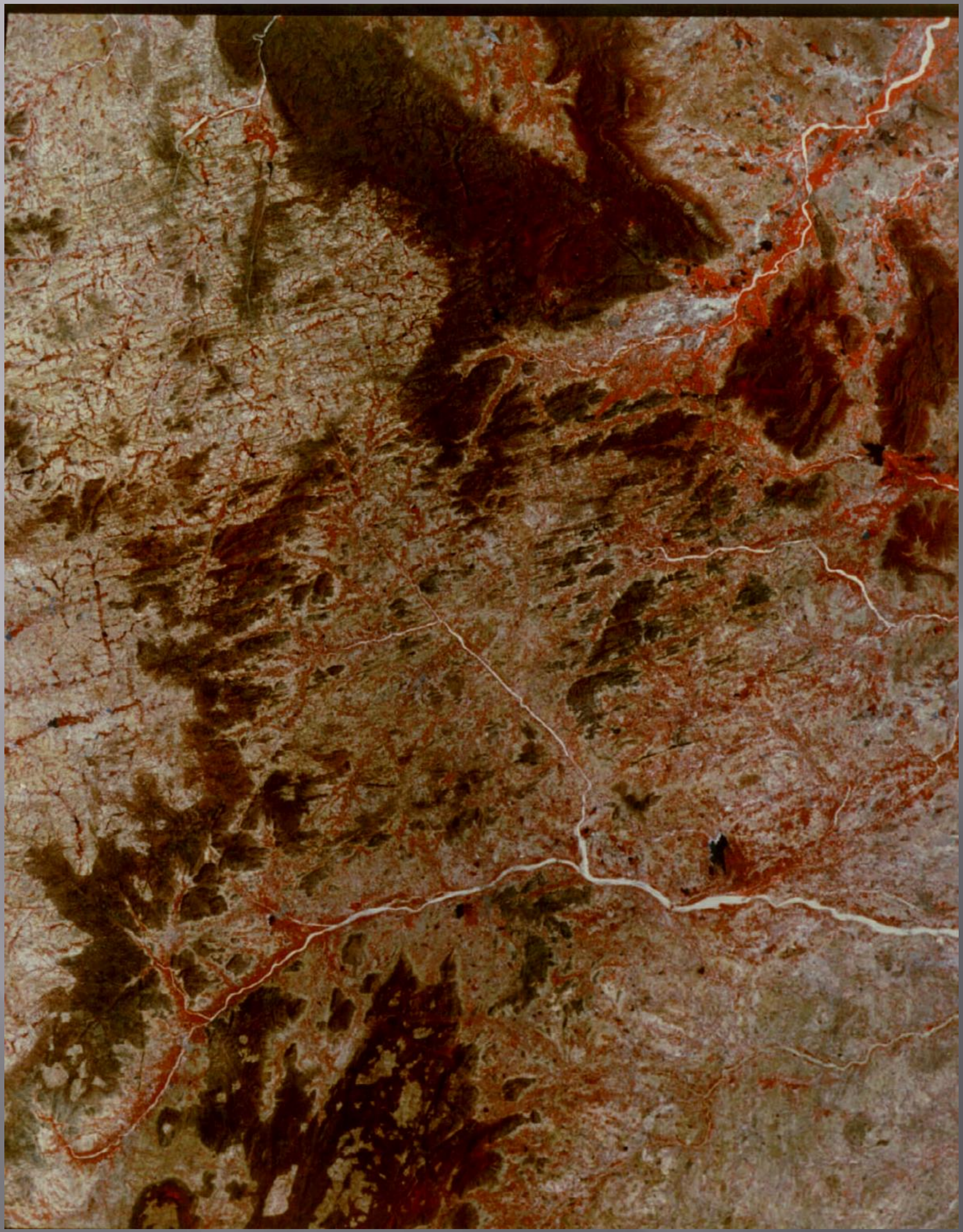
LITHOLOGICAL INTERPRETATION

- ***Land form***
  - ❖**Strength of morphological out look**
  - ❖**Relation to climatological Conditions**
  - ❖**Stages of geomorphological development**
  - ❖**Mode of occurrences**
- ***Drainage***
  - ❖**Pattern**
  - ❖**Texture**
- ***Tone***
  - ❖**In Non Vegetated area**



Granite in arid terrain

Basaltic flow



Dyke swarms

SEDIMENTARY ROCKS

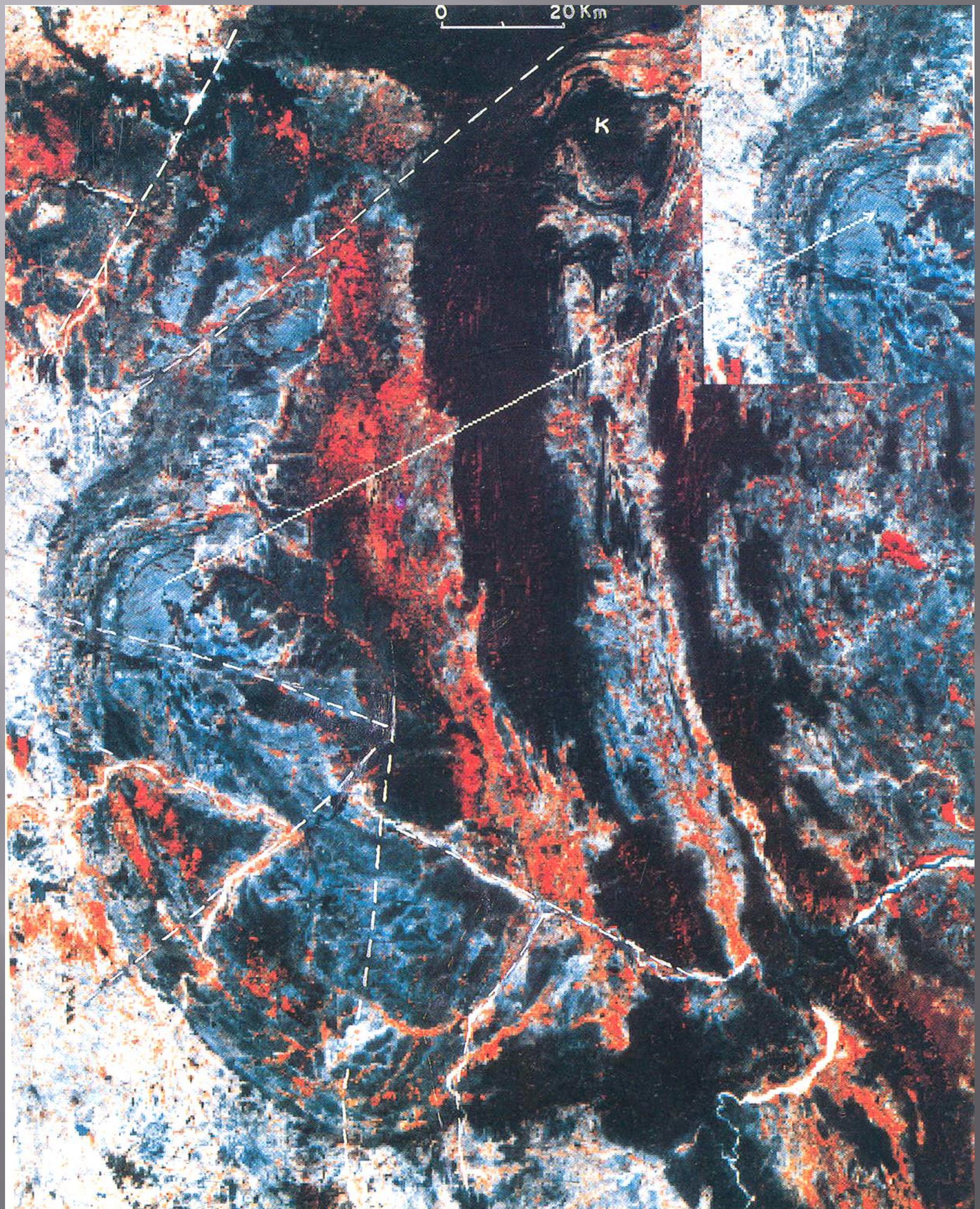
CONSOLIDATED SEDIMENTS

- ❖Differential resistance to erosion
- ❖Tonal contrast
- ❖Difference in permeability-related drainage
- ❖Geomorphic features(Cuesta hills, plateau tops)

UNCONSOLIDATED SEDIMENTS

- ❖Land Forms: Dune, Alluvial plains

  Alluvial fans, terraces.
- ❖Drainages:



CUDDAPAH BASIN

WiFs FCC -

CUDDAPAH BASIN

IRS-1C LISS III

A-Paniam qtz

B-Owk shale

C-Nargi L.st

D-Banganpalli SST

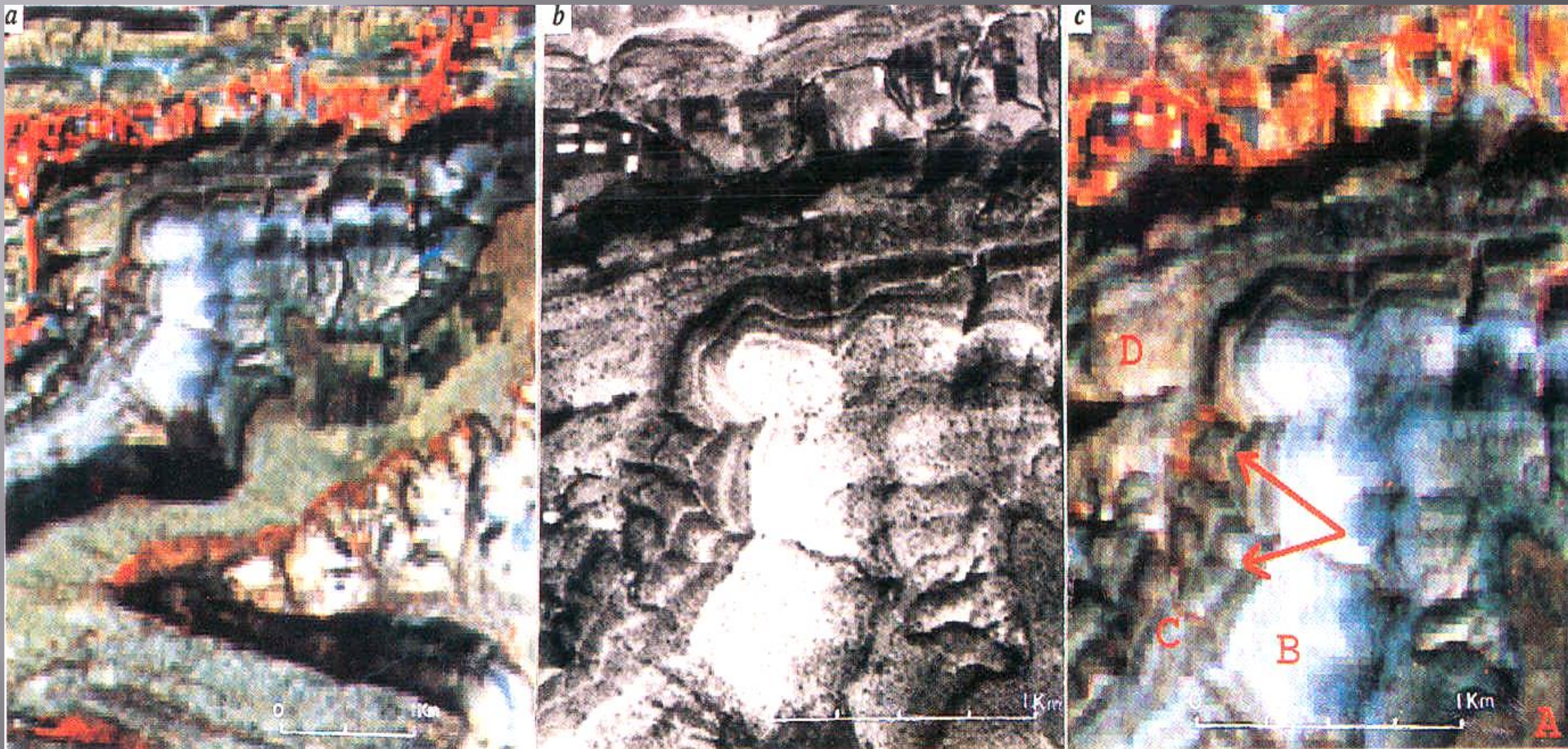
E-Tadpatri shale

F-Basic sills

T-Dip facet

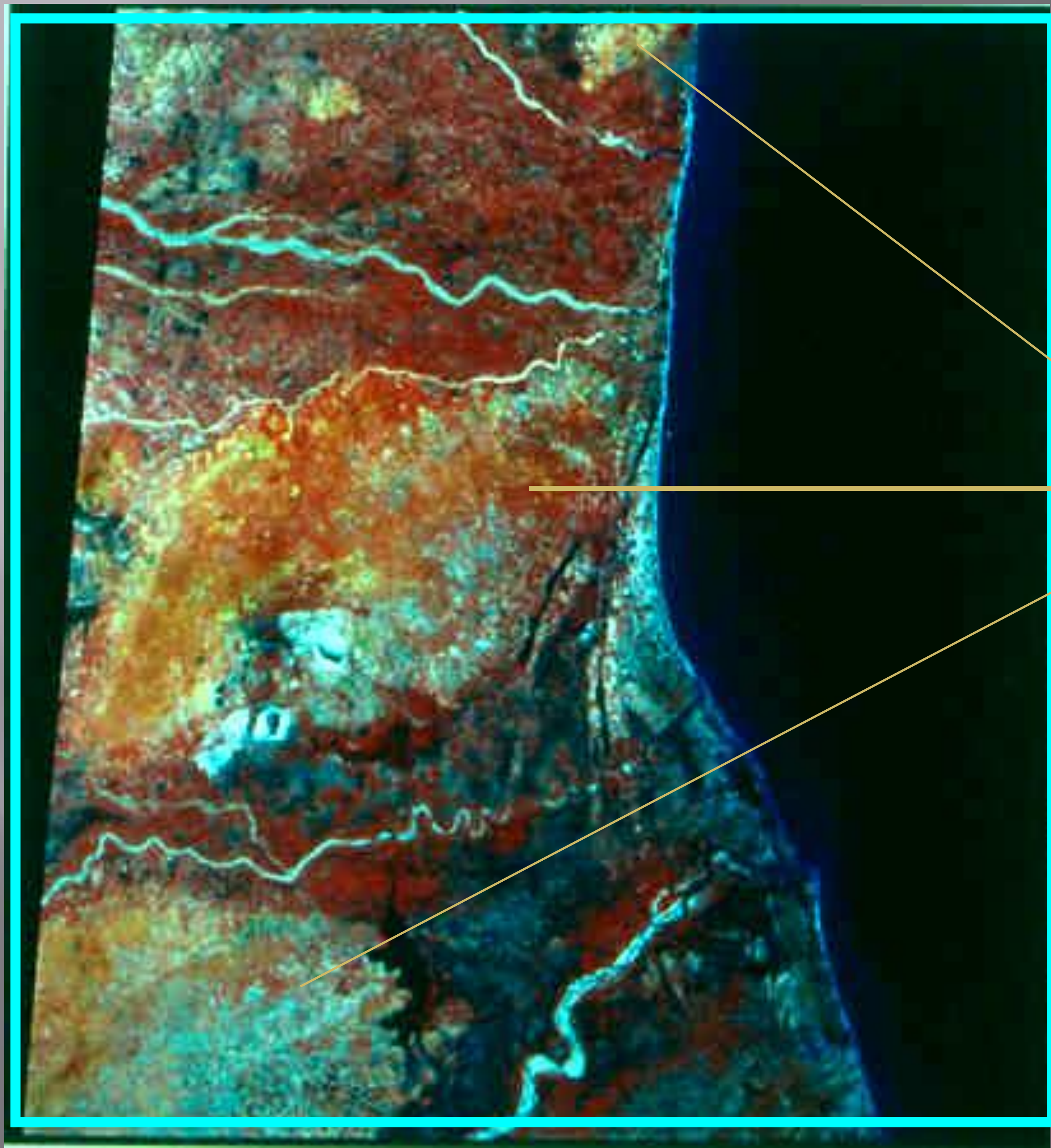
SF- Scarp face

CUDDAPAH BASIN



a b c

IRS-1C - a)FCC 432, b) Pan c)FCC – LISS III (43=RG) & Pan (Blue)



Tertiary S.St

METAMORPHIC ROCKS

More difficult

Significant: Structural features

a. Bedding- Flat, moderate,steep

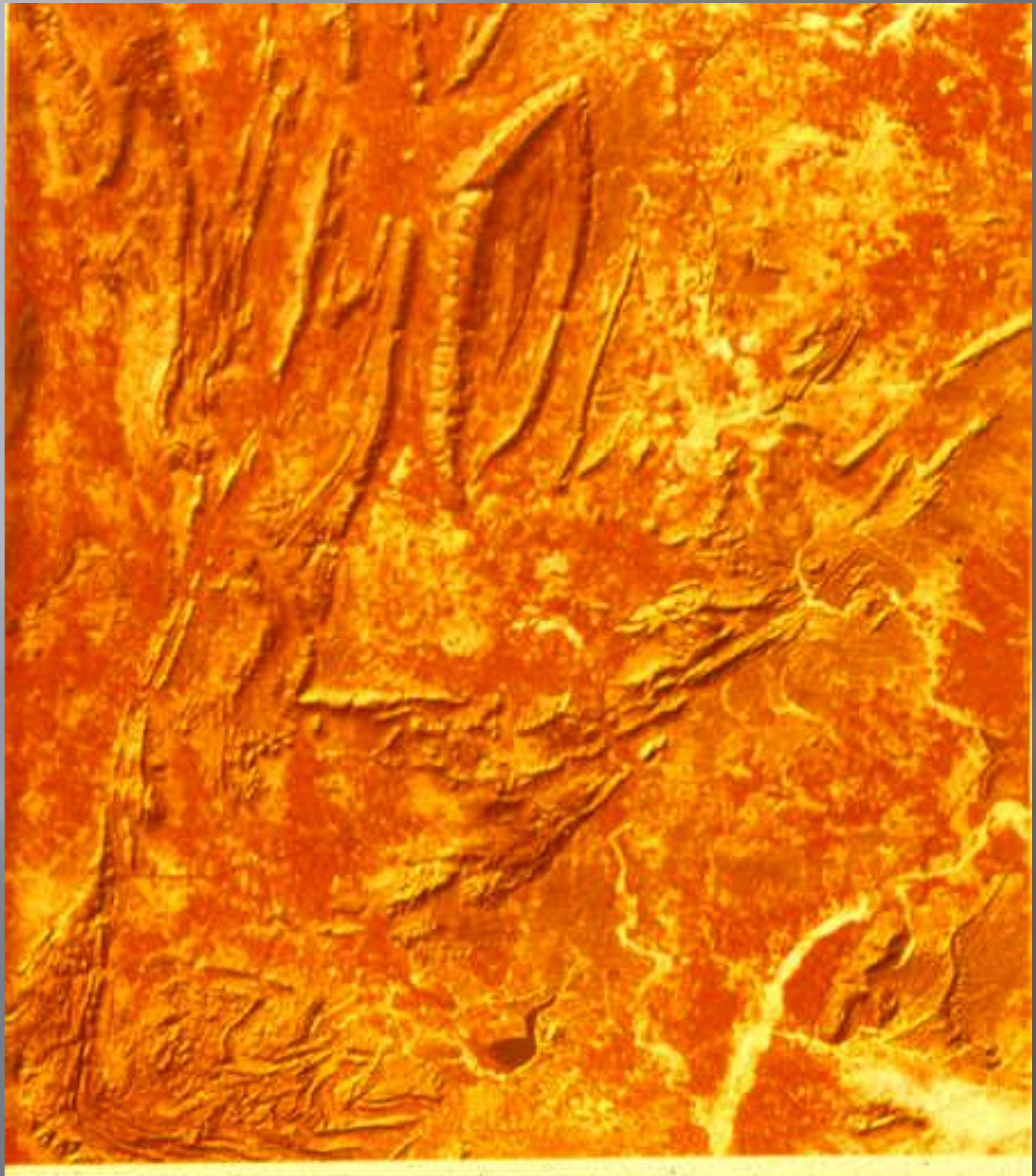
b. Folds, faults, joints

Land forms: Generally alternating ridges & valleys

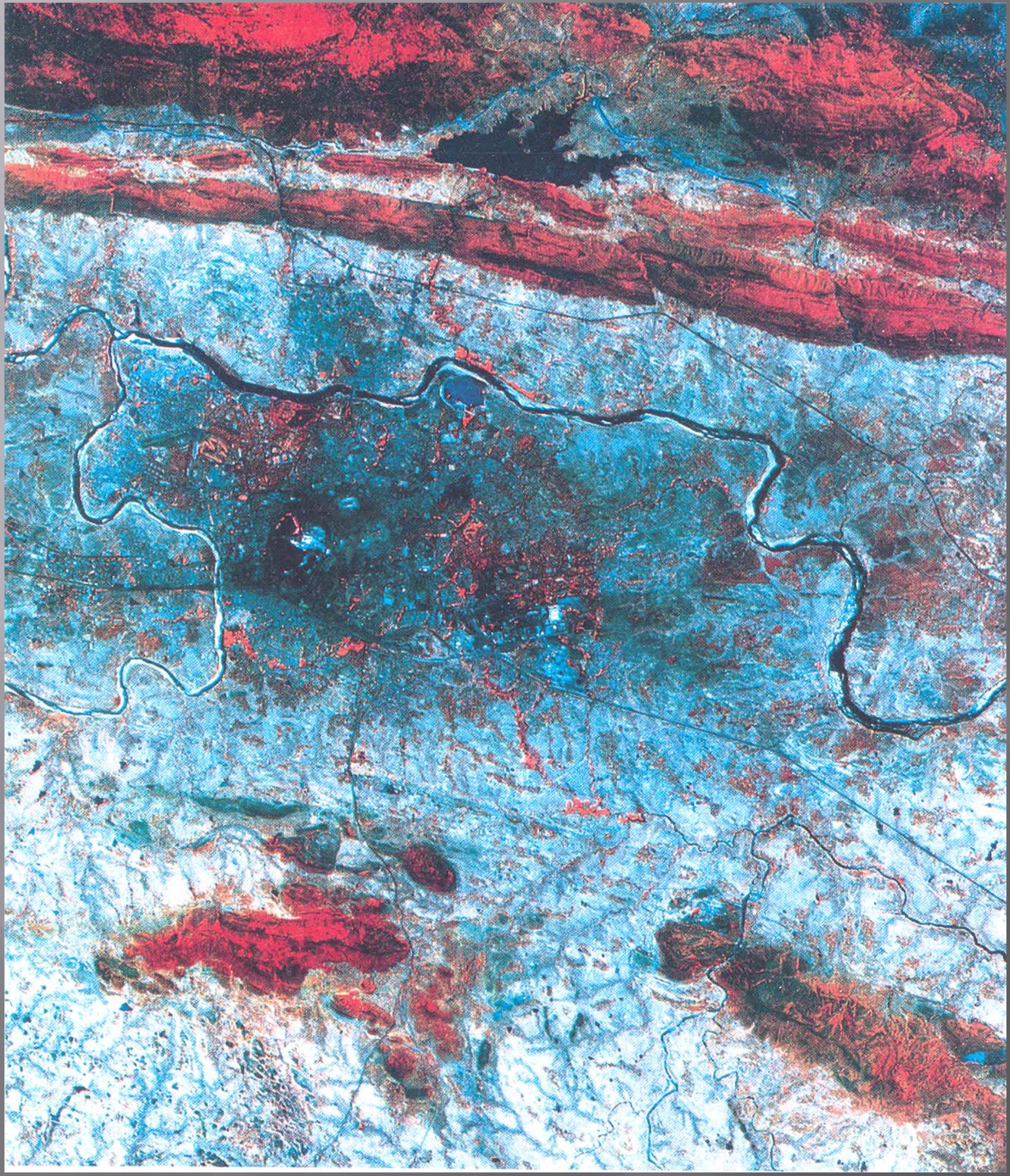
Drainage : Generally parallel with dendritic and trellis

IRS 1C – ARAVALLI

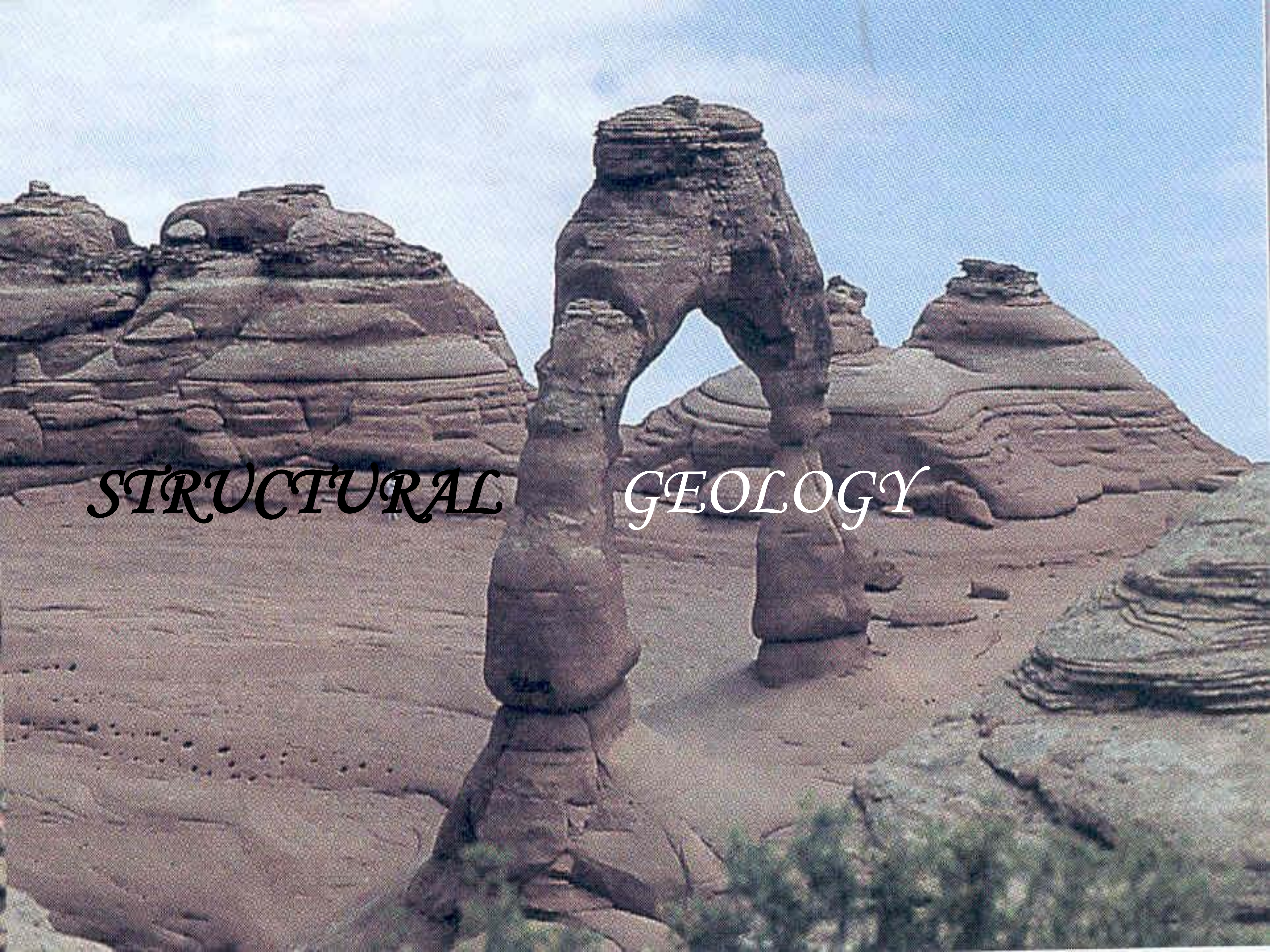
Eastern ghats



ALWAR Quartzites



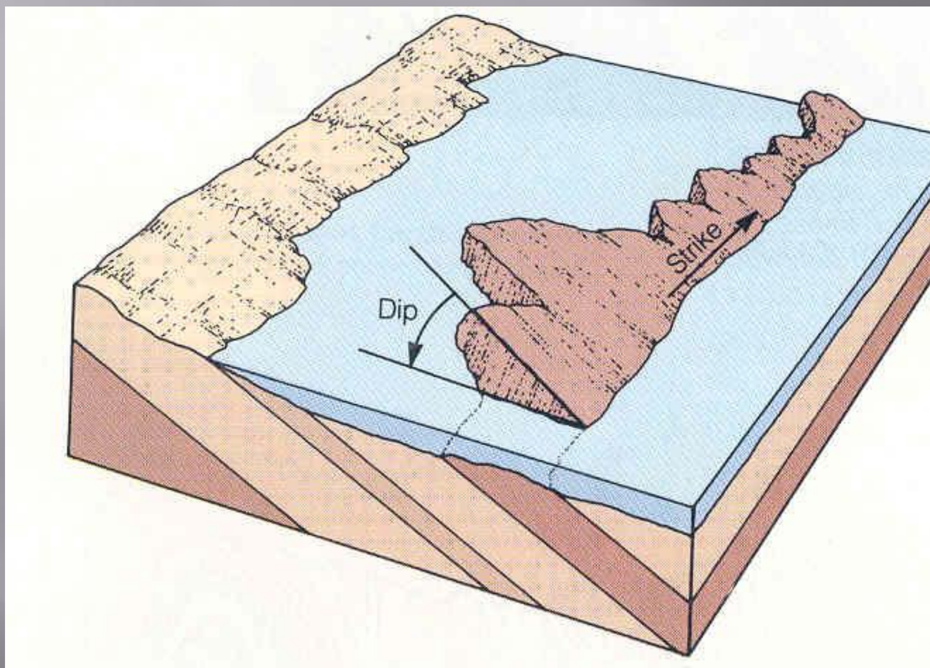
LISS III – JAMSHEDPUR

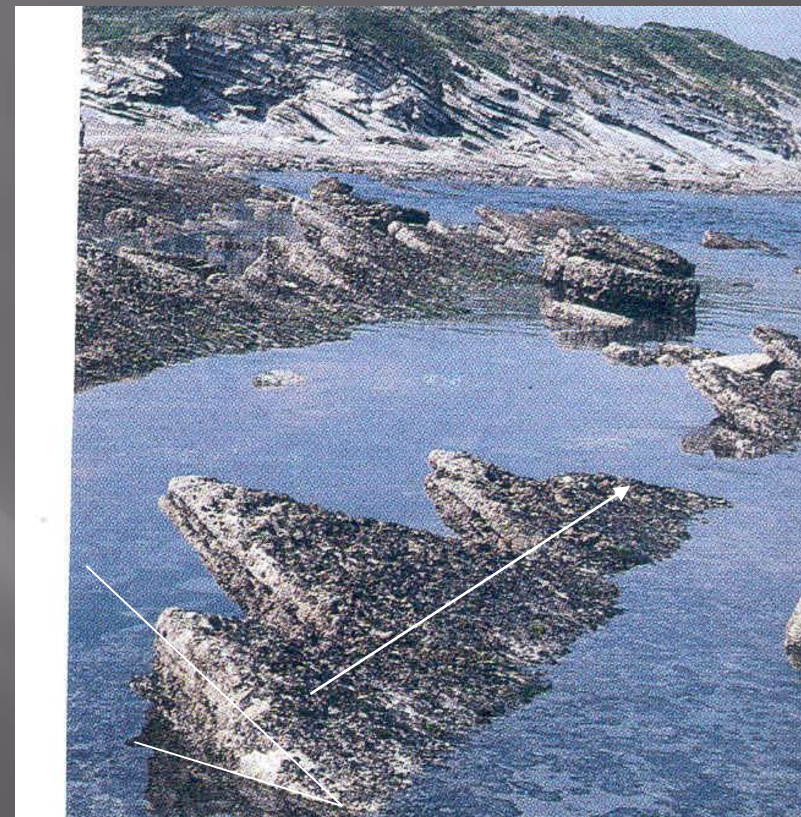

STRUCTURAL GEOLOGY

STRUCTURE

- SCIENTIFIC STUDY OF GEOLOGICAL STRUCTURES, THEIR FORMATION, IMPORTANCE IS KNOWN AS STRUCTURAL GEOLOGY
- Folds, faults, geotectonics and their significance
- Folds and Faults are very important for the occurrence of variety of natural resources
- At the same time they help us in identifying and delineating disaster hazard zones
- Tectonic history of terrain can be easily understood by studying these structures and the formation

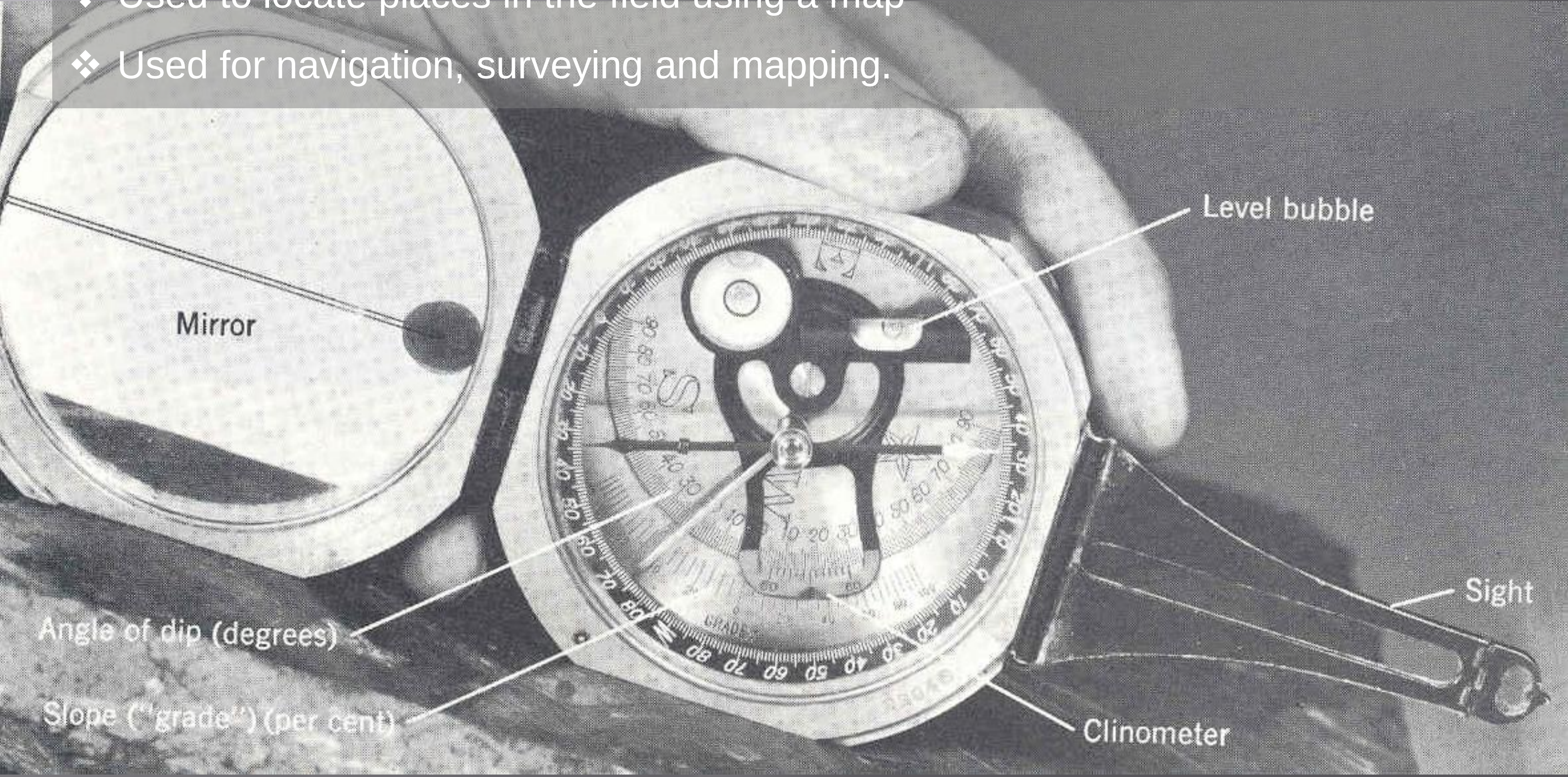
Horizontal bedding

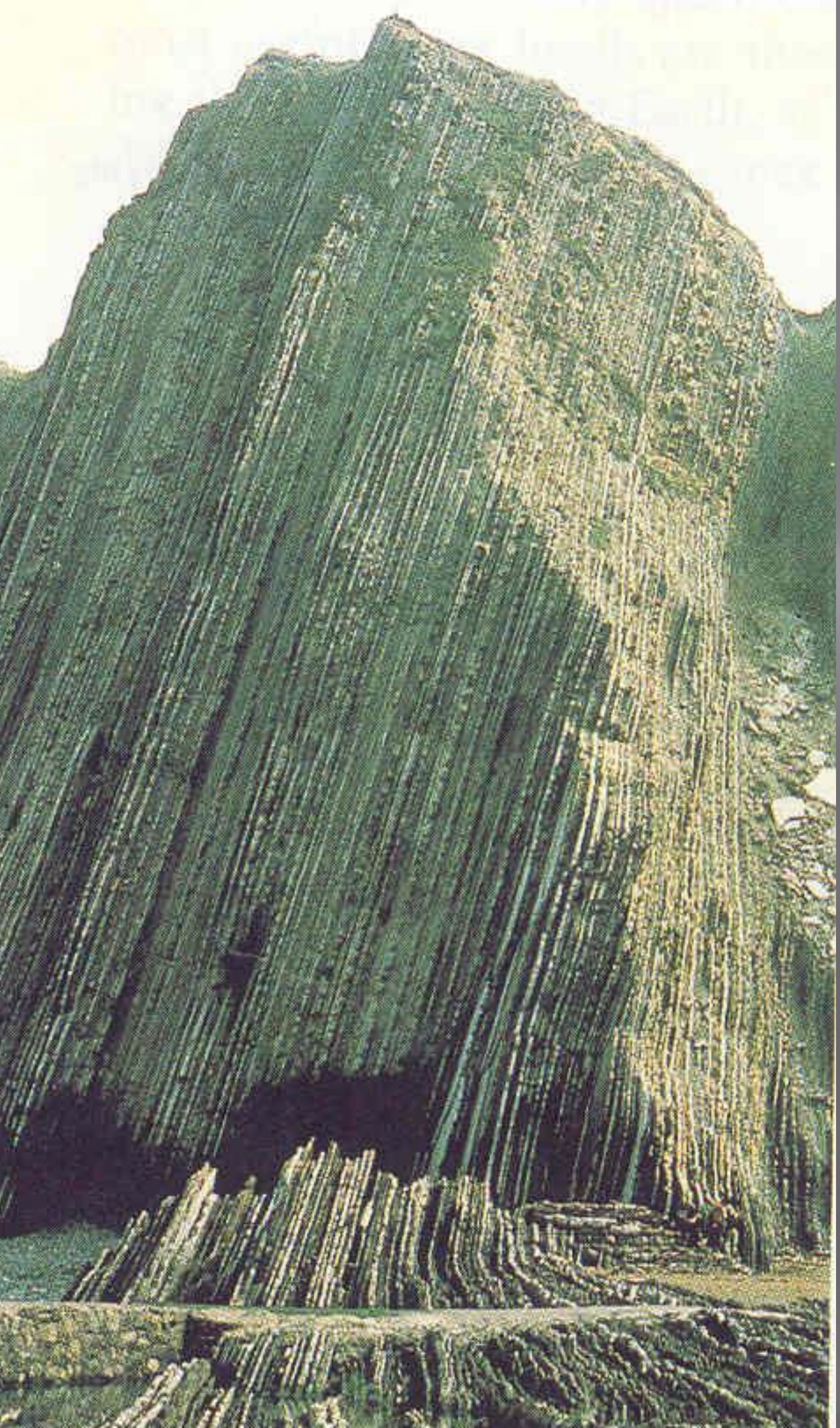

Dip
Strike



Brunton Compass

- Used in field to measure attitudes of formations such as, Strike of the formation, Dip direction and amount of dip the formation, so as to understand the structural features of formations such as **anticline, syncline, basin, dome, doubly plunging syncline….Anticlinorium, Synclinorium & Faults - Normal fault, Reverse Fault,** ….
- Used to locate places in the field using a map
- Used for navigation, surveying and mapping.



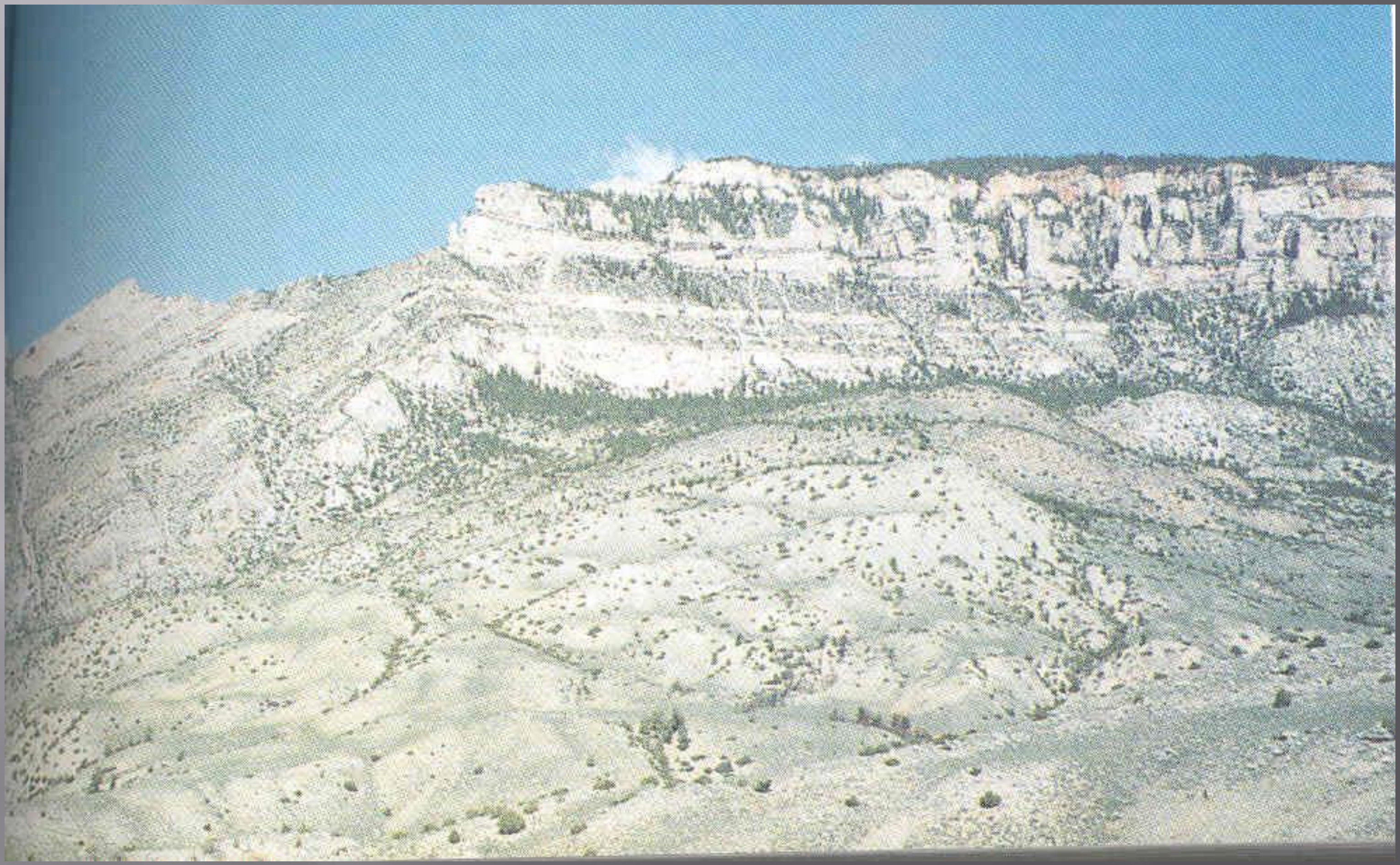


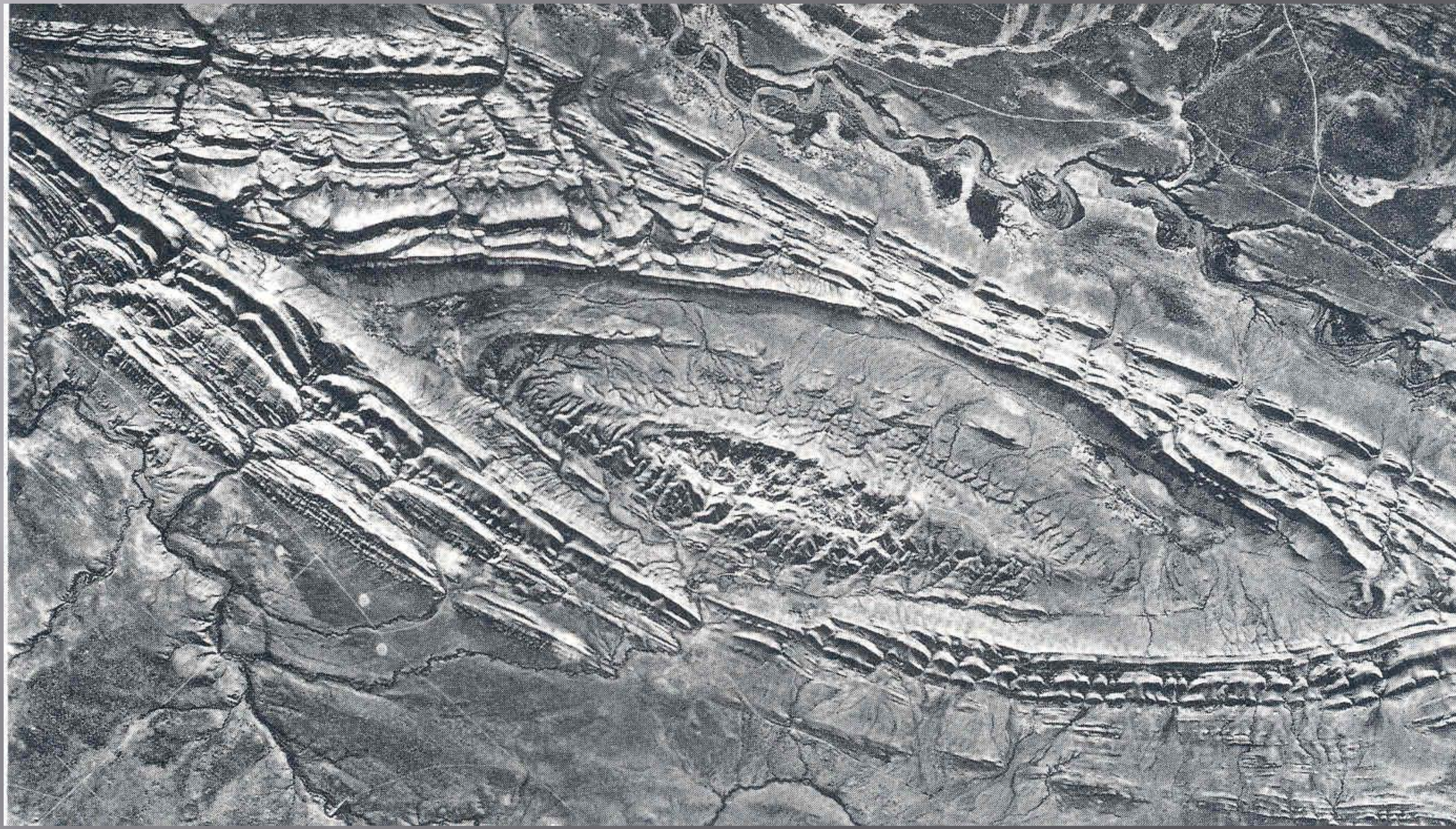
Inclined beds

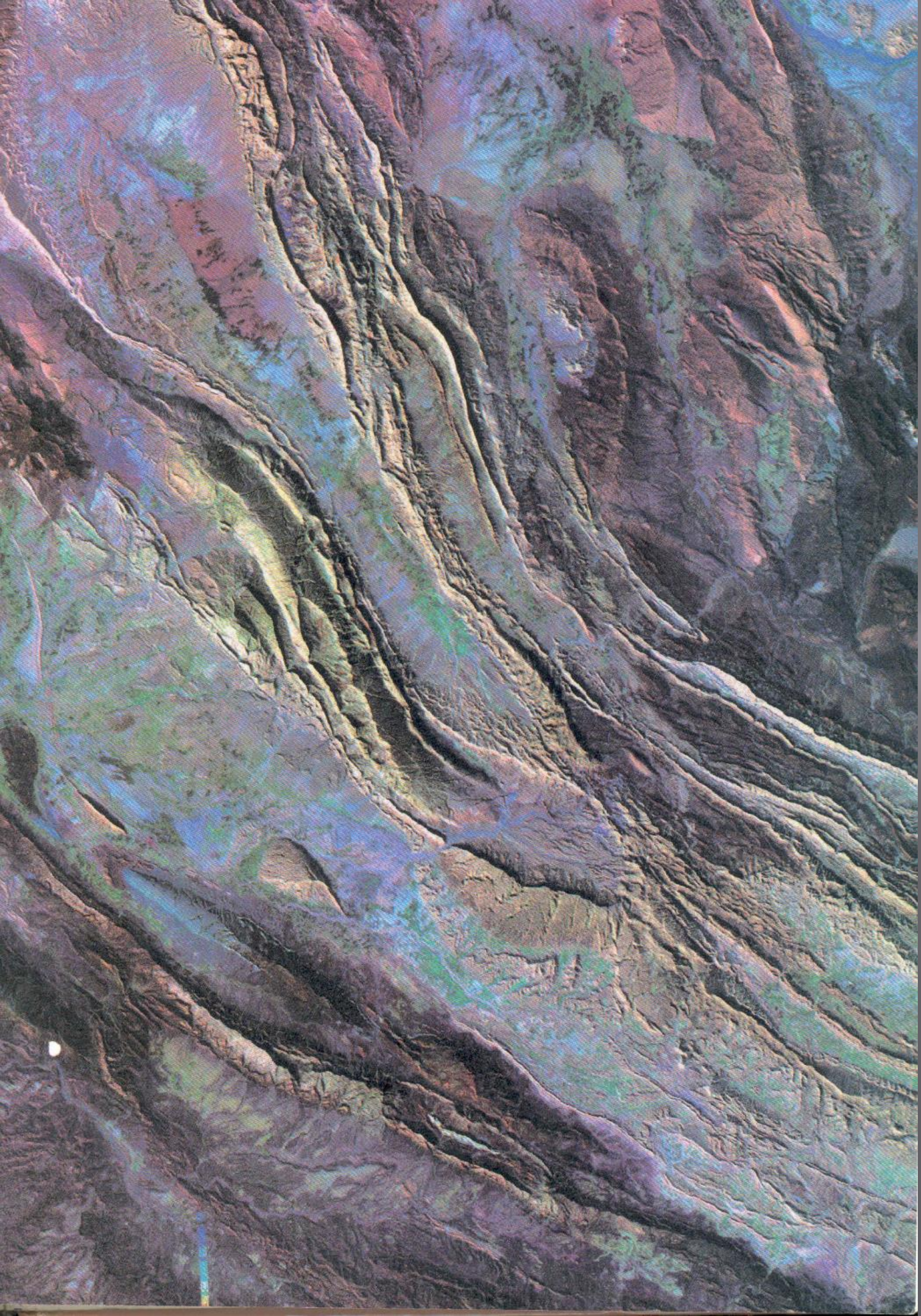
(Tilted turbidite beds, Zumaya, Spain)

Monocline

Bighorn Mountains, Wyoming







Folded rocks, Kootenay National Park, British Columbia, Canada

It shows that anticlines and synclines do not necessarily correspond to mountains and valleys, respectively. Notice that the fold at the mountain peak is a syncline

Plunging fold, Sheep mountain anticline, Wyoming

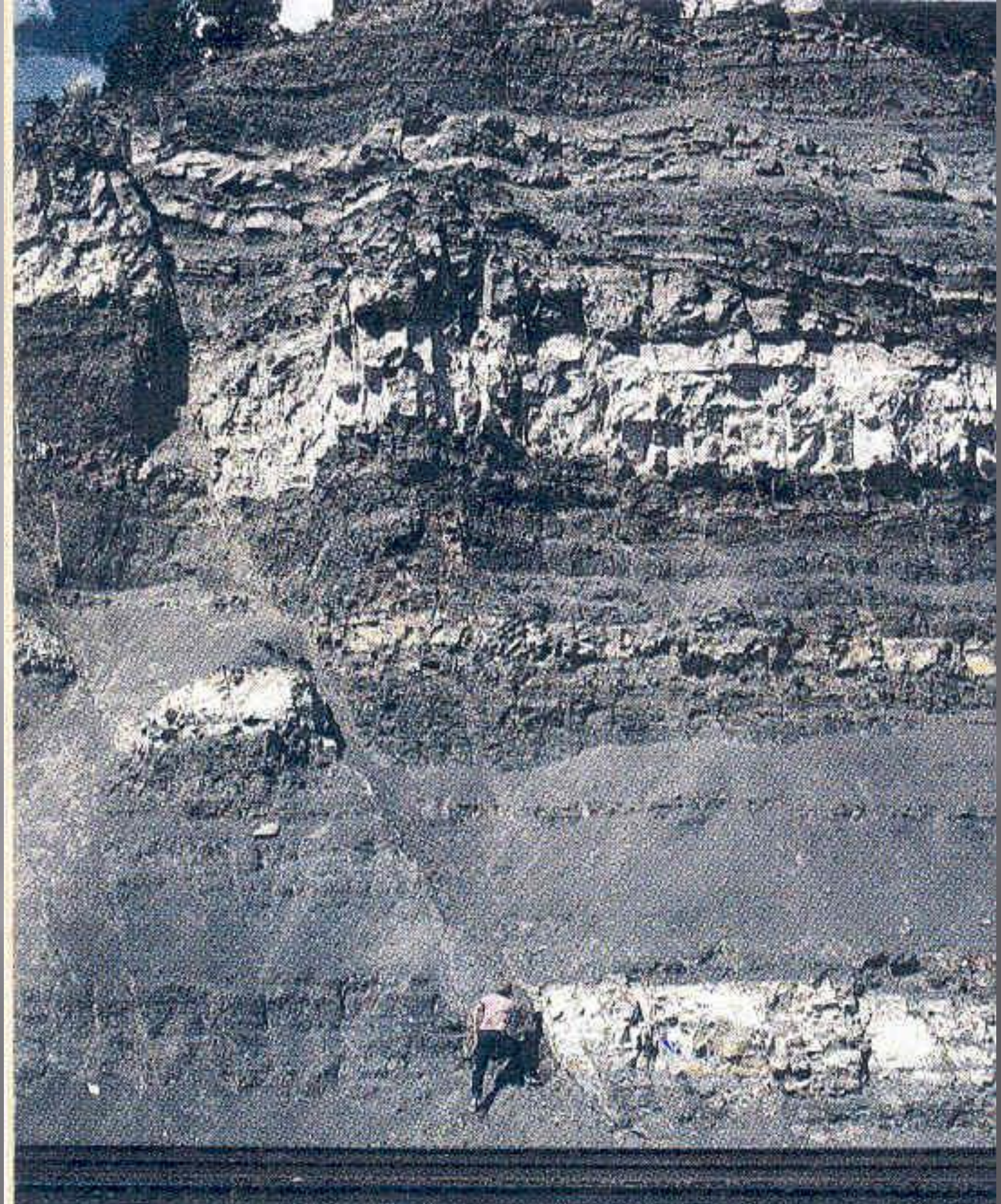
Surface view of the eroded, plunging anticline. This anticline plunges toward the observer

Deformed accretionary wedge rocks

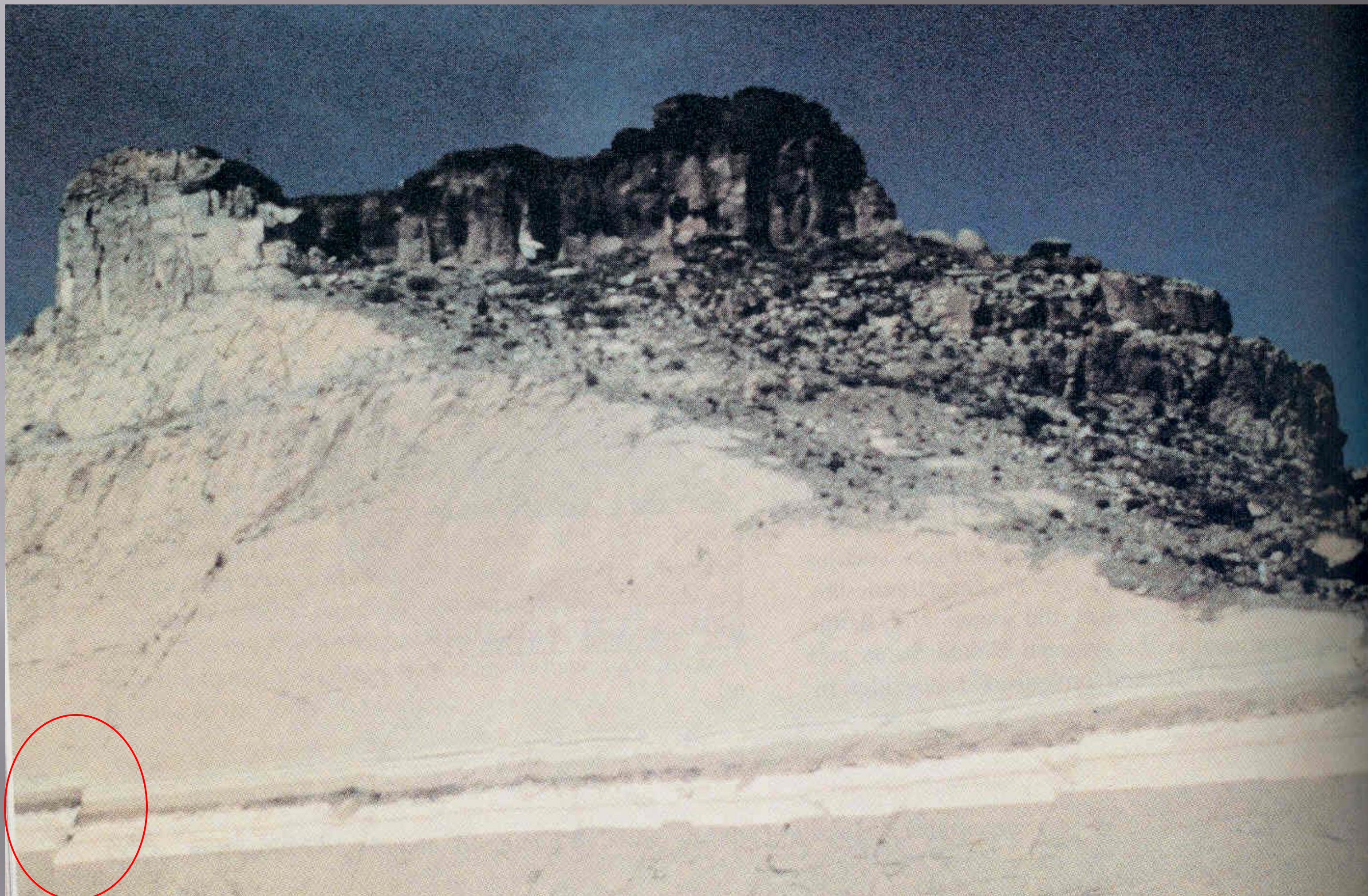
(Franciscan Group, Marin county, California)

Fault Breccia

Bighorn Mountains, Wyoming



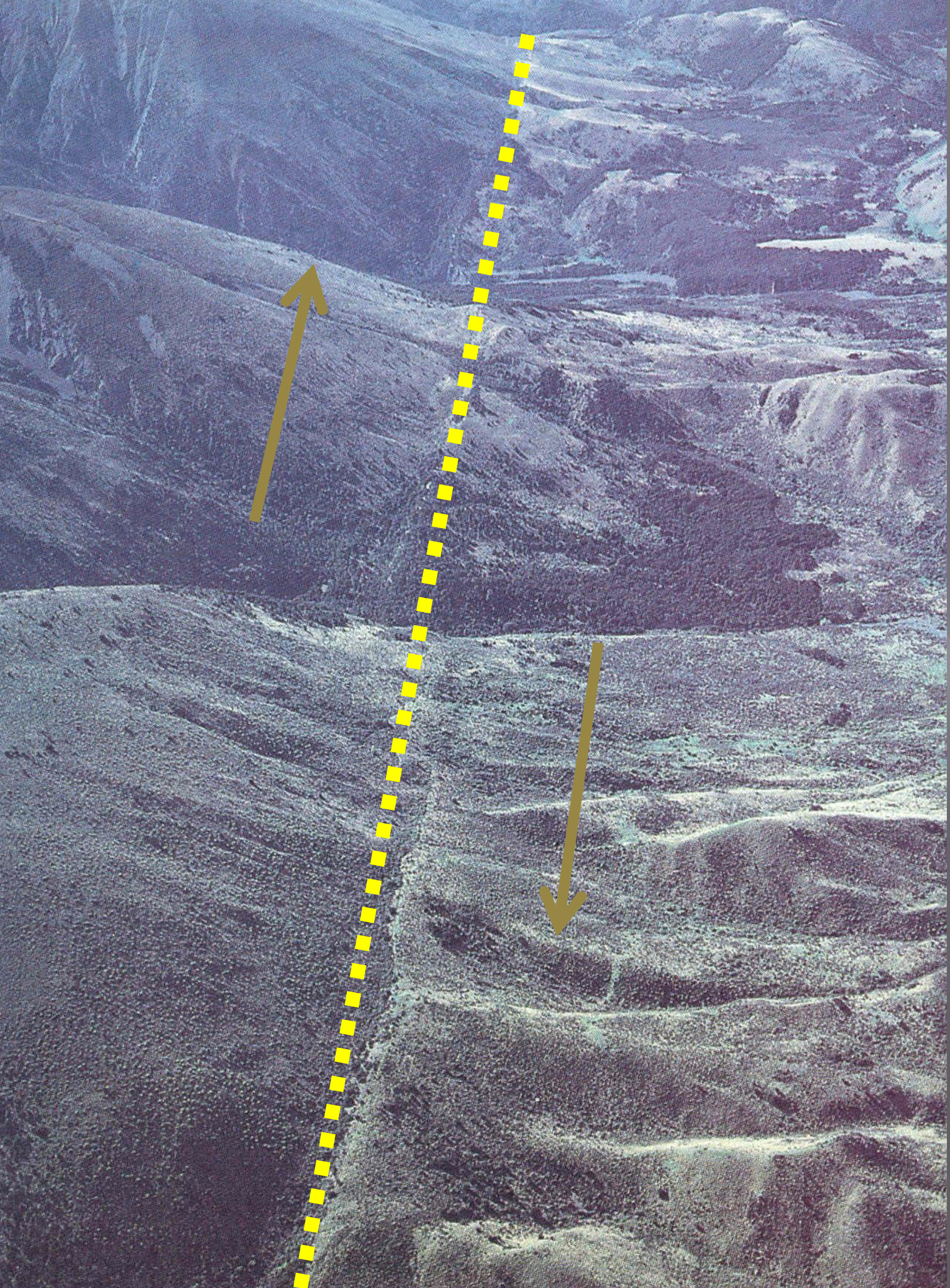
Reverse fault - (in welded tuff)



Fault plane

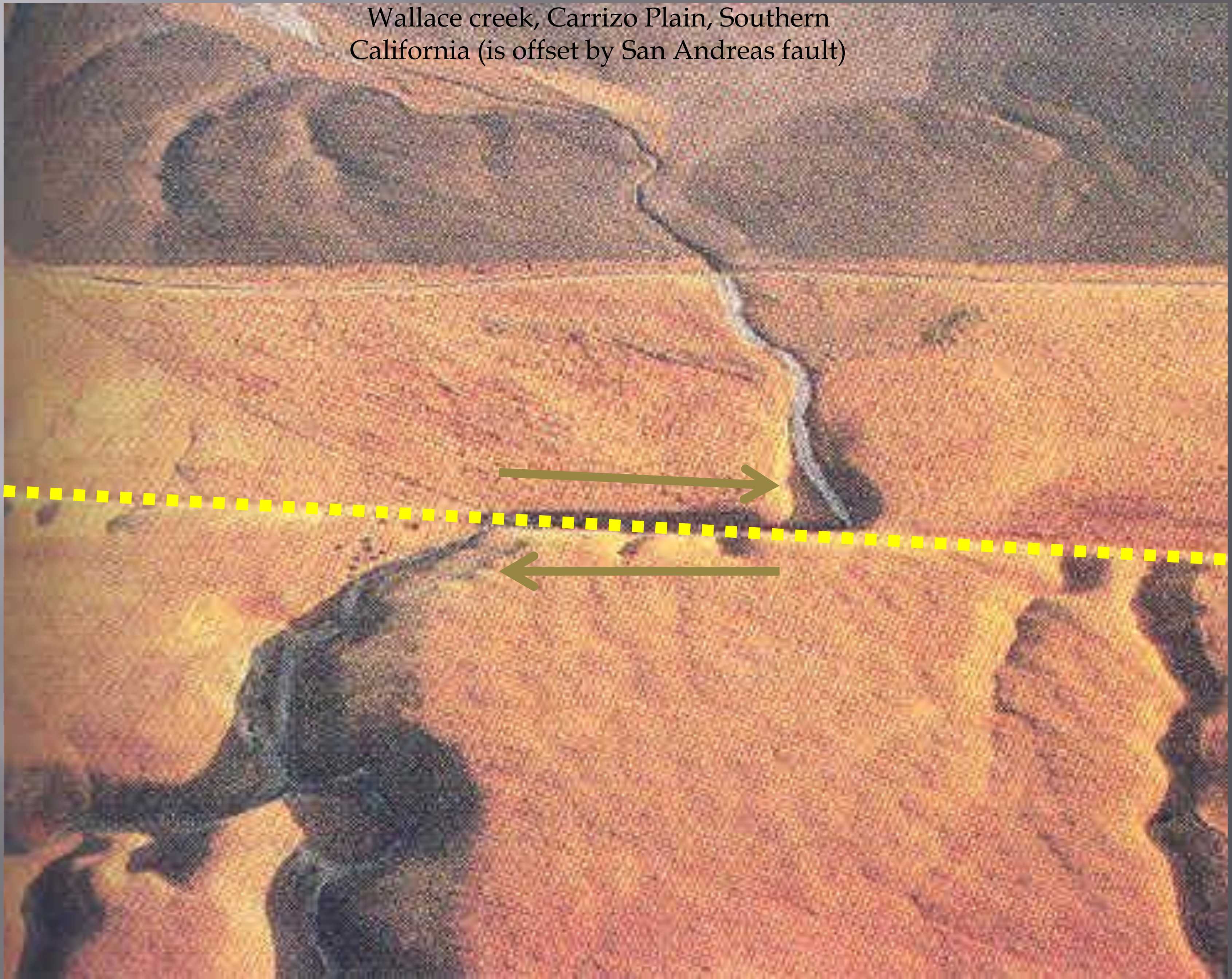
(polished, scratched fault plane and fault scarp)

Klamath falls, Oregan

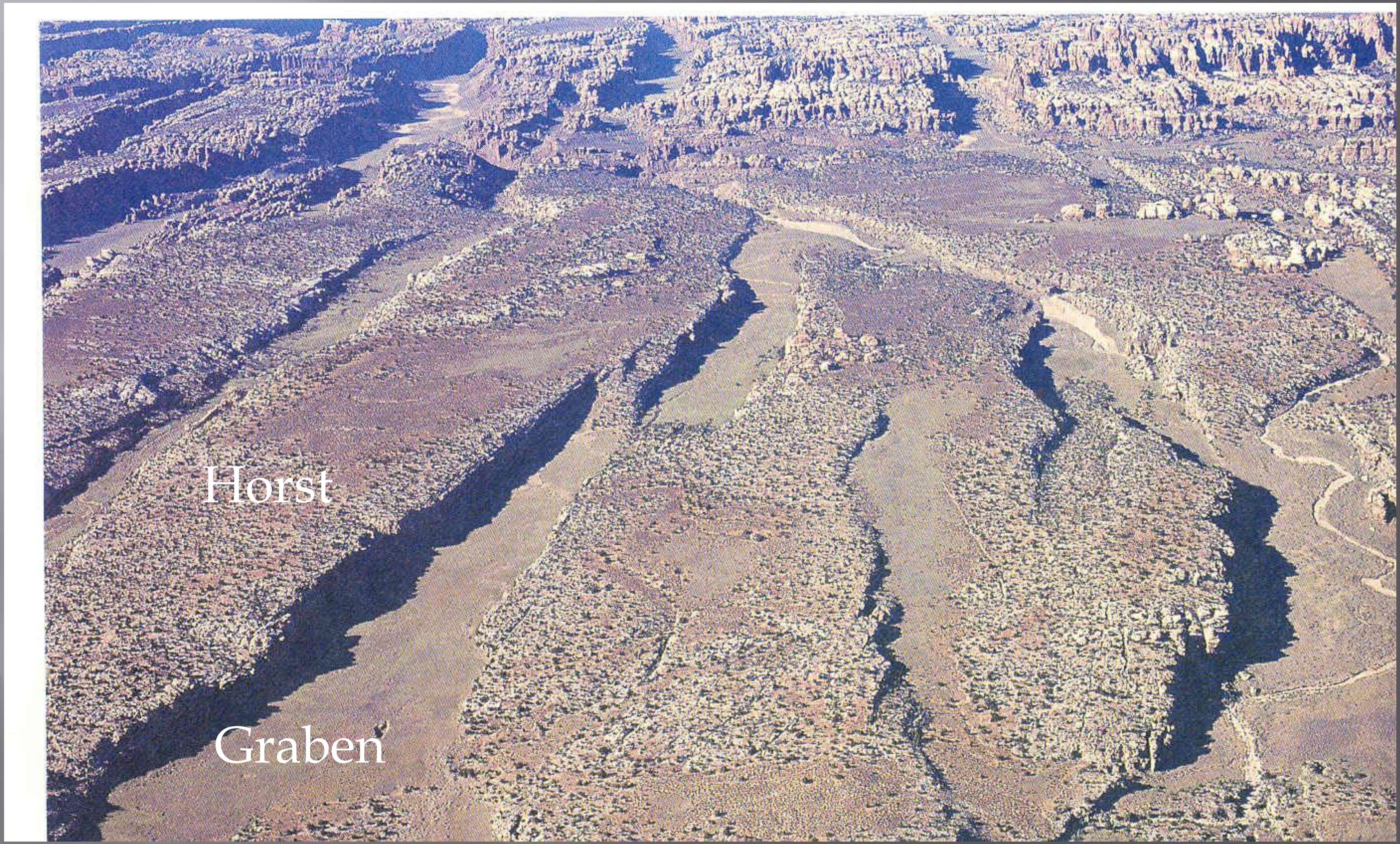


San Andrea's Fault, California

Drainage offset

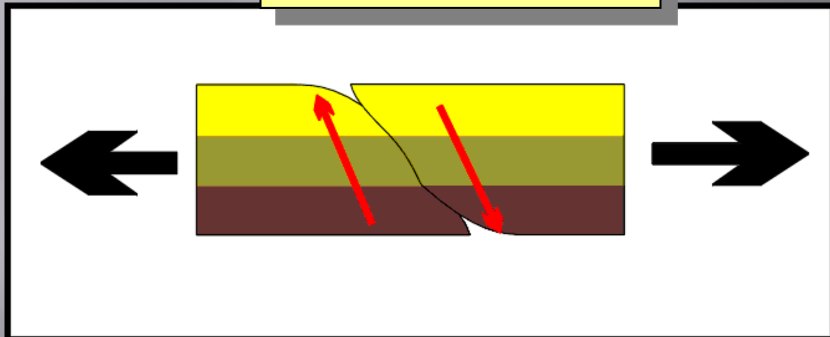


Right lateral offset of a gully by the San Andreas fault in southern California. The gully is offset about 21 m

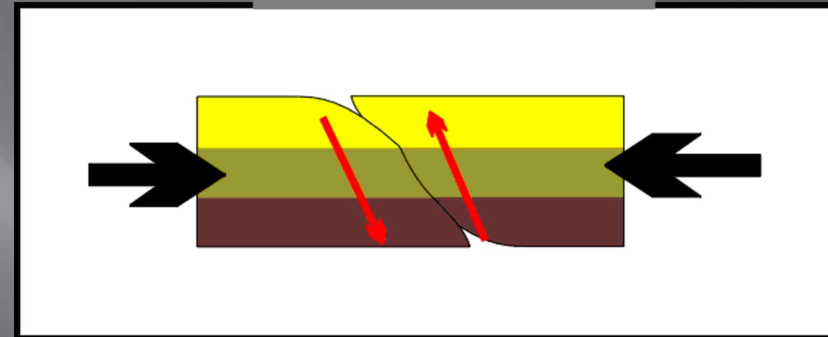

Horst
Graben

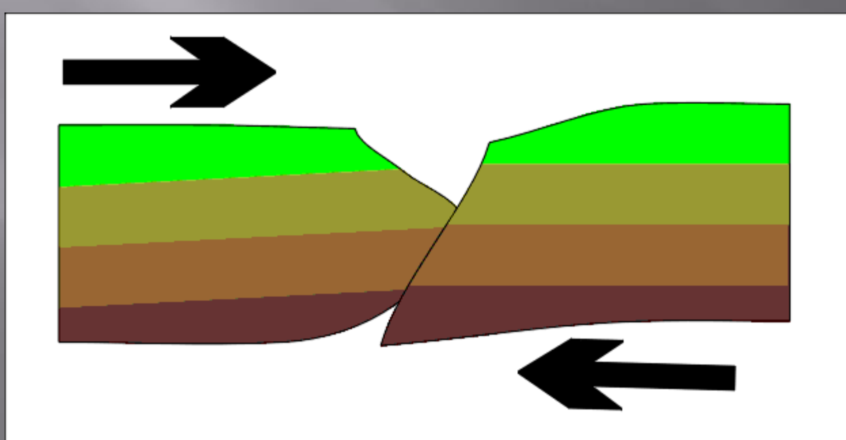
Types of Faults

NORMAL FAULT

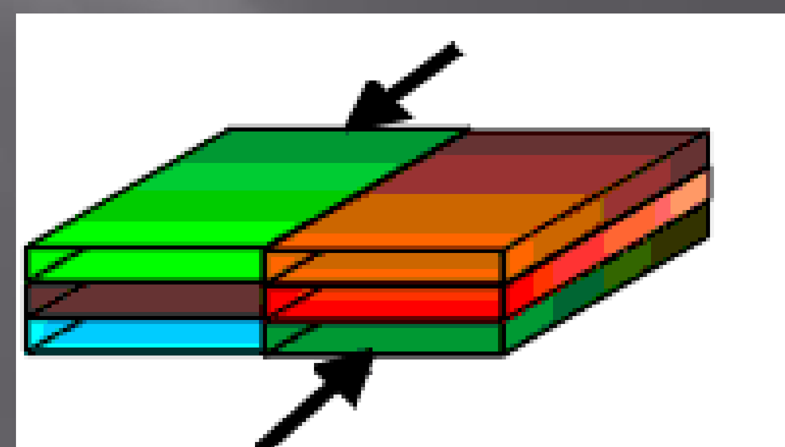


REVERSE FAULT

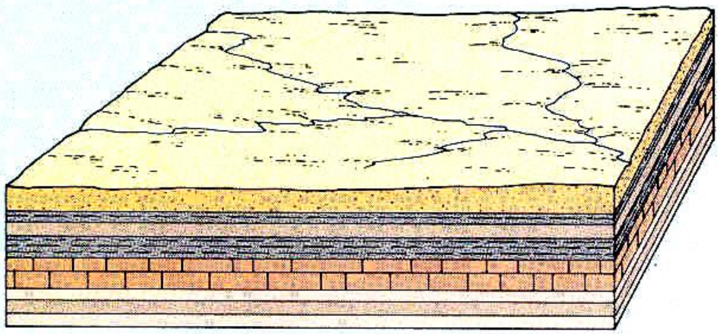
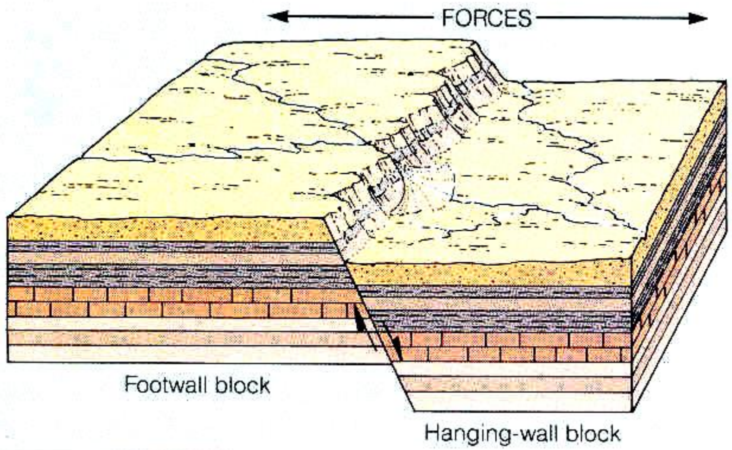
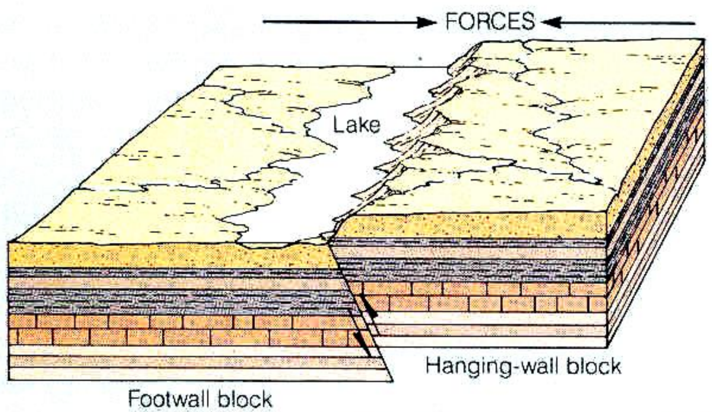


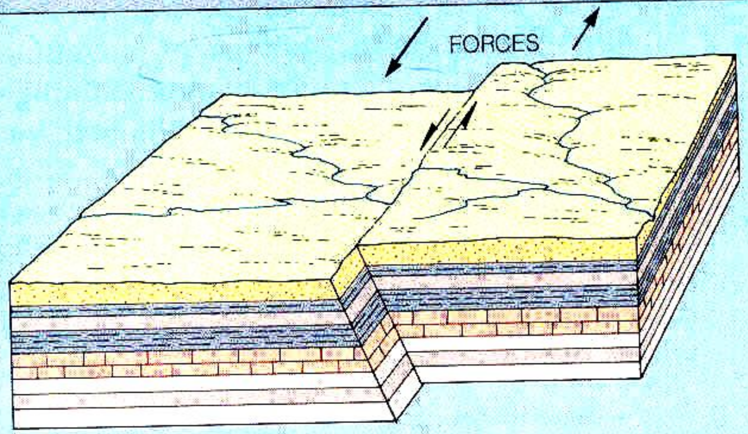
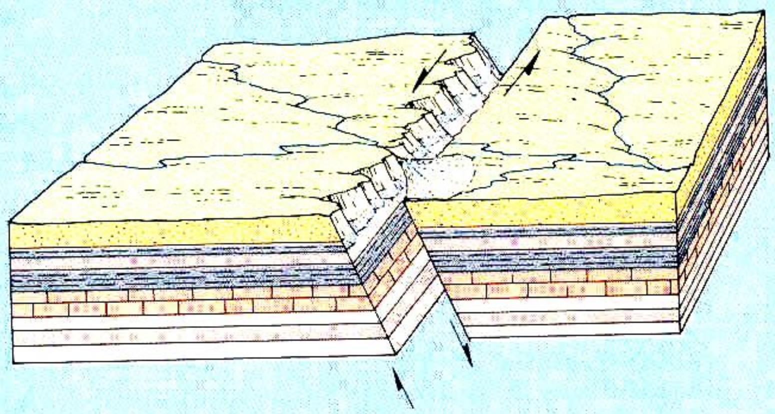
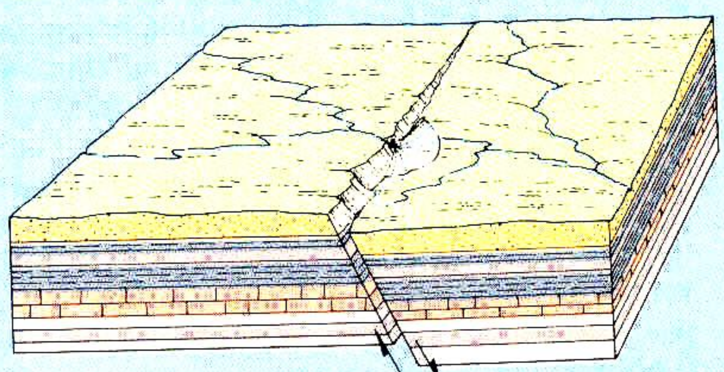


THRUST FAULT

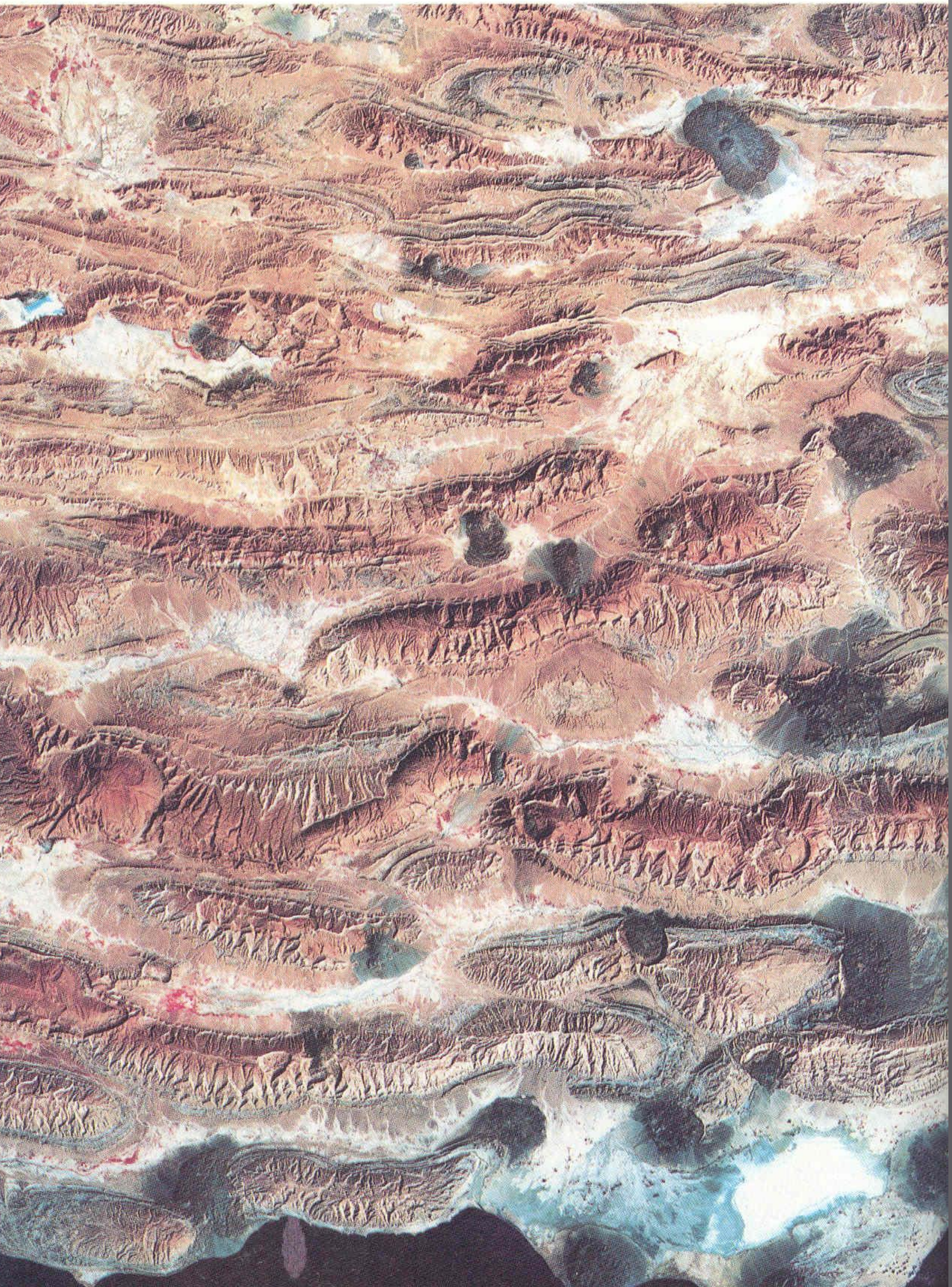


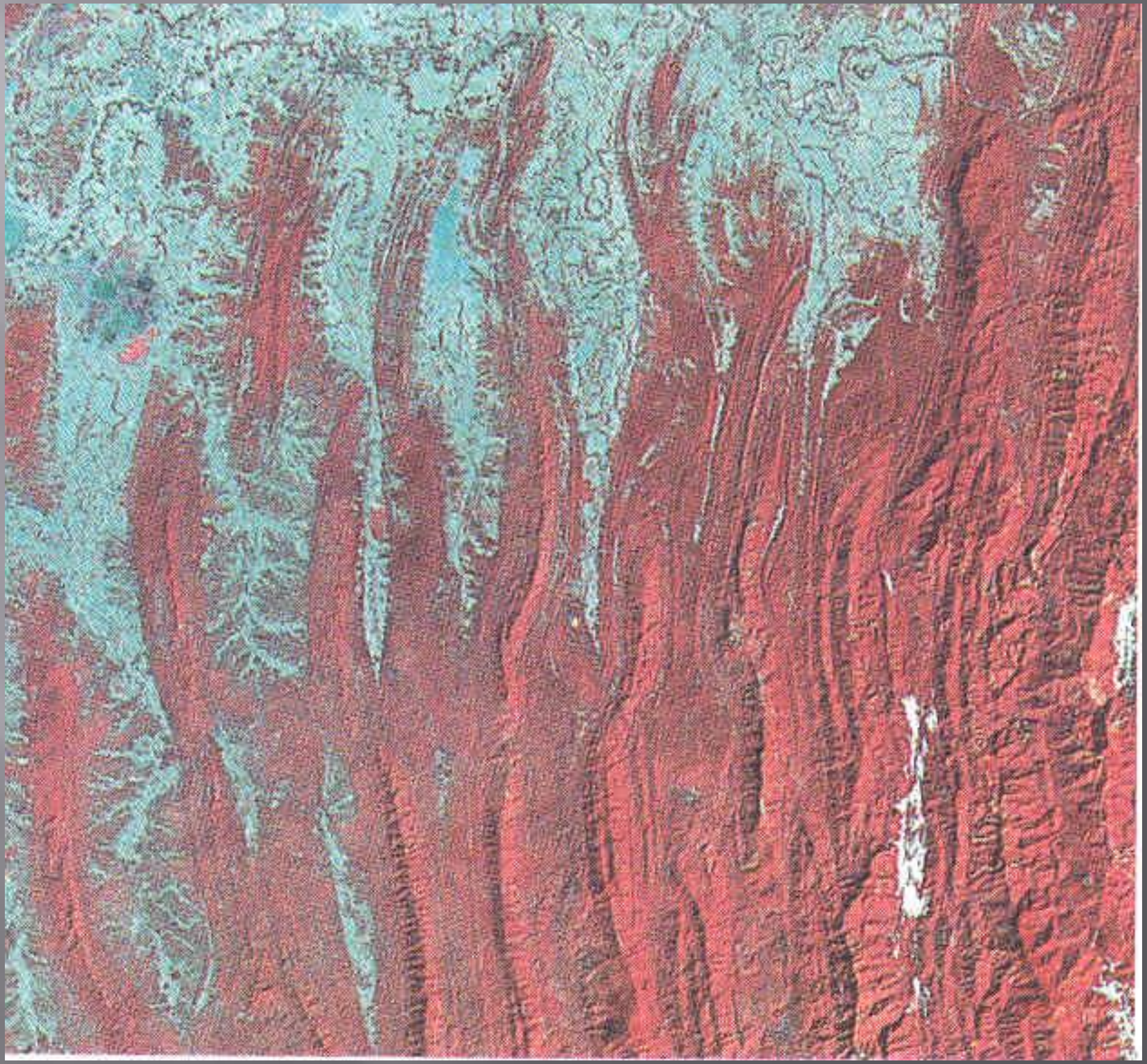
LATERAL FAULT

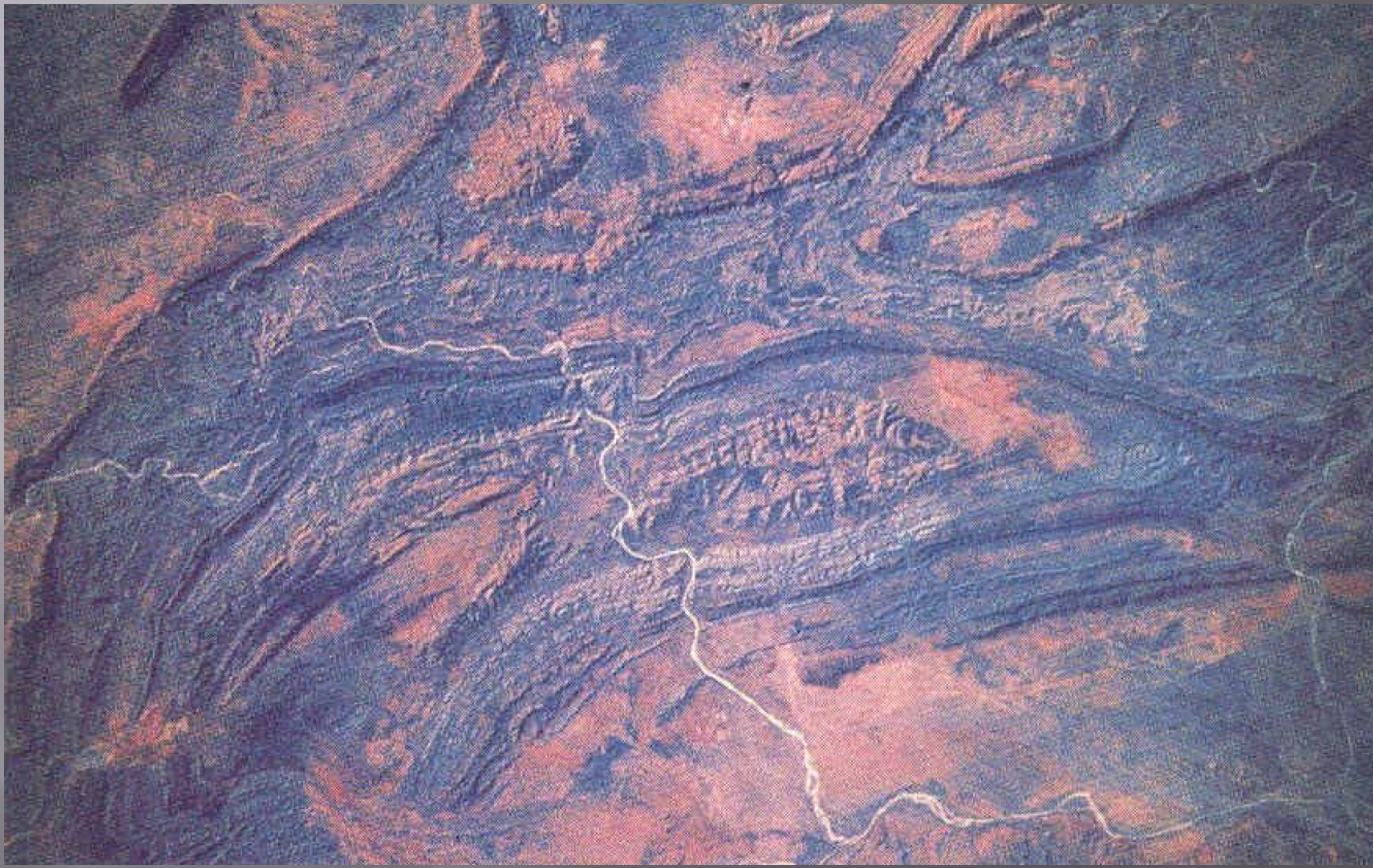
Block diagram	Name of fault	Definition
		Reference block before faulting Drainage is from left to right.
	*Normal fault*	*A fault, generally steeply inclined, along which the hanging-wall block has moved relatively downward.*
	*Reverse fault*	*A fault, generally steeply inclined, along which the hanging-wall block has moved relatively upward.* A normal or reverse fault on which the only component of movement lies in a vertical plane normal to the strike of the fault surface is a *dip-slip fault*.

Block diagram	Name of fault	Definition
	*Strike-slip fault*	*A fault on which displacement has been horizontal*. Movement of a strike-slip fault is described by looking directly across the fault and by noting which way the block on the opposite side has moved. The example shown is a *left-lateral fault* because the opposite block has moved to the left. If the opposite block has moved to the rithe it is a *right-lateral fault*. Notice that horizontal strata show no vertical displacement.
	*Oblique-slip fault*	*A fault on which movement includes both horizontal and vertical components*. See also Fig 15.8. Forces are a combination of forces causing strike-slip and normal faulting.
	*Hinge fault*	*A fault on which displacement dies out (perceptibly) along strike and ends at a definite point*. Figure 15.8 shows a small example located in the foreground of the photograph, between the viewer and the man walking away from the camera. Forces are the same as those causing normal faulting.

DOME







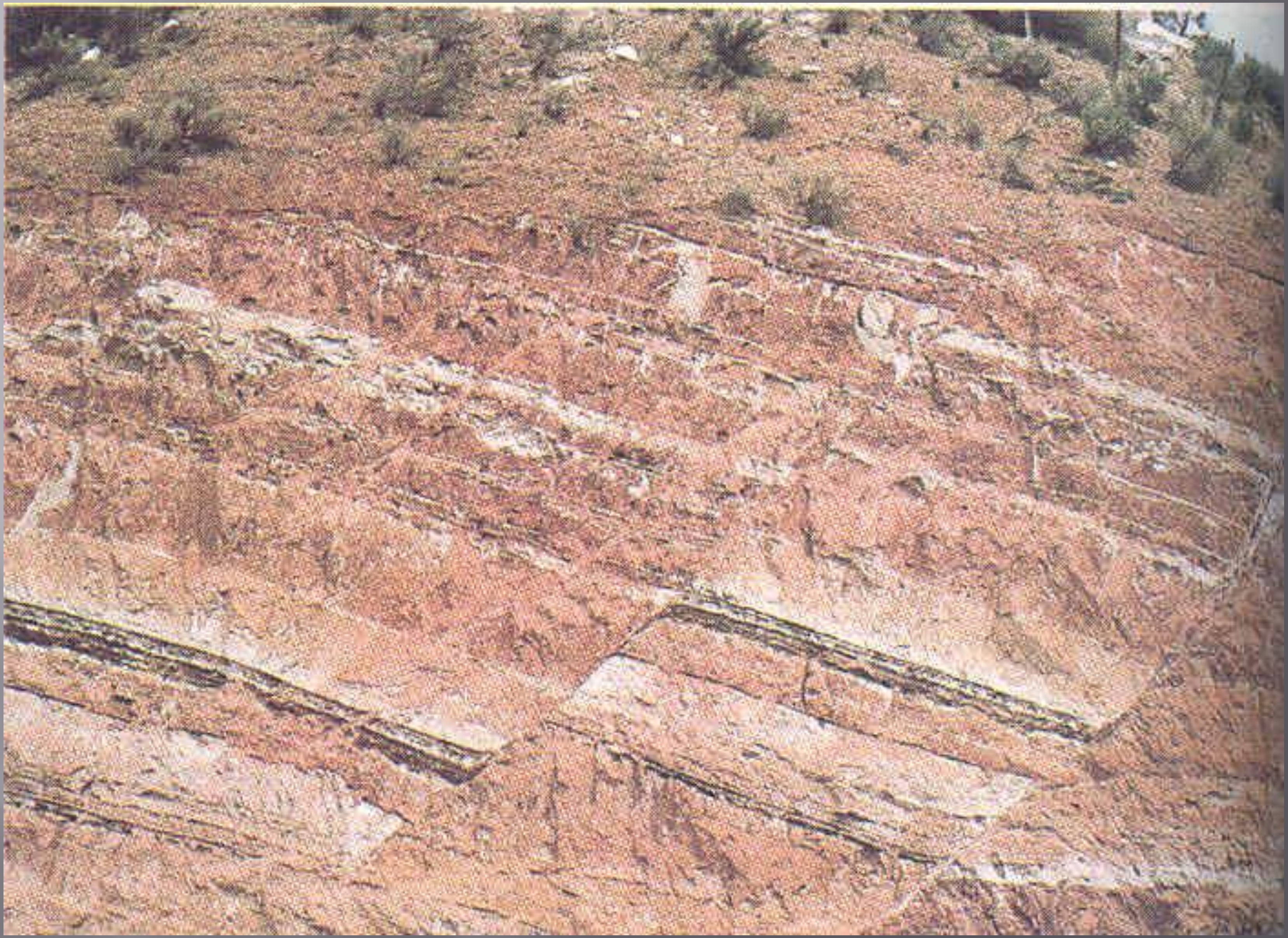
Brittle Failure in Surface rocks

These rocks from Acadia National Park in Maine have been fractured by the application of a variety of stresses, including the weight of the glaciers that once sat upon them, the cracking that occurs during mechanical exfoliation, the contraction that accompanies the cooling of plutonic igneous rock and the stress from past plat-edge interactions

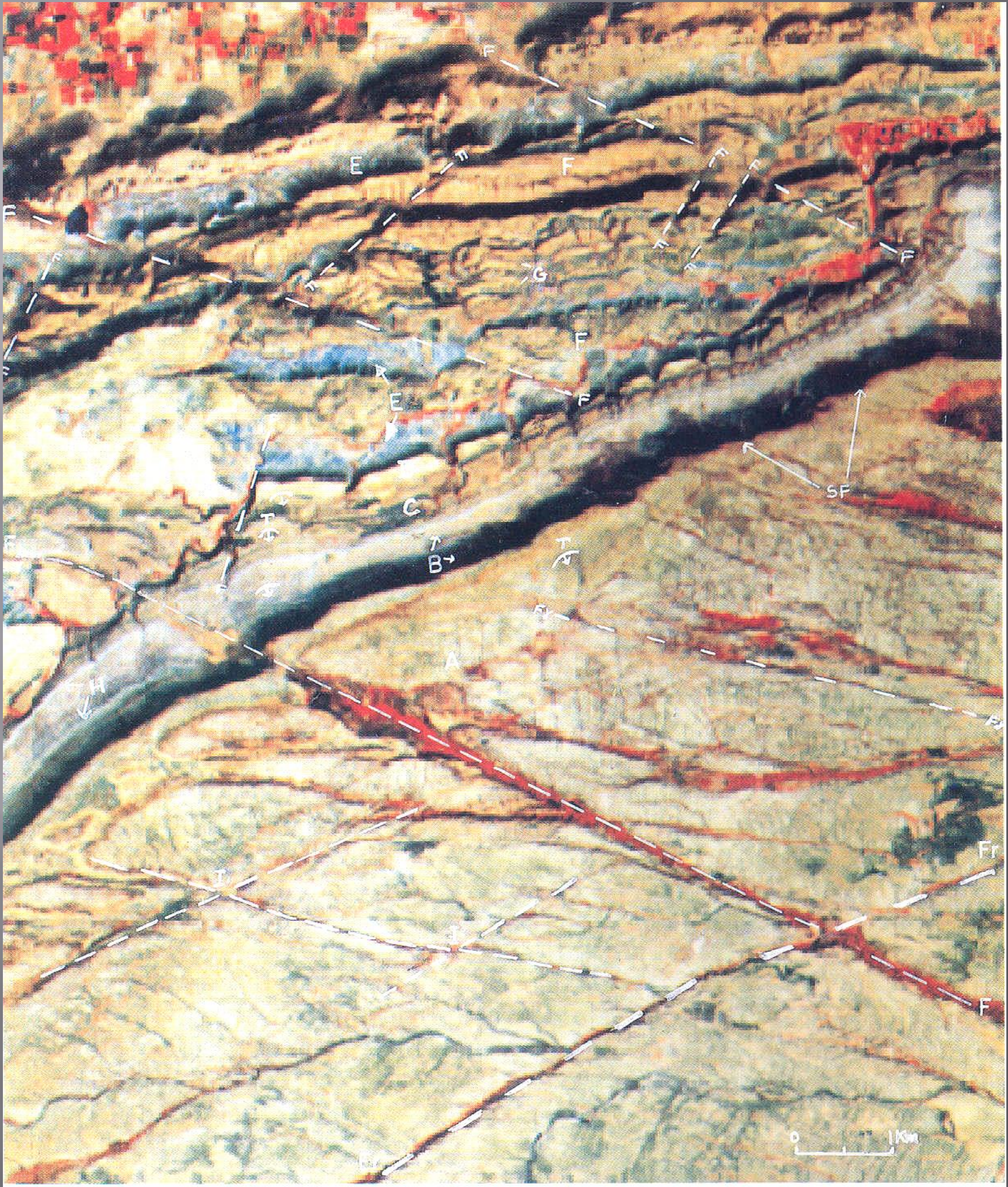
Brittle Failure in Surface rocks

The patterned appearance of these joints in Arches National Park, Utah indicates that these rocks experienced some type of regional stress, perhaps related to plate interactions

Brittle Failure in Surface rocks



These faulted rocks have clearly moved relative to each other, as can be seen by the displacement of the various colored rock types



F
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SF
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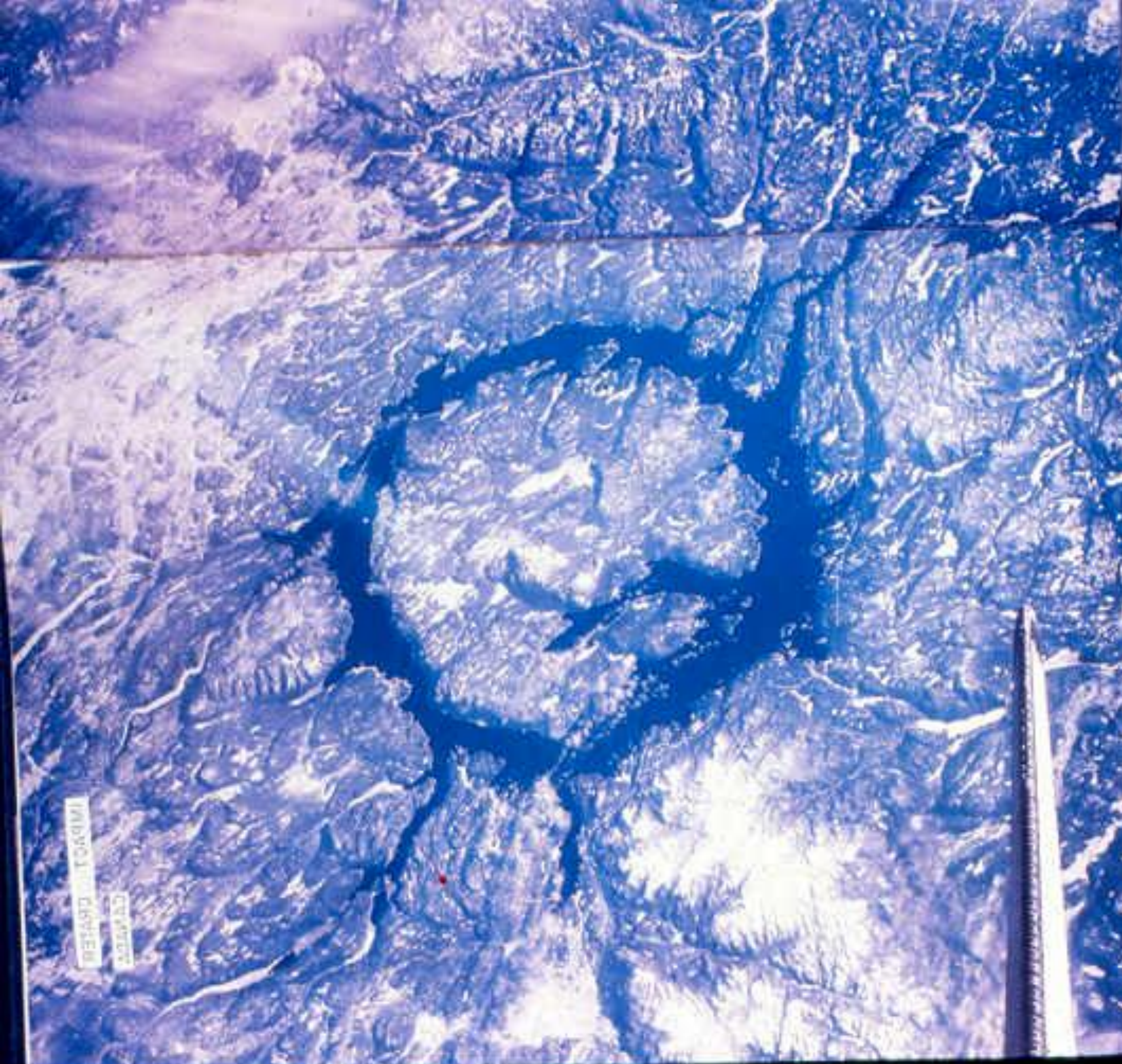
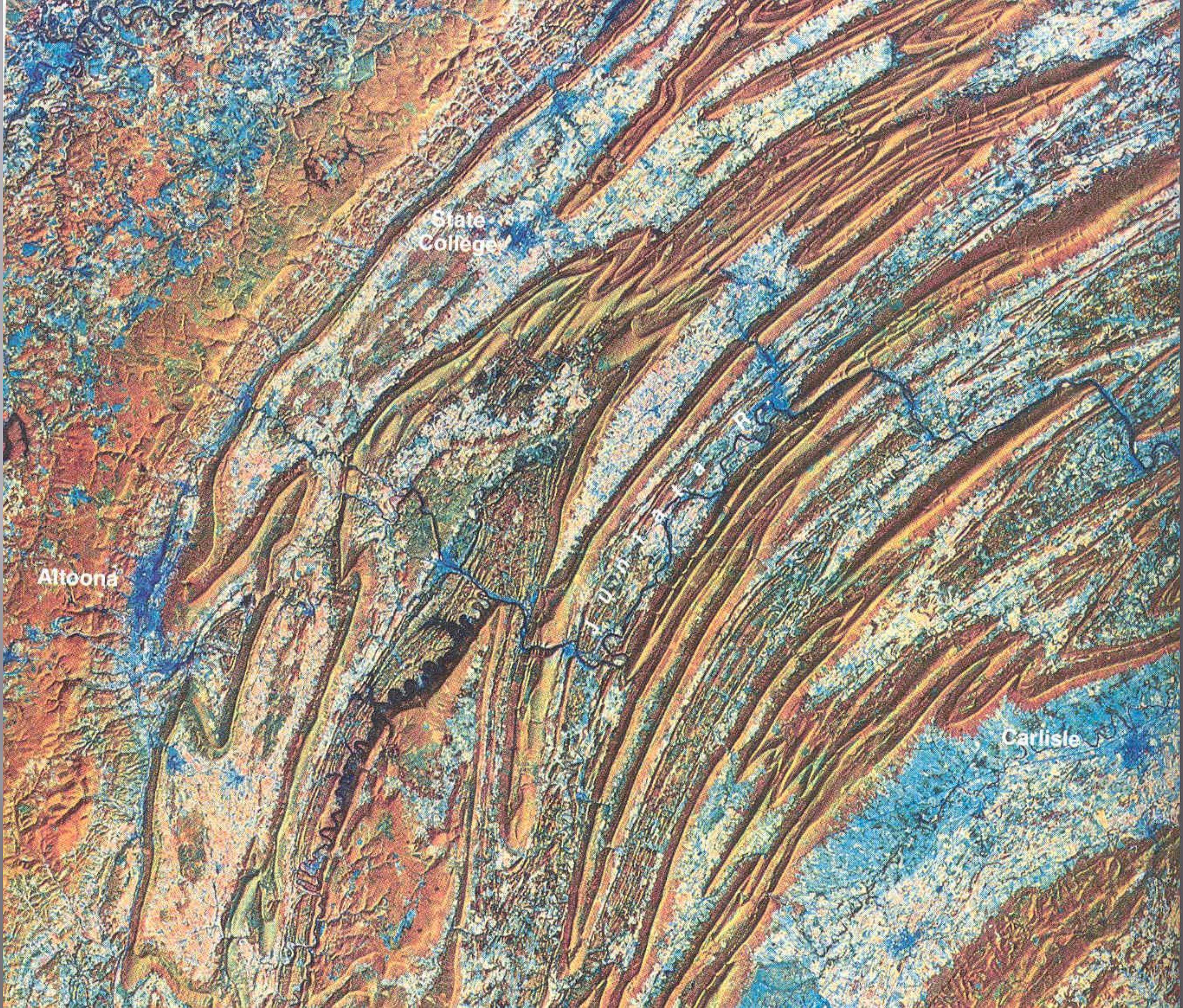
questa


IMPACT CRATER
CANADA



State College
Altoona
Juniata R.
Carlisle

GEOMORPHOLOGY

Scientific study of landforms developed on the Earth surface due to different systematic process of Earth is known as Geomorphology.

SUBDISCIPLINES OF GEOMORPHOLOGY Based on the dominating geological processes for their formation

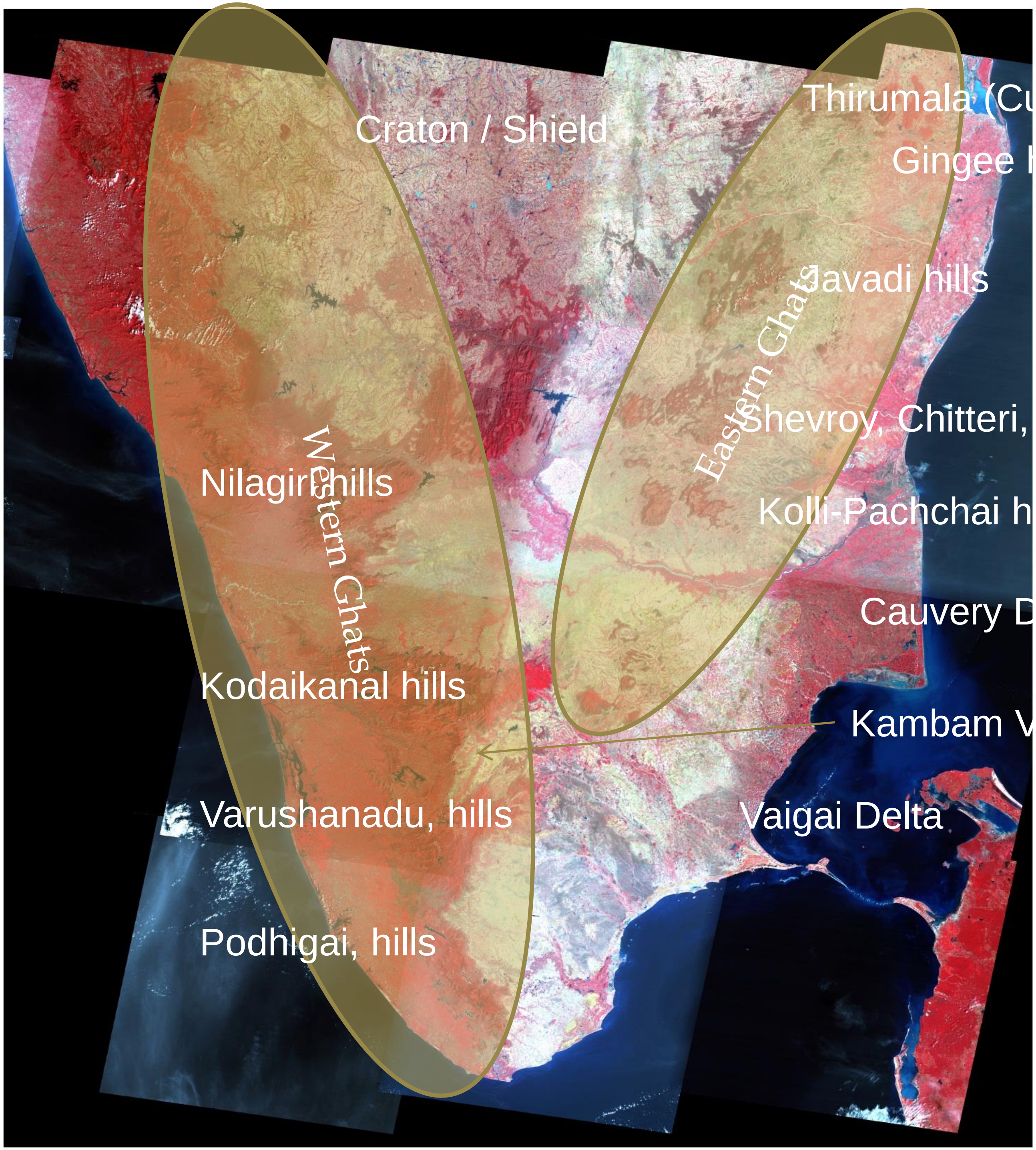
- STRUCTURAL GEOMORPHOLOGY
- DENUDATIONAL GEOMORPHOLOGY
- GLACIAL GEOMORPHOLOGY
- FLUVIAL GEOMORPHOLOGY
- AEOLIAN GEOMORPHOLOGY
- COASTAL GEOMORPHOLOGY
- FLUVIO-MARINE GEOMORPHOLOGY, etc.

Regional geomorphic landforms in India

- Structural hills and denudational hills of Himalayas, Aravalli, Satpura mountains in the north-east, North and North-west accordingly,
- Eastern Ghats (Kolli-Pachchai hills, Shevroy, Chitteri, Kalrayan, Gingee & Javadi hills in Tamil Nadu, Cuddappah in Andhra Pradesh) and Western Ghats (Podhigai, Varushanadu, Kodaikanal, Nilagiri hills) in the South India
- Plateau (plateaux) of Deccan trap rocks in Maharashtra
- Central plains covering the Madhya Pradesh, and parts of Karnataka, A.P, Odissa, and other central states of India.

SOUTH INDIA

LANDSAT TM FCC Mosaicked SATELLITE IMAGE



GEOMORPHOLOGY UNITS (based on NRSC guidelines) (for satellite image interpretation)

HILLS & PLATEAUS

<u>Hills</u>
Structural hills
Denudational hills
Residual hills

<u>Other landforms</u>

Plateau
Valley
Linear-curvilinear ridge
Valley fill shallow/moderate/deep
Cuesta
Dyke ridge
Mesa
Escarpment slope
Butte
Valley flat
Inselberg
Residual mound
Fracture / fault line valley
Sheet rock
Intermontane valley

<u>PIEDMONT ZONE</u>
Piedmont slope
Pediment
Pediment-inselberg complex
Piedmont alluvium
Bazada
Other landforms
Gullied land
Ravenous land
Talus cone

<u>PLAINS</u>
<u>Pediplain</u>
Weathered Pediplain
Buried Pediplain
Lateritic plain
Stripped plain
<u>Alluvial plain</u>
older/upper
younger/lower
<u>Flood plain</u>
older/upper
younger/lower

Coastal Geomorphic features

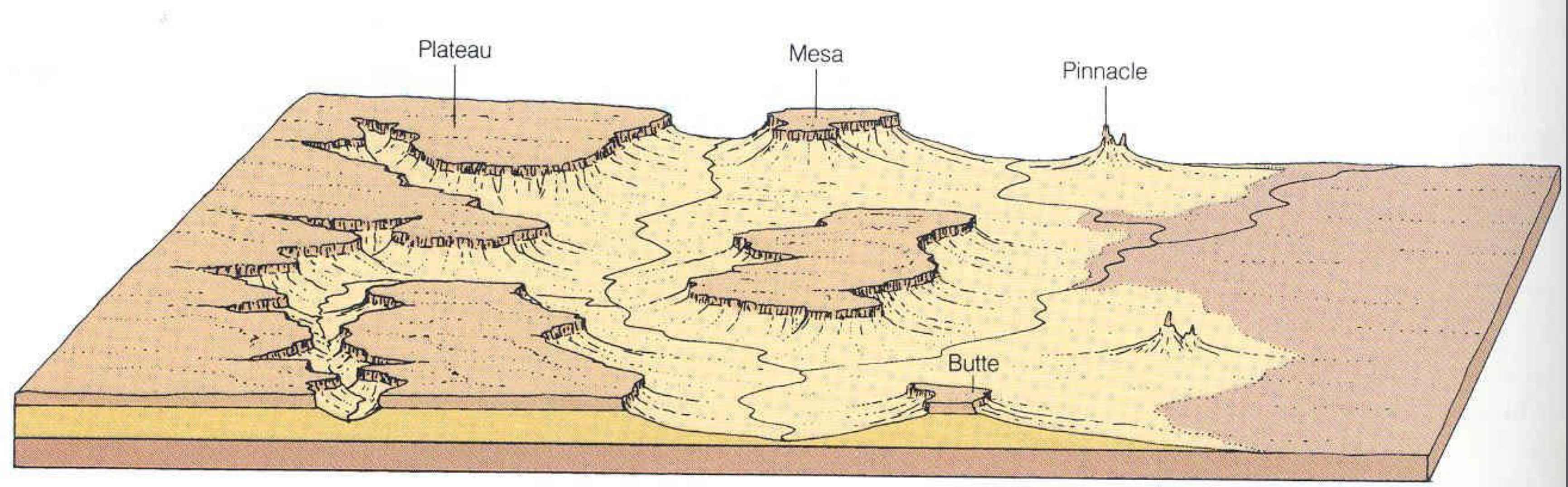
Beach	Older mud flat
Beach ridge	Tidal flat
Palaeo beach ridge	Salt flat
Beach ridge & swale complex	Lagoon
Palaeo beach ridge & swale complex	Channel island
Swale	Offshore island
Offshore bar	Reef island
Spit	Palaeochannel
Mud flat	Buried channel

Fluvial Geomorphic features

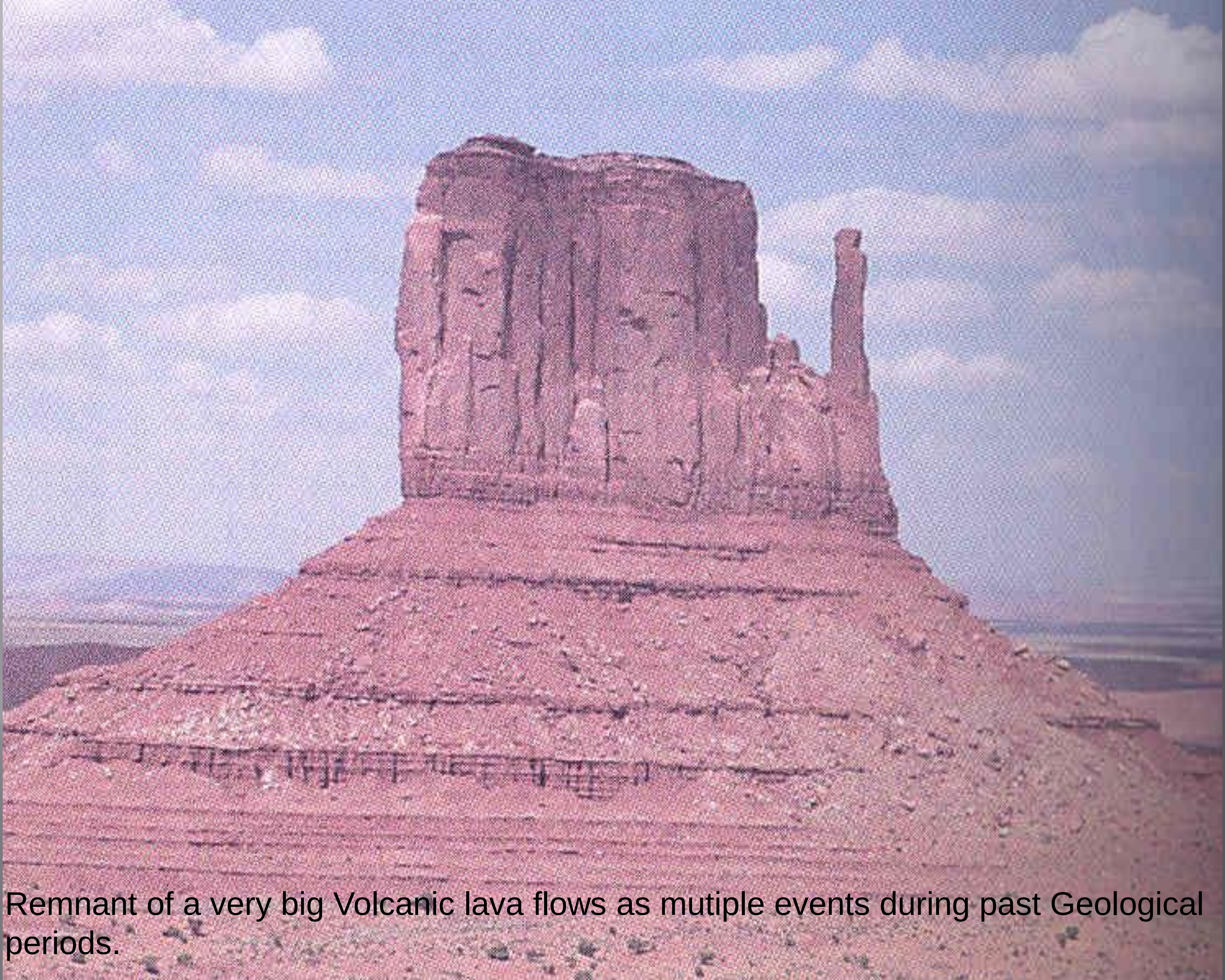
Channel bar	Meander scar
Point bar	Palaeo channel
Natural levee	Buried channel
Back swamp	Migrated river course
Cut-off meander	River terrace
Ox-bow / serpentine lake	

Aeolian Geomorphic features

Sand dune	Playa
Stabilized dune	Desert pavement
Dune complex	Loess plain
Interdunal depression	Palaeo channel
Interdunal flat	Buried channel


Plateau
Mesa
Pinnacle
Butte


Deccan Plateau / Trap



Remnant of a very big Volcanic lava flows as mutiple events during past Geological periods.

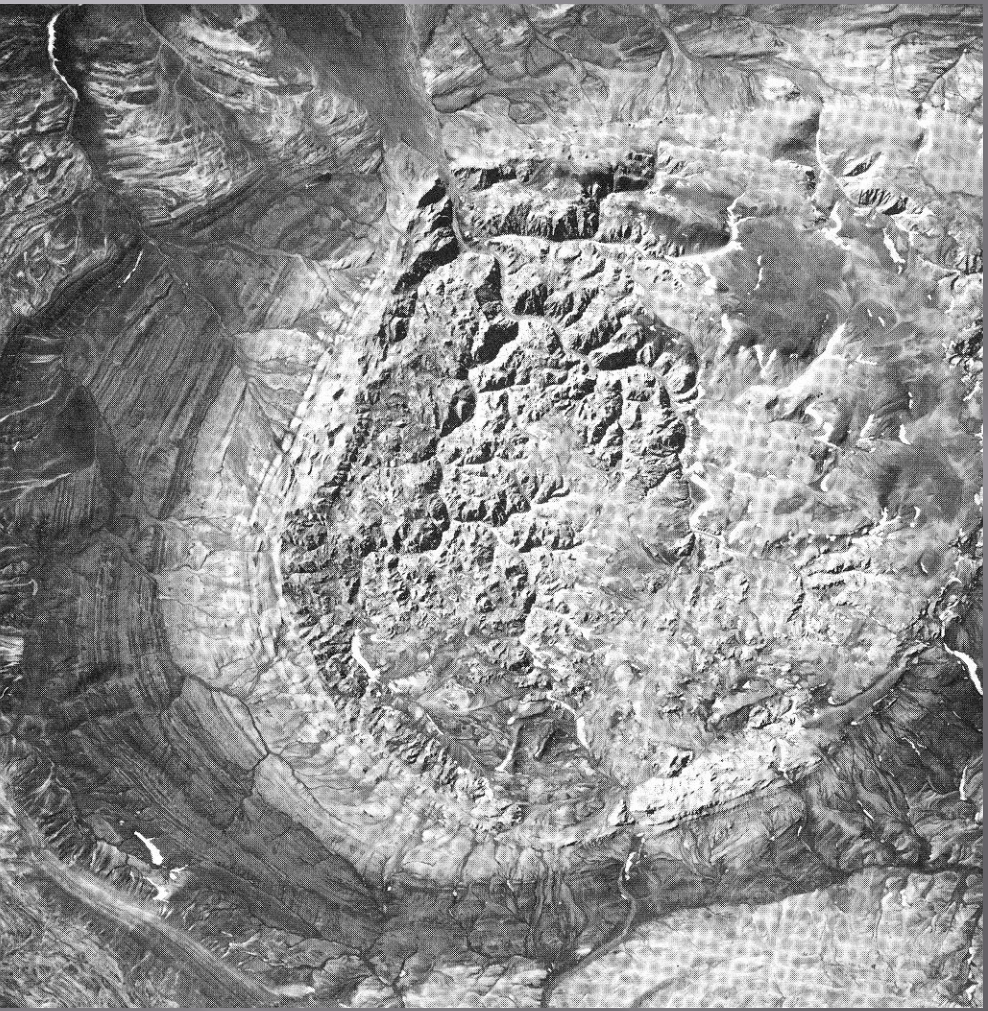
Pinnacles

- Oblique aerial view

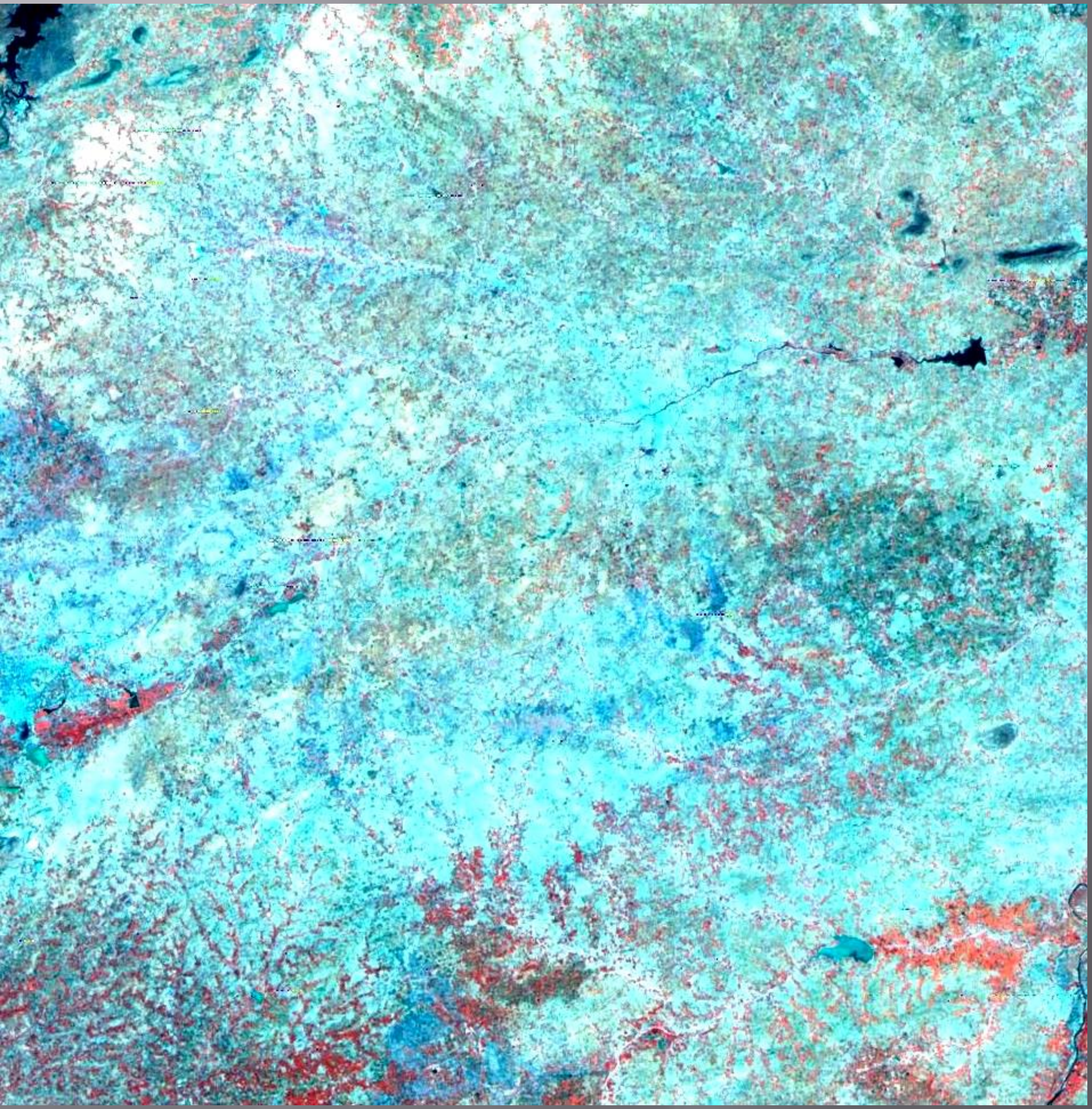
COASTAL GEOMORPHOLOGY

- a satellite view

Dome



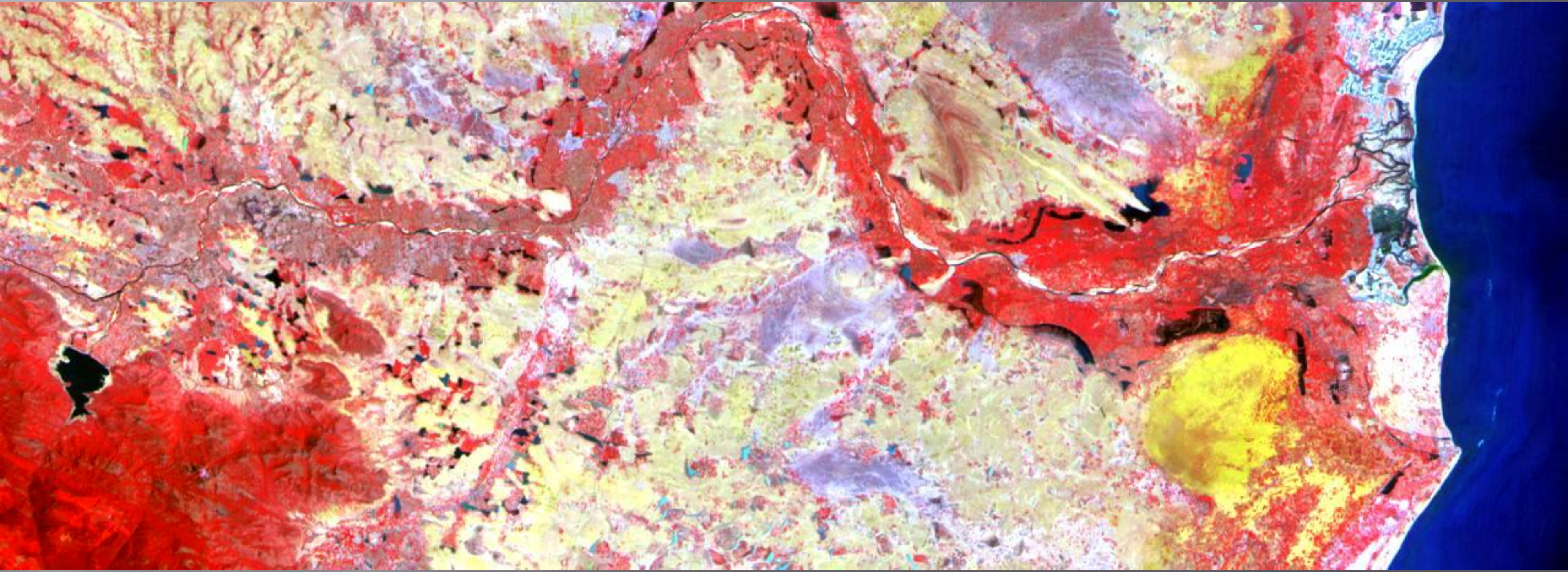
Pediplain



Coimbatore Area

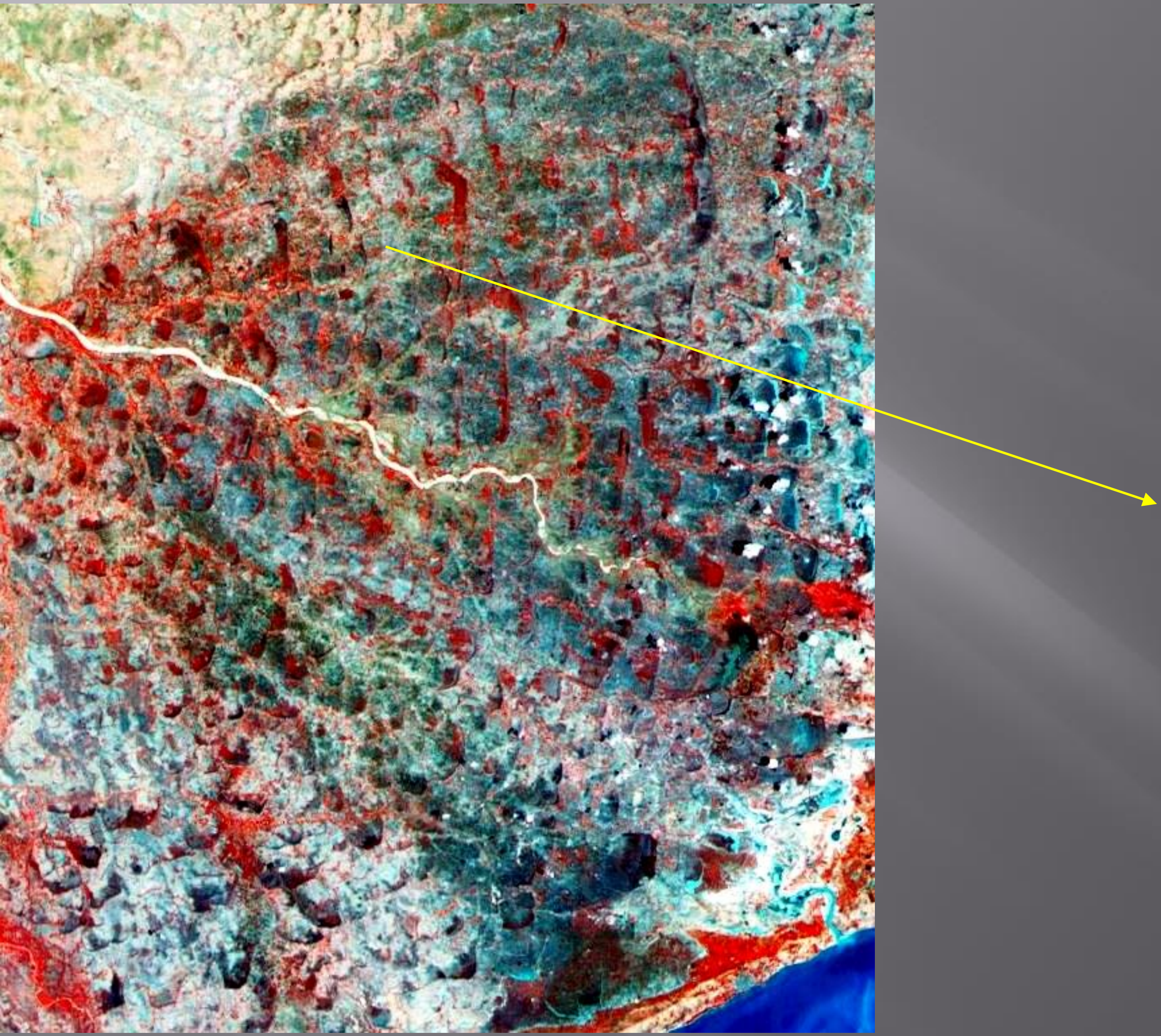
Alluvial plain

FLOOD PLAIN



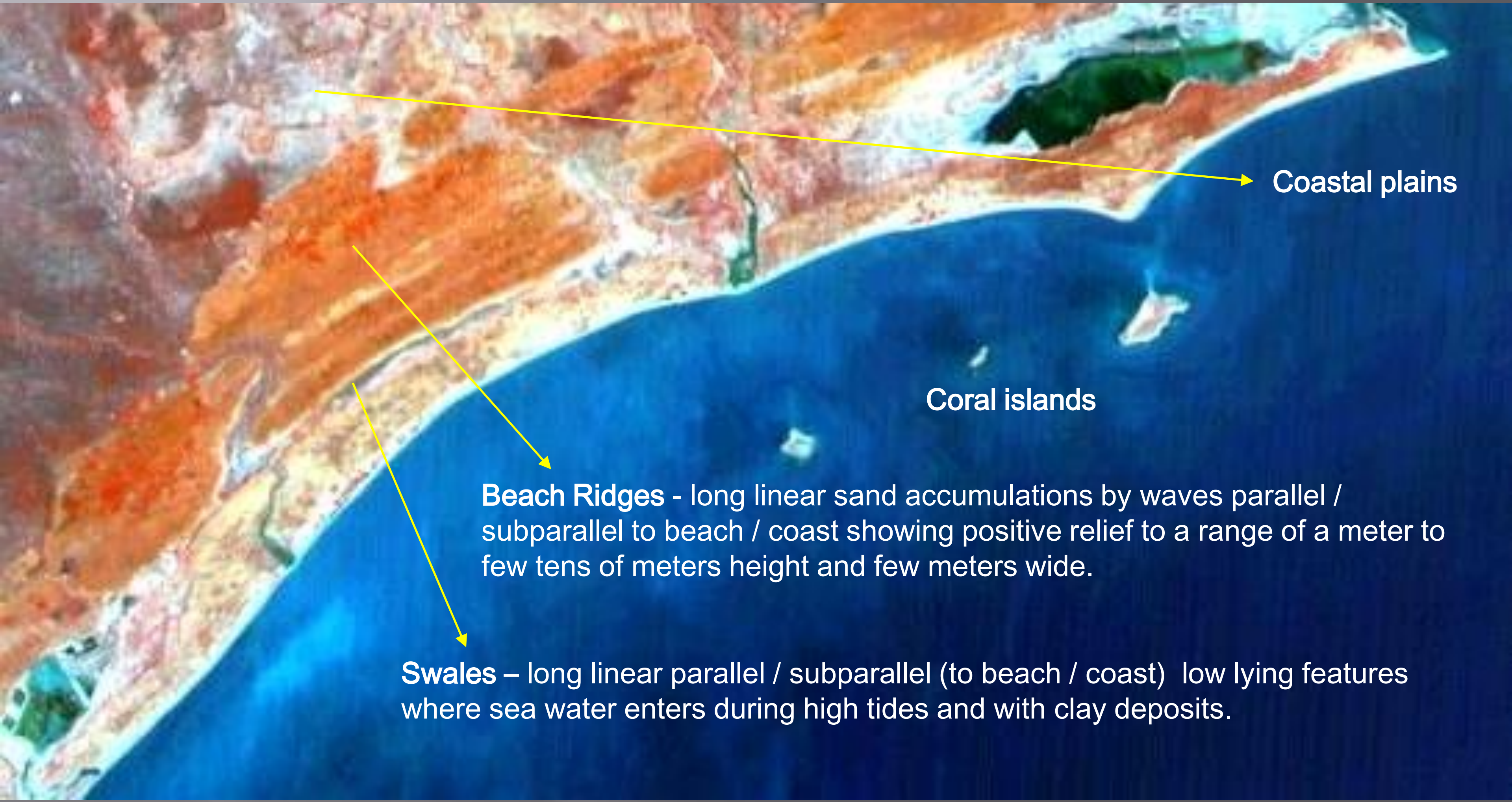
Tamrabarani river

Deltaic plain



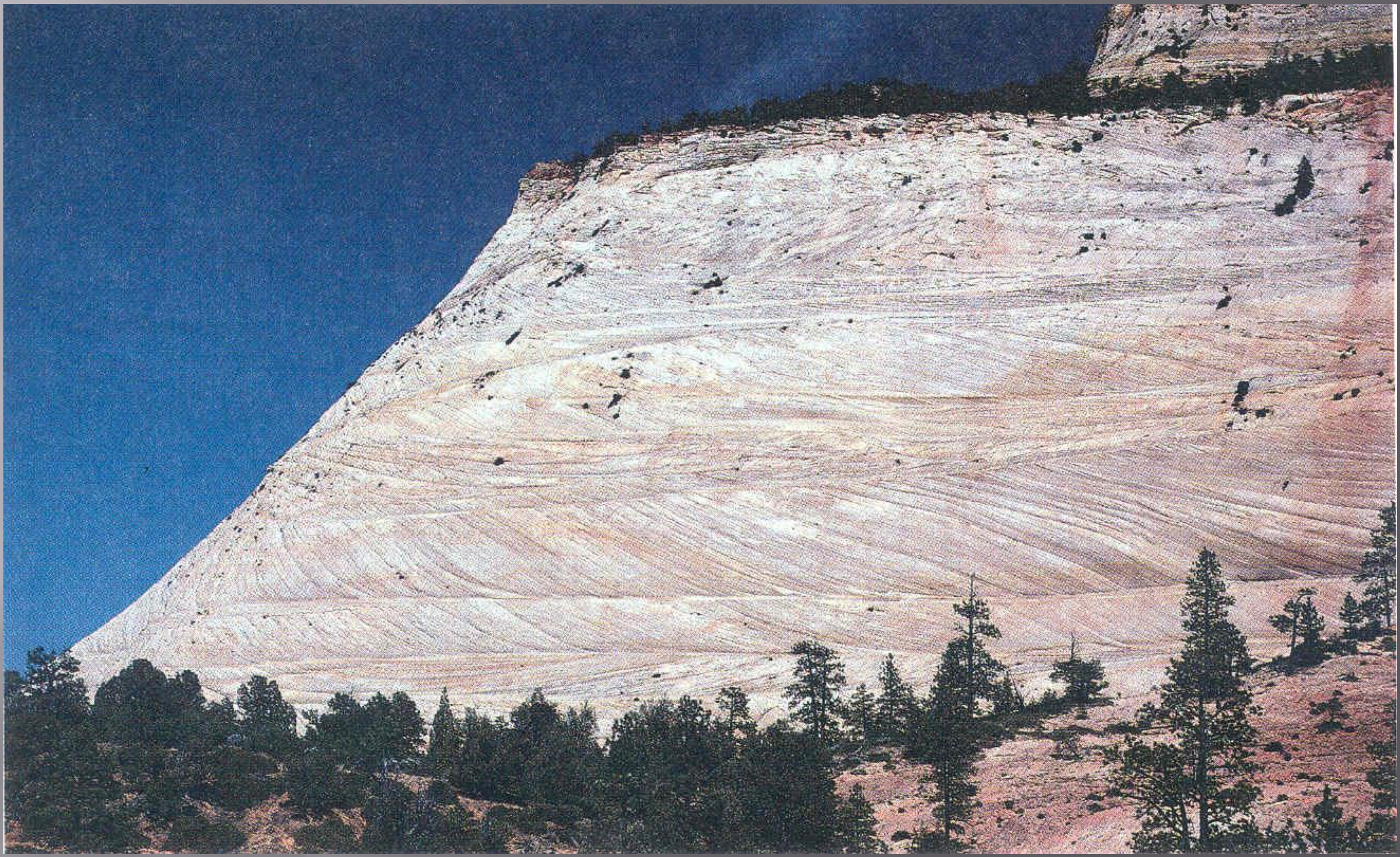
Vaigai delta, Ramanathapuram area

IRS FCC Satellite image of Coastal plain



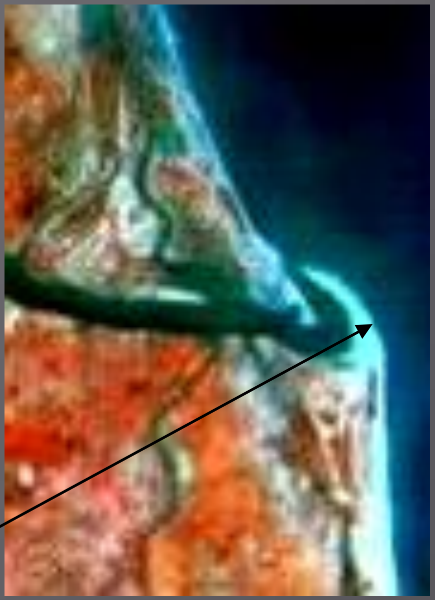
Coastal area between Tutucorin and Kilakkarai, Tamil Nadu

Satellite True colour image showing Flood plain features



River derived sediments are deposited over various Geological periods under variety of climates. This photograph shows a part of river dumped sediments showing layering, flow pattern, direction of flow, environment of deposition, etc., and now emerged as a hill after deep burial, compaction, cementation and induration.

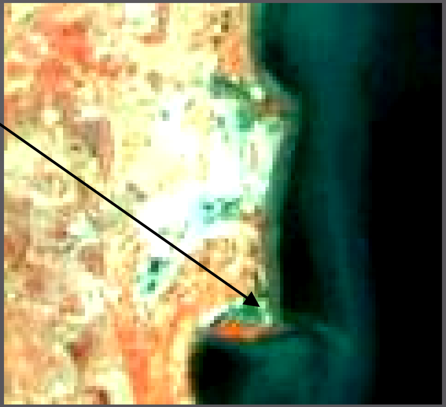
Valinokkam area, Ramanathapuram



Coleroon river mouth

Spit

Manemelkudi

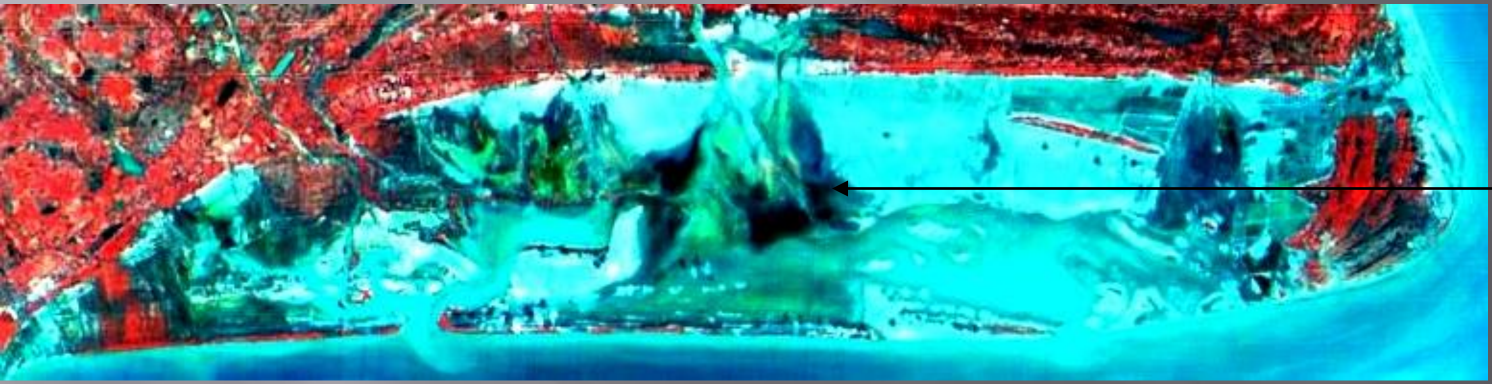


Devipattinam area

Pitchavaram area, Cuddalore

Thanushkodi-Rameshwaram

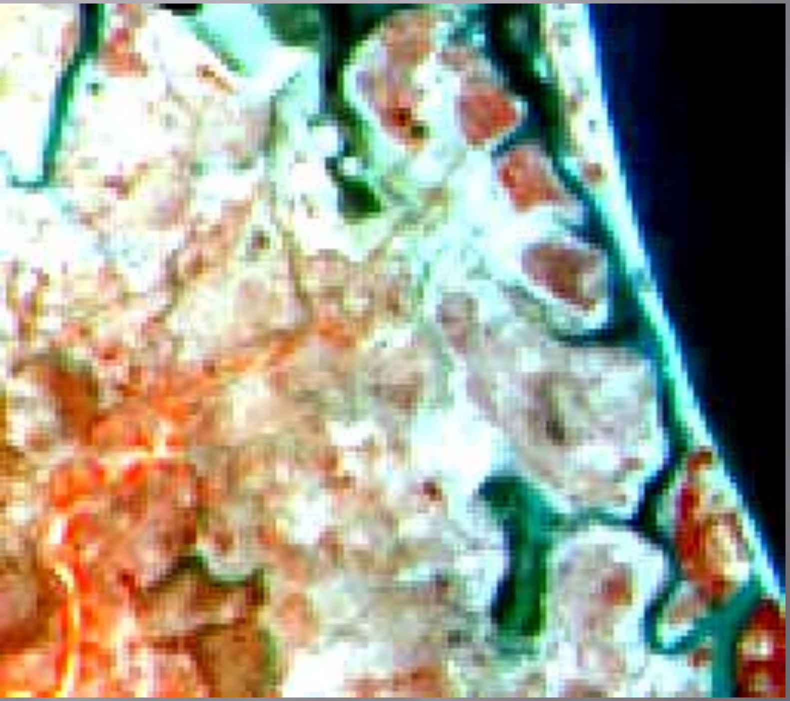
Backwater



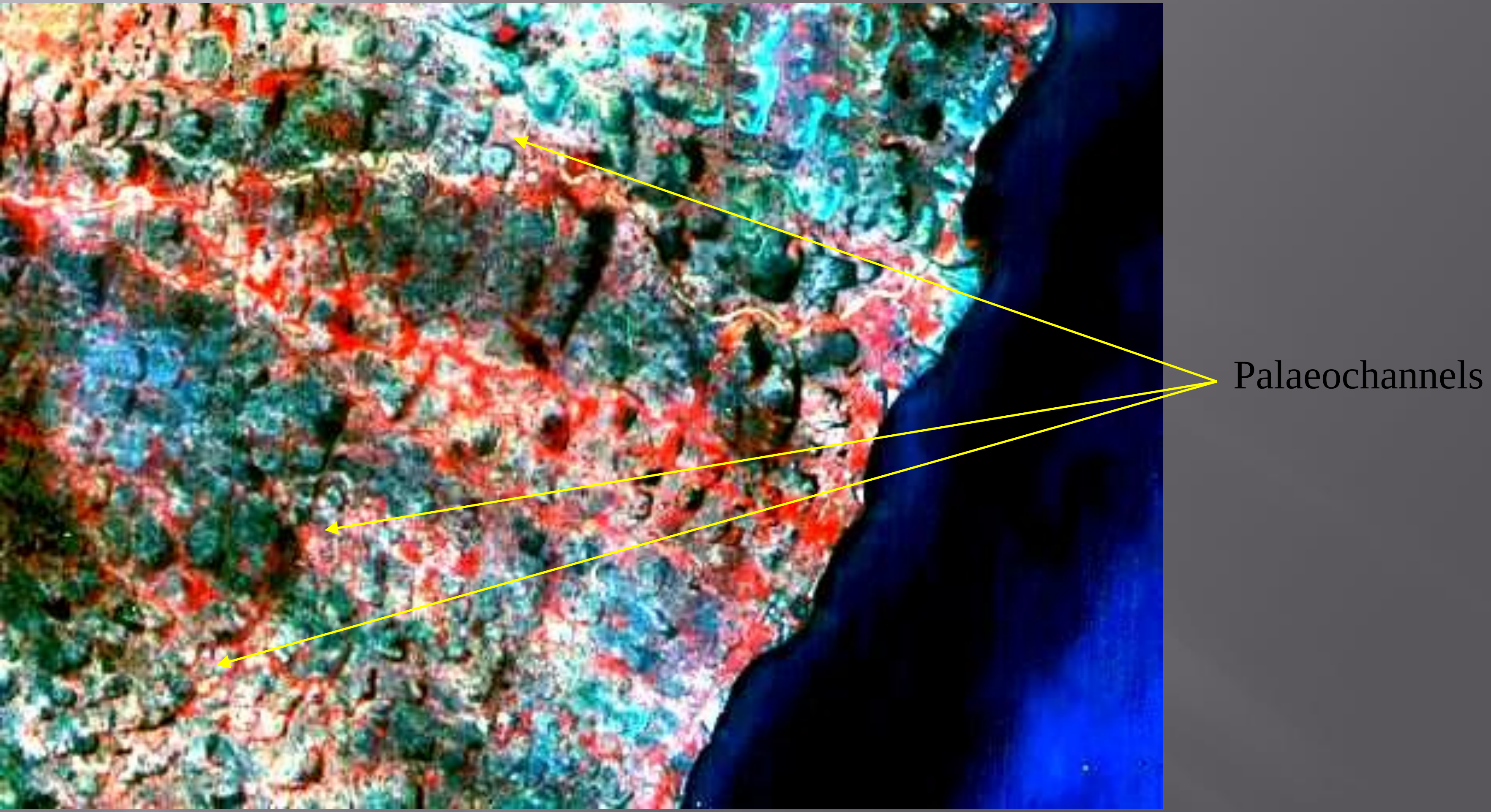
Muthupettai backwater, vedaranniyam

valinokkam

Mud flat



North Chennai region

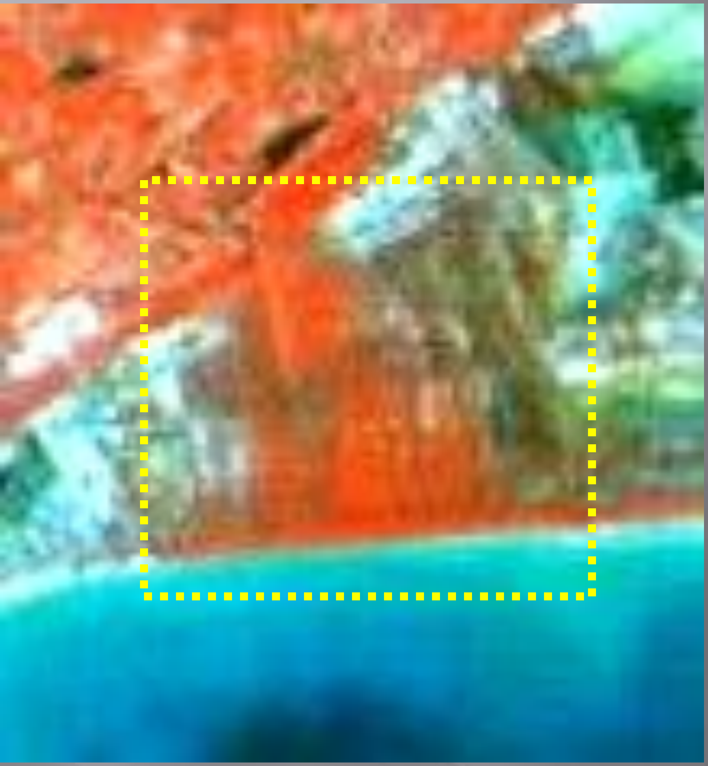


Manimuttar river

Inter Deltaic Lakes (Deltaic lobes)

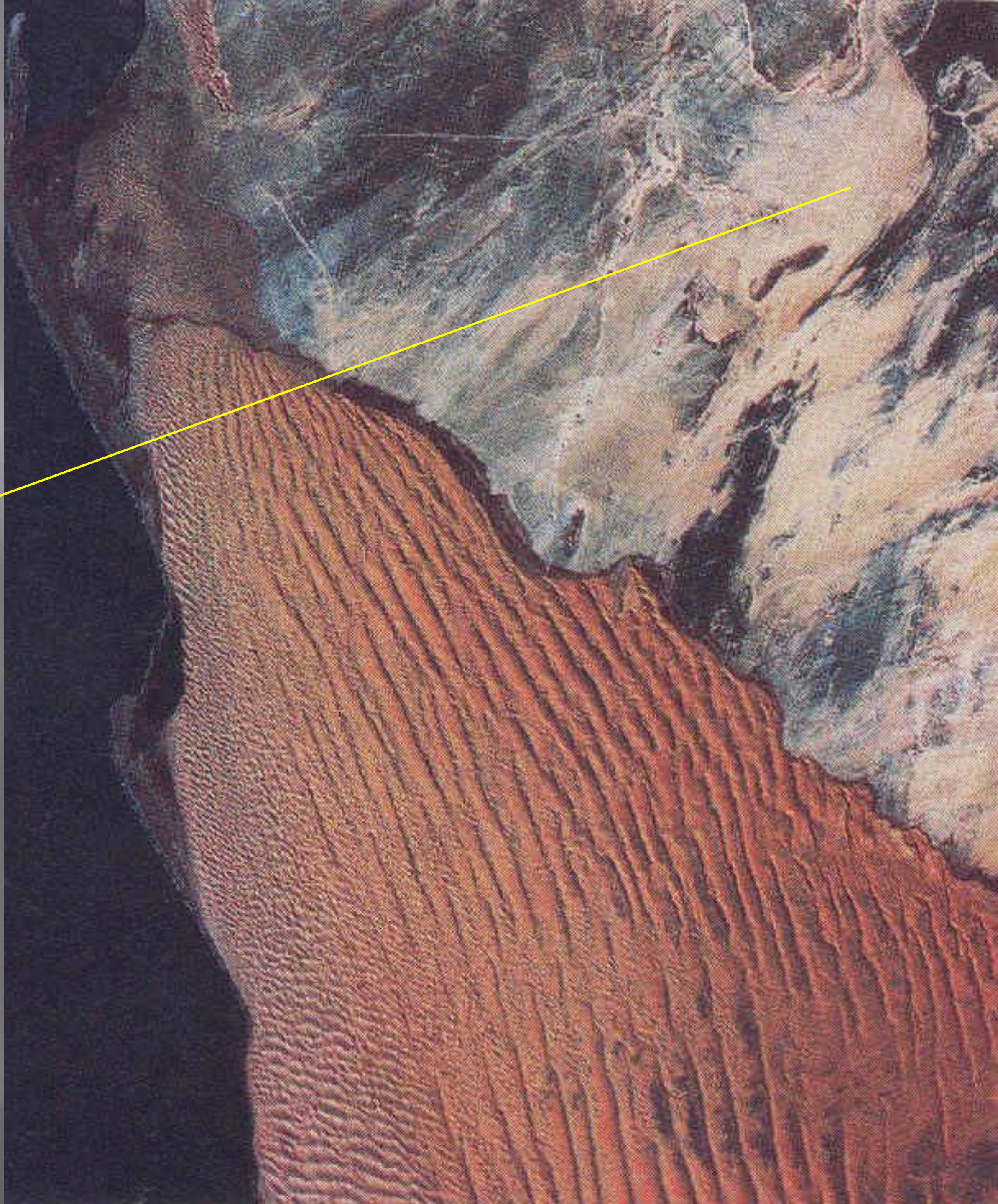
Manemelkudi region of Pudukkottai district

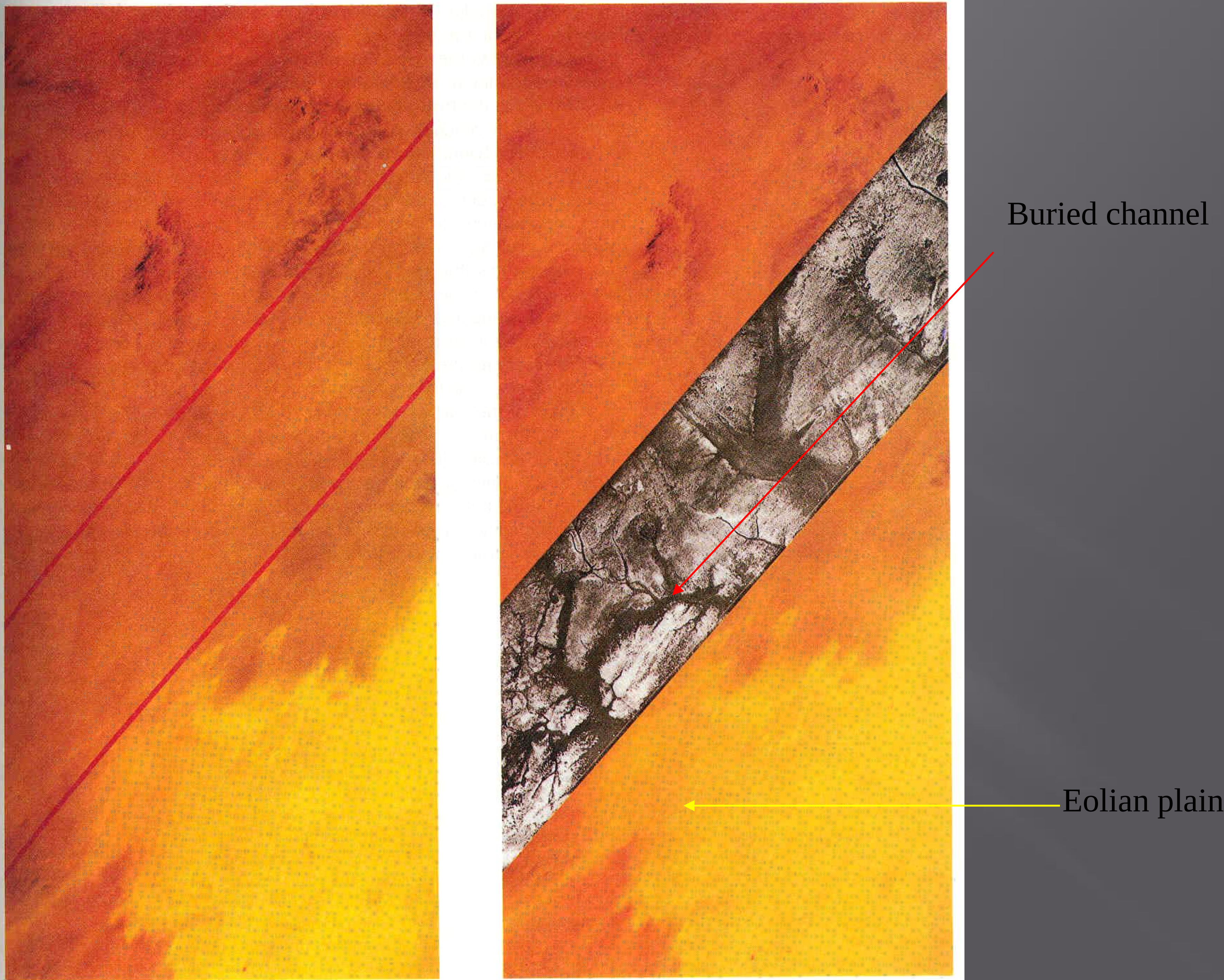
Mangrove Forest



Muthupet Backwater, Maravakkadu

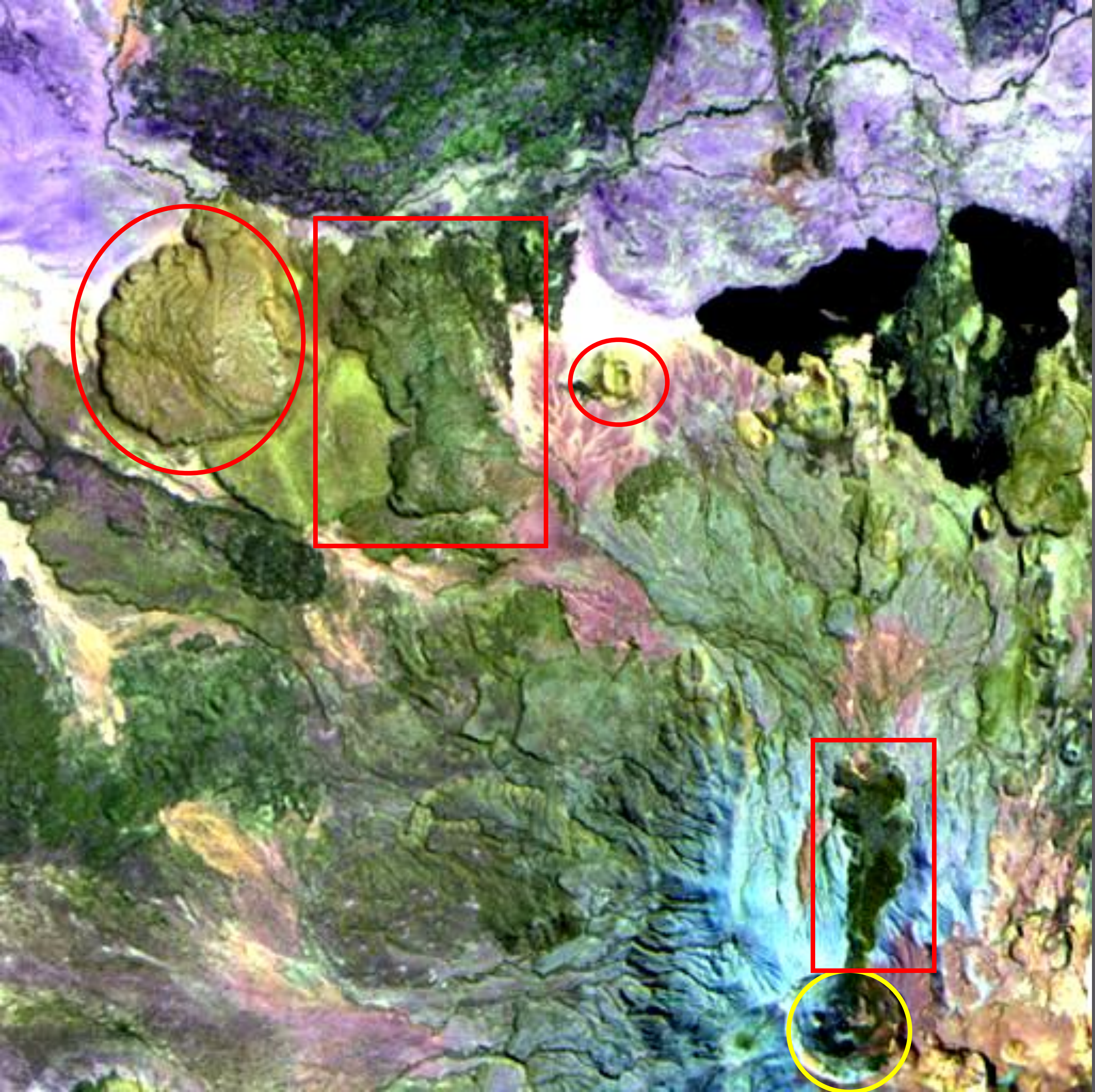
Loess plain





Buried channel
Eolian plain

Glacial environment



Volcanic terrain, Kenya

466px-SonghuaRiver_ASTER_20020401Oxbowlake

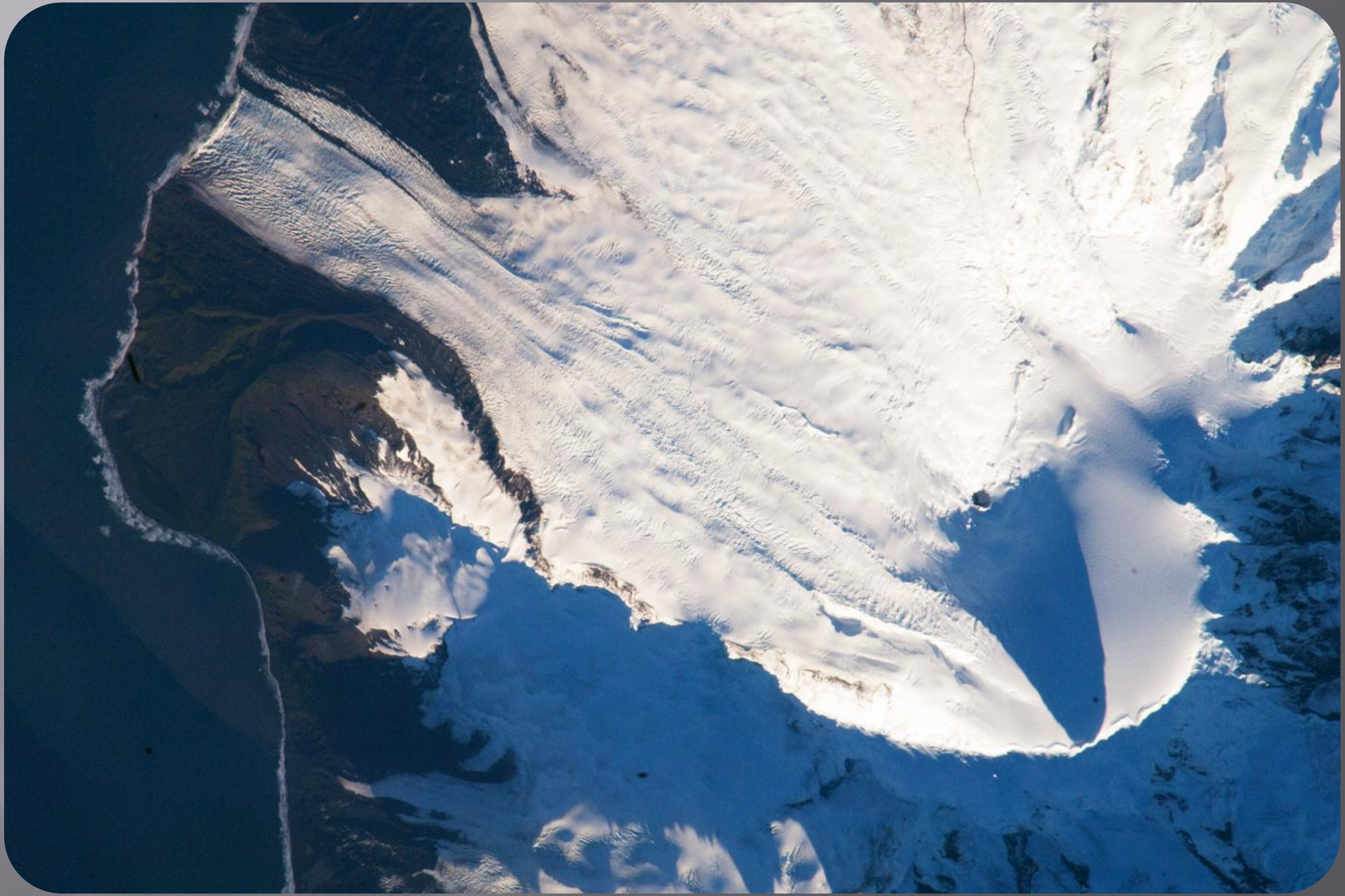
Oxbow Lakes,
Meanders,
Meander Scars,
Floodplains

Natural Arch

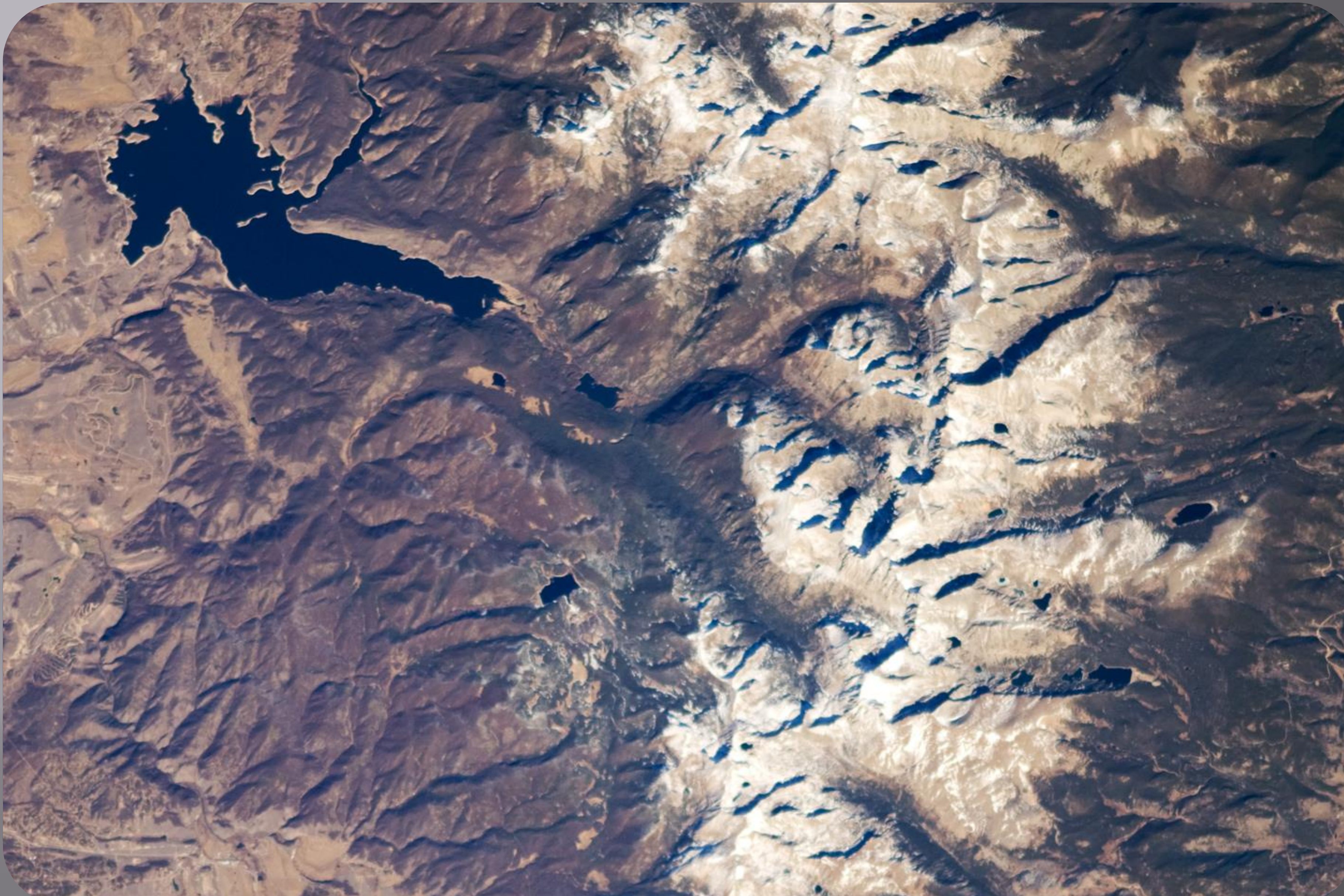
LaSalle Natural Arch , formed due to fluvial and denudational geomorphic processes.

Glacio-Fluvial

Frozen_Waterfall_Wappinger_Creek



glacial volcano_lrg



ISS018-E-GREAT DIVIDE_lrg

Coastal Geomorphology – Coastal Plain – Salt encrusted

800px-Aralship2

Denudational Geomorphology

Mass_Waste_Palo_Duro_2002

Aeolian Geomorphology

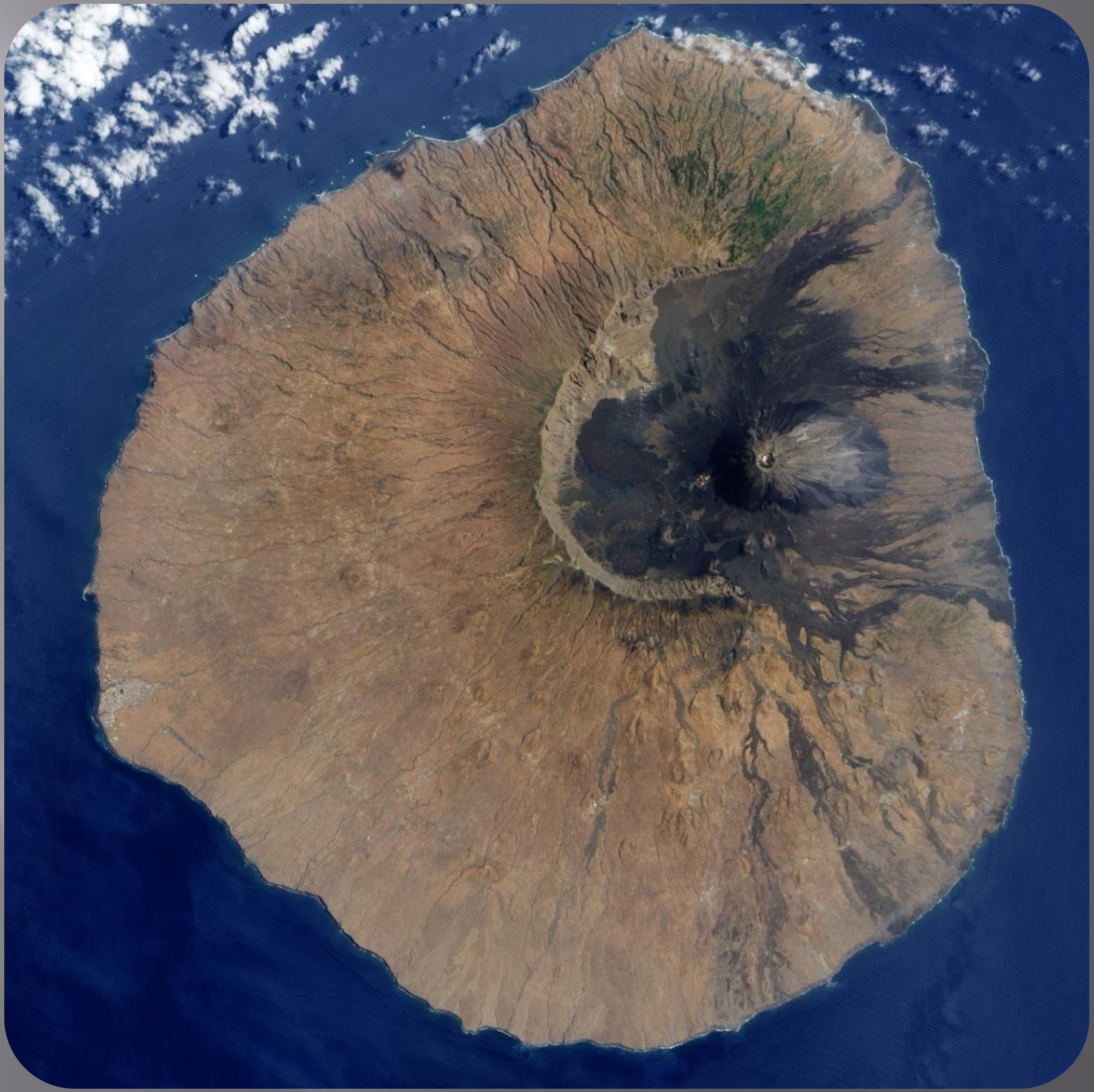
Mesquite_Sand_Dunes

MoabAlcove_aeolian_cave

ISS017-E-013025_lrg

Yellowstone geyser

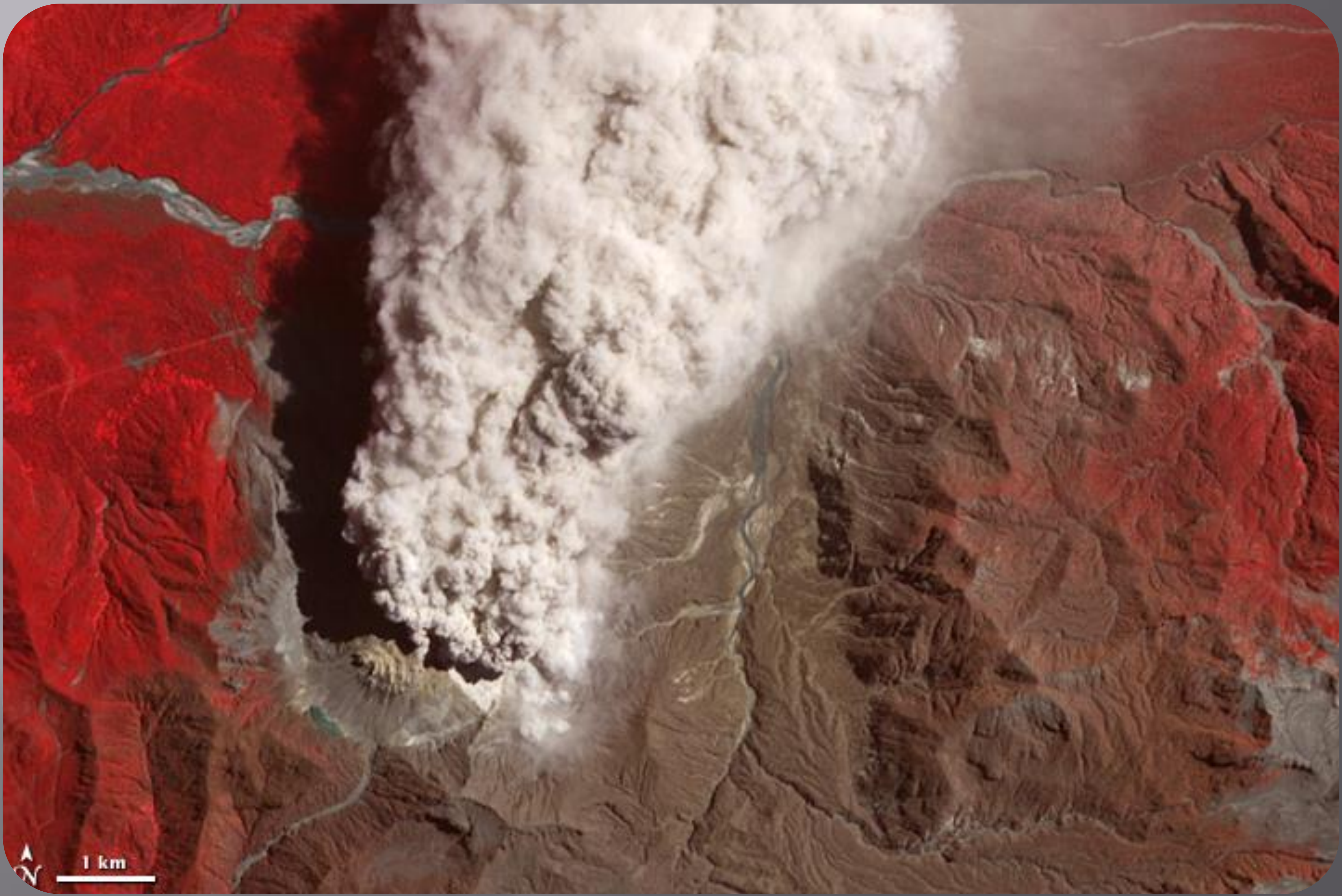
Volcanic Geomorphology



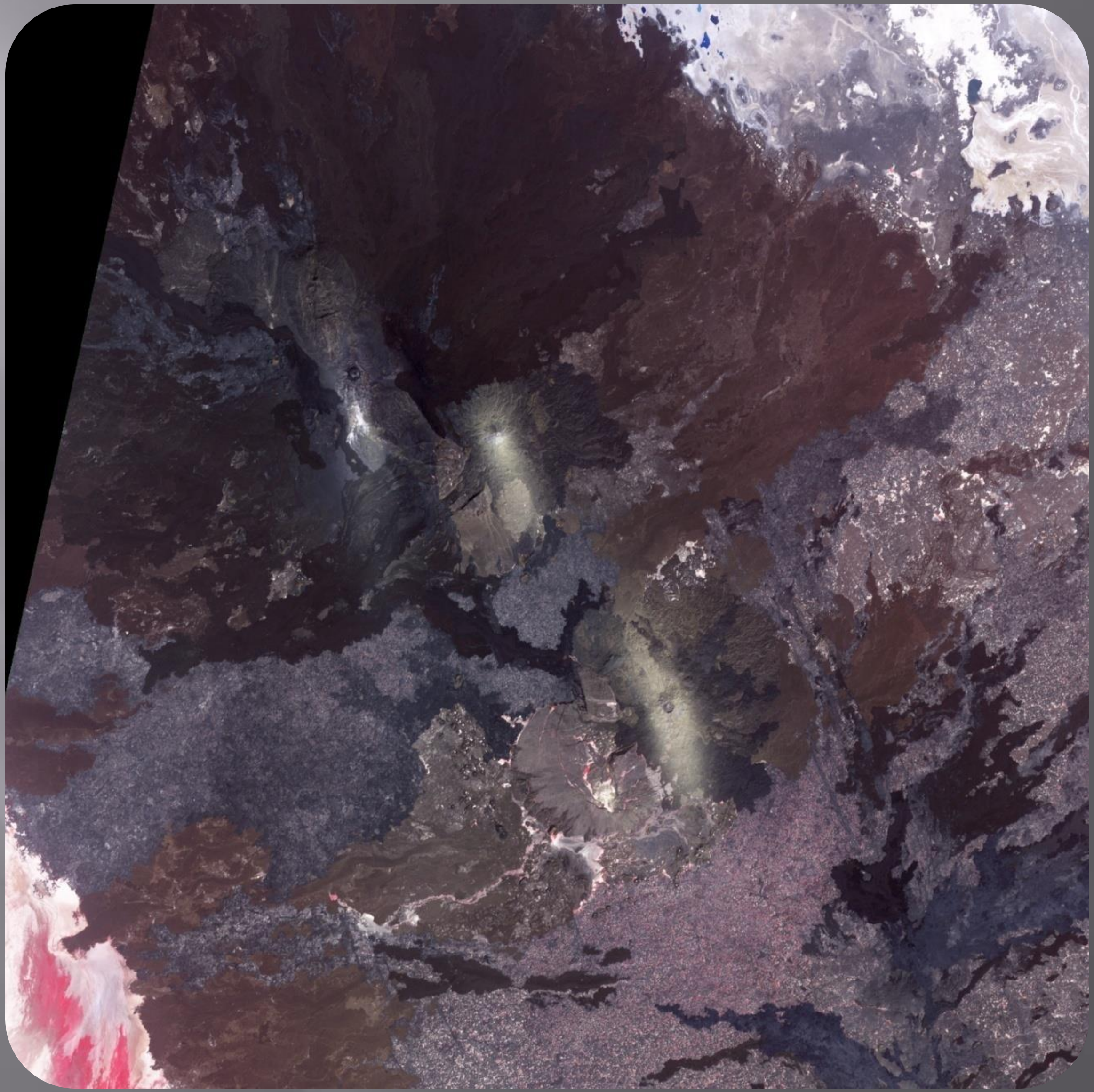
9km dia volcanic neck fogo_ali_2009161_lrg

363382main_image_1397_946-710

chaiten_volcanoe1



chaiten_volcanoe



ertaale_ast_volcanoes_lrg

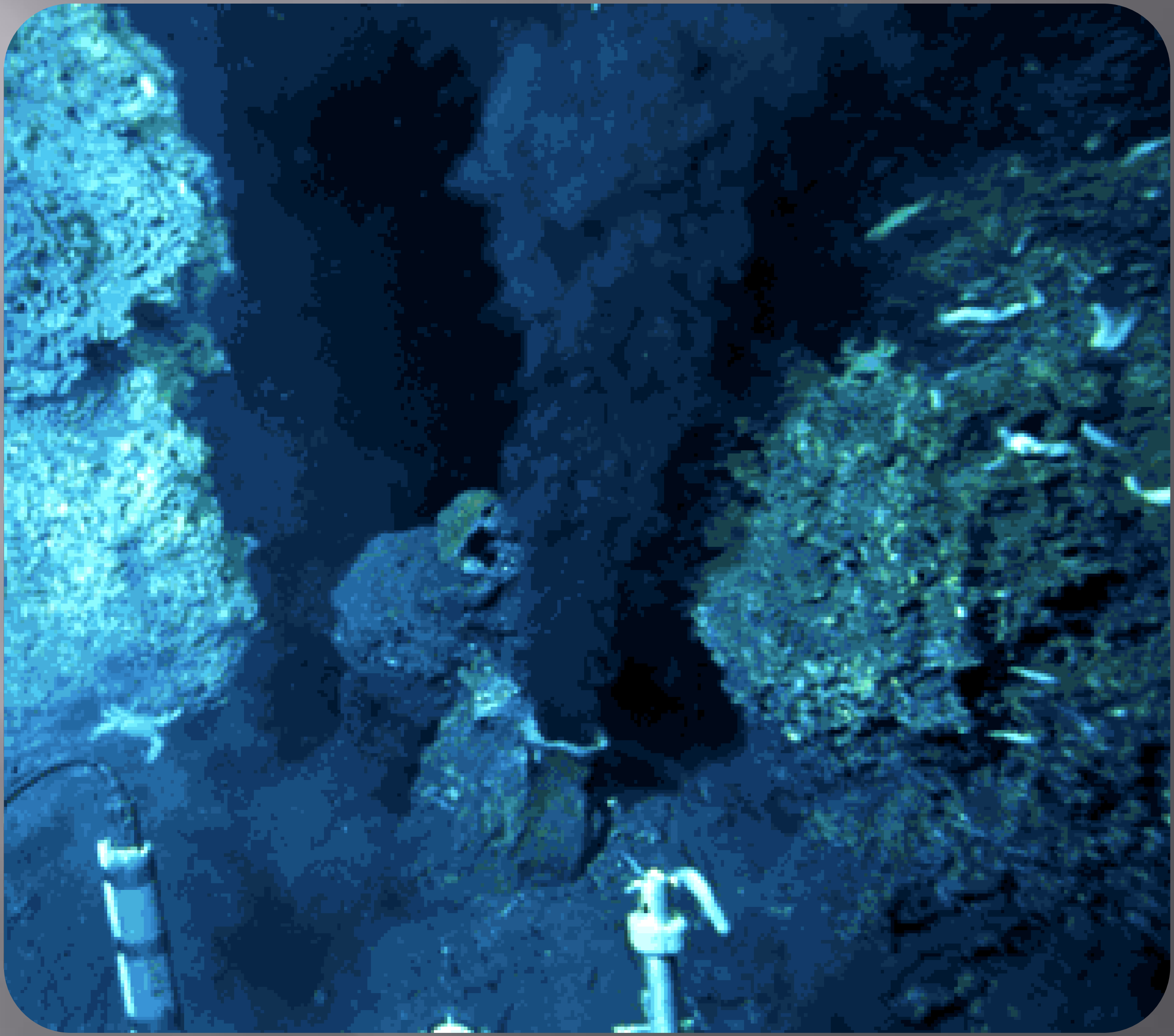
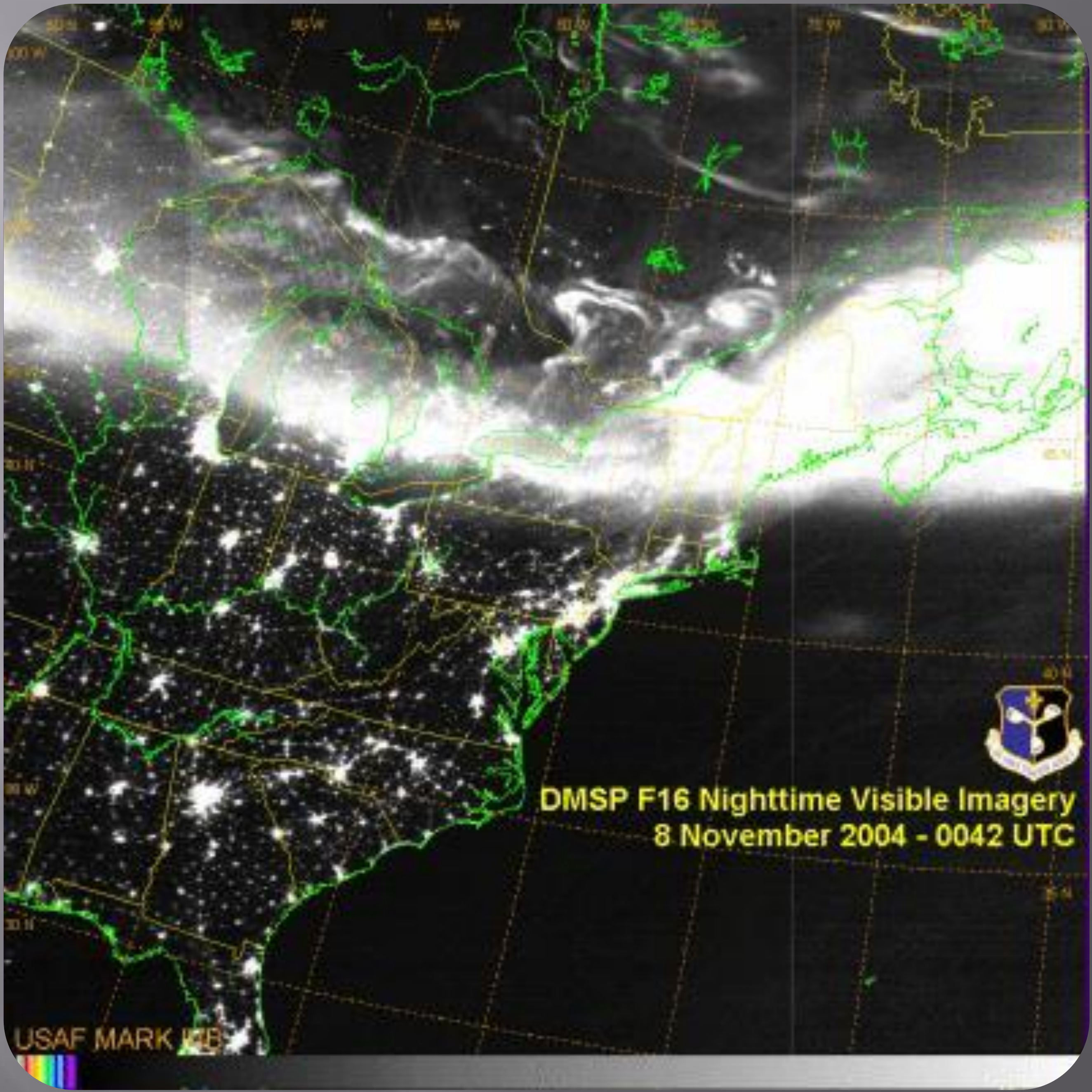


Fig Deep sea smoker-hot springs



main_aurora-f16-08nov2004-0042utc