TECTONIC GEOMORPHOLOGY

(TECTONIC LANDFORMS)

e-Learning Material: Unit-3

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DEFINITION: Land forms formed or produced by denudational processes or physico- chemical breaking down processes but retained their original tectonic fabric.

***Tectonic geomorphology*: how tectonic activity affects process and morphology in geomorphic systems and how landforms can be used to assess tectonic activity.**

Landform of structural origin is related to structural aspect of the area.

Most of the landform under this class has genesis related to underlying structure.

Structure plays an important role for reducing the resistance of rock which manifests itself in different geomorphic forms.

REASONS FOR STUDYING TECTONIC LANDFORMS

(i) Mineral targetting (structurally controlled deposits)

- Bauxites in plateau
- Copper in escarpments (Vindhyans)
- Minerals in Strain maxima zones in folds
- Remobilised deposits in fractures / maximas

(ii) Groundwater in younger fractures

(iii) Hotwater springs in younger fractures

(iv) Detection of zones of Active tectonics

(v) Landslides mapping etc.,

(vi) Earthquake vulnerability mapping

CLIMATE FAVOURABLE FOR TECTONIC LANDFORMS

i) Temperate
ii) Humid
iii) Subhumid
iv) Arid - rarely

PARENT ROCKS

i) Sedimentary
ii) Meta sedimentary
iii) Volcanic

AGENTS

i) Atmosphere
ii) Wind
iii) Water

TECTONIC LANDFORMS

Structural Hills

- Highly Dissected
- Moderately dissected
- Poorly dissected

Tors complexes

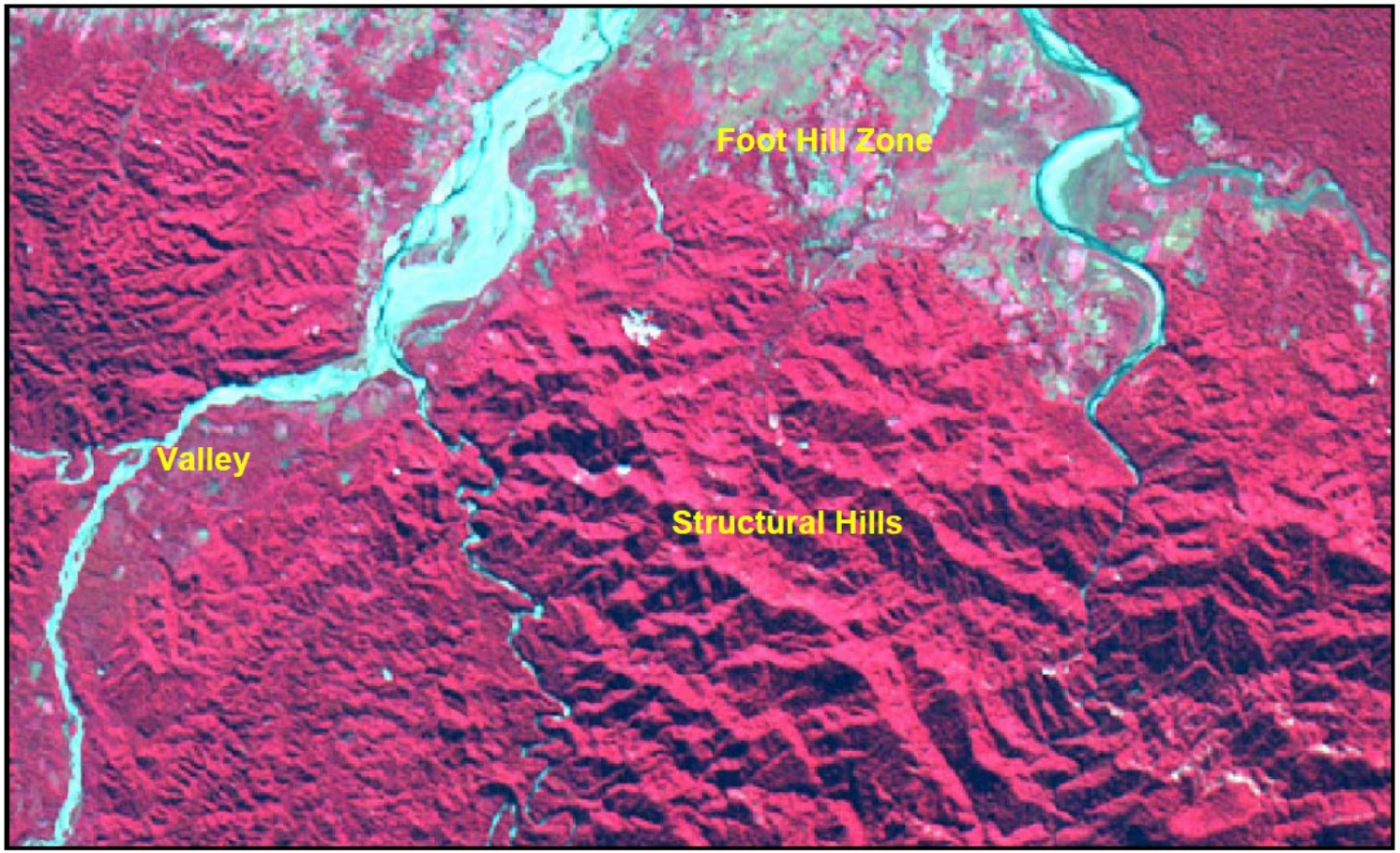
Horizontal Landforms

- Tectonic Plateau
  - Highly Dissected
  - Moderately dissected
  - Poorly dissected
- Tectonic Mesa / Butte
  - Highly Dissected
  - Moderately dissected
  - Poorly dissected

LANDFORMS IN UNDEFORMED ROCKS

Structural Hills: **Hills are originated due to tectonic process and If are highly dissected by the drainage lines, then can be further classified as highly, moderately and low dissection depending on the density of joints and drainage.**

Fig. 4.24: Satellite image of Himalayan region showing the structural landforms.



Structural Hills:

Pre-Cordillera: Patagonian Andes, Argentina

Structural Hills:

Aerial view,
Himalayan Foothills,
northern Pakistan

Plunging folds

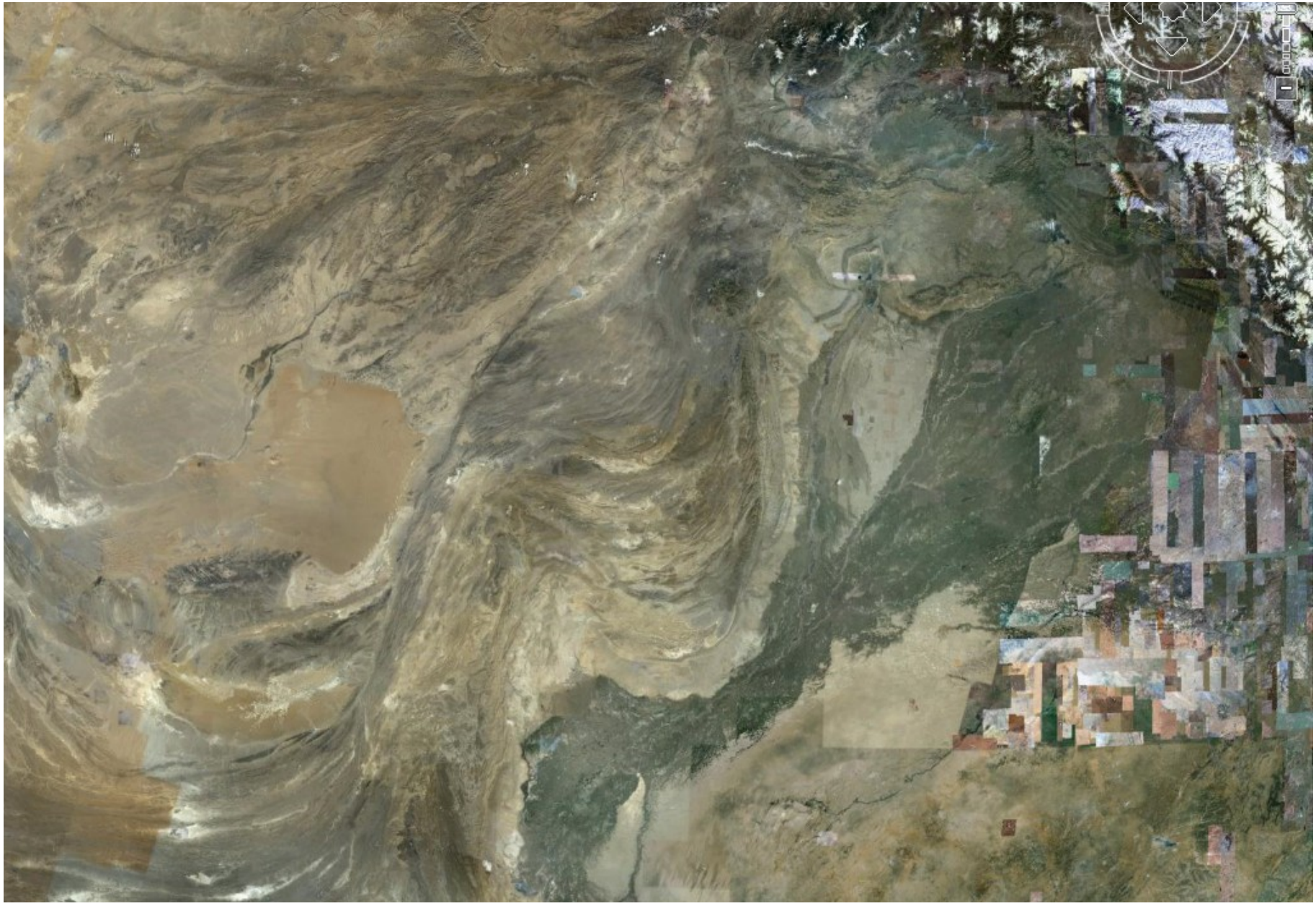
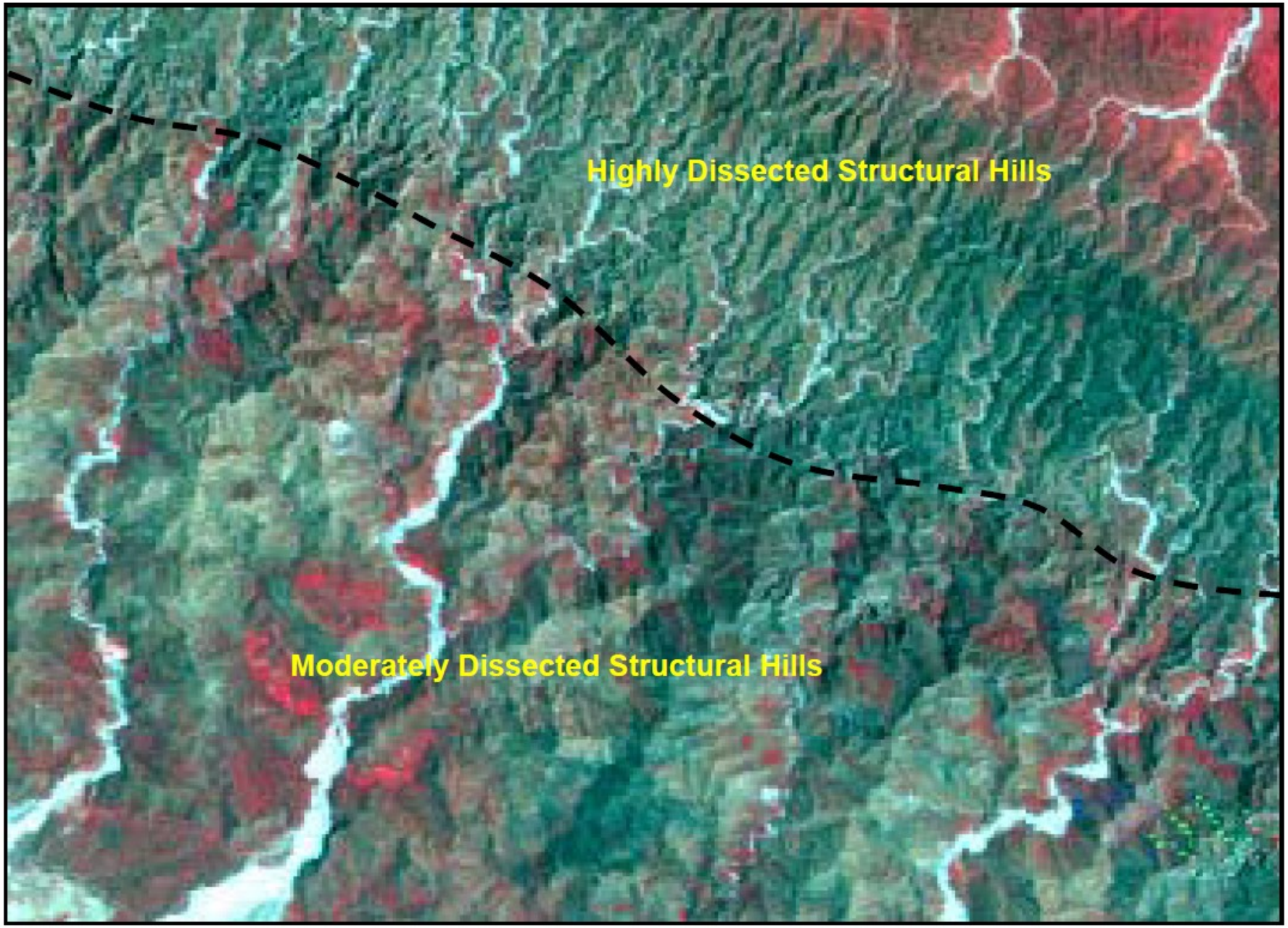


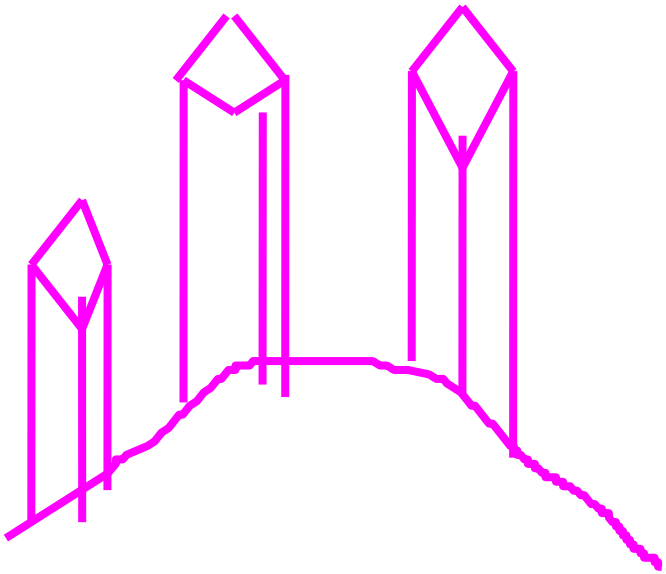
Fig. 4.26: Satellite image of Himalayan region showing dissected structural hills.



TORS

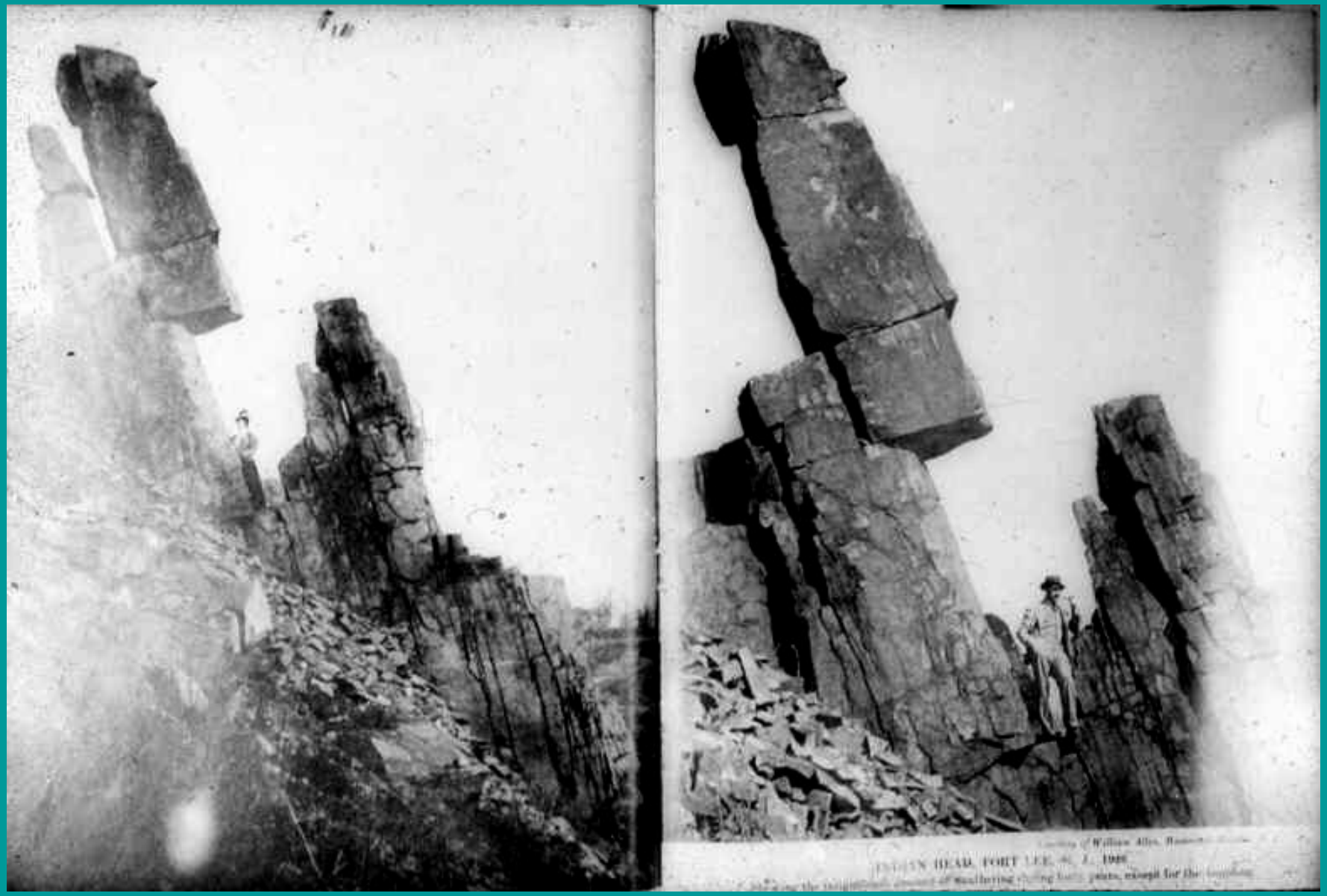
Tor is a complexly jointed blocked hills

(a) Tor complex



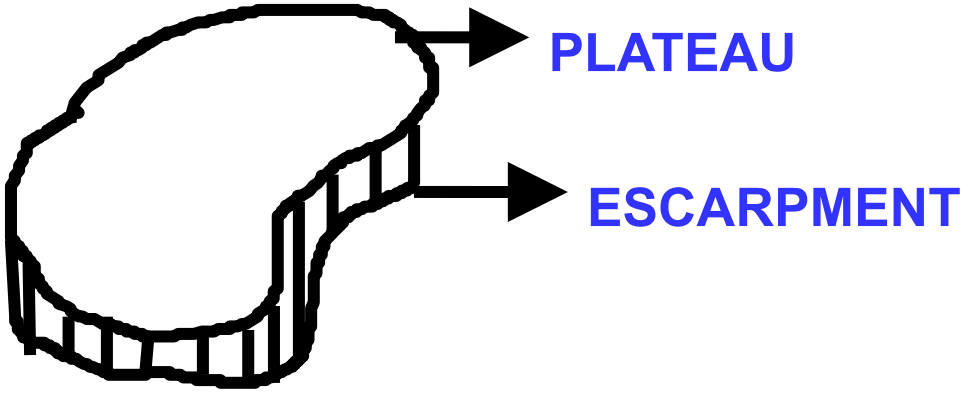
Tor: A high, isolated, craggy hill, pinnacle, or rocky peak; or a pile of rocks, much-jointed and usually granitic, exposed to considerable weathering, and often assuming peculiar or fantastic shapes.

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



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

Landforms and Rock Structure

Landforms of Horizontal Strata and Coastal Plains

Arid climate landforms: horizontal strata in an arid climate often produce plateaus, mesas, and buttes

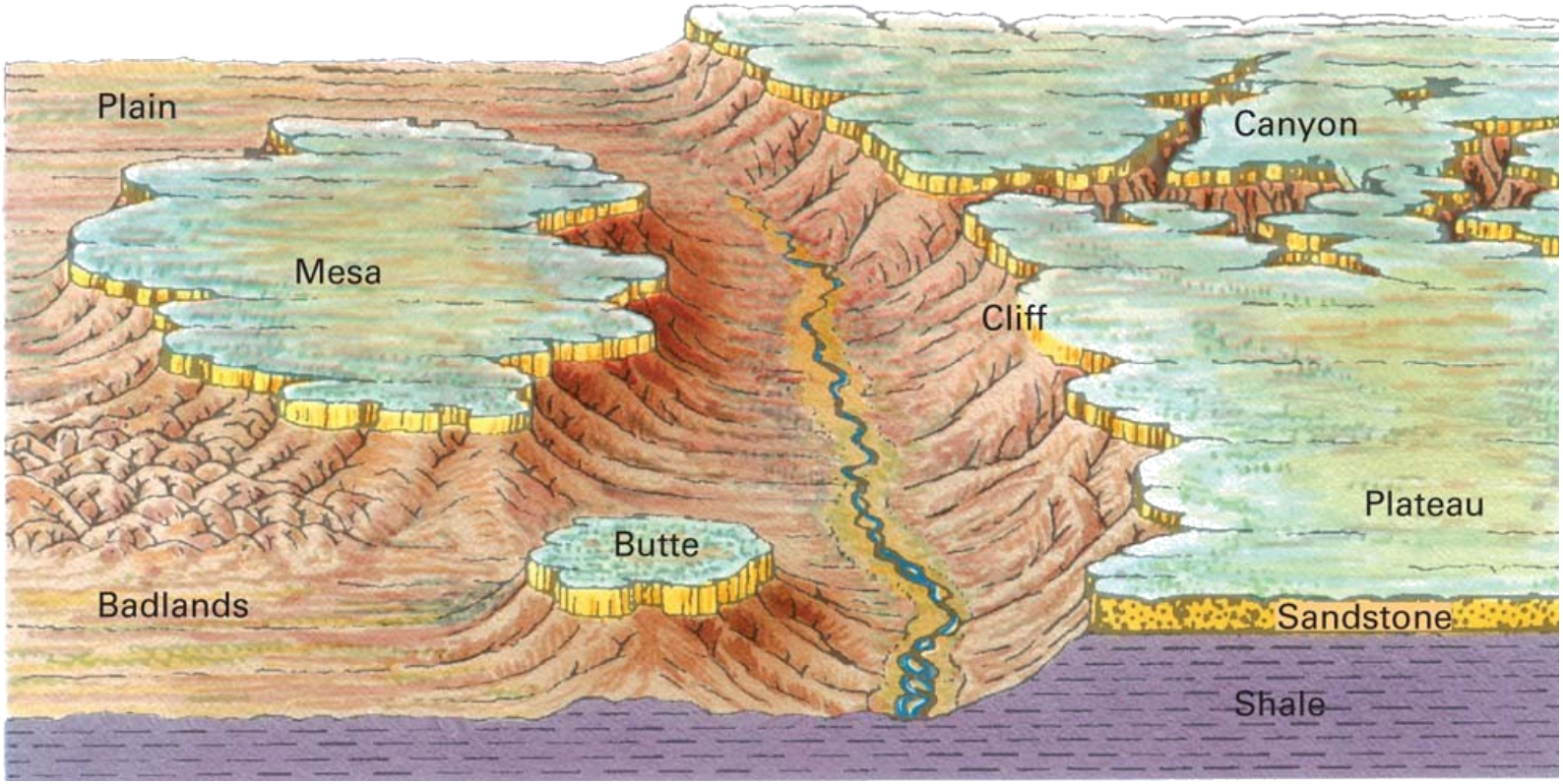
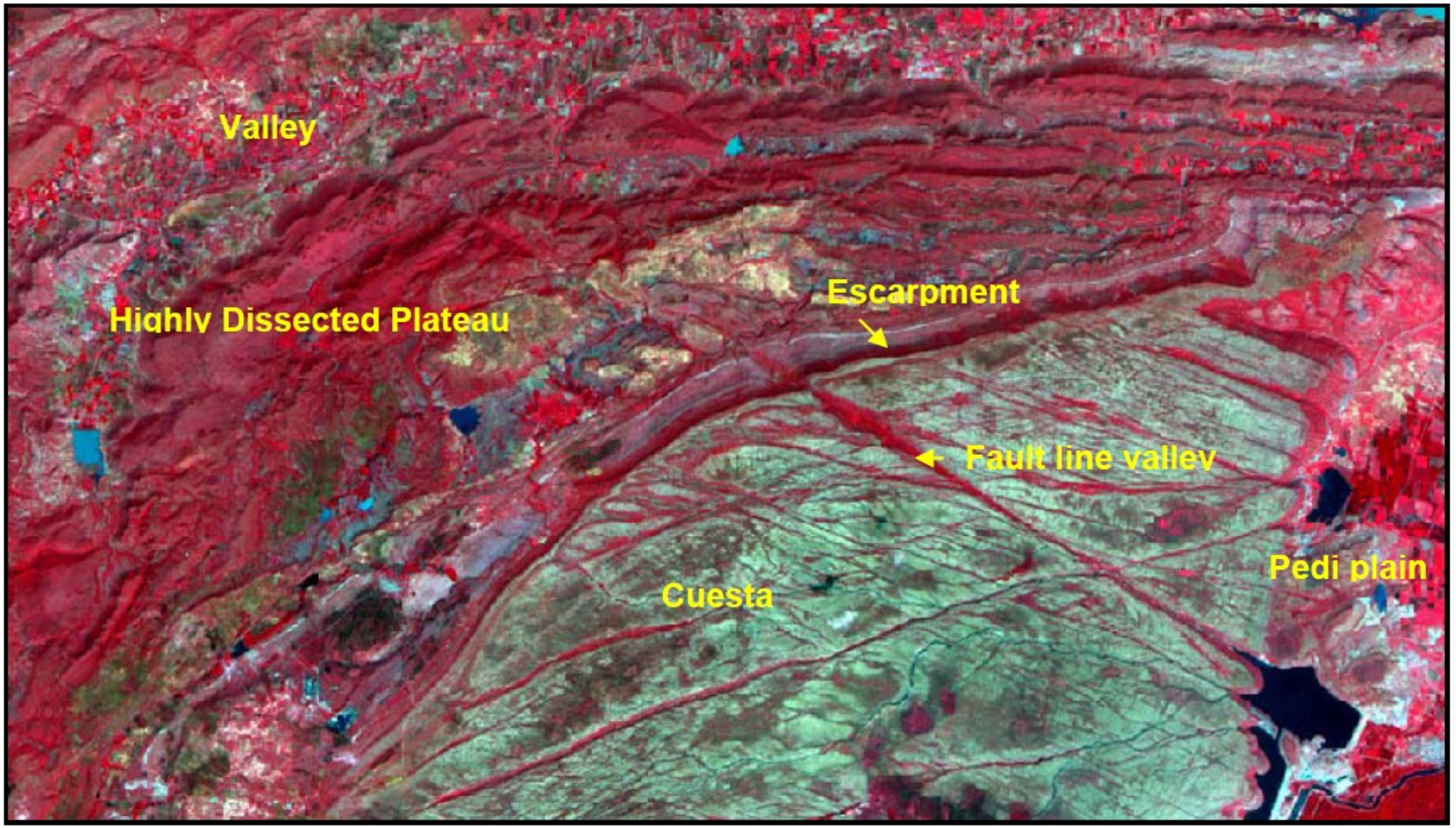


Fig. 4.21: Satellite image of Cuddapah basin showing the Structural landforms.

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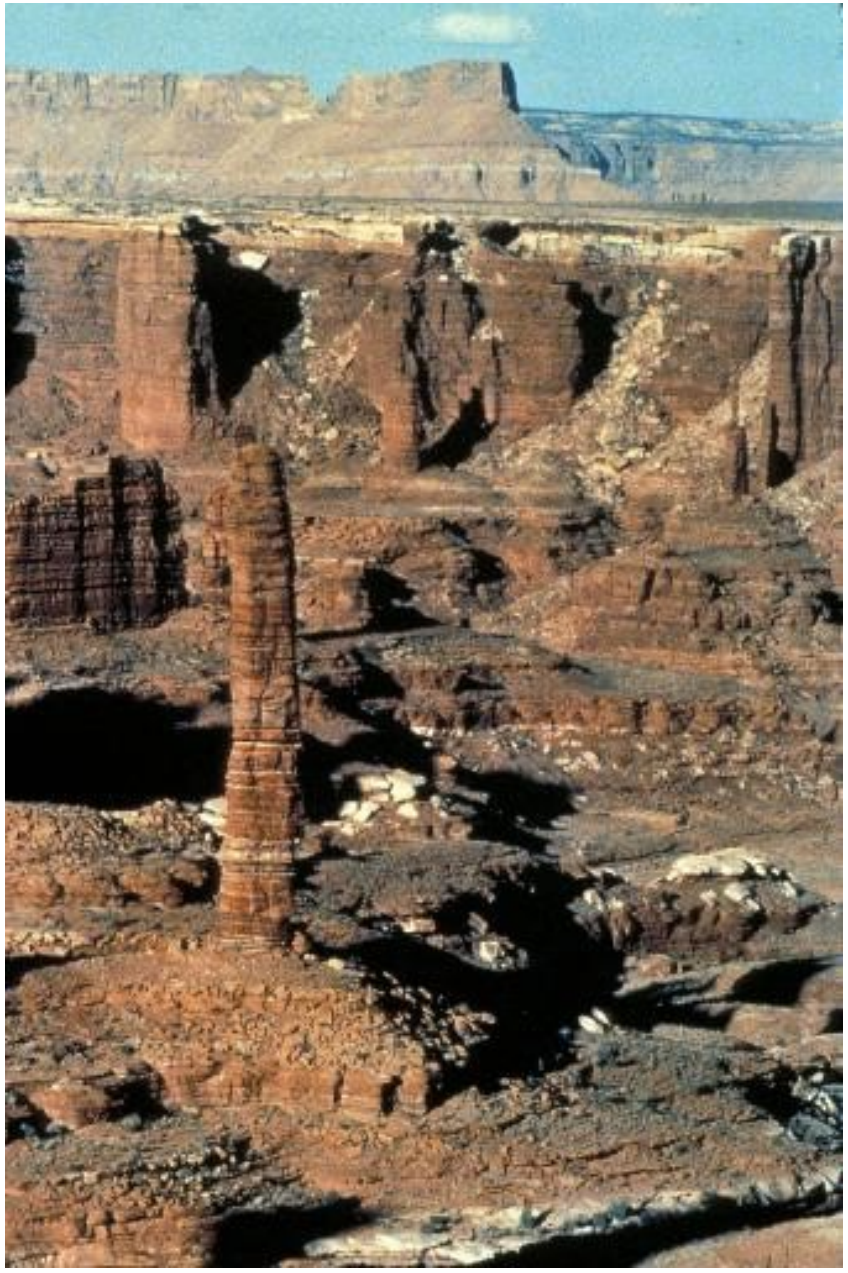


Cedar Mesa Sandstone;
Colorado Plateau;
Erosional Features;
Geomorphology

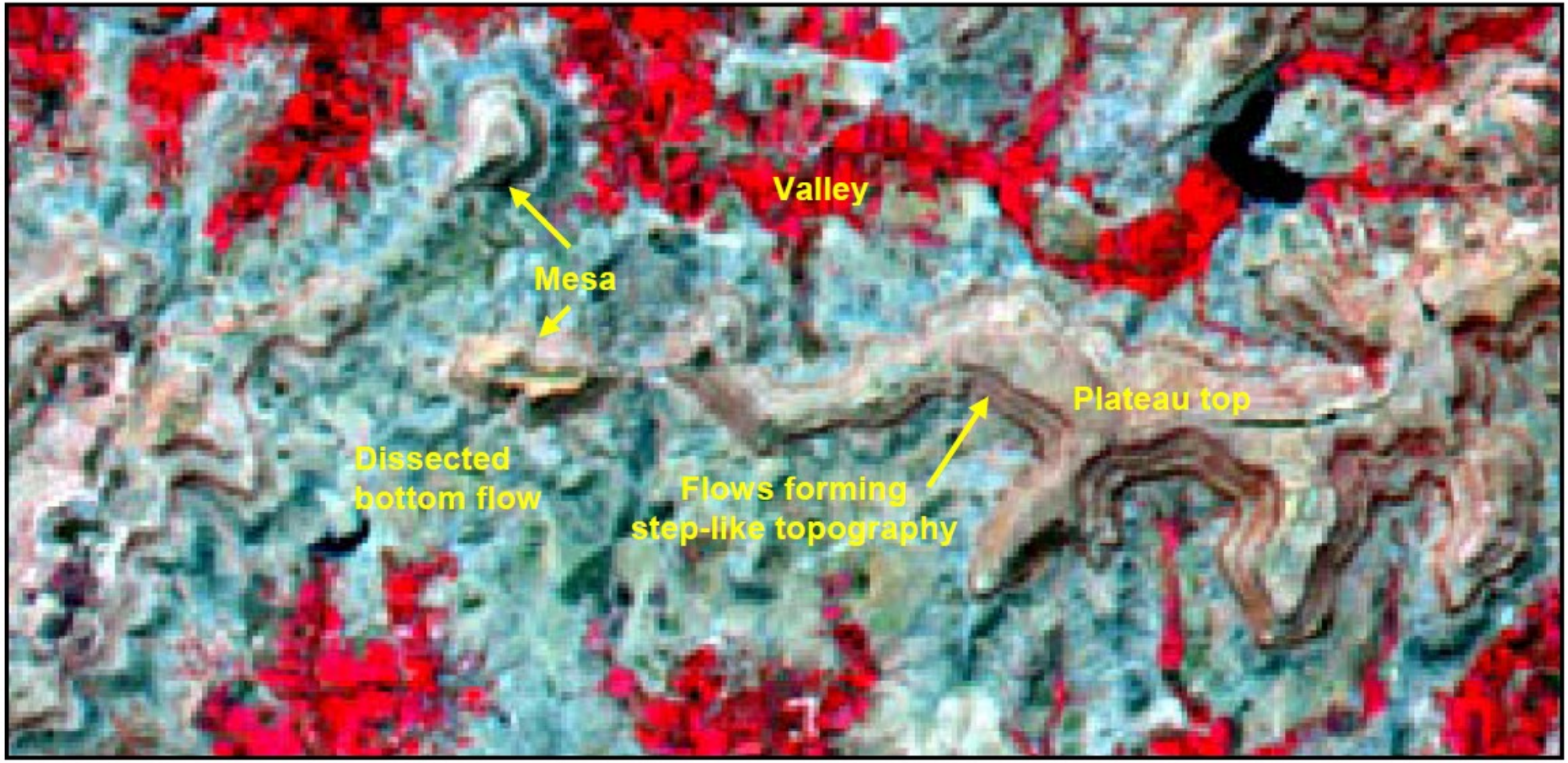
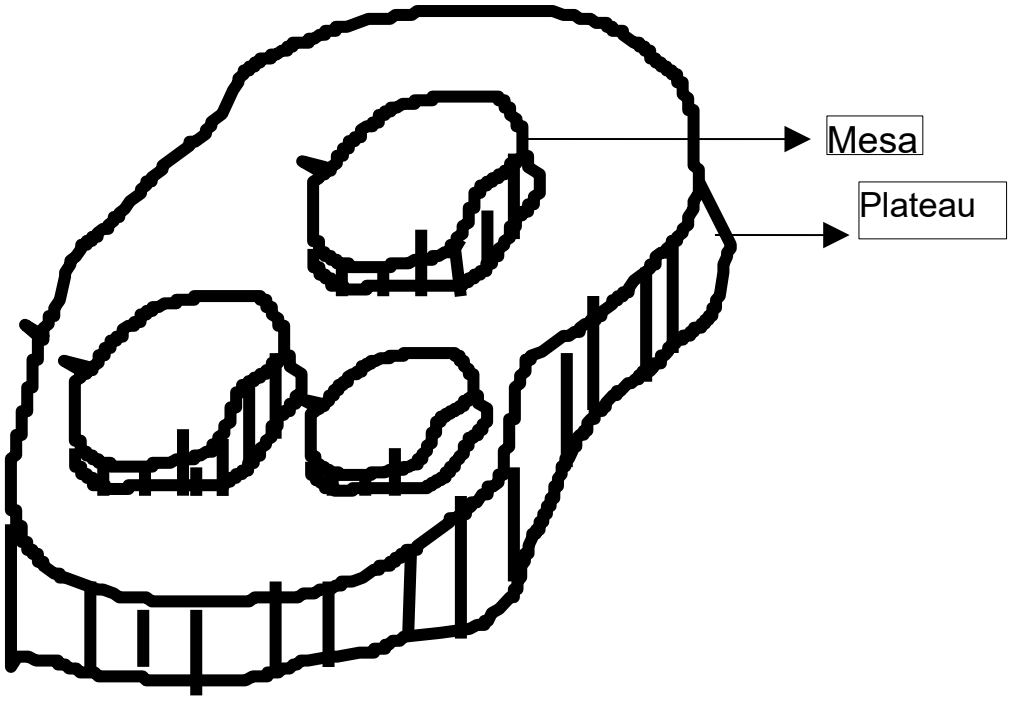


Fig. 4.7: Satellite image of Deccan trap area
showing a pile of basalt flows forming step like topography

Mesa: ***Plateau of small aerial extent***

An isolated flat-topped hill with steep sides found in landscapes with horizontal strata.

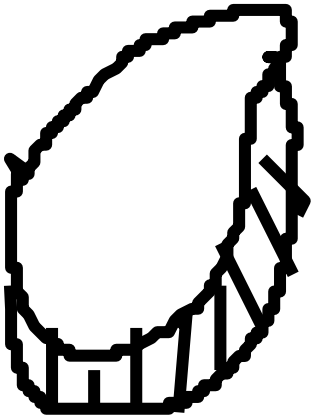


Mesas and buttes

- **Mesa: an aerially-extensive, flat-topped hill with upper layer more resistant to erosion than lower layer**
- **Butte: an eroded remnant of a mesa**
- **Both are formed by mass wasting and slope and tectonic upliftment of strata in arid to semi-arid environments**

Mesas

Butte



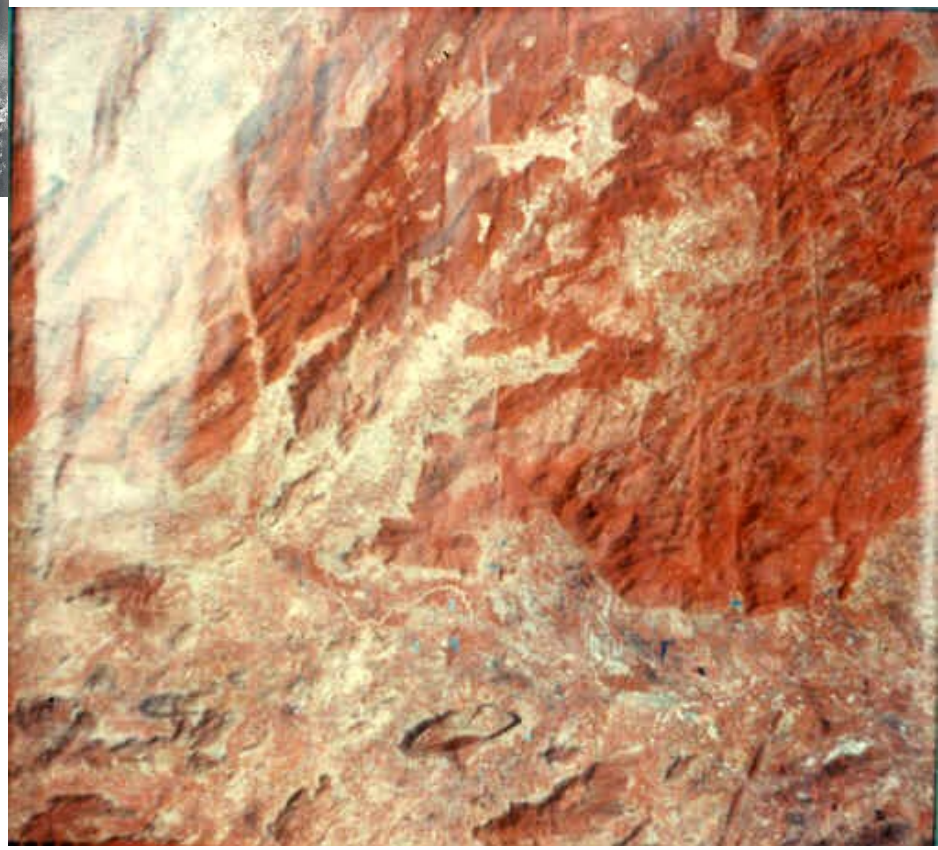
- **Mesa: an aerially-extensive, flat-topped hill with upper layer more resistant to erosion than lower layer**
- **Butte: an eroded remnant of a mesa**
- **Both are formed by mass wasting and slope and tectonic upliftment of strata in arid to semi-arid environments**

➡ relict isolated Mesas of small magnitudes
➡ suggest advance stage of denudation
➡ indicate maturity in denudation

- Plateau>mesa>butte>chimney
- Ratio surface area of top to height


Dry Climate, intermittent strong storms

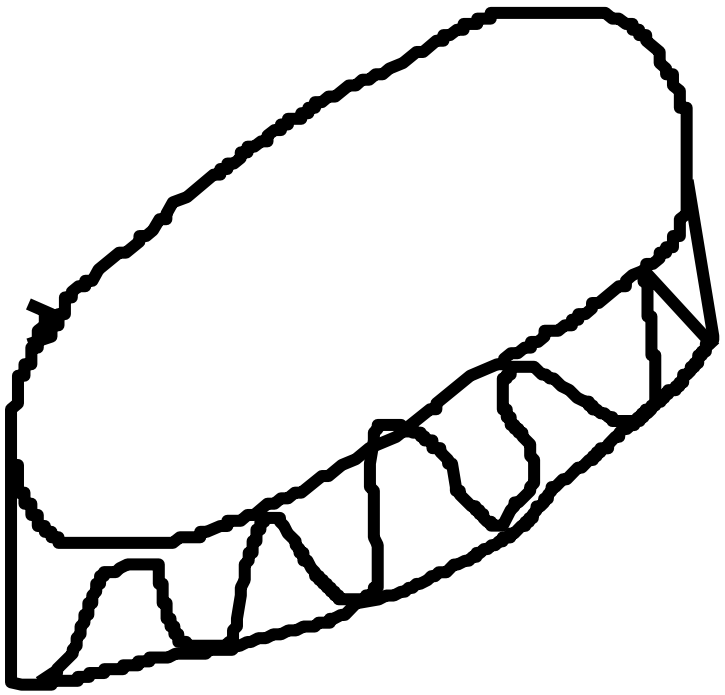
PLATEAU - HIGHLY DISSECTED

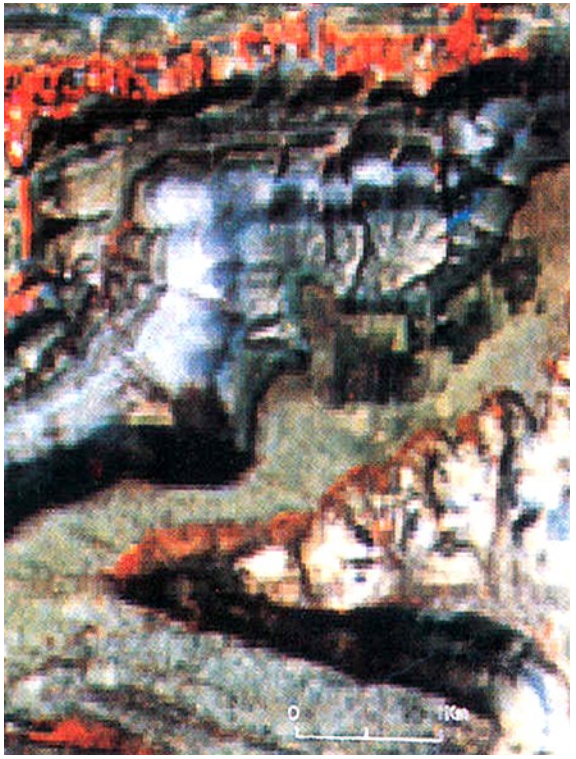


HIGHLY DISSECTED PLATEAU

(*Tower View, Bryce, Canyon*)

Plateaus in the folded basement



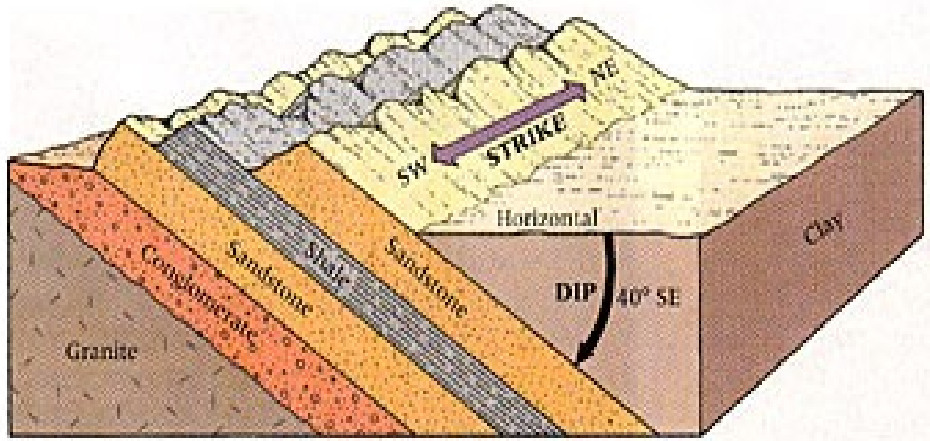


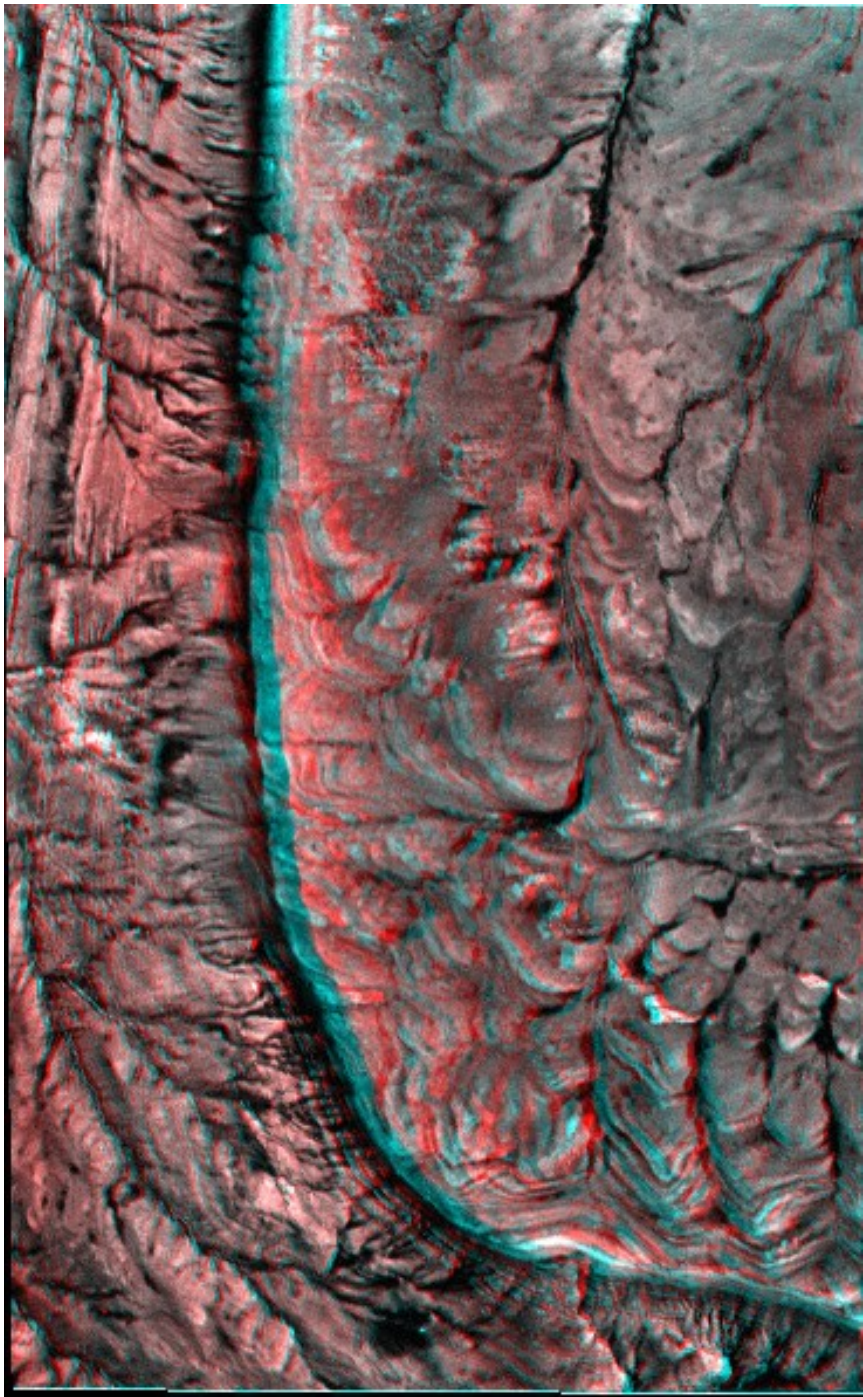
- better groundwater prospects in axis
- groundwater heterogenous in metamorphic plateau
- sheet flow in volcanic plateau
- erosion generally less, except in metamorphic plateau

LANDFORMS IN MARGINALLY DEFORMED ROCKS

Tilted Strata

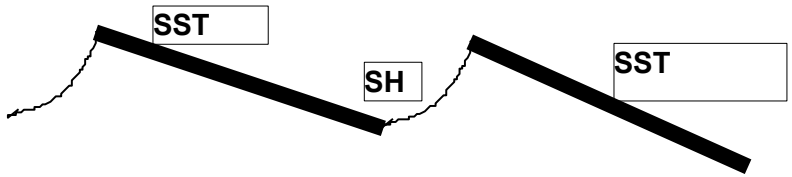
- Monoclinal folds, or one side (limb) of a fold
- Name = f(dip angle)
  - Cuesta (gentle)
  - Hogback (steep)
  - Flatiron remnant of dissected Hogback w triangular face





DIPPING LANDFORMS

Cuesta



Cuesta: A hill or ridge with a gentle slope on one side and a steep slope on the other; specifically an asymmetric ridge with one face (dip slope) long and gentle and conforming with the dip of the resistant bed or beds that form it, and the opposite face (scarp slope) steep or even cliff-like and formed by the out crop of the resistant rocks, the formation of the ridge being controlled by the differential erosion of the gently inclined strata.

- **dip less than 25^{o}**
- **cap or sheet rock at top**
- **obsequent slope by shale**
- **runoff area**
- **valleys better for reservoirs / storage**

Cuestas - <30° dip
Hogbacks - >30° dip

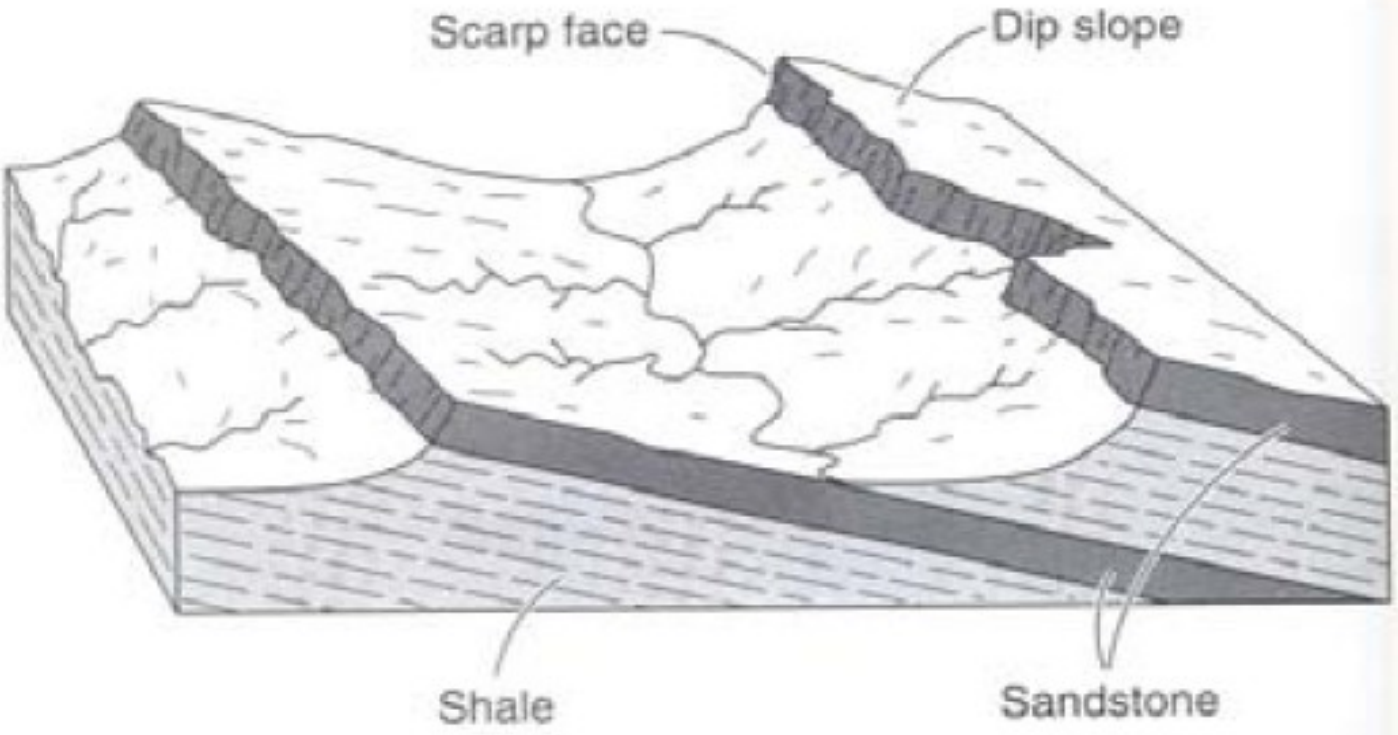


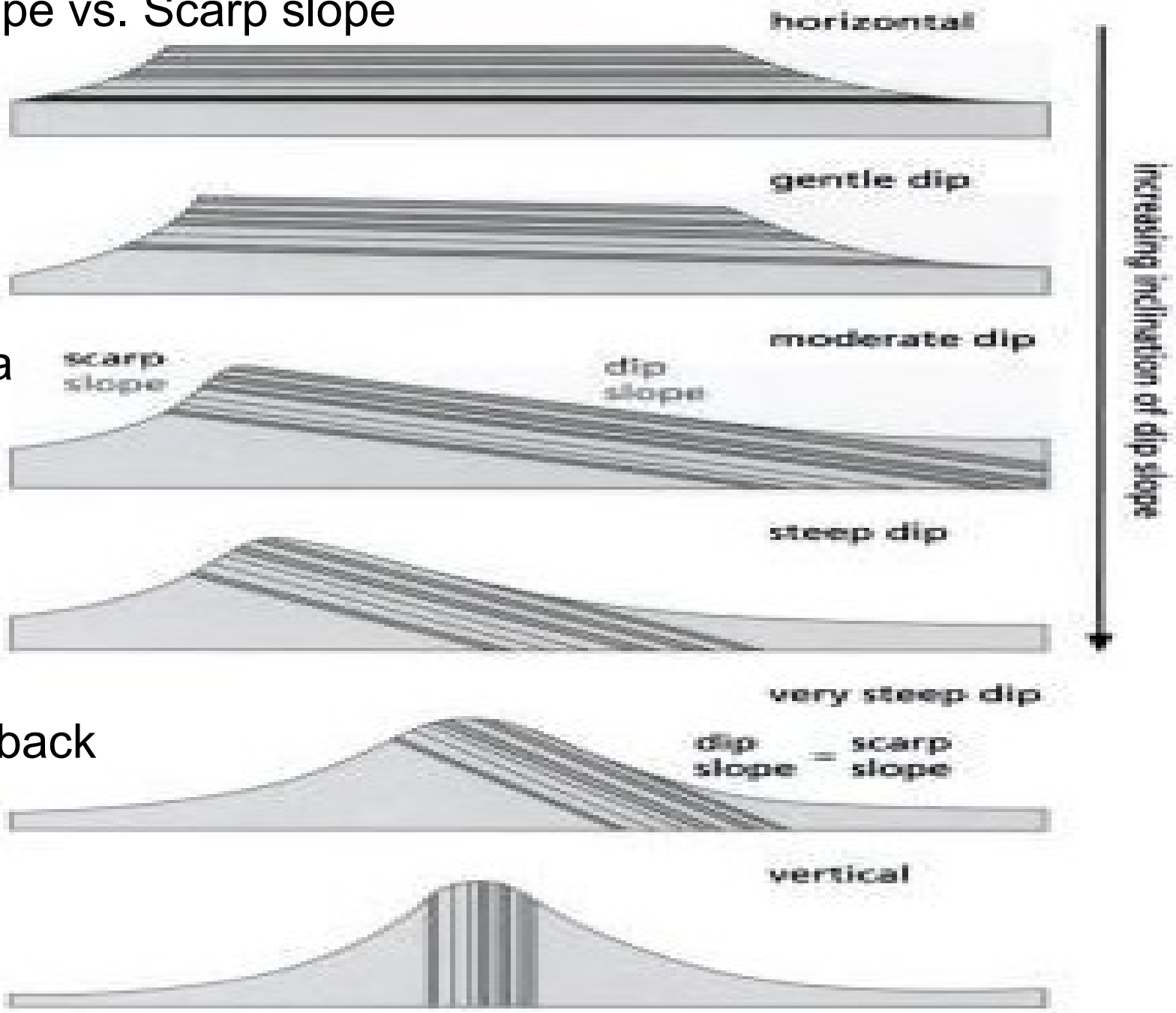
FIGURE 9–6
Adjustment of topography to geologic structure.

TECTONIC CUESTA

PASSIVE DIP SLOPE

CUESTA SCRAP PASSIVE
OBSEQUENT SLOPE

Dip Slope vs. Scarp slope

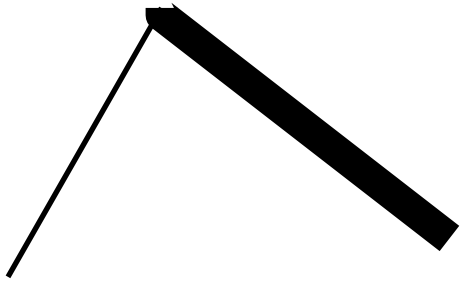


Cuesta

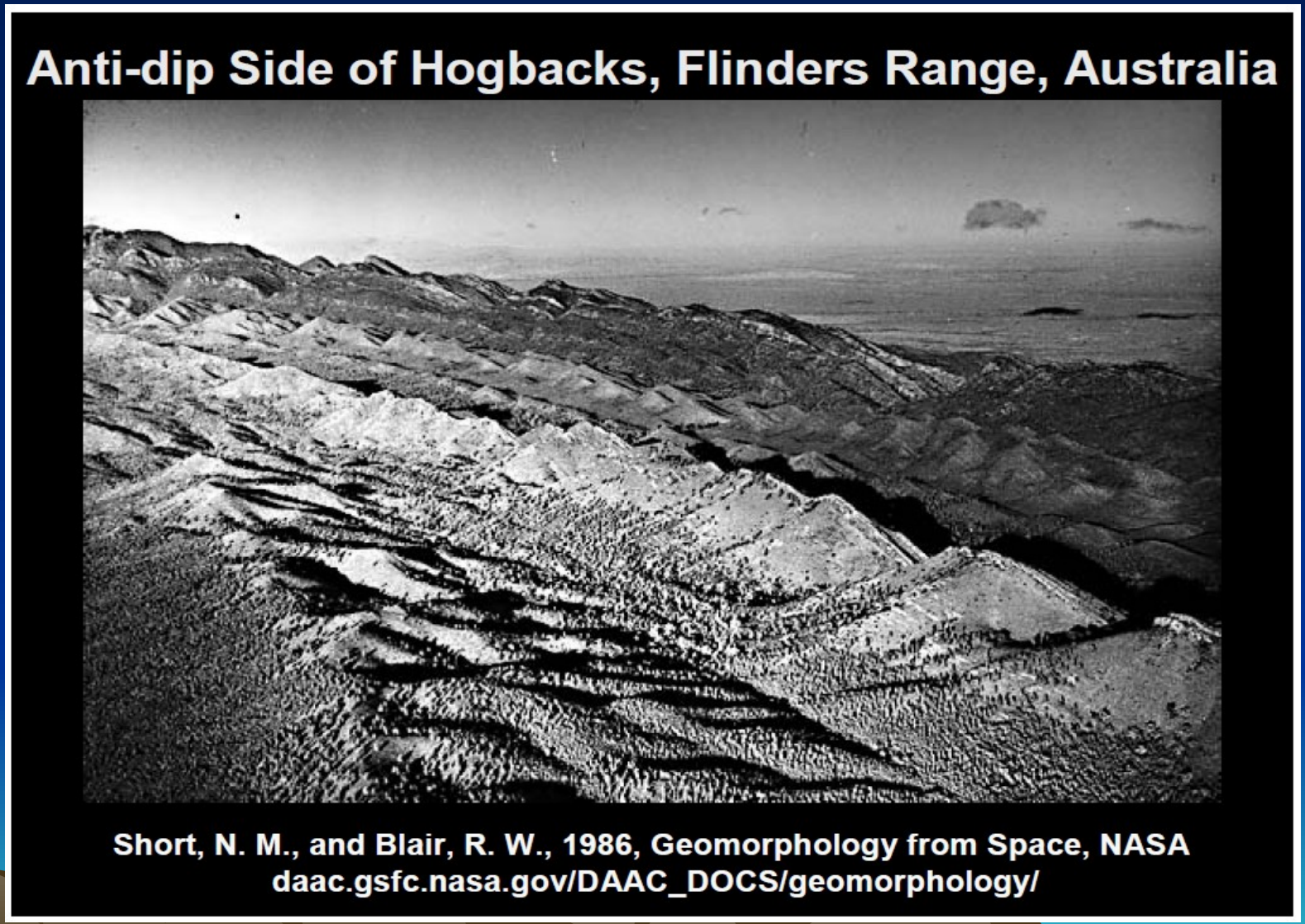
Hogback

Hogbacks

- ***dip more than 25^{o}***
- ***dip and obsequent slope will look almost similar in expression***
- ***dip and obsequent slopes are equal***



–Flatiron remnant of dissected Hogback with triangular face



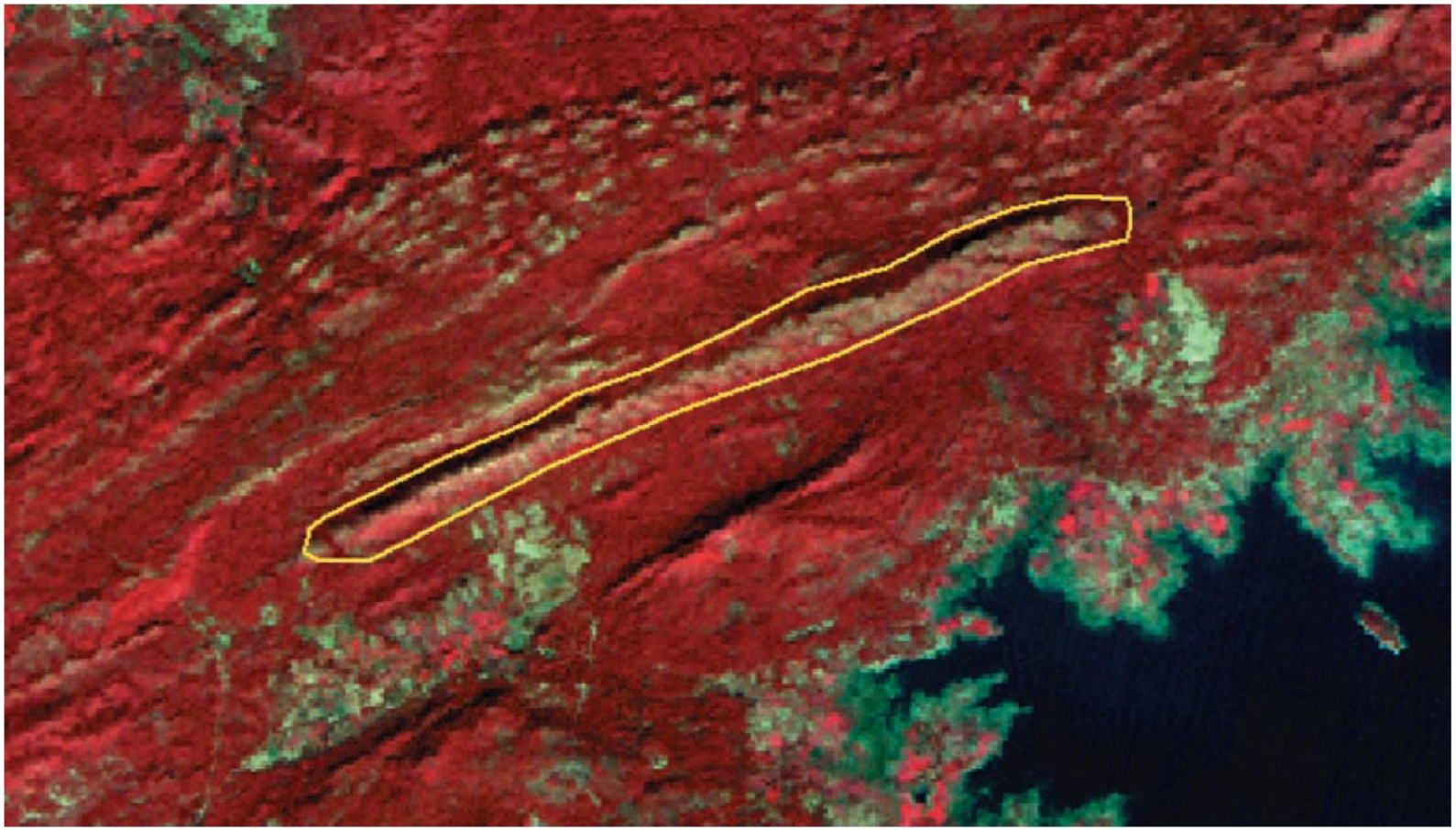


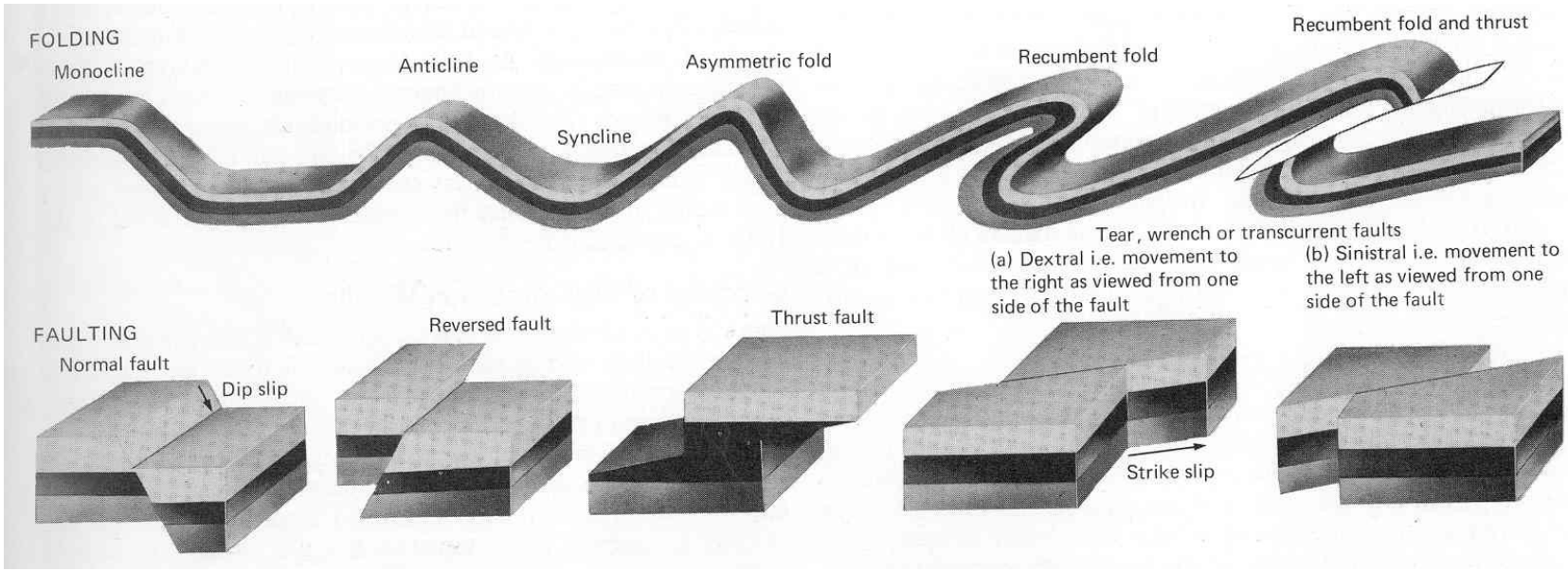
Fig. 2.1 Hogback in the Low dissected structural hills and valleys in Hoshangabad district, Madhya Pradesh state. Ridge with a sharp summit and steep slopes of nearly equal inclination on both flanks, and resembling in outline the back of a hog.

LANDFORMS IN FOLDED ROCKS

FOLDS

- Bends or wave-like features in layered rocks
  - –Plastic strain, compressive stress
- Geometry of folds:
  - **–Anticline vs. syncline**
    - ***Hinge line, limb, axial plane***
  - –Plunging fold (hinge lines dip)
  - –Structural dome
  - –Structural basin

FOLDING


FOLDING
Monocline
Anticline
Syncline
Asymmetric fold
Recumbent fold
Recumbent fold and thrust
Tear, wrench or transcurrent faults
(a) Dextral i.e. movement to the right as viewed from one side of the fault
(b) Sinistral i.e. movement to the left as viewed from one side of the fault
FAULTING
Normal fault
Dip slip
Reversed fault
Thrust fault
Strike slip

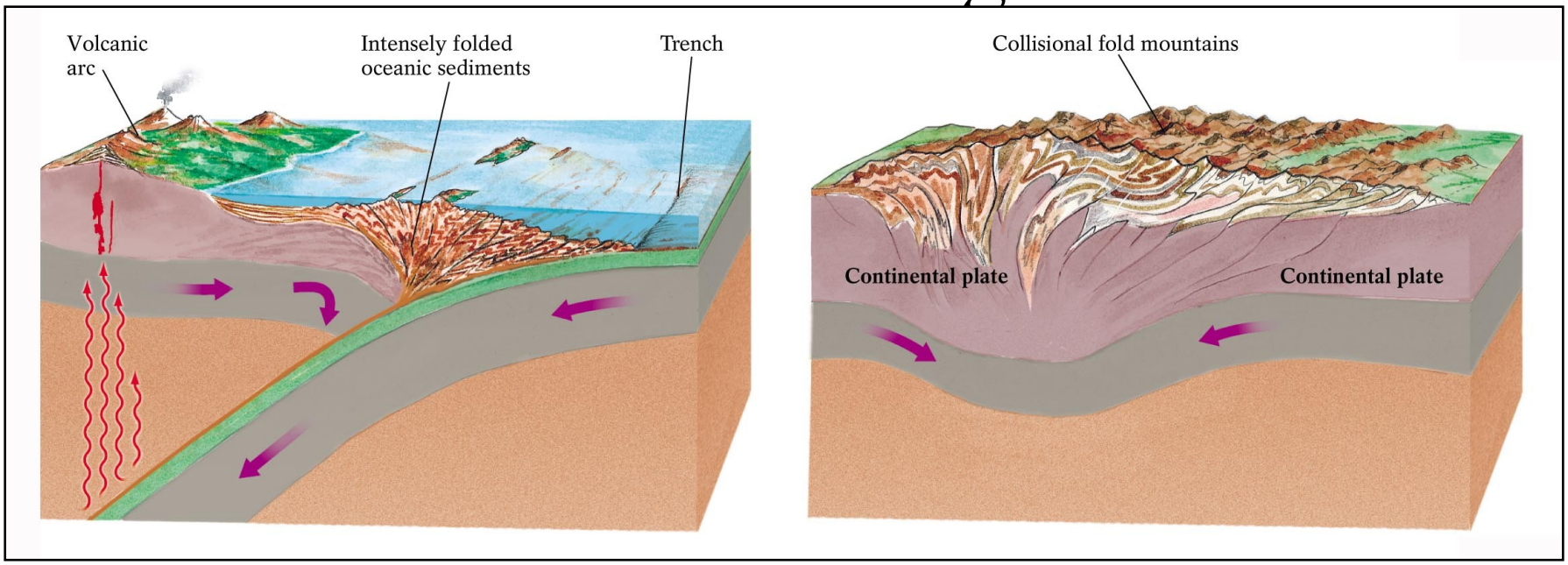
Folds Related Landforms

Folded Mountains
Anticline
Syncline
Domes
Salt dome
Basins
Annular Hills
Linear Ridges & Linear valleys
- **Anticlinal ridge**
- **Synclinal valley**
- **Homoclinal ridge**
- **Anticlinal Valley**
- **Homoclinal valley**
- **Synclinal Ridges**

Folded mountains

- **mountains with tight folding** (E-g) **Aravalli, Delhi, Bhimas, Cuddapah, himalayas**
- **contour in curved pattern**
- **curved ridges and valleys**
- **images, show curvilinear and contoured & vegetation banding radial, annular, drainage anomalies**

Convergent Plate Boundaries and Folding



Subduction causes Arc: Under Ocean Lithosphere Japan, Aleutians, Cent. Am.; under continent Andes, Cascades

Continent-Continent collision forms Fold and Thrust Mountains: Alps, Himalayans, Appalachians

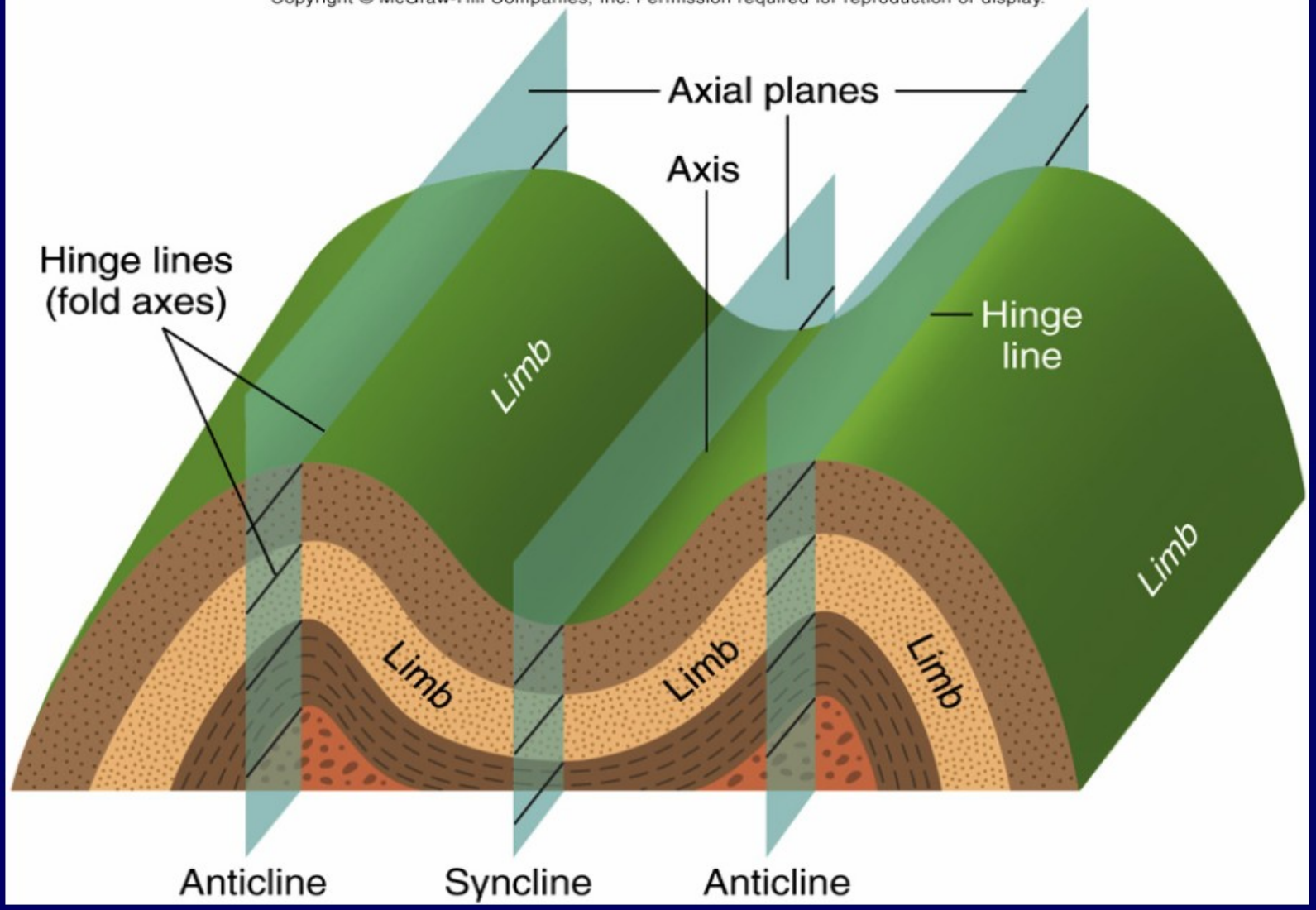

Carboniferous rocks, Bay of Fundy

Landforms : Anticline and Syncline

Anticline ridge: A fold, the core of which contains the stratigraphically older rocks.

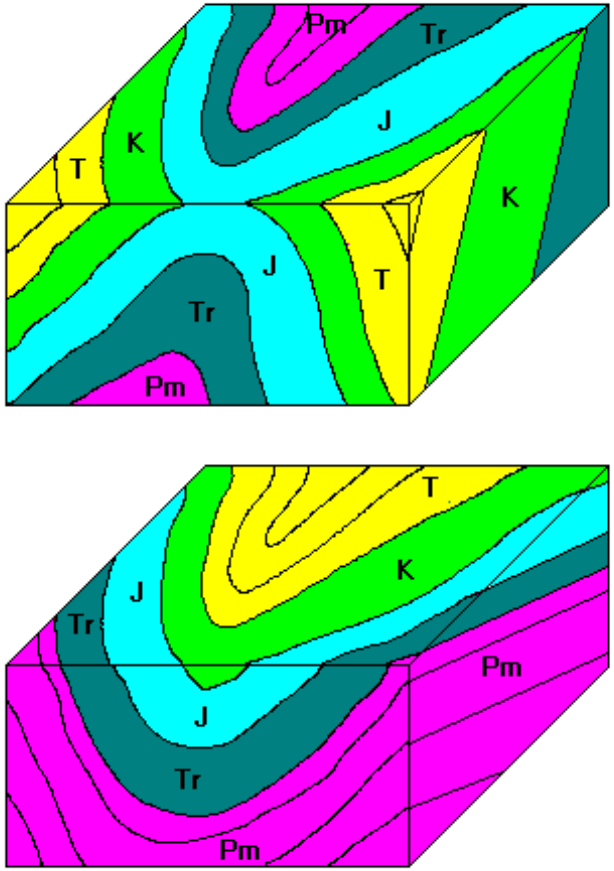
Antiform/Anticlinal ridge : A breached/unbreached uplift, where the structure is shown directly in the topography and perhaps by drainage pattern. In case of the presence of older rock in the core of the uplift the antiform is called as anticline.

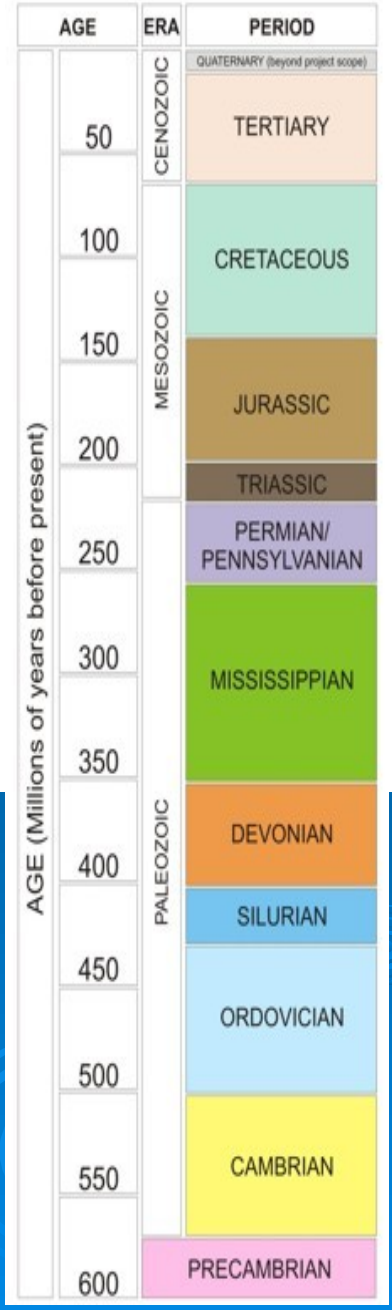
Synform / Synclinal valley: A breached/unbreached depression, where the structure is shown directly in the topography and perhaps by drainage pattern. In case of the presence of younger rock in the core of the depression the synform is called as syncline



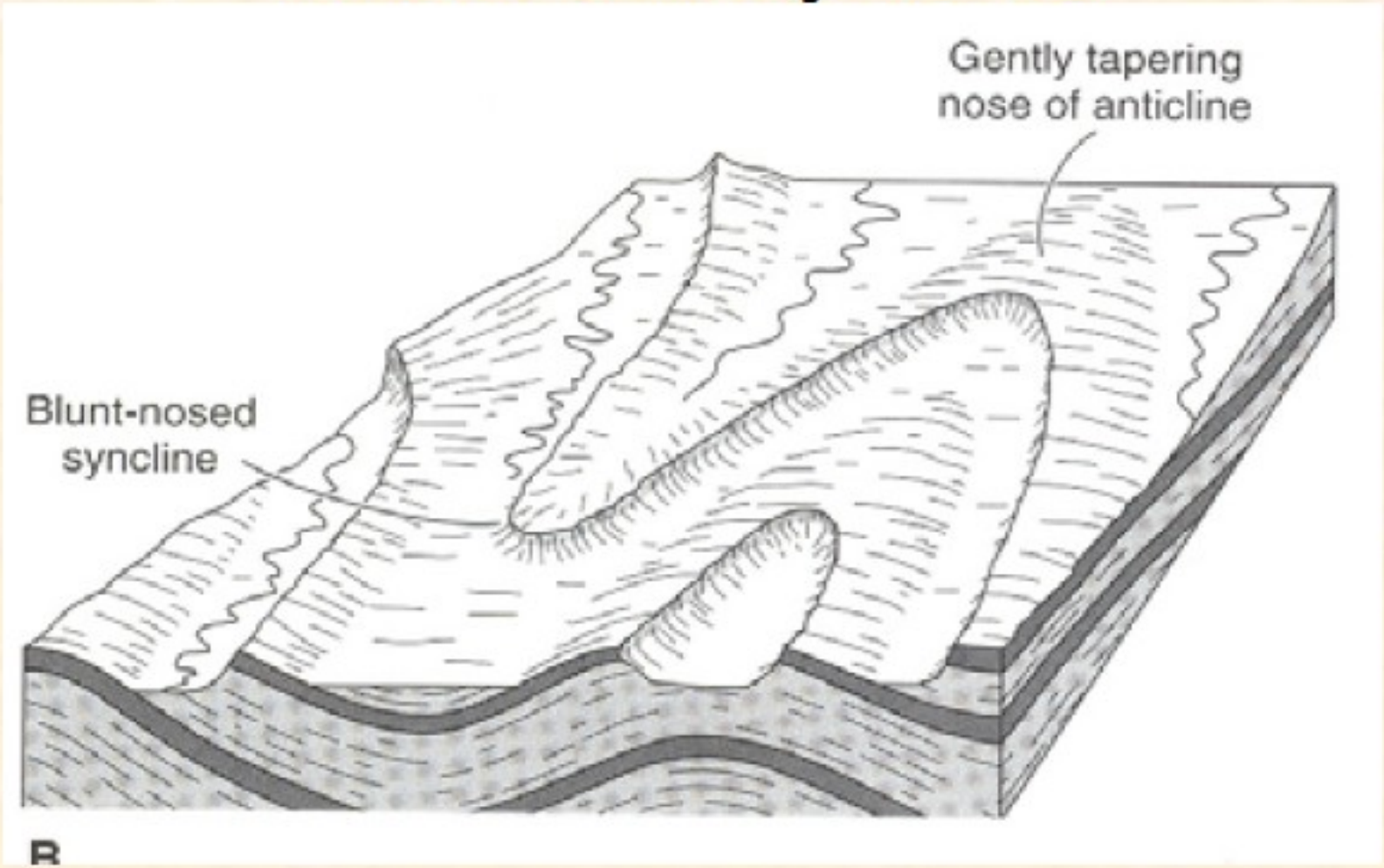
Folds and Block Diagrams

- Anticline = oldest rocks exposed in the center.
- Syncline = youngest rocks exposed in the center



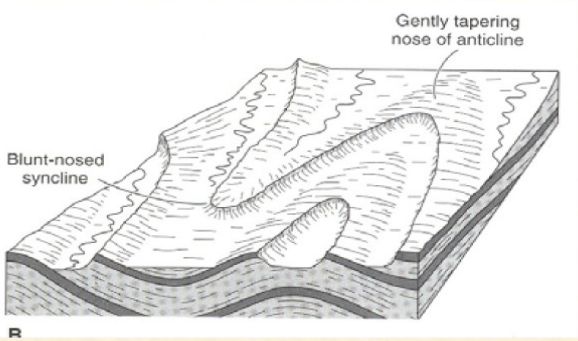


Apex of the outcrop pattern: Anticline or syncline?



Sheep Mountain, Wyoming.

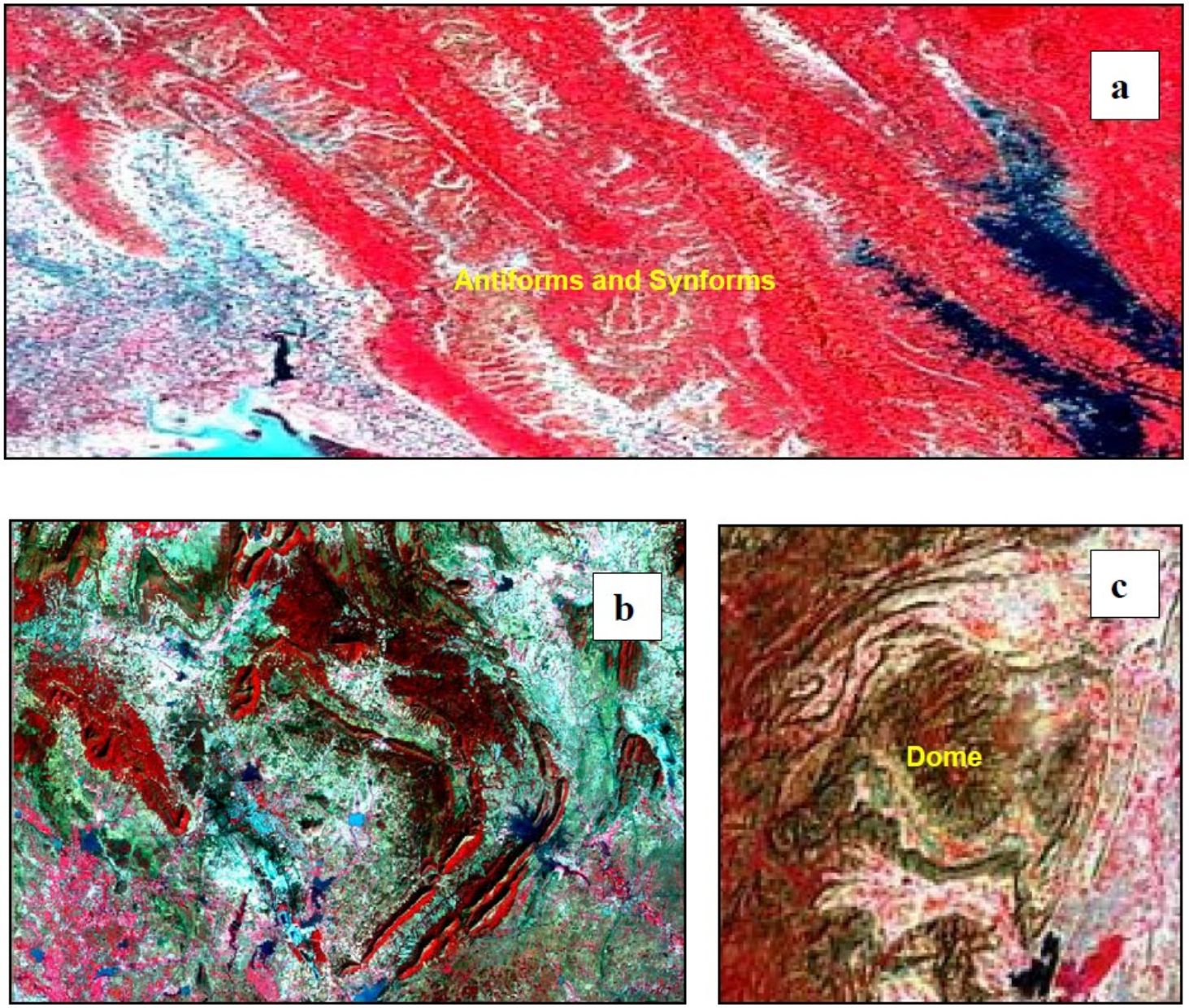
Apex of the outcrop pattern:
Anticline or syncline?



www.geology.wisc.edu/courses/g112

CFW '07

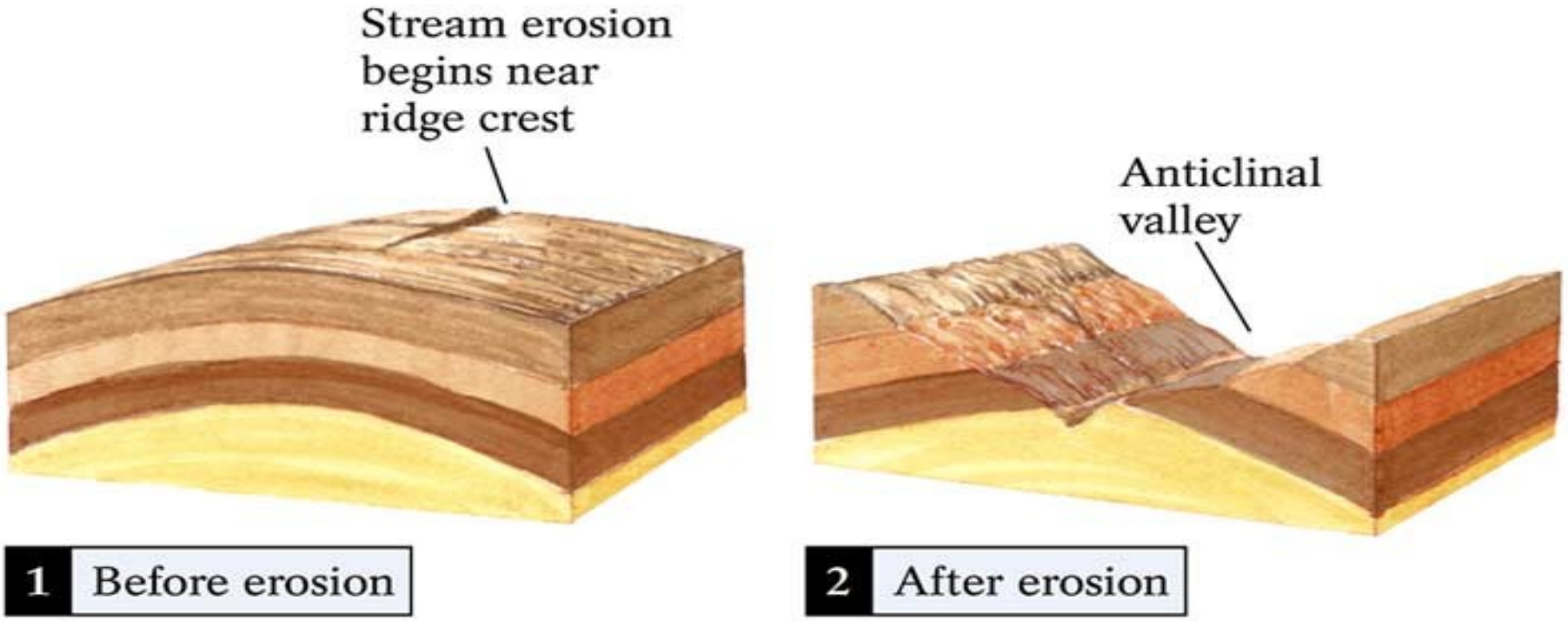
Fig. 4.15: Satellite image of a) Northeastern region b) part of Madhya Pradesh and b) Cuddapah basin showing folds



ANTICLINAL VALLEY

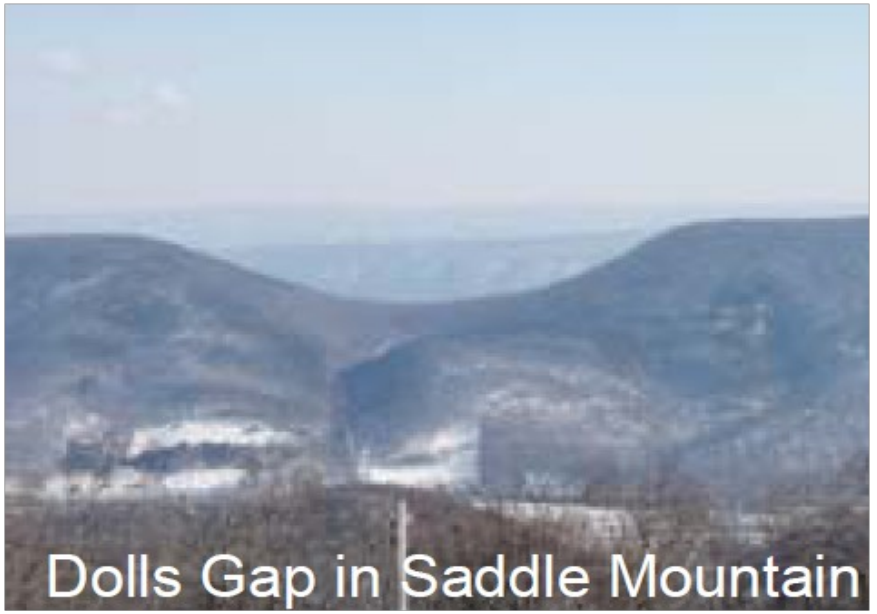
Topography may be opposite of Structure

Anticline Before/After Erosion



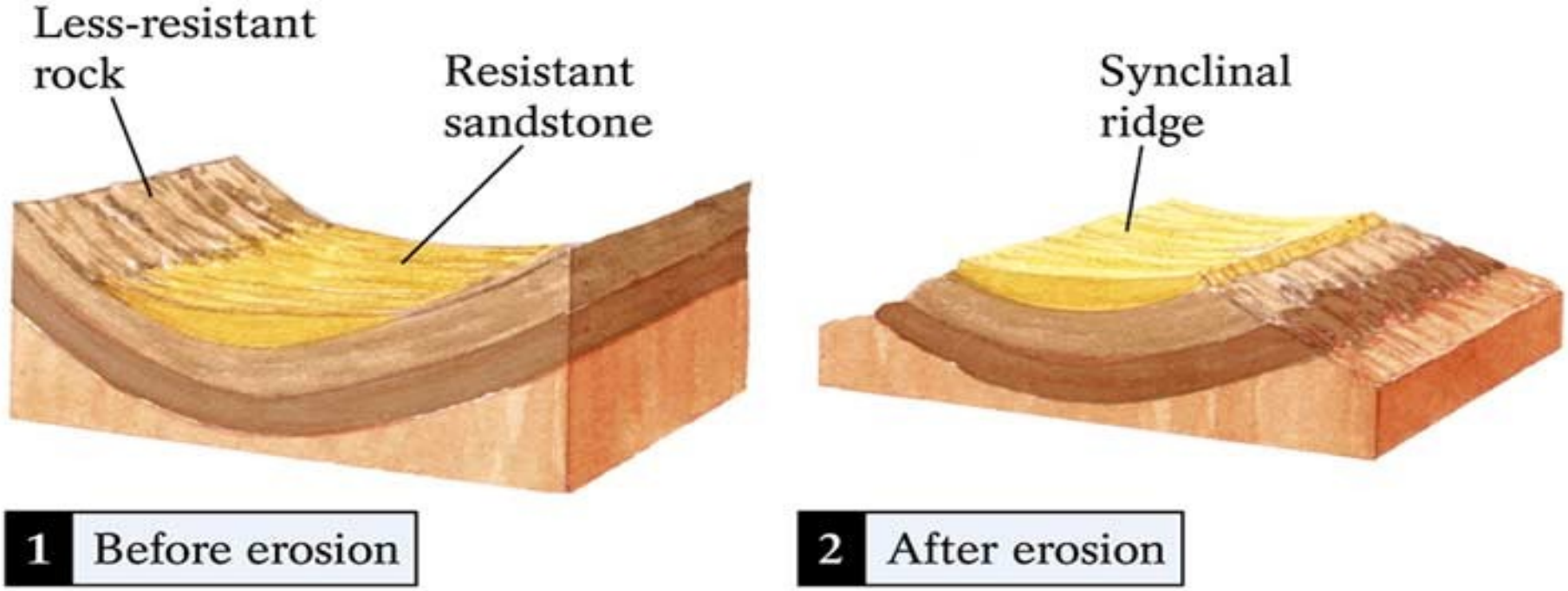
(a) Anticline with highly erodible surface **Notice center rock oldest**

Wills Mountain (Breached) Anticline



Topography may be opposite of Structure

Syncline Before/After Erosion



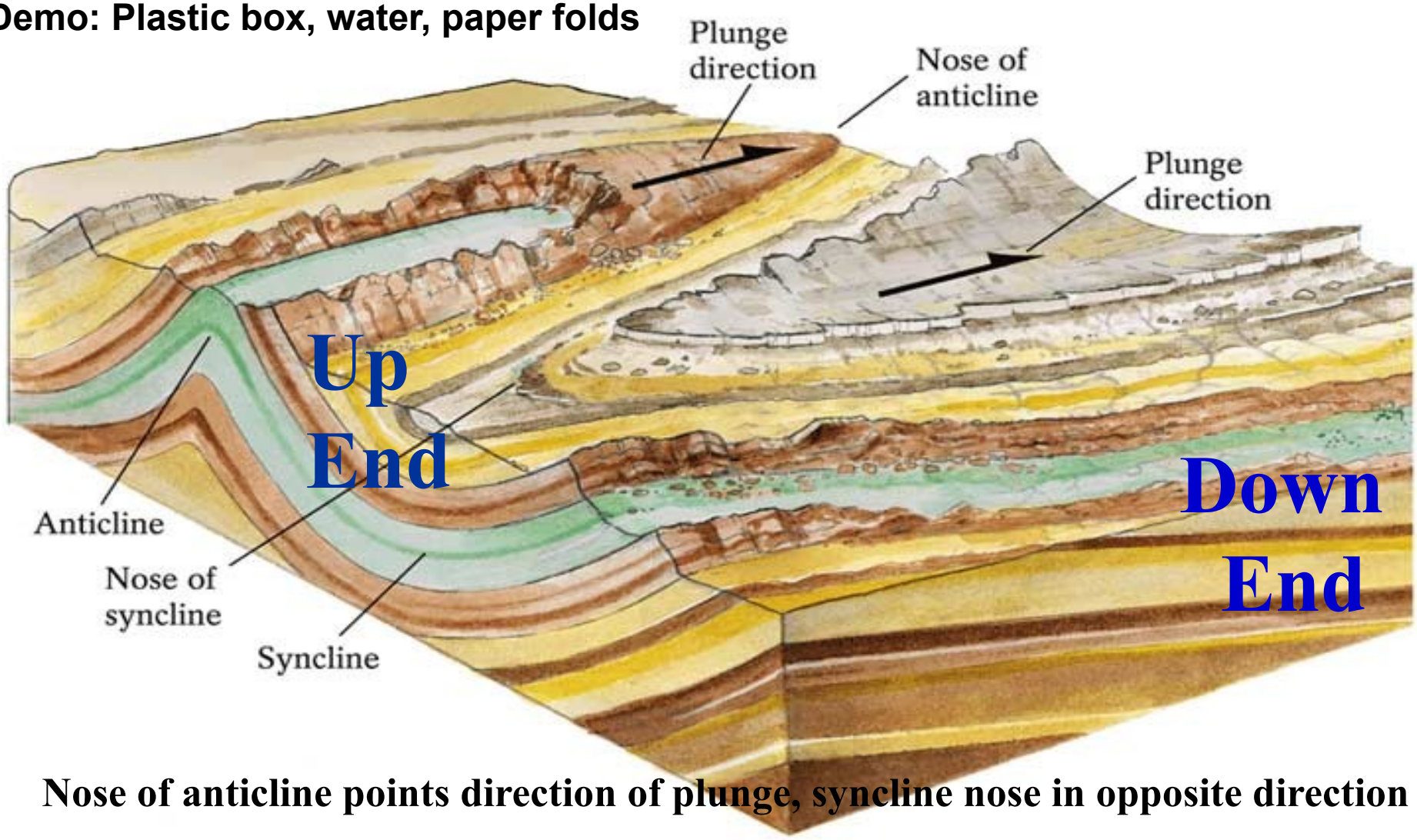
(b) Syncline with resistant rock at axis

Notice center rock youngest

Sideling Hill, MD-WV-PA, Synclinal Ridge

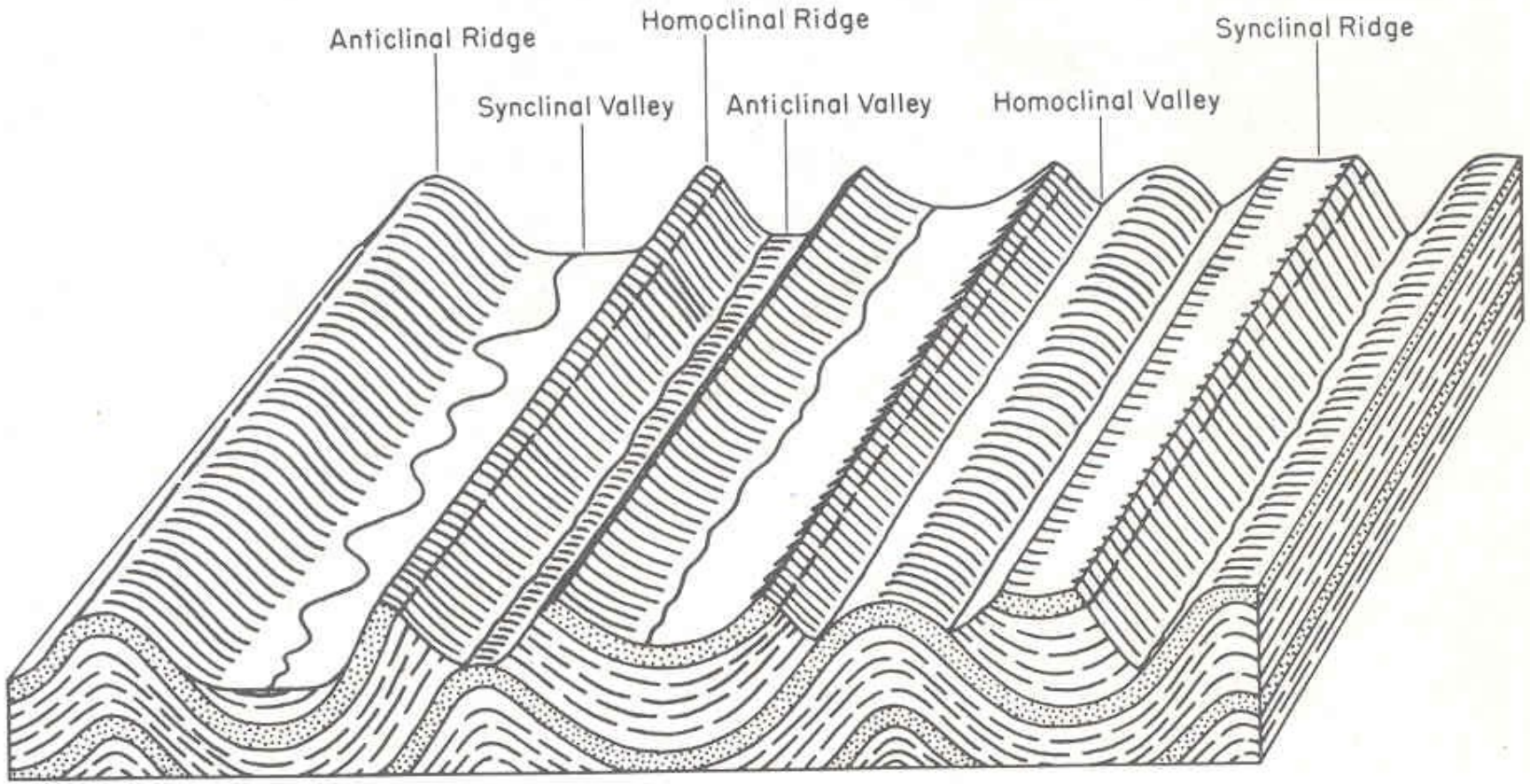
Plunging Folds and Nose Rules

Demo: Plastic box, water, paper folds



Nose of anticline points direction of plunge, syncline nose in opposite direction

HOMOCLINAL RIDGES AND HOMOCLINAL VALLEY



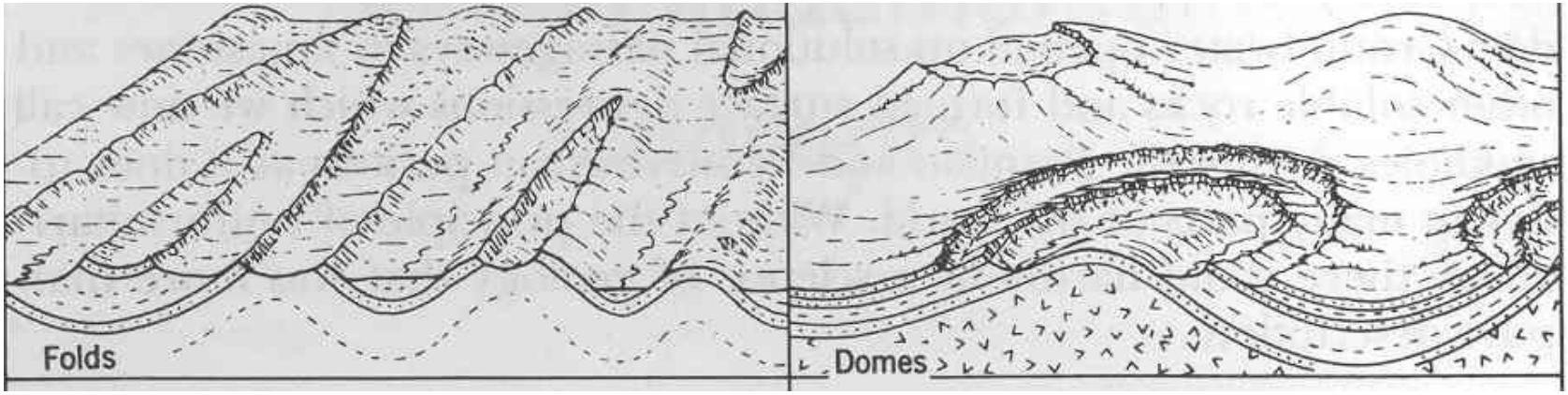
Differential weathering weak and strong beds causes the Homoclinal ridges and valleys

Short, N. M., and Blair, R. W., 1986, Geomorphology from Space, NASA
daac.gsfc.nasa.gov/DAAC_DOCS/geomorphology/
GEO_2/GEO_PLATE_T-42.HTML

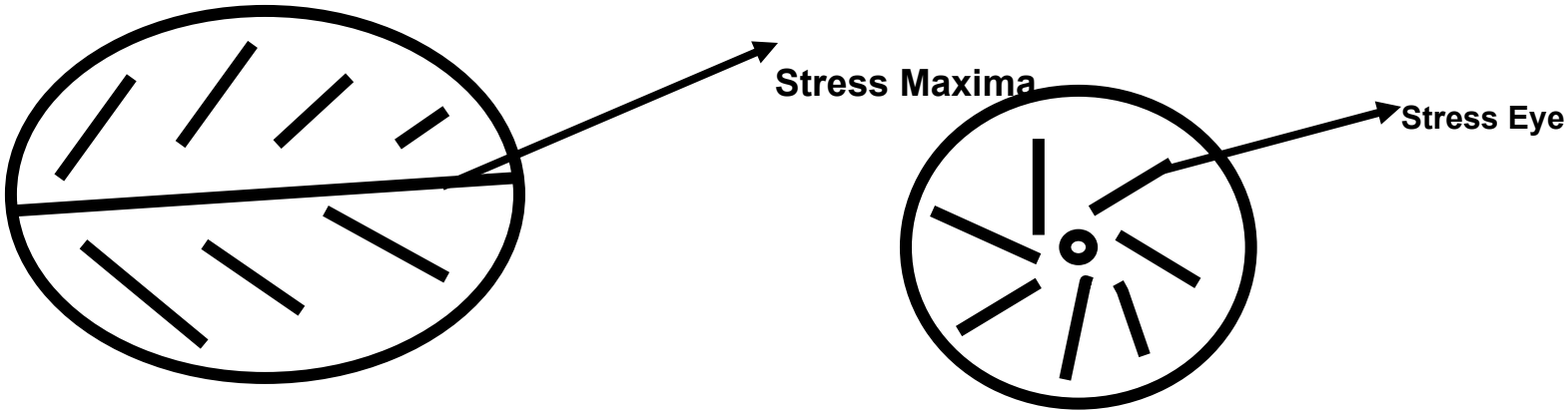
Homoclinal Ridges, near Rawlings, Wyoming

Short, N. M., and Blair, R. W., 1986, Geomorphology from Space, NASA daac.gsfc.nasa.gov/DAAC_DOCS/geomorphology/

FOLDS DOMES



(3.6.3.3) DOMED MOUNTAINS / BASINAL MOUNTAINS



- ➔ qua-quaversal dips
- ➔ radial centripetal / centrifugal drainage

Domes

unstable, seismic prone, crest stress accumulated domain, erosion prone, unsafe for dams

Basins

- ➔ Aseismic, suitable for dams - better groundwater prospects.
- ➔ suitable for waste disposals
- ➔ suitable for water storage

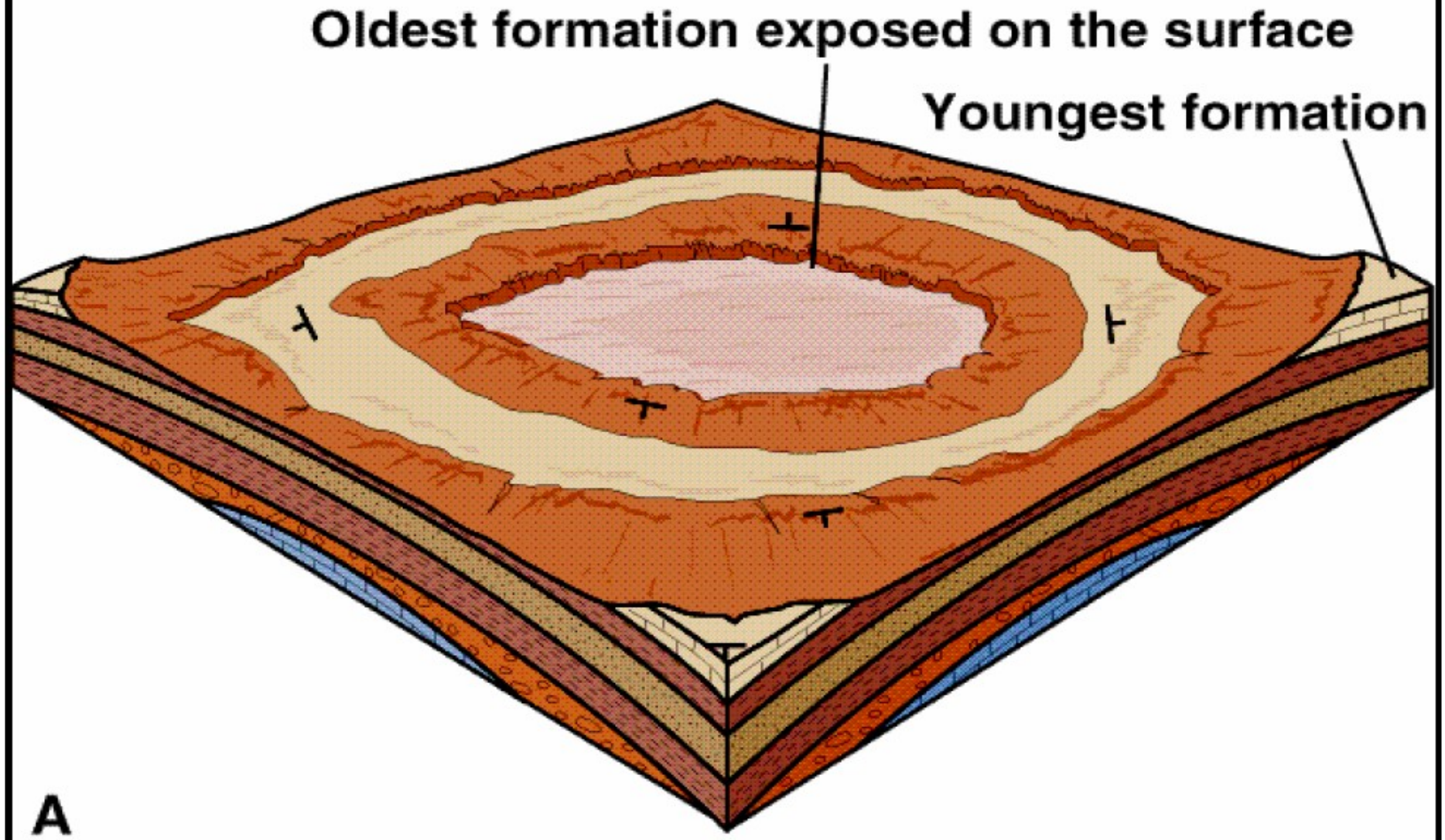
Domes

- **Domes** are a broad upwarping in the rock underlying an area may deform the overlying sedimentary layers. The Black Hills of South Dakota.

Sedimentary Basins

- **Basins** are downwarped structures that have a roughly circular shape. An example of a basin is the bowl-shaped Michigan basin.

Structural Dome



Richât Structure, Mauritania
Surface Expression of a Dome

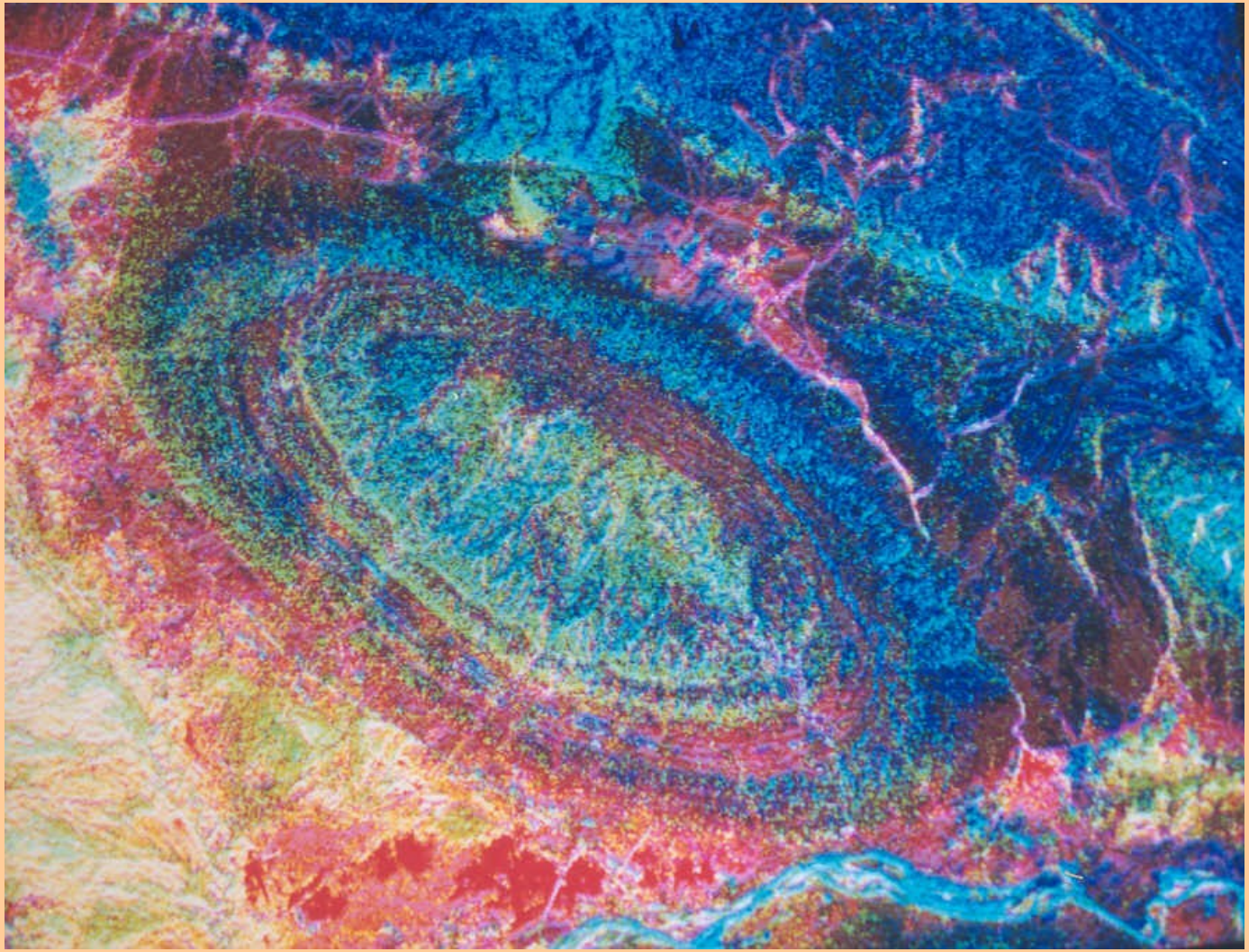
Beds dip away from center.

Note Fractures.

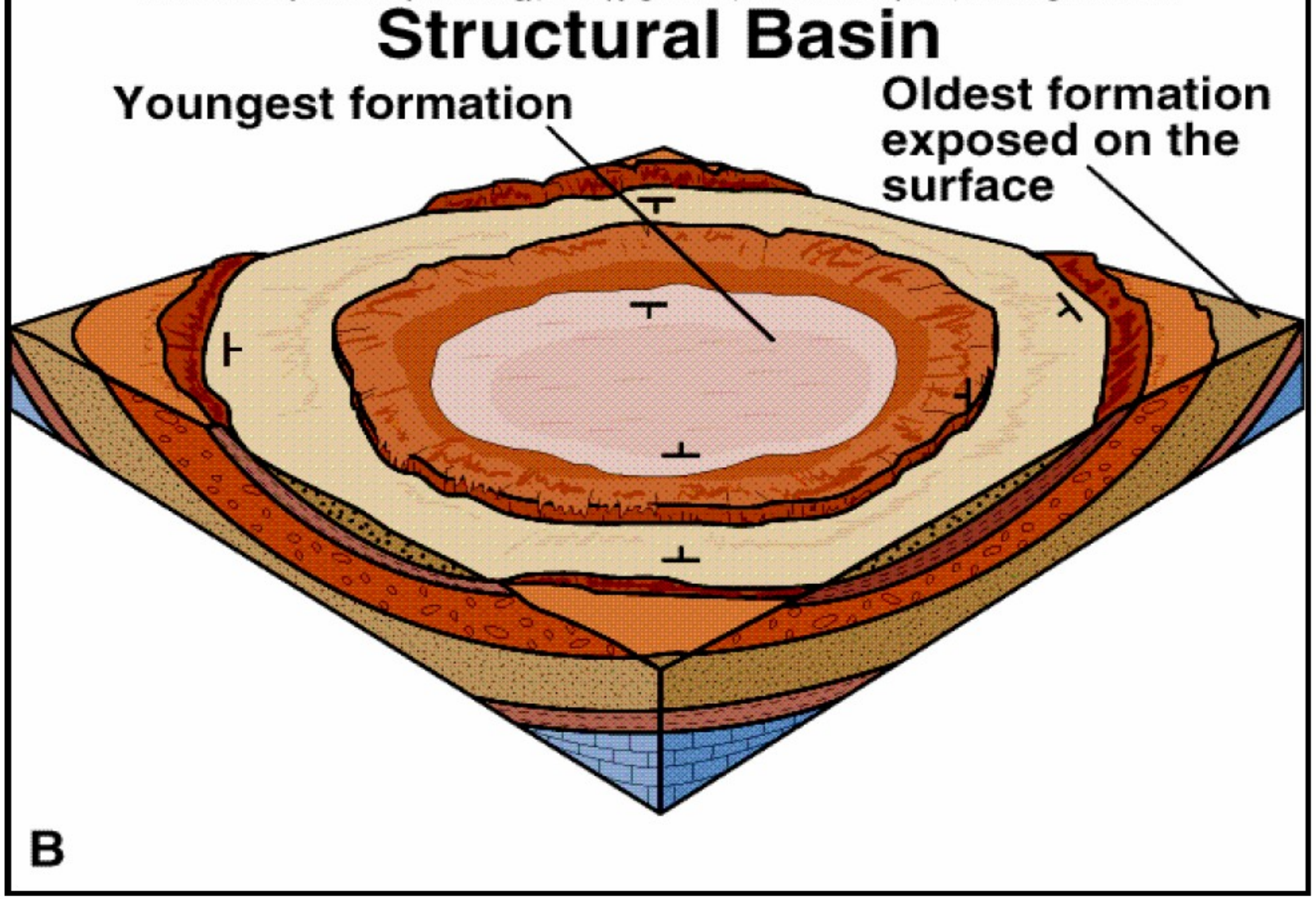
http://daac.gsfc.nasa.gov/DAAC_DOCS/geomorphology/GEO_2/GEO_PLATE_T-31.HTML

Grenville Dome, Wyoming

DOMES - IRAN



Structural Basin



BASINAL HILLS or Synclinal Mountains

Synclinal mountains may vary from elongate narrow ridges to broad plateau like expanses, but typically they are broader than aticlinal mountains

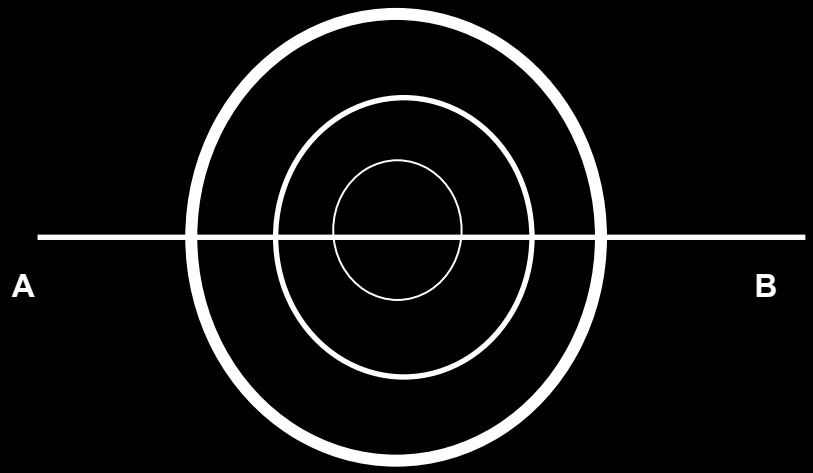
Salt Dome

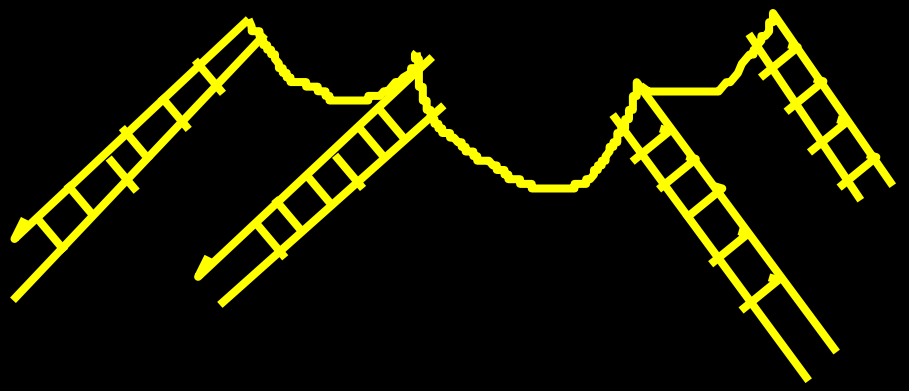
Low density
Buoyant
Diapirs

Surrounding sediments upwarped

Petroleum exploration

Annular Hills



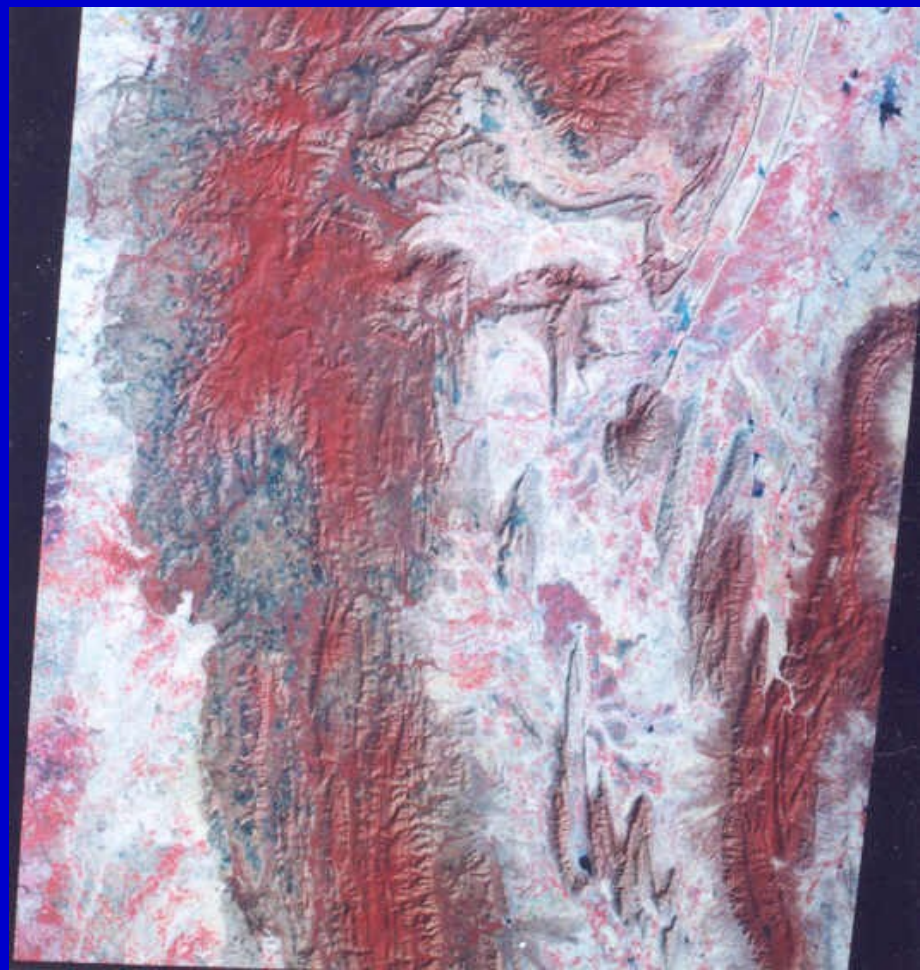


➔ circular ridges & valleys

➔ radial annual centrifugal / centripetal drainage

(E-g) Ramgarh dome, Ishwarakuppam dome

ANNULAR HILLS & VALLEYS

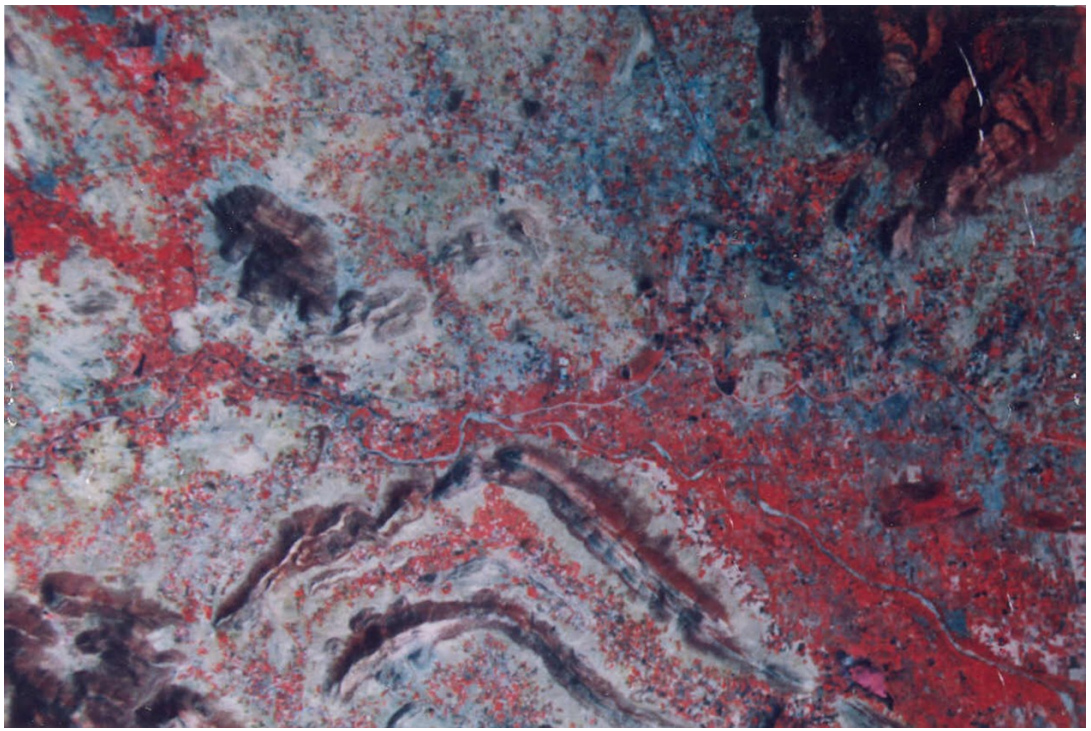


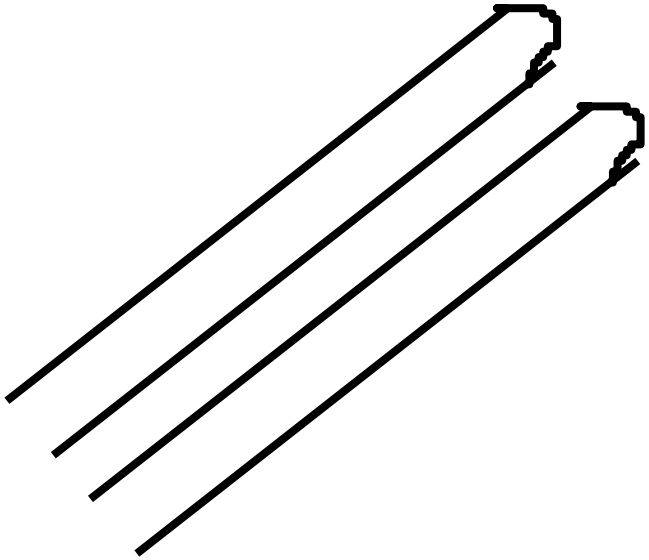
Linear Ridges

➔ steep dipping hills form ridges

➔ no debris slope

➔ least erosion

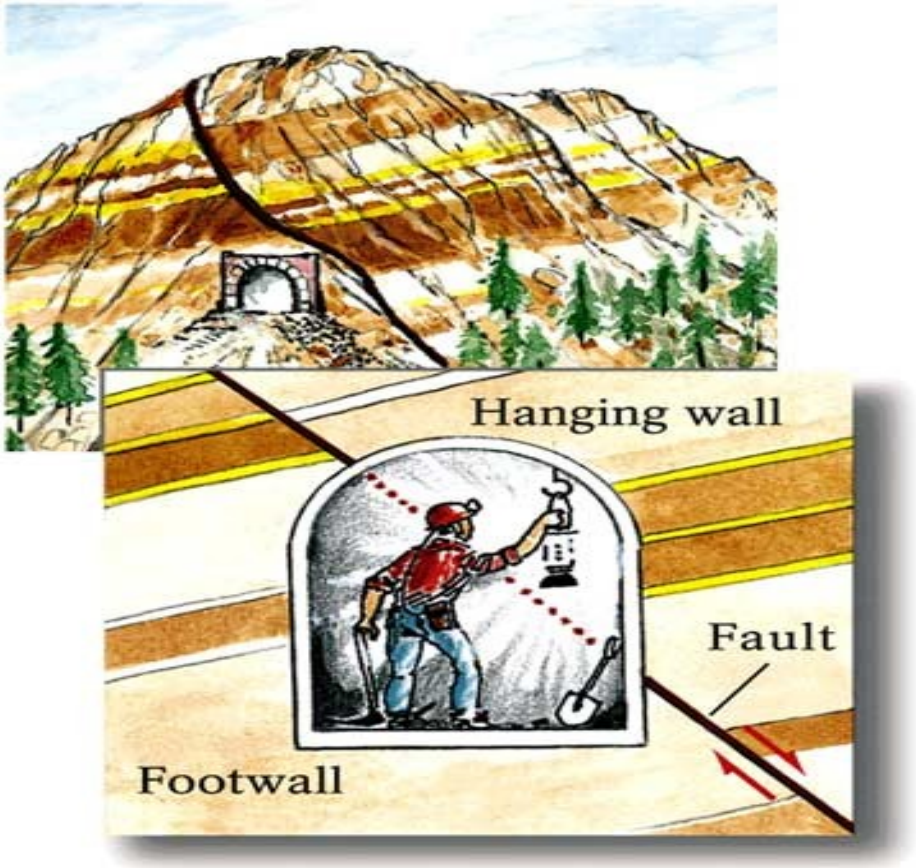


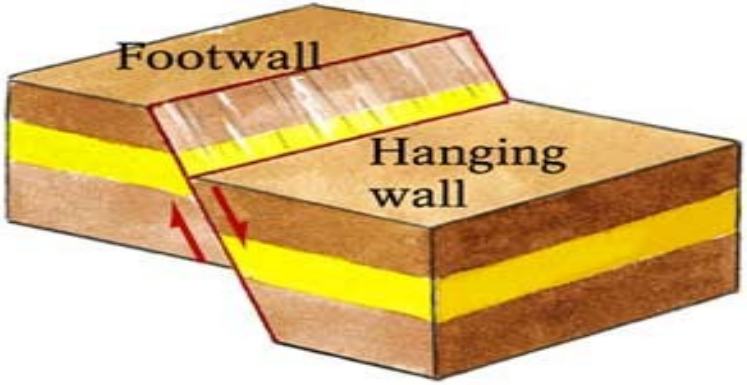


LANDFORMS IN FAULTED ROCKS

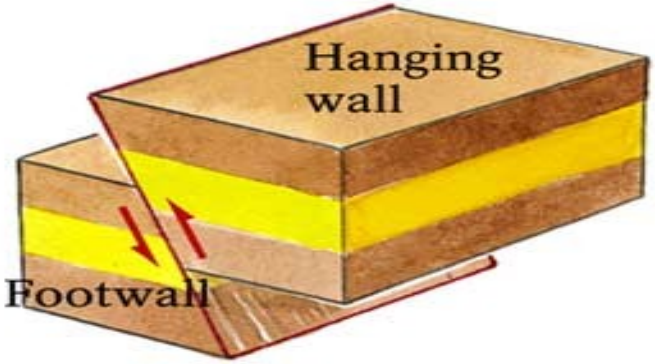
Demo: Cardboard Models

Dip-Slip Faults





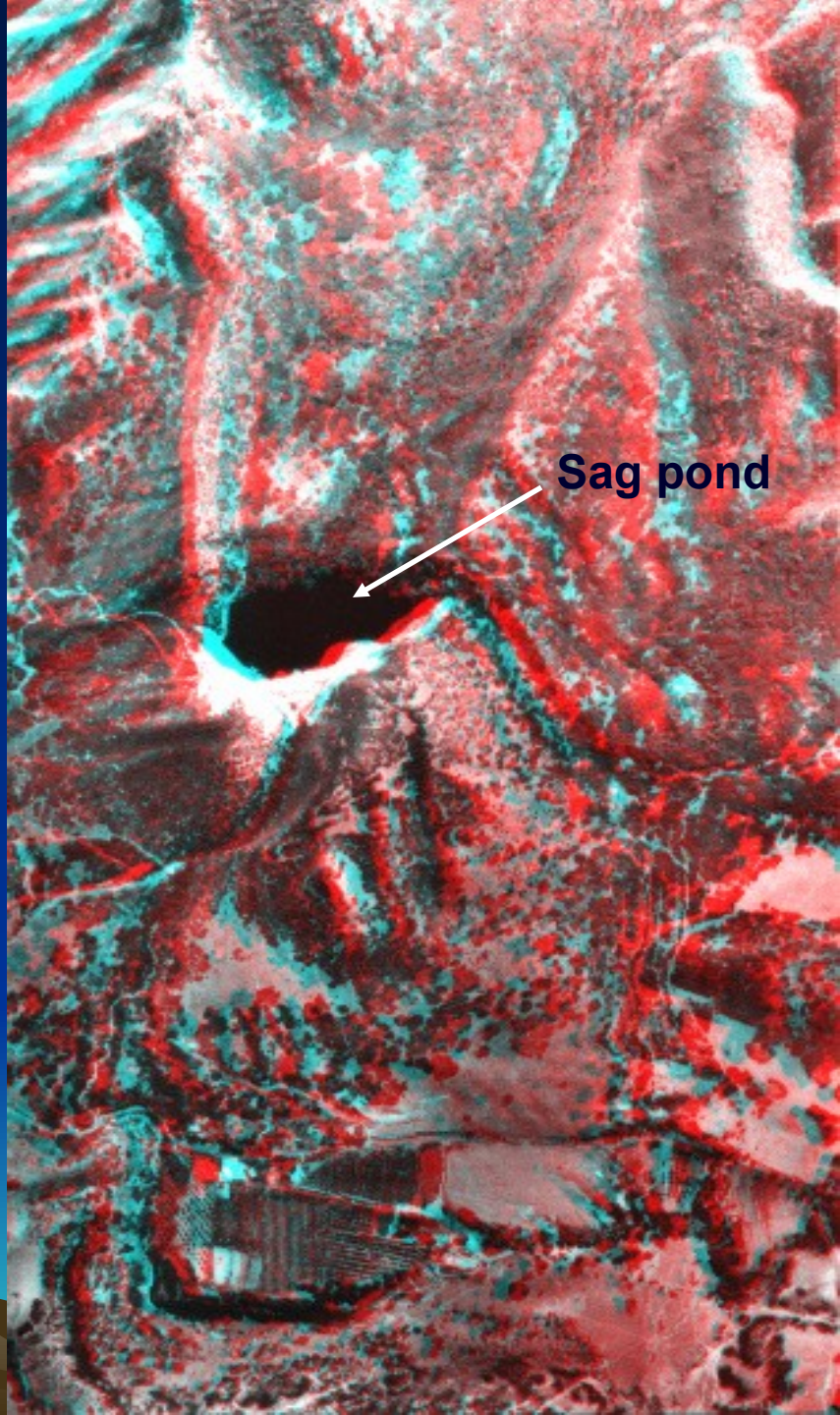
Normal Fault



Reverse Fault

Faults 1: Normal Faults

- Typical of Divergent Margins
- Rift Valleys and Mid-Ocean Ridges
- High-angle and Listric
- Horst and Graben Structure
- Hanging wall is down



A typical sag pond caused by fault-induced tilting.

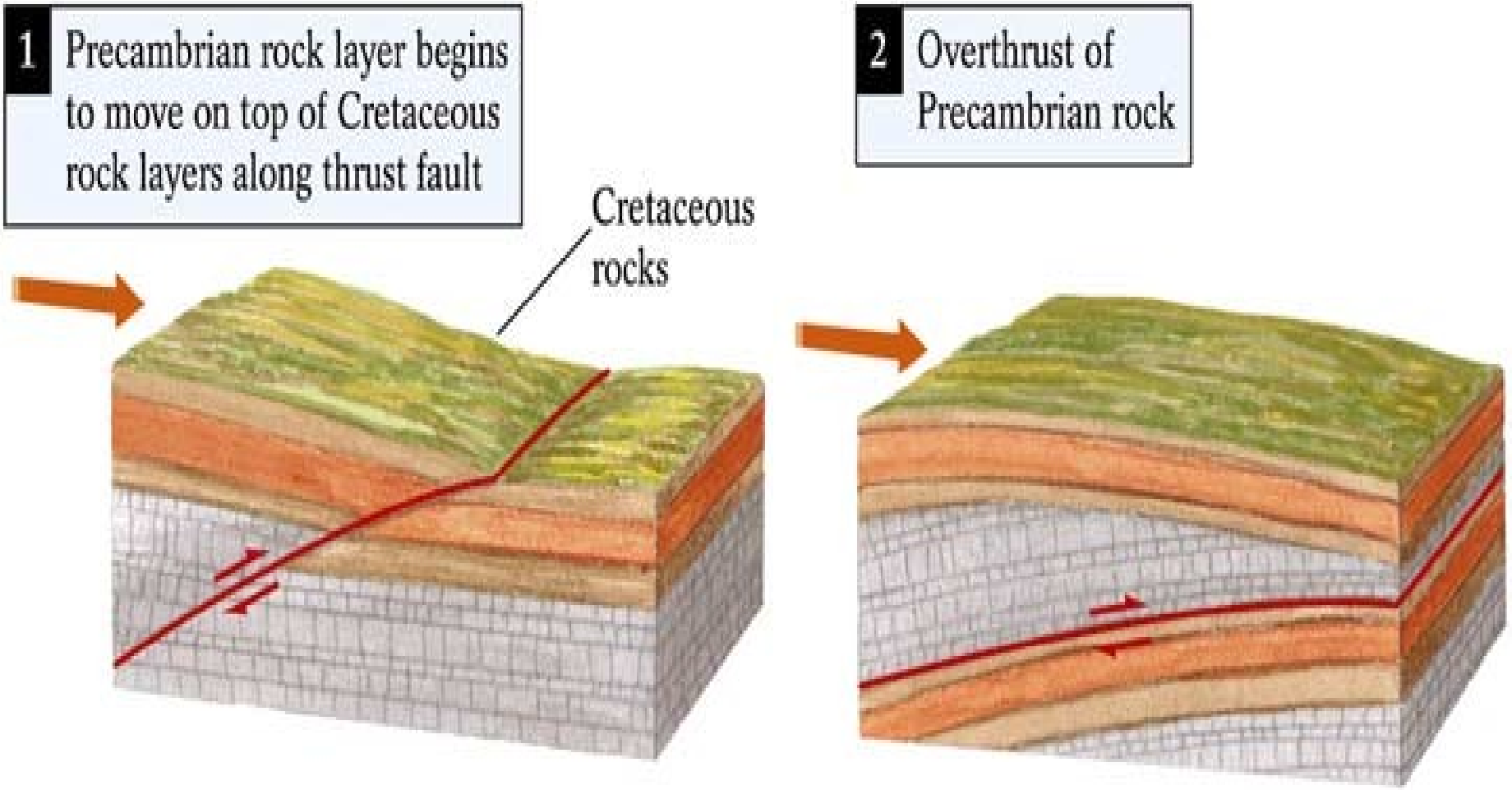
From Drury, Ch 4

Faults 2: Reverse Fault Structures

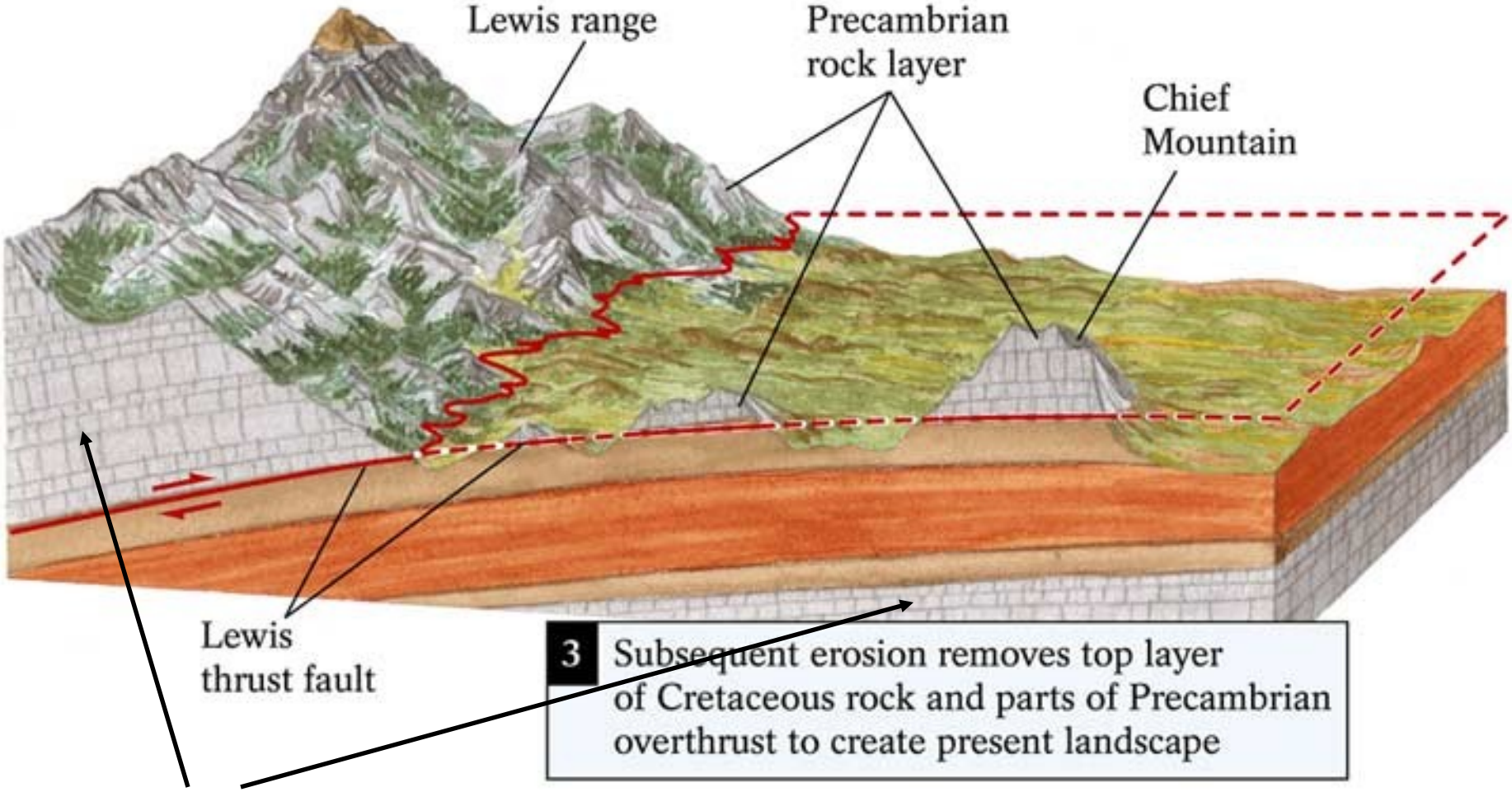
- Typical of Convergent Margins
- E.g. Accretionary Wedges (Santa Catalina Island) and Fold and Thrust Mountains (Himalayas, Alps, Appalachians)
- Often low-angle thrusts
- Hanging wall is up

http://rst.gsfc.nasa.gov/Sect2/05-01_reverse_fault-jyougashima_DSC8766.jpg

Shallow Reverse Fault = Thrust Fault



Lewis Thrust Fault (cont'd)



Same layer

Klippe - Thrust Fault Remnant

A feature of thrust fault terranes. The klippe is the remnant portion of a nappe after erosion.

http://www.pbase.com/dougsherman/image/93469147

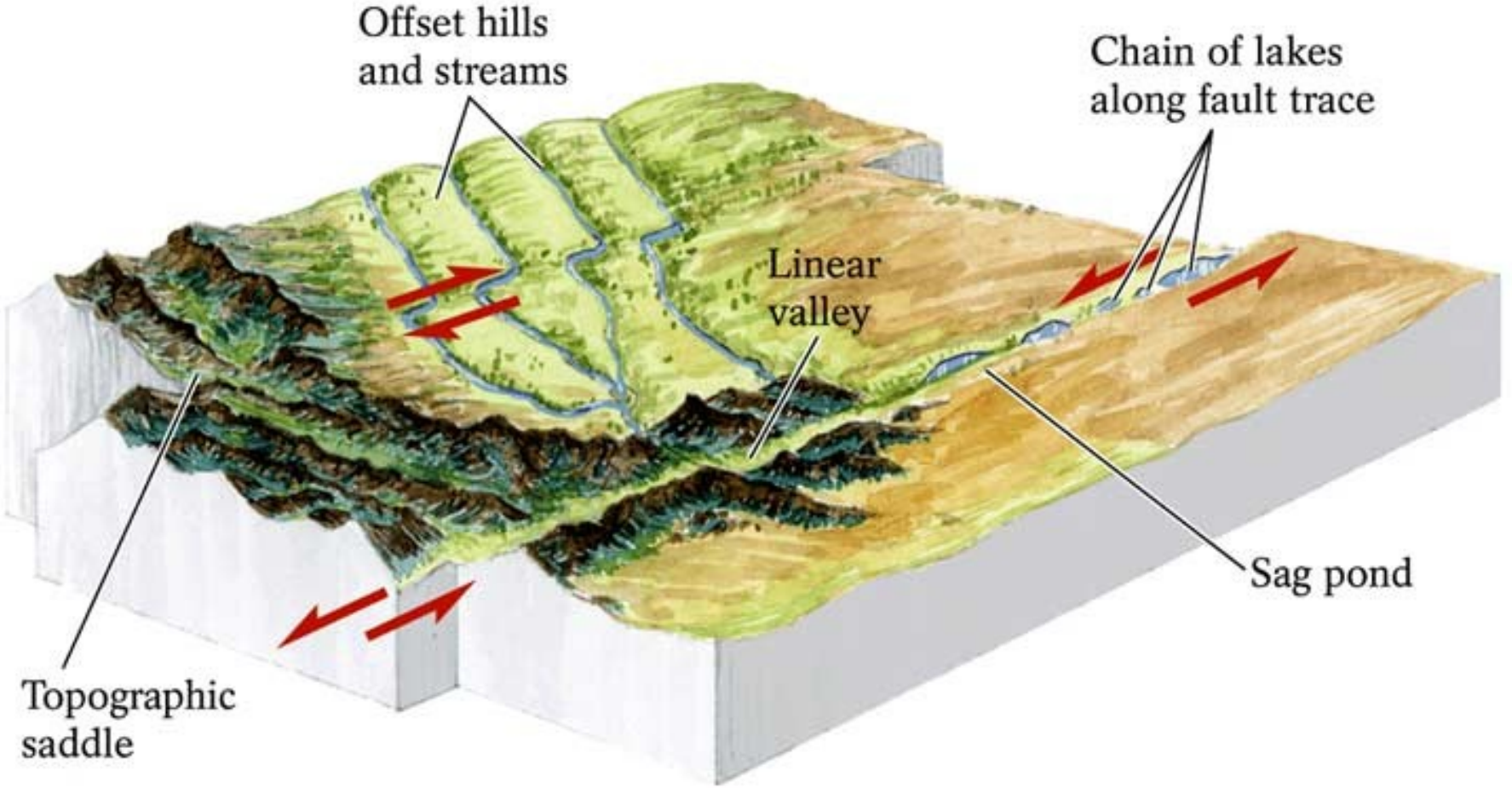
Chief Mountain, a klippe outlier of the Lewis Thrust, Glacier National Park, MT

Lewis Thrust Fault (cont'd)

Source: Breck P. Kent

PreCambrian Limestone over Cretaceous Shales

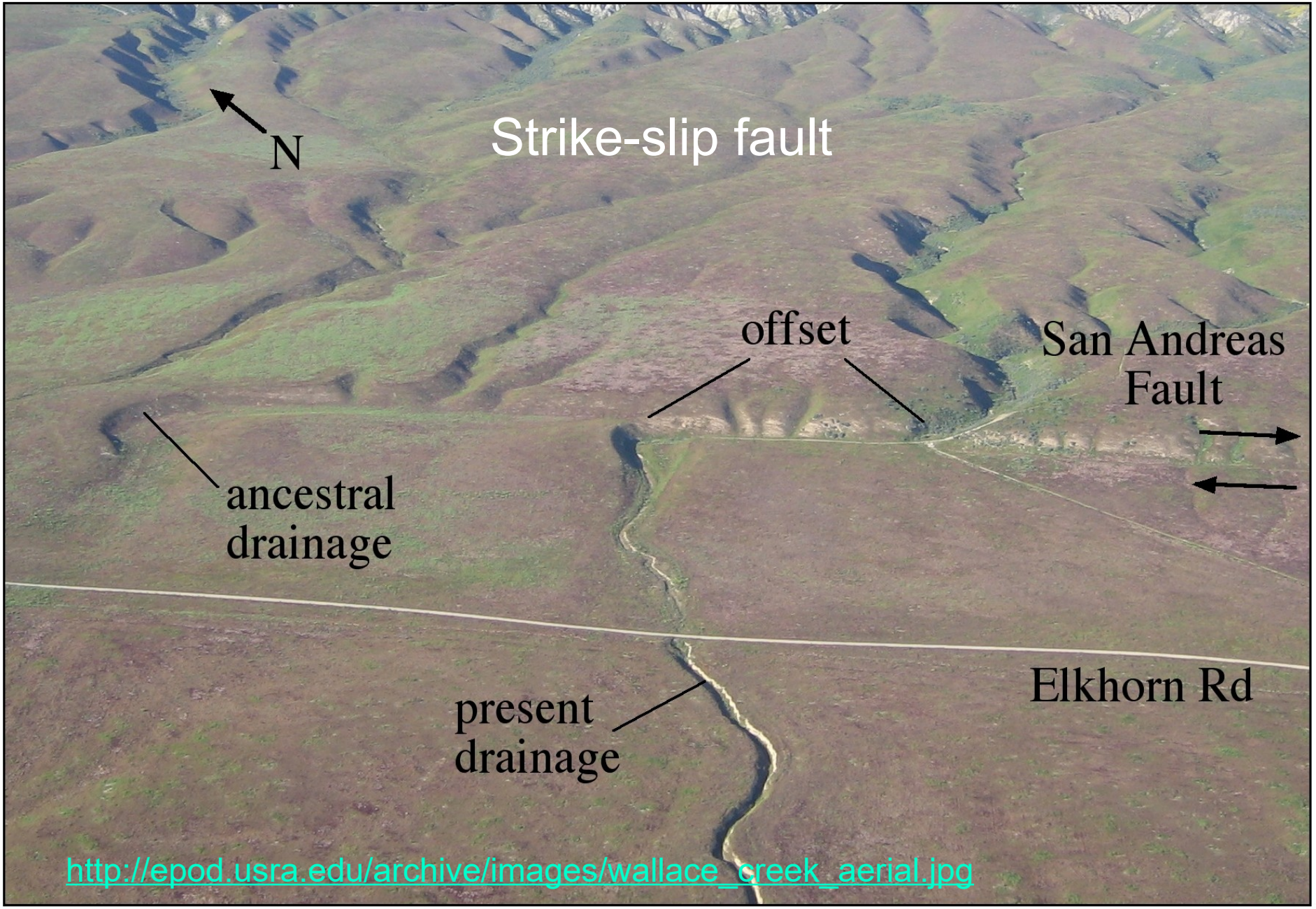
Horizontal Movement Along Strike-Slip Fault



Tectonic Landforms

Faults and Fault Landforms

The East African Rift Valley is a graben


N
Strike-slip fault
offset
San Andreas Fault
ancestral drainage
present drainage
Elkhorn Rd
http://epod.usra.edu/archive/images/wallace_creek_aerial.jpg

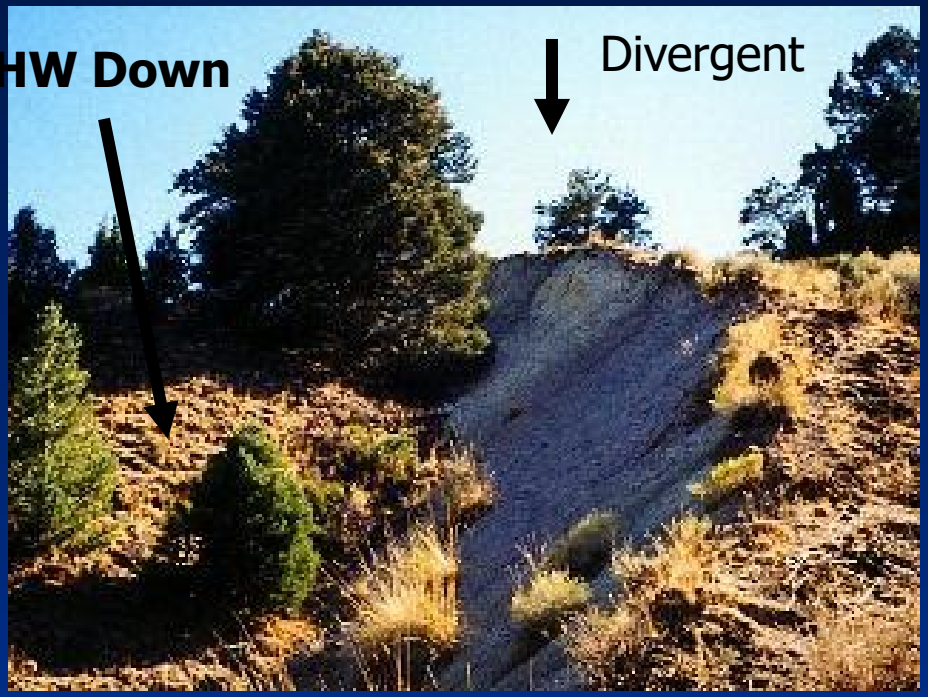
~ 100 yards

Landscape Shifting, Wallace Creek

San Andreas Fault

Reverse Fault Quake - Japan

Normal Fault Quake - Nevada



Strike Slip Fault Quake - California

Geomorphic features

- Fault scarp
- Fault-line scarps
- triangular facets
- alignment of facets
- increase of stream gradients at the fault line
- hanging valleys
- aligned springs and vegetation
- landslides
- displaced stream courses

Fault Related Landforms

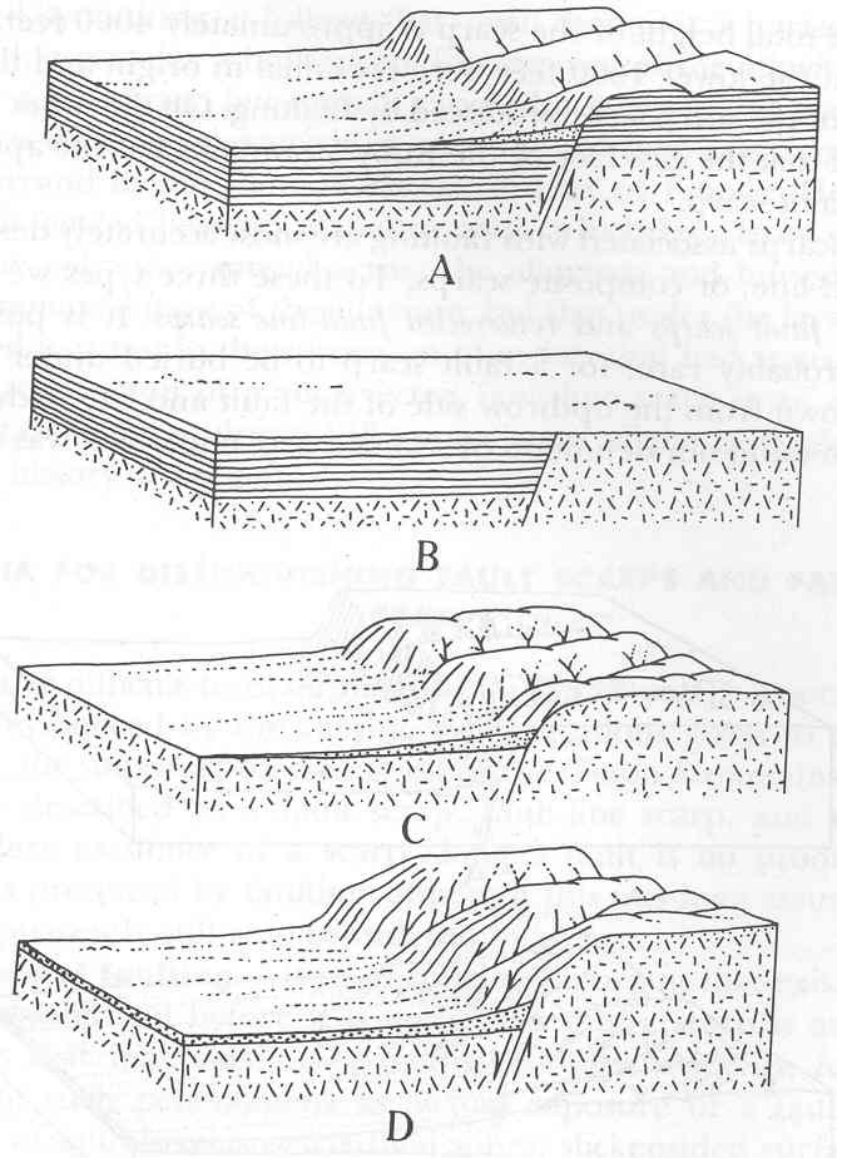
- Fault scarp
- Fault-line scarps
- Triangular facets
- Horst and Graben

- Fracture valleys
  - Filled
  - Barren

- Fault valleys

- Rift valleys

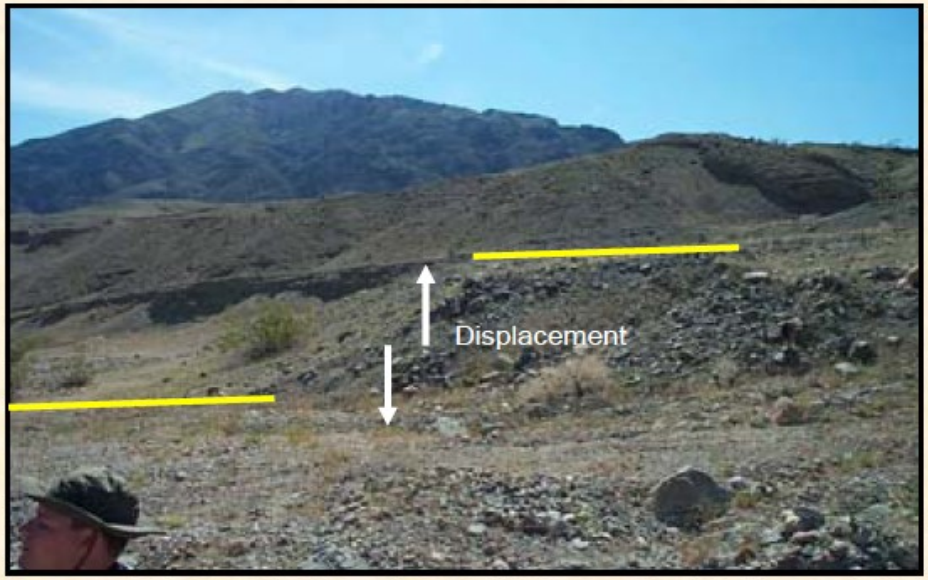
FAULT SCARP: The scarp produced directly by the faulting is called fault scarp



Different stages in the formation of the scarps

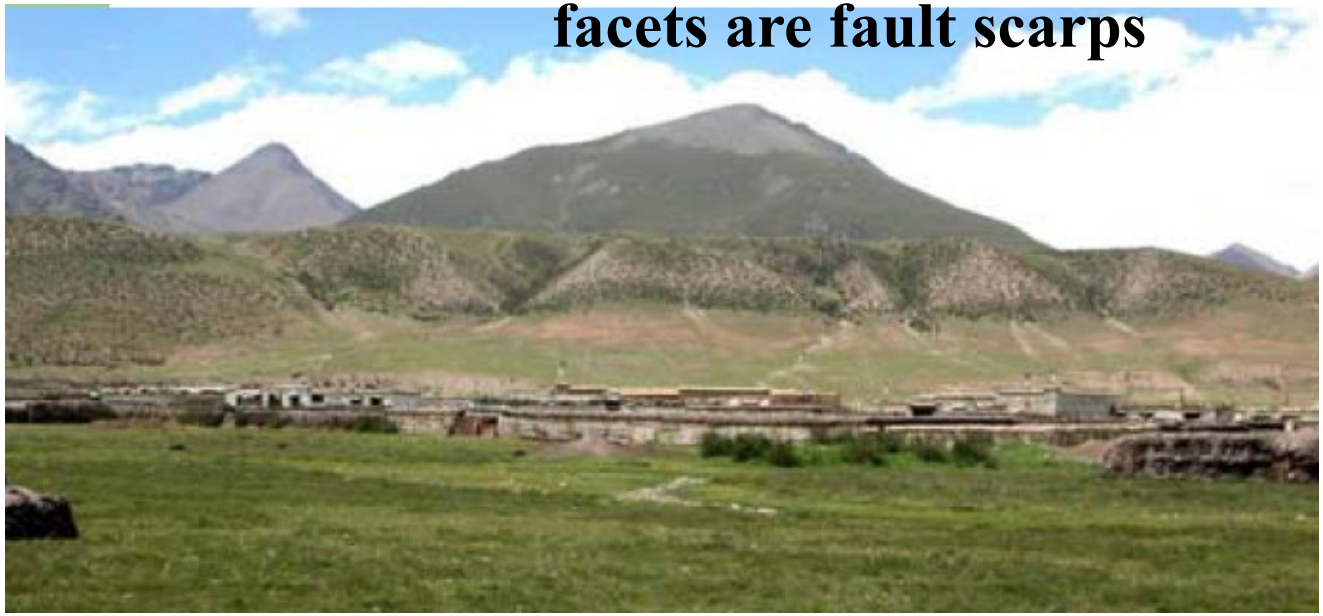
A) Formation of Fault Scarp
B) Destruction of fault scarp by erosion
C) Renewal of erosion, following upliftment, with development of fault line scarp
D) Renewal of faulting with composite scarp, whose upper part is of erosional and lower part of fault origin

Fault scarp on alluvial fan



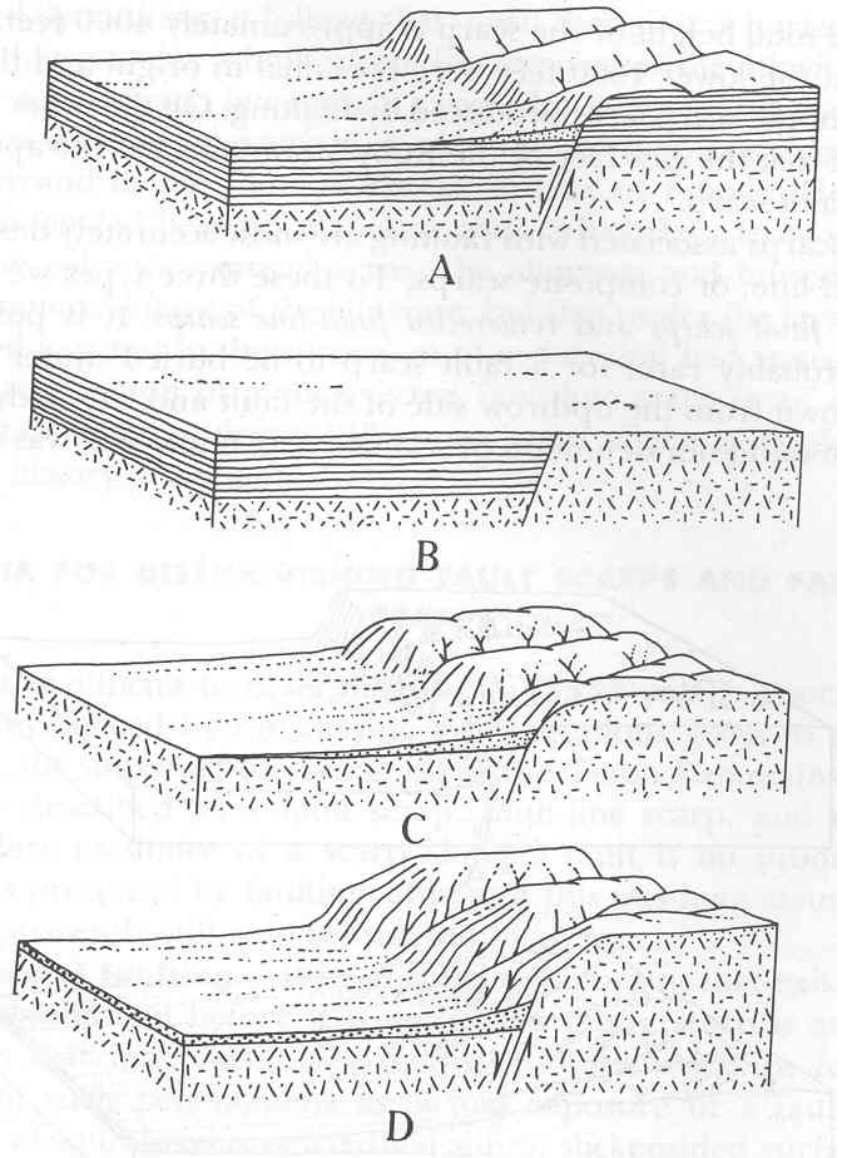
Death Valley National Park, CA. Photo by Stephen Hlowjski, 2004

Northern Tibet: Triangular facets are fault scarps



Fault Scarp

FAULT LINE SCARP: **Fault line scarp produced by the differential erosion along the fault line**



Different stages in the formation of the scarps

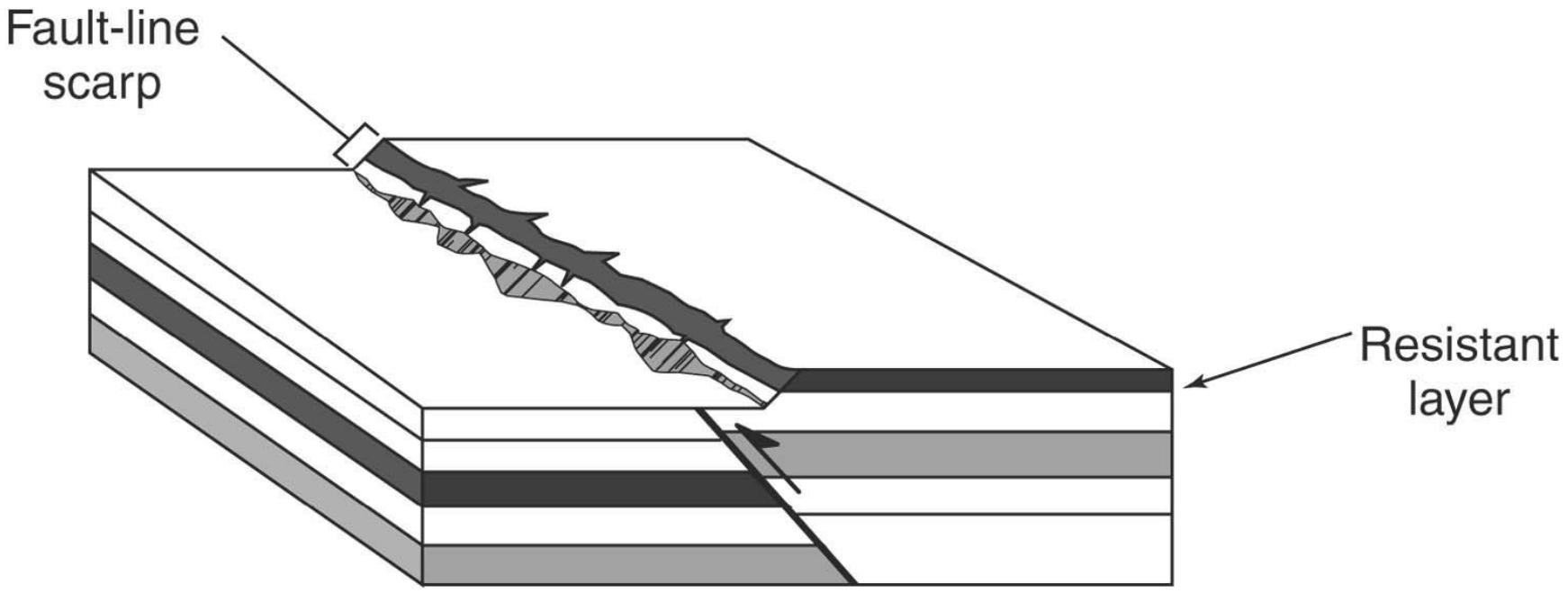
A) **Formation of Fault Scarp**

B) **Destruction of fault scarp by erosion**

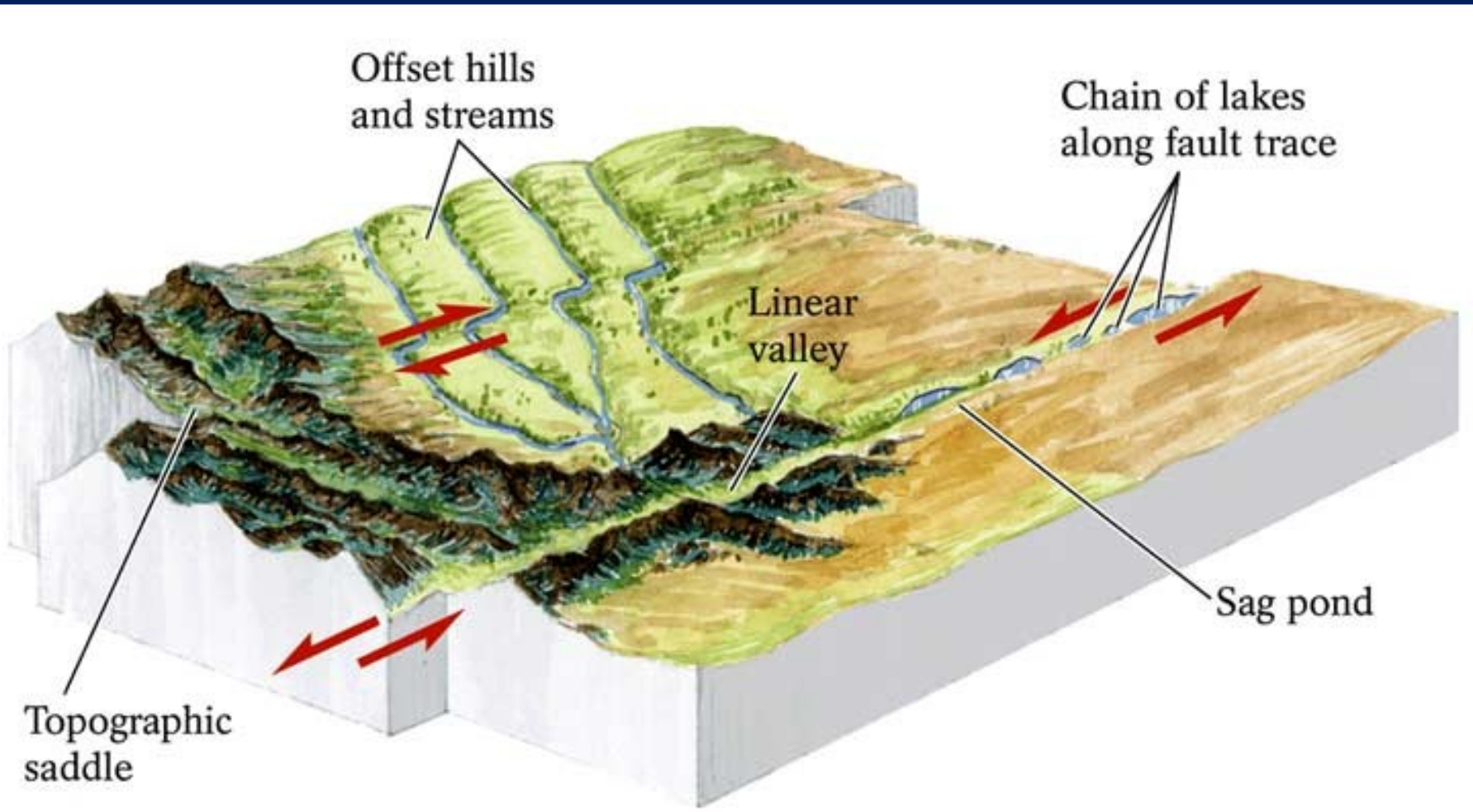
C) **Renewal of erosion, following upliftment, with development of fault line scarp**

D) **Renewal of faulting with composite scarp, whose upper part is of erosional and lower part of fault origin**

Fault-line scarp caused by faulting of a resistant layer

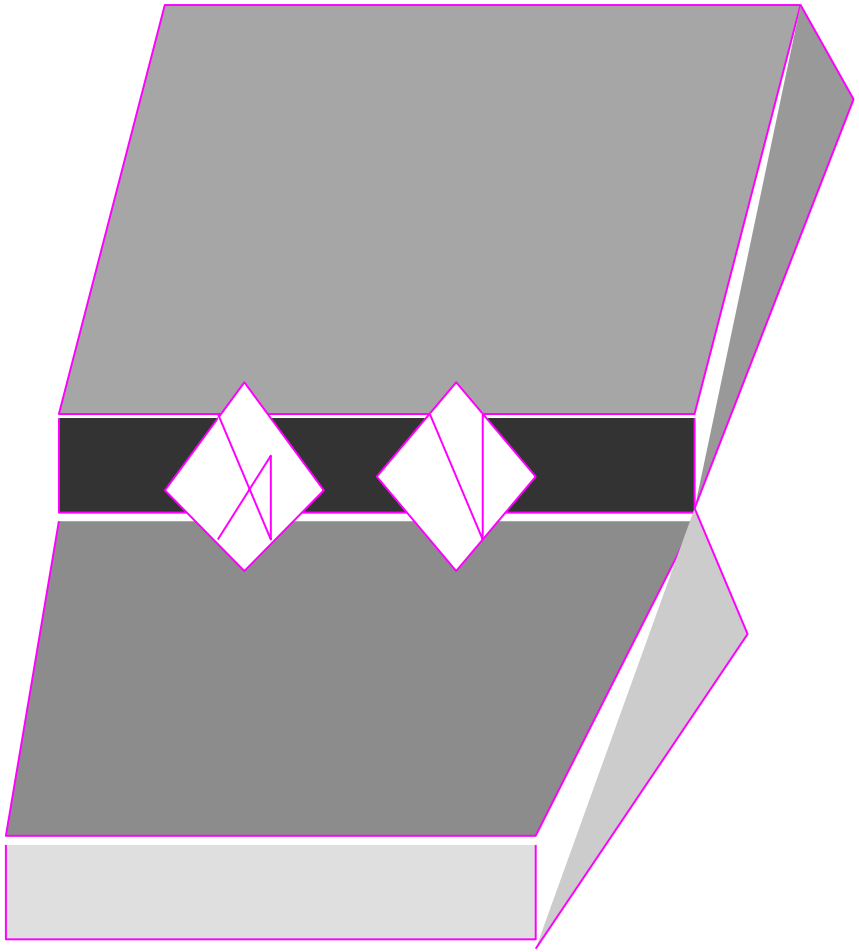



Fault Line scarp
(High-angle
Normal Fault)


Offset hills
and streams
Chain of lakes
along fault trace
Linear
valley
Sag pond
Topographic
saddle

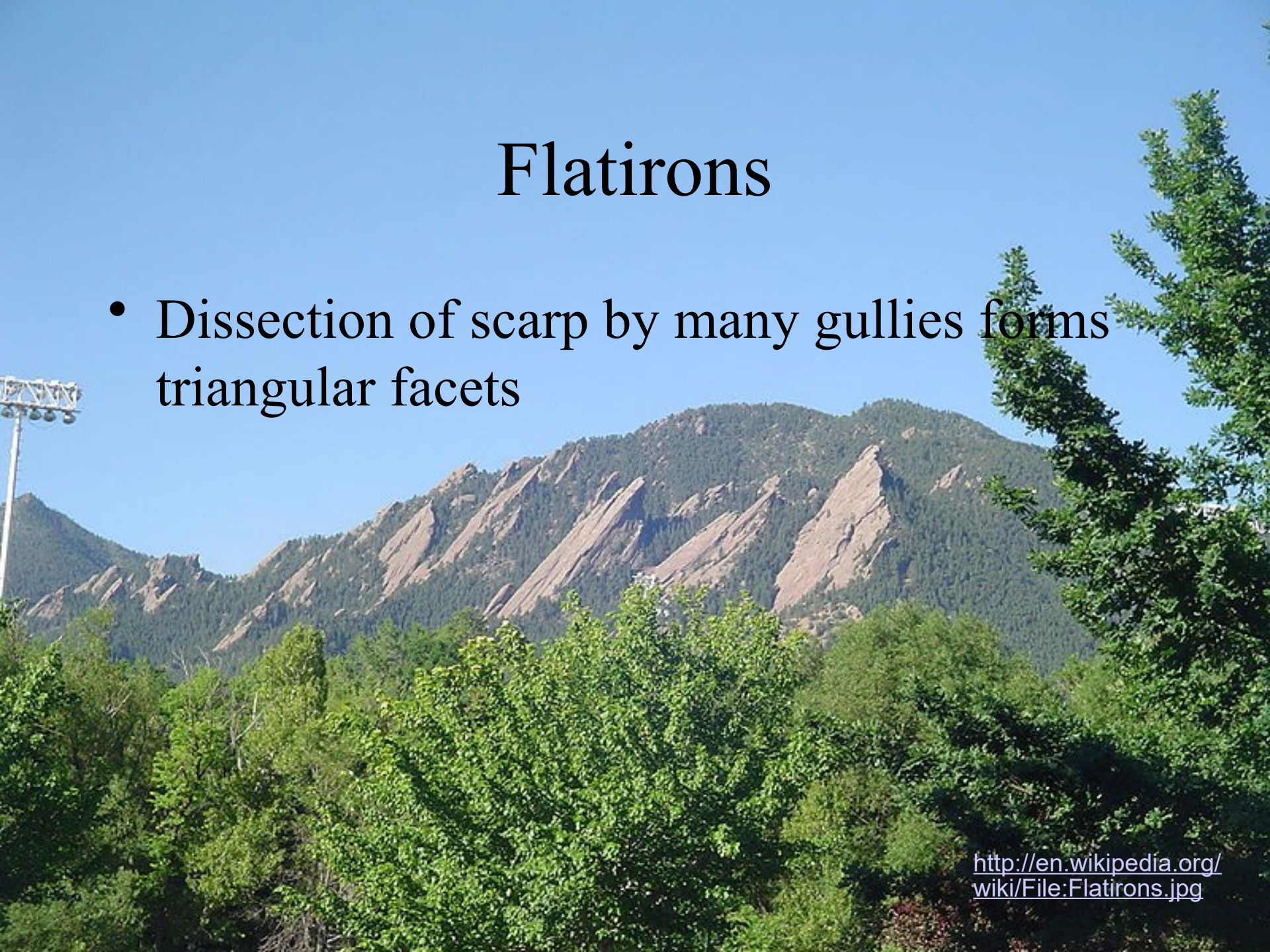
Sag pond on trace of 1906 break along San Andreas fault. California

Triangular facets : Due to erosion along the Fault scarp and Fault line scarp develop the Triangular facet



Flatirons

- Dissection of scarp by many gullies forms triangular facets



http://en.wikipedia.org/wiki/File:Flatirons.jpg

TRIANGULAR FACETS

(*Jagged, Cappadocia, Turkey*)

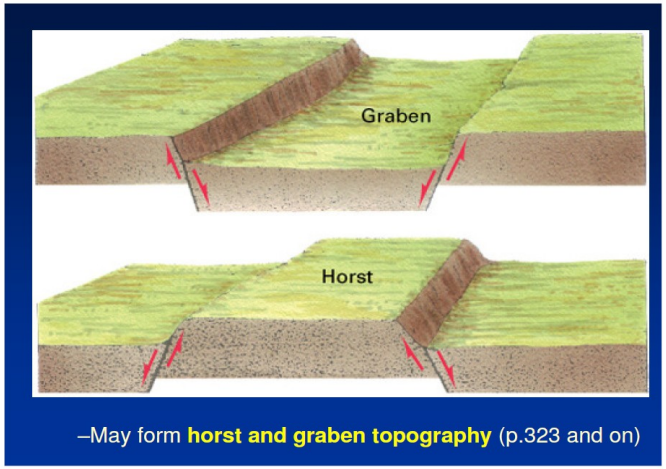
Horst and Graben

Blocks of the earth's crust may be relatively raised or lowered between more or less parallel faults without pronounced tilting.

The relatively raised blocks are commonly called horst and the lowered blocks are called as graben

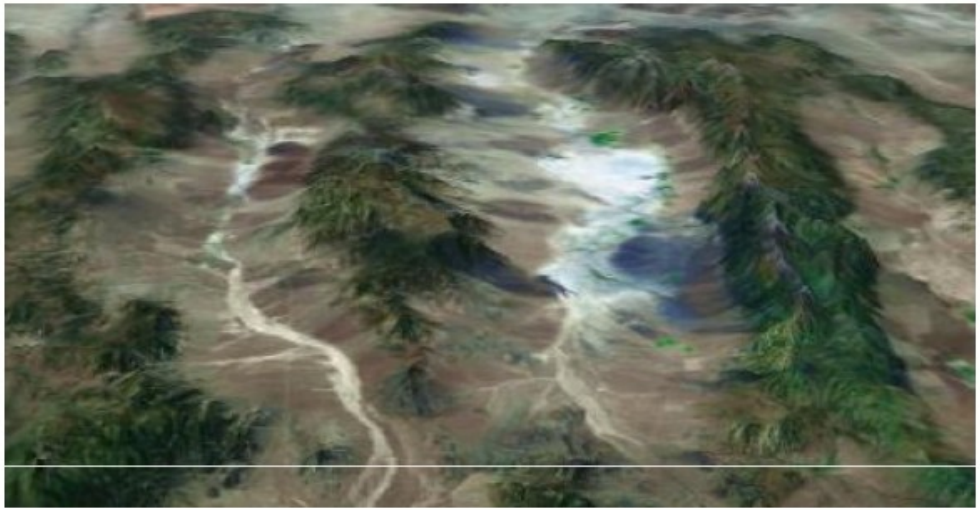
The Jordan-Dead sea depression, Death valley, the Rhine graben, the rift valleys of east Africa - GRABEN

The Vosgas Mountains to the west of Rhine graben and Block forest plateau to the east of it, the Palaestine plateau to the west of dead sea



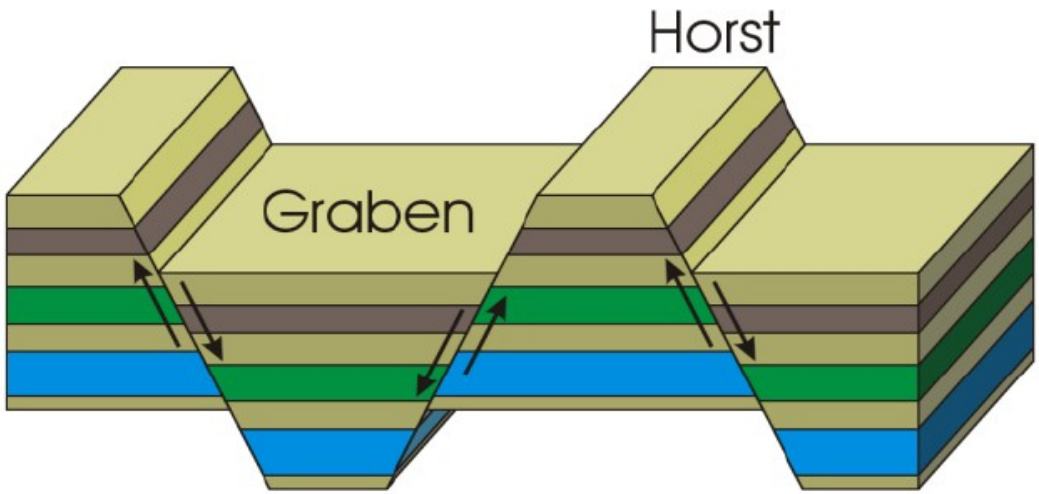
Graben

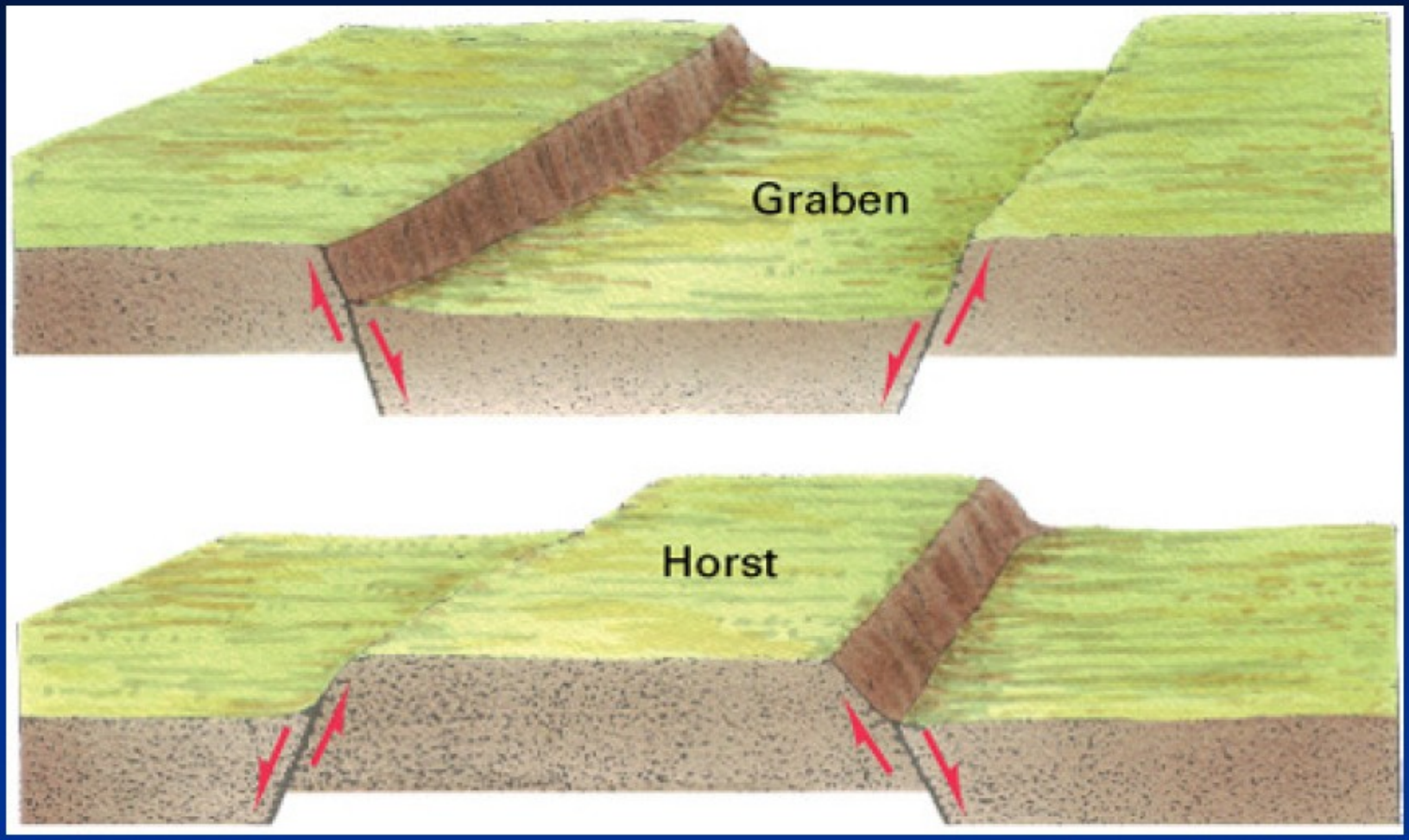
- As the crust is stretched, a block called a **graben**, which is bounded by normal faults, drops down. Graben is a German word for ditch or trench.



Horsts

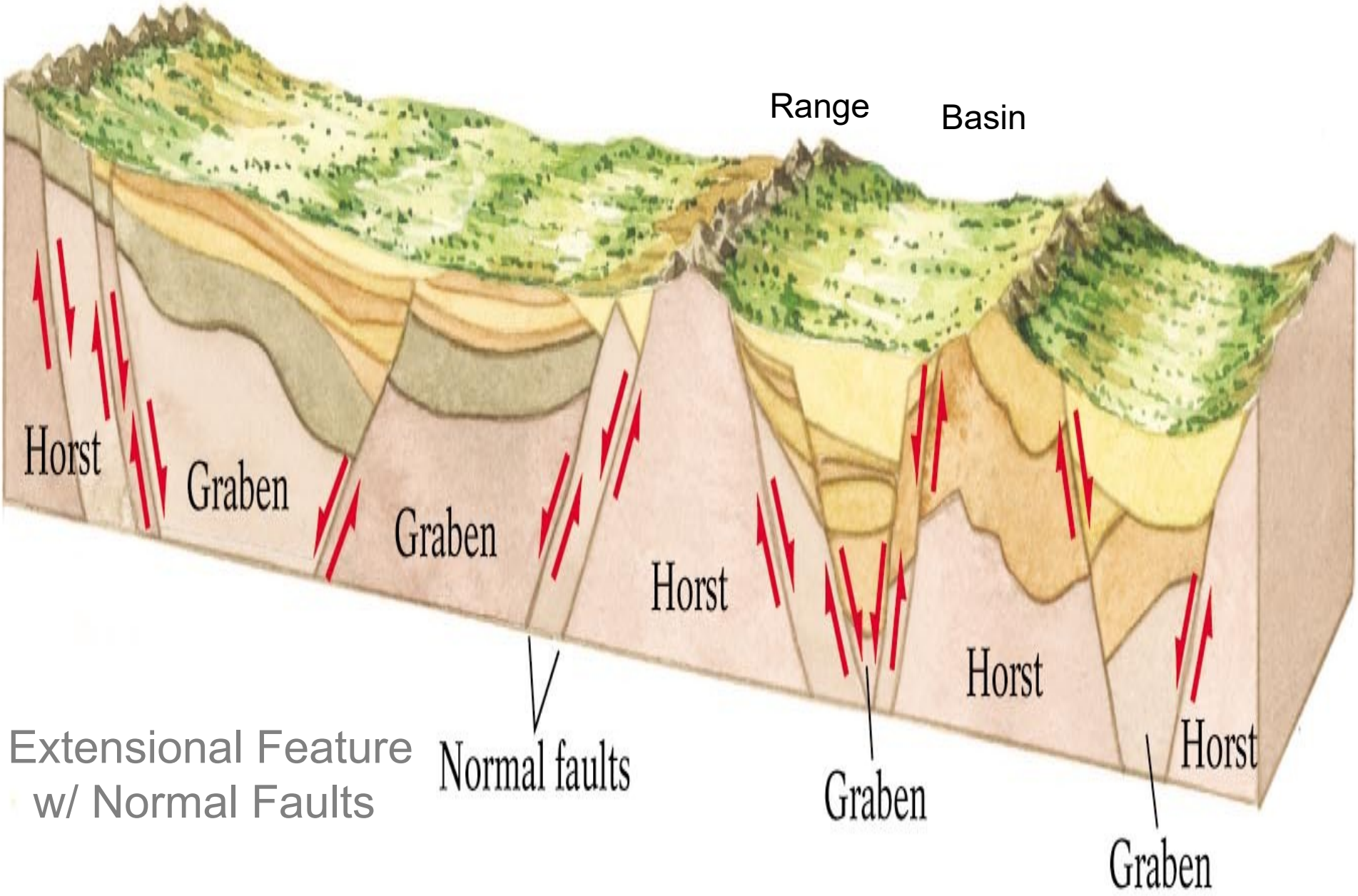
- Grabens produce an elongated valley bordered by relatively uplifted structures called **horsts**.





–May form **horst and graben topography** (p.323 and on)

Horst and Graben

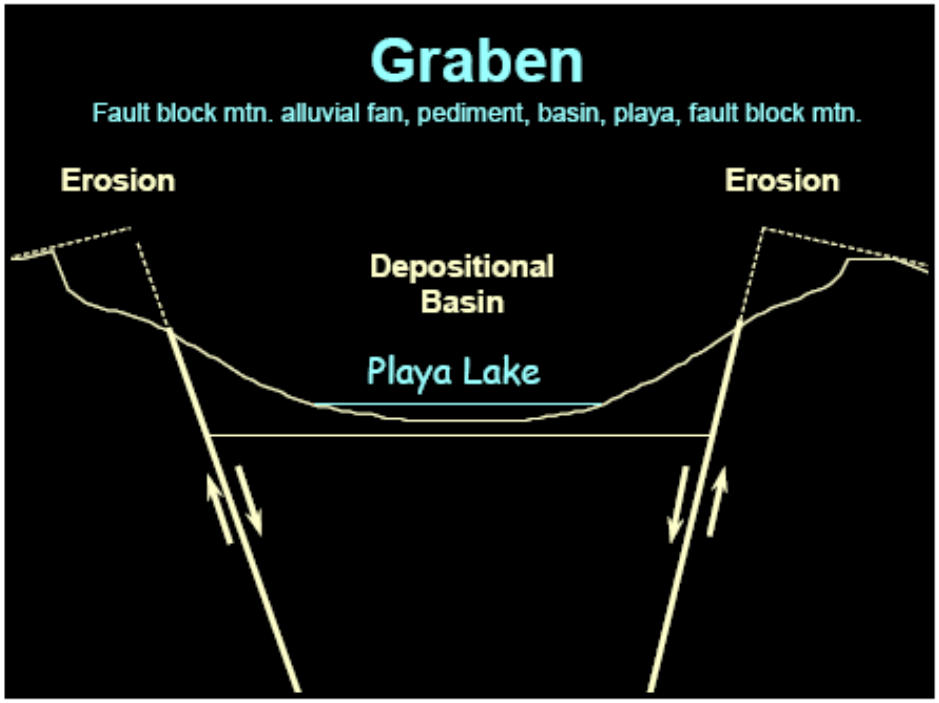


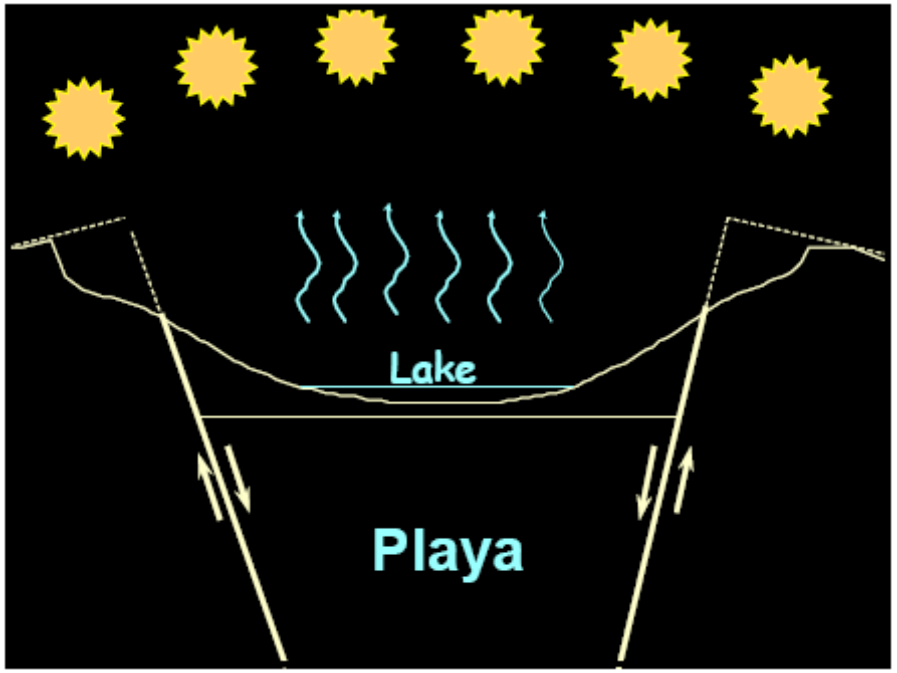
Extensional Feature
w/ Normal Faults

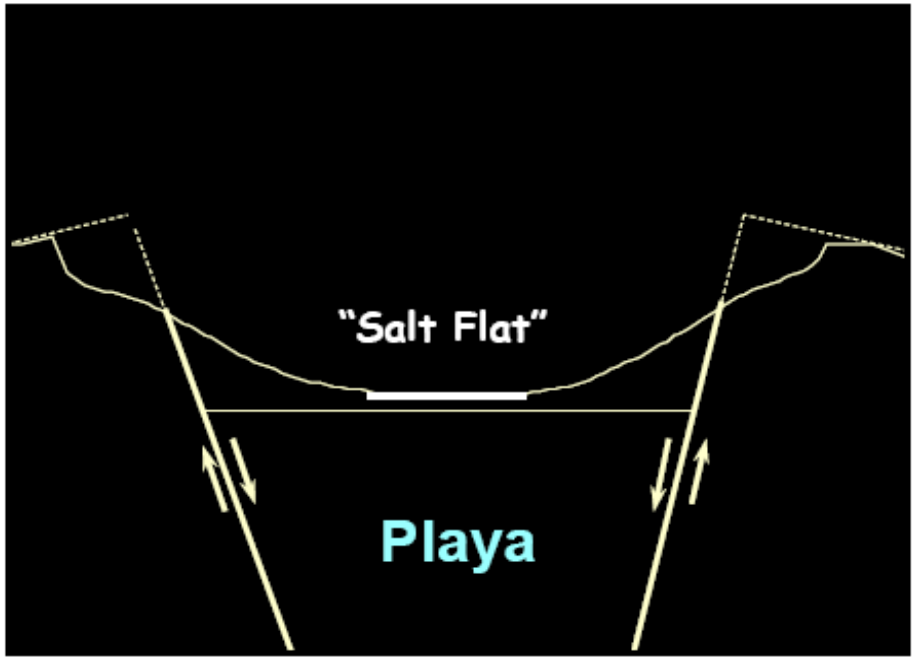

Fault scarp, Death Valley

Graben

Fault block mtn. alluvial fan, pediment, basin, playa, fault block mtn.

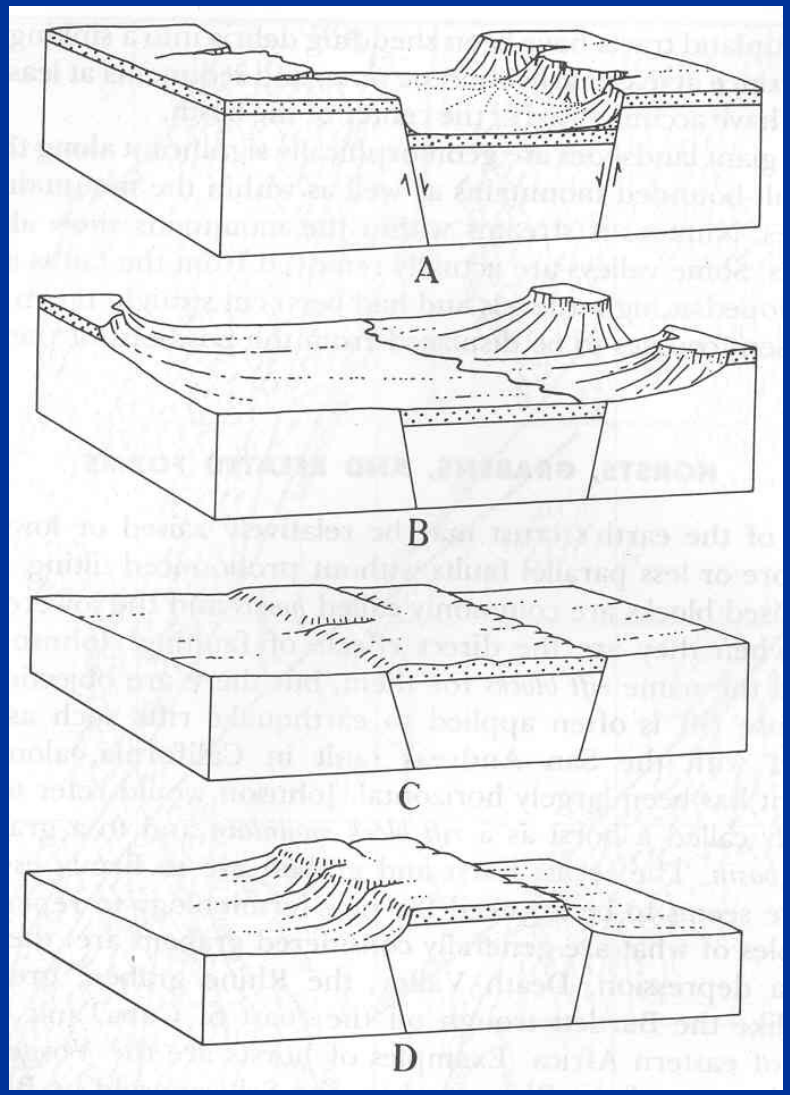






Salt Pan, Death Valley

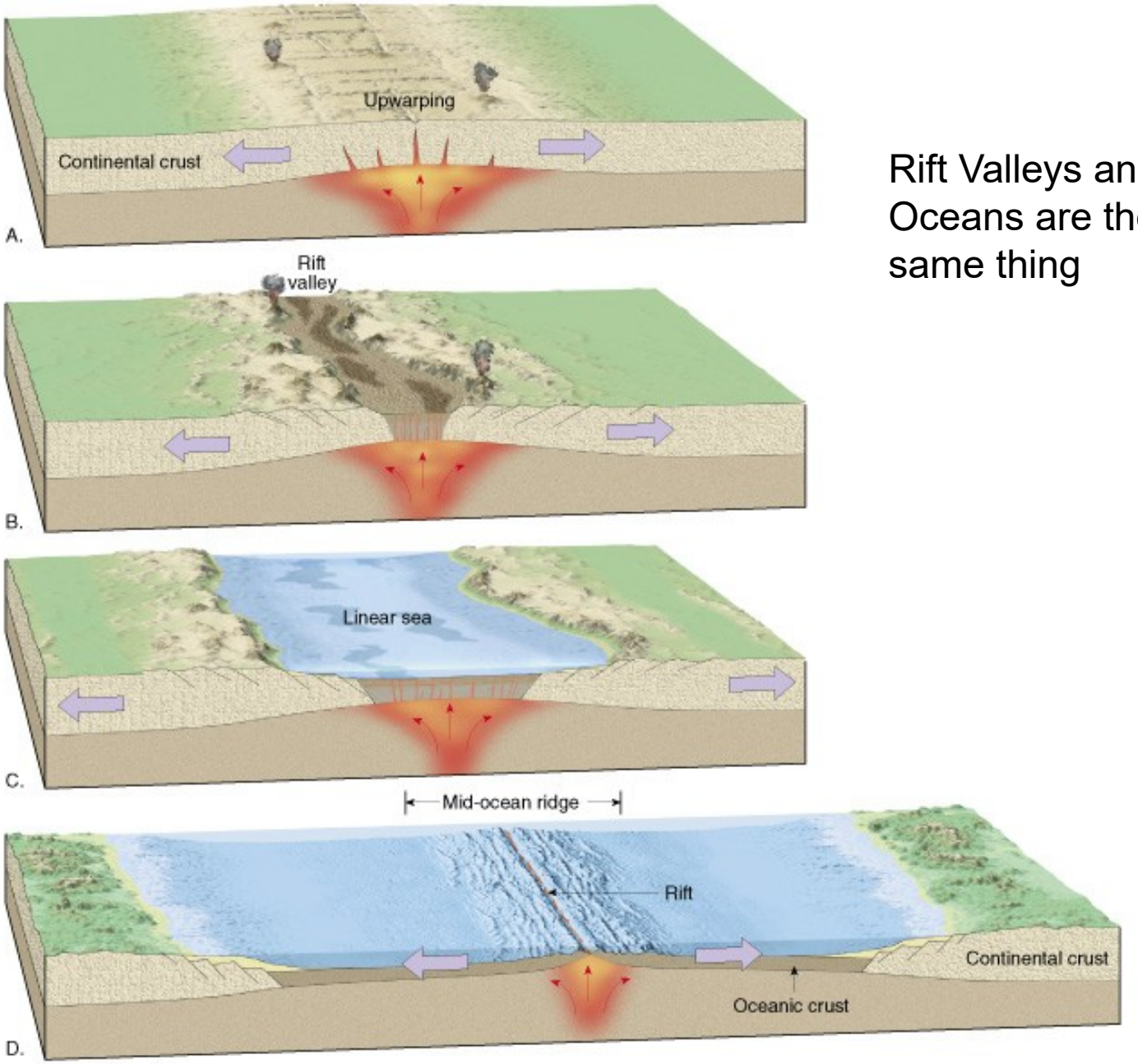
INVERSION OF TOPOGRAPHY



Stages of development of inversion topography upon a graben

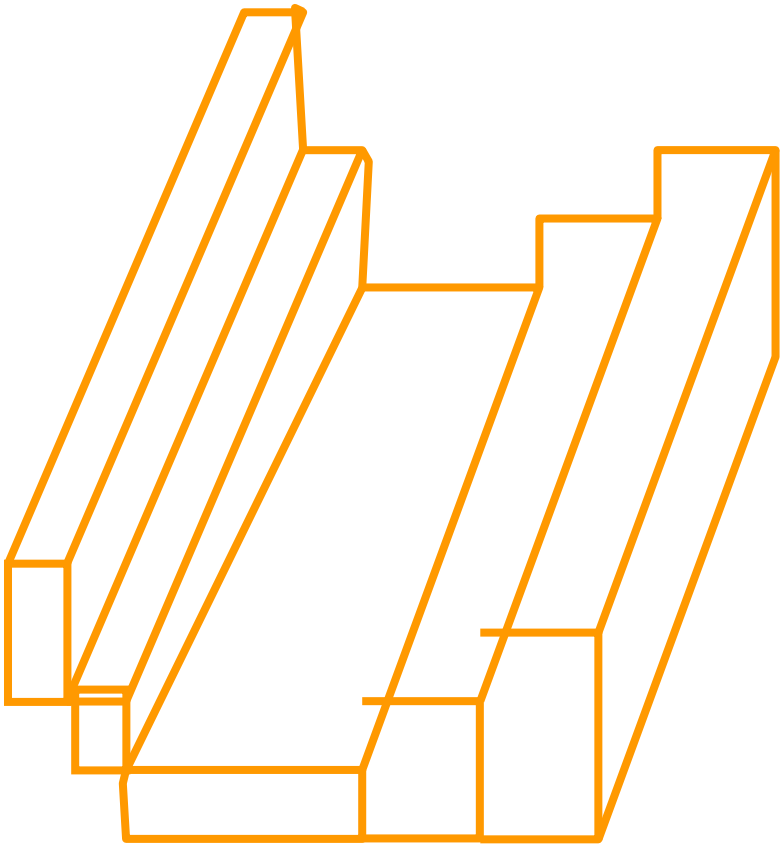
A) Formation of graben by fauting
B) Destruction by erosion of the fault produced topography
C) Renewal of erosion accompanying uplift
D) Development of an obsequent rift block mountains where the originally graben exits

Continental Rift into Ocean Basin - Tension => Divergence



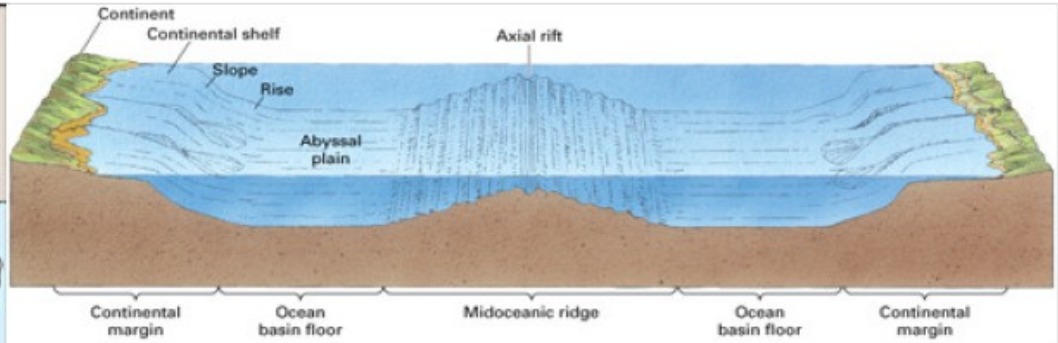
Rift Valleys and Oceans are the same thing

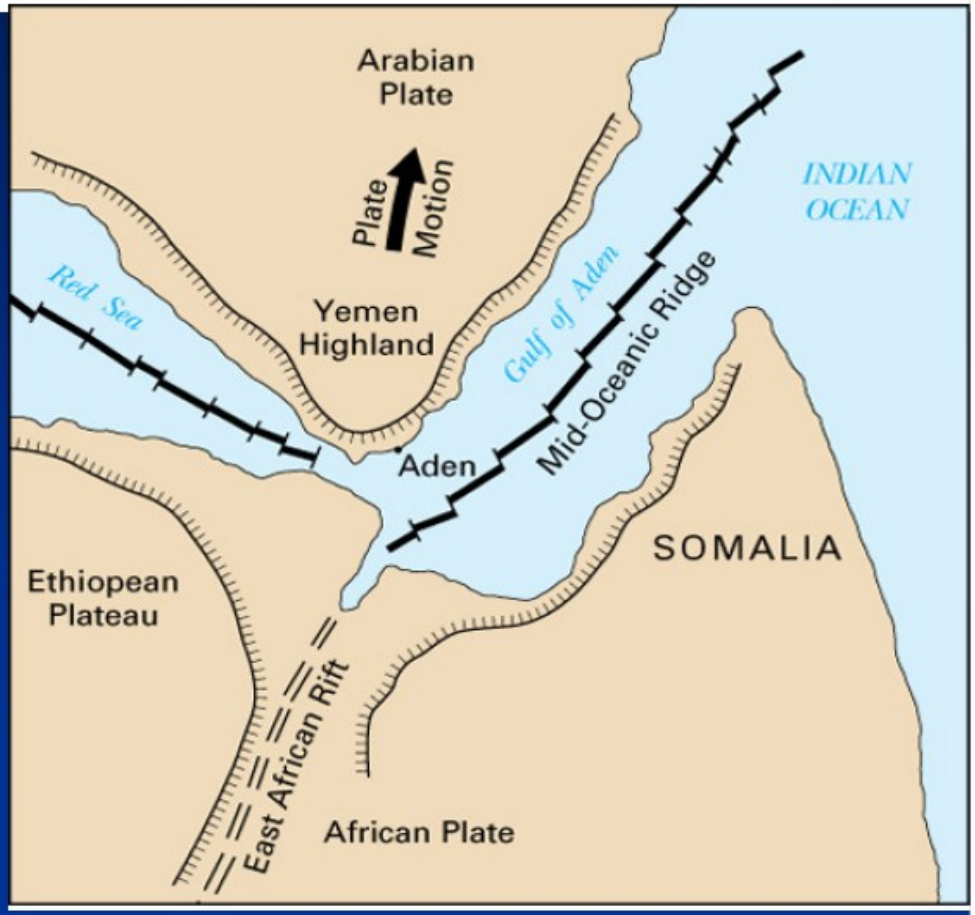
<u>Rift valleys:</u> The term rift valley applied to the great trough or great grabens of East Africa and elsewhere. Rift valley may develop on a block of weak rock bounded by parallel faults. Such feature is called as rift block valley



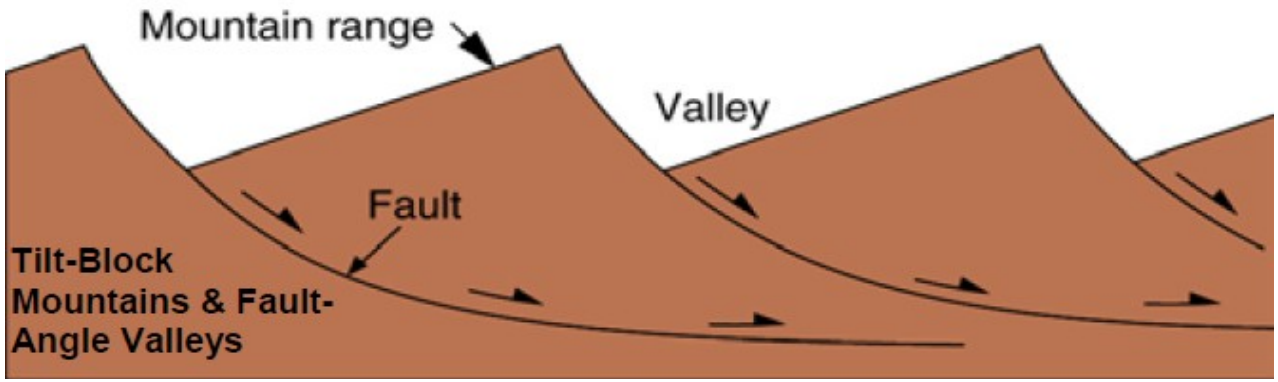
- seismic prone
- hot water / geothermal


0
1000 km
0
500 mi
Graben
30°N
20°N
10°N
0°
10°S
AFRICA
ARABIAN PENINSULA
Red Sea
Gulf of Aden
Ethiopian highlands
Somalia
Lake Turkana
Lake Victoria
Mt. Kenya
Mt. Kilimanjaro
Indian Ocean
Lake Tanganyika
EAST AFRICAN RIFT VALLEY SYSTEM
Lake Nyasa
MADAGASCAR


Continent
Continental shelf
Axial rift
Slope
Rise
Abyssal plain
Continental margin
Ocean basin floor
Midoceanic ridge
Ocean basin floor
Continental margin


Arabian Plate
Plate Motion
INDIAN OCEAN
Red Sea
Yemen Highland
Gulf of Aden
Mid-Oceanic Ridge
Aden
SOMALIA
Ethiopean Plateau
East African Rift
African Plate

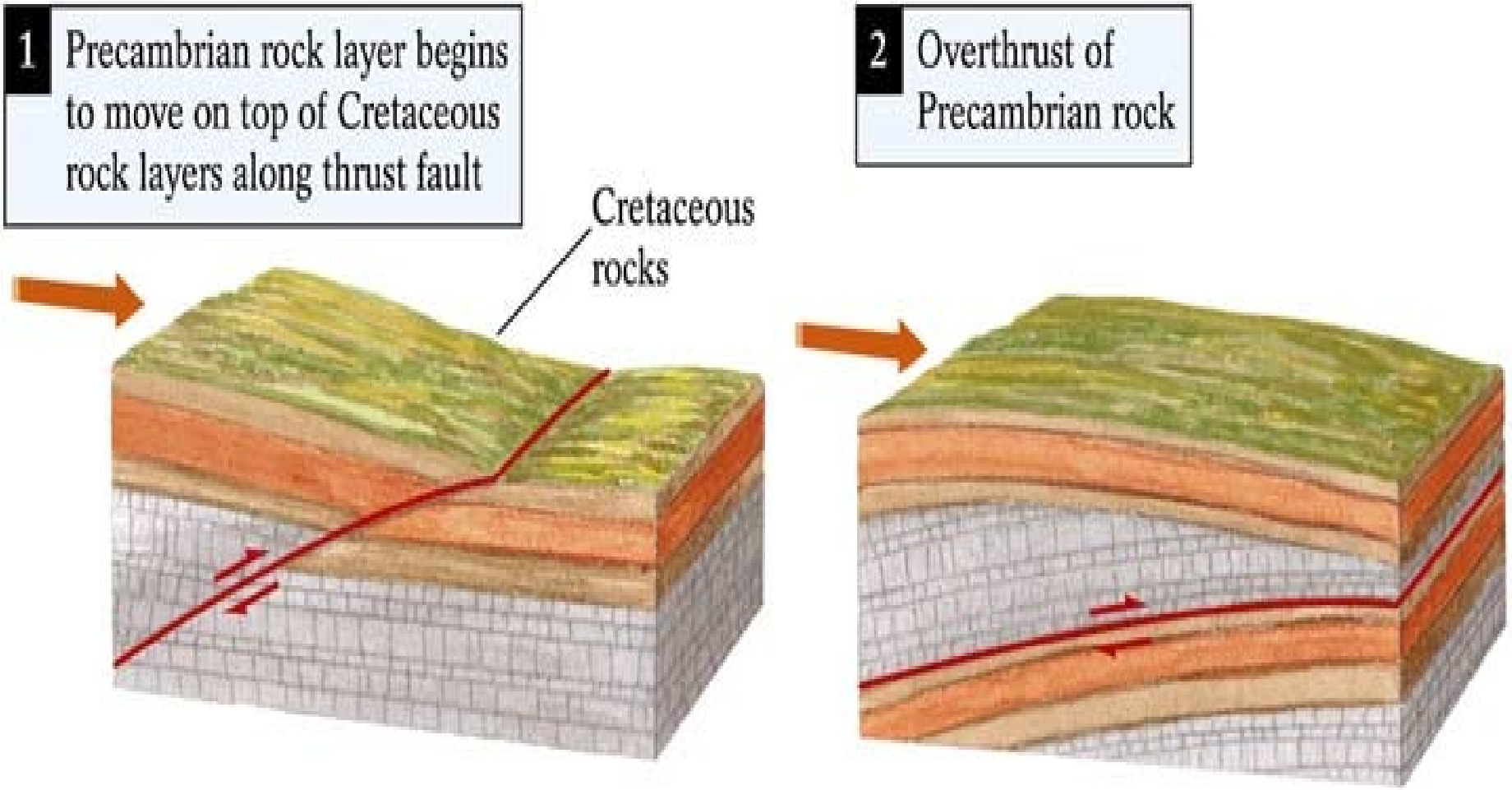
Basins and Range Topography



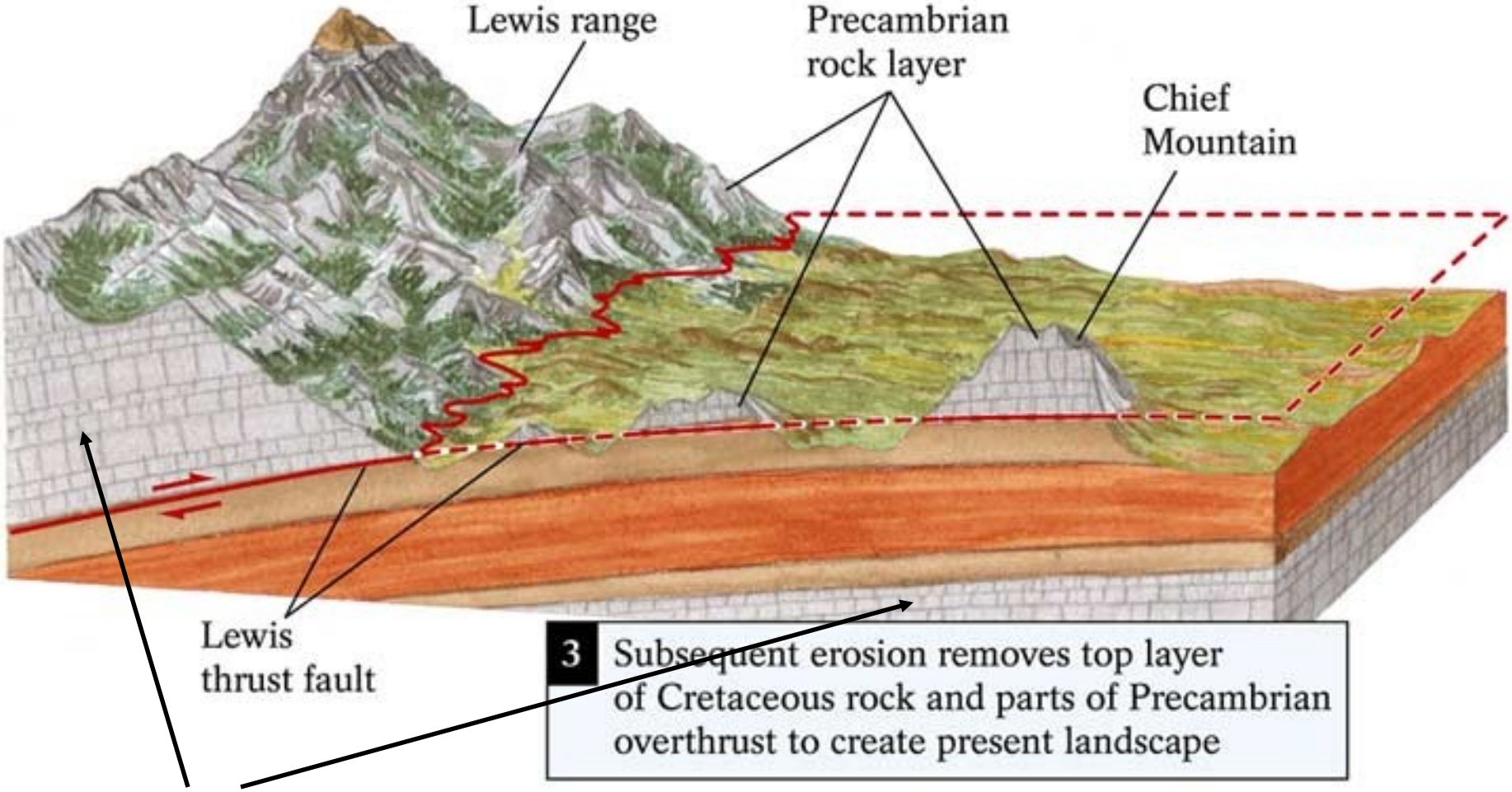
Faulted and tilted monoclinal blocks that had been raised above the adjacent basins along range-front fault

Basins and Range Topography – Western United state

Shallow Reverse Fault = Thrust Fault



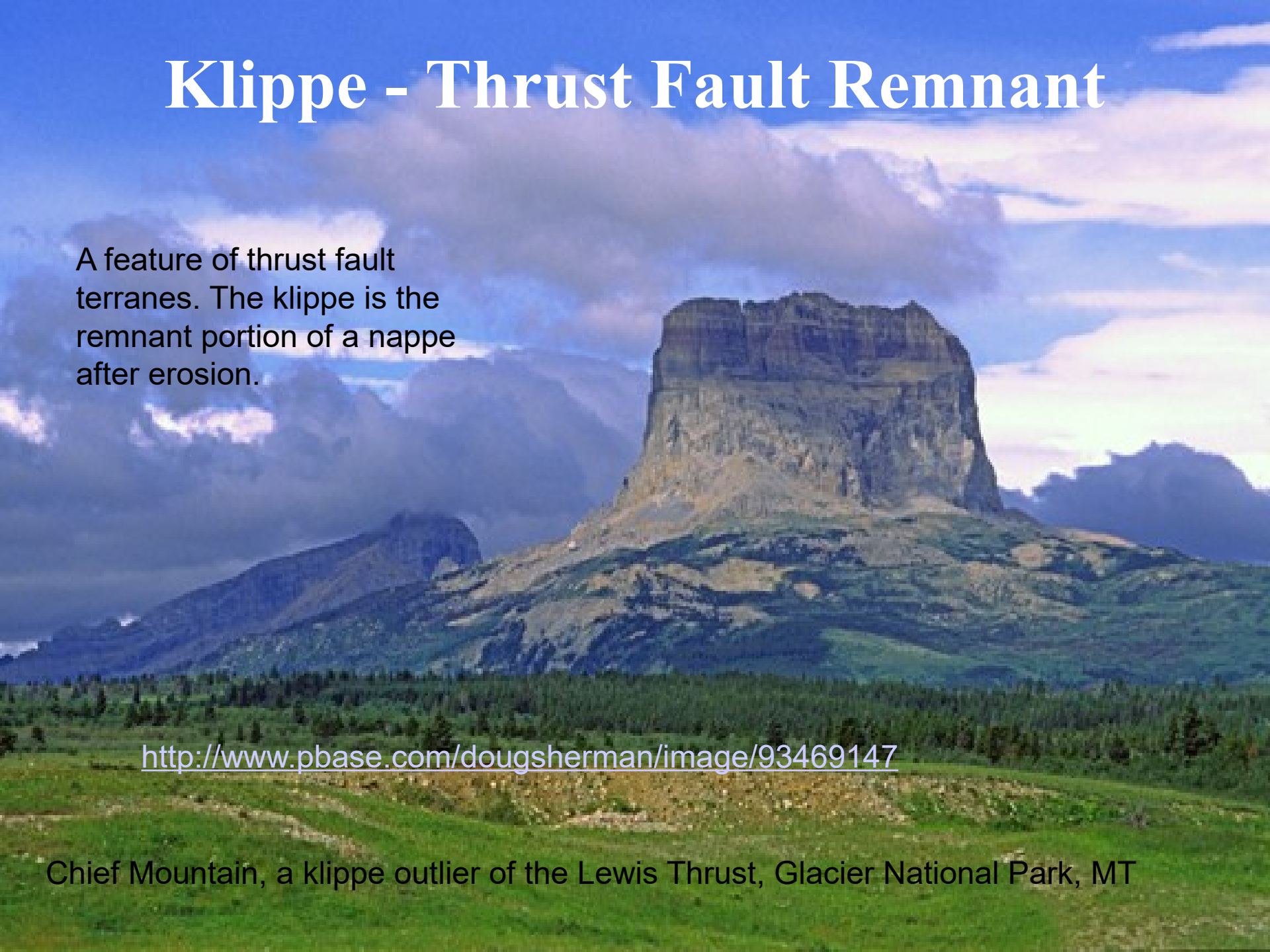
Lewis Thrust Fault (cont'd)



Same layer

Klippe - Thrust Fault Remnant

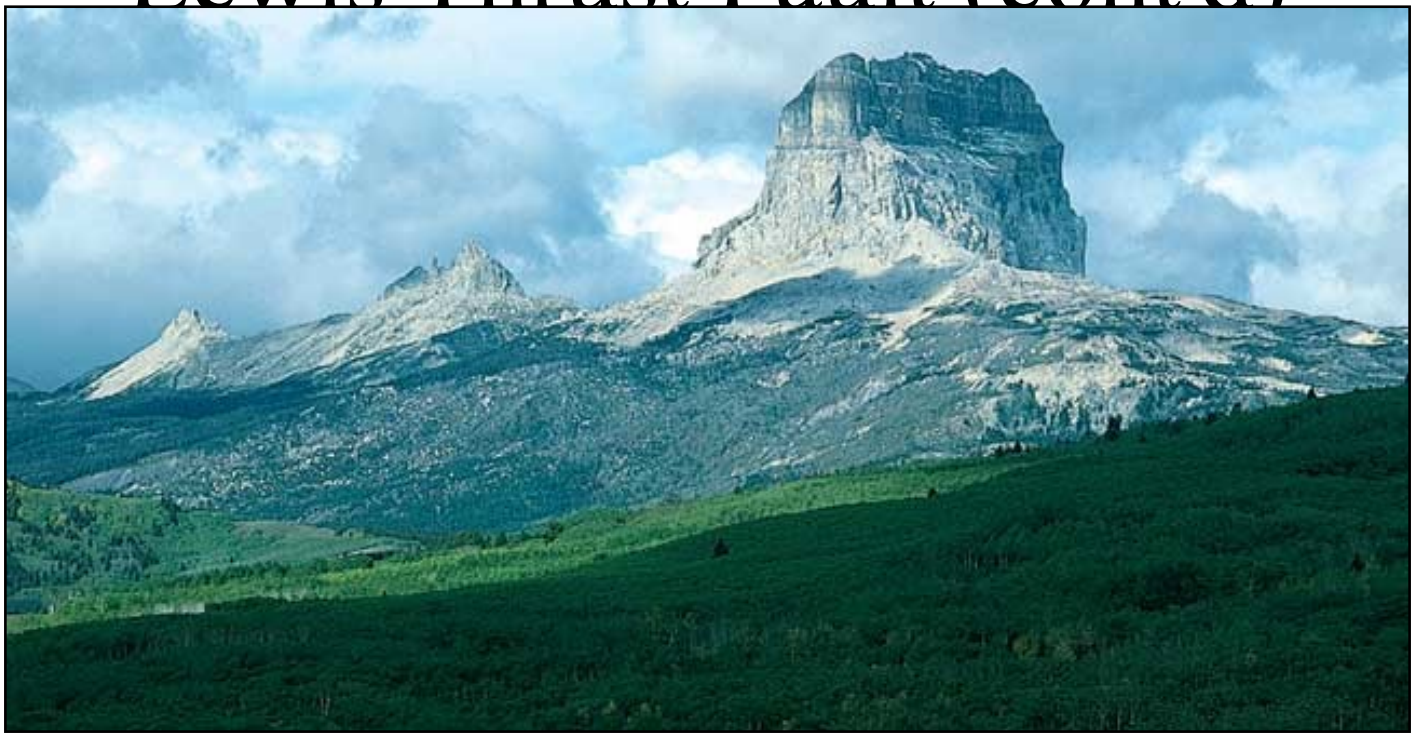
A feature of thrust fault terranes. The klippe is the remnant portion of a nappe after erosion.



http://www.pbase.com/dougsherman/image/93469147

Chief Mountain, a klippe outlier of the Lewis Thrust, Glacier National Park, MT

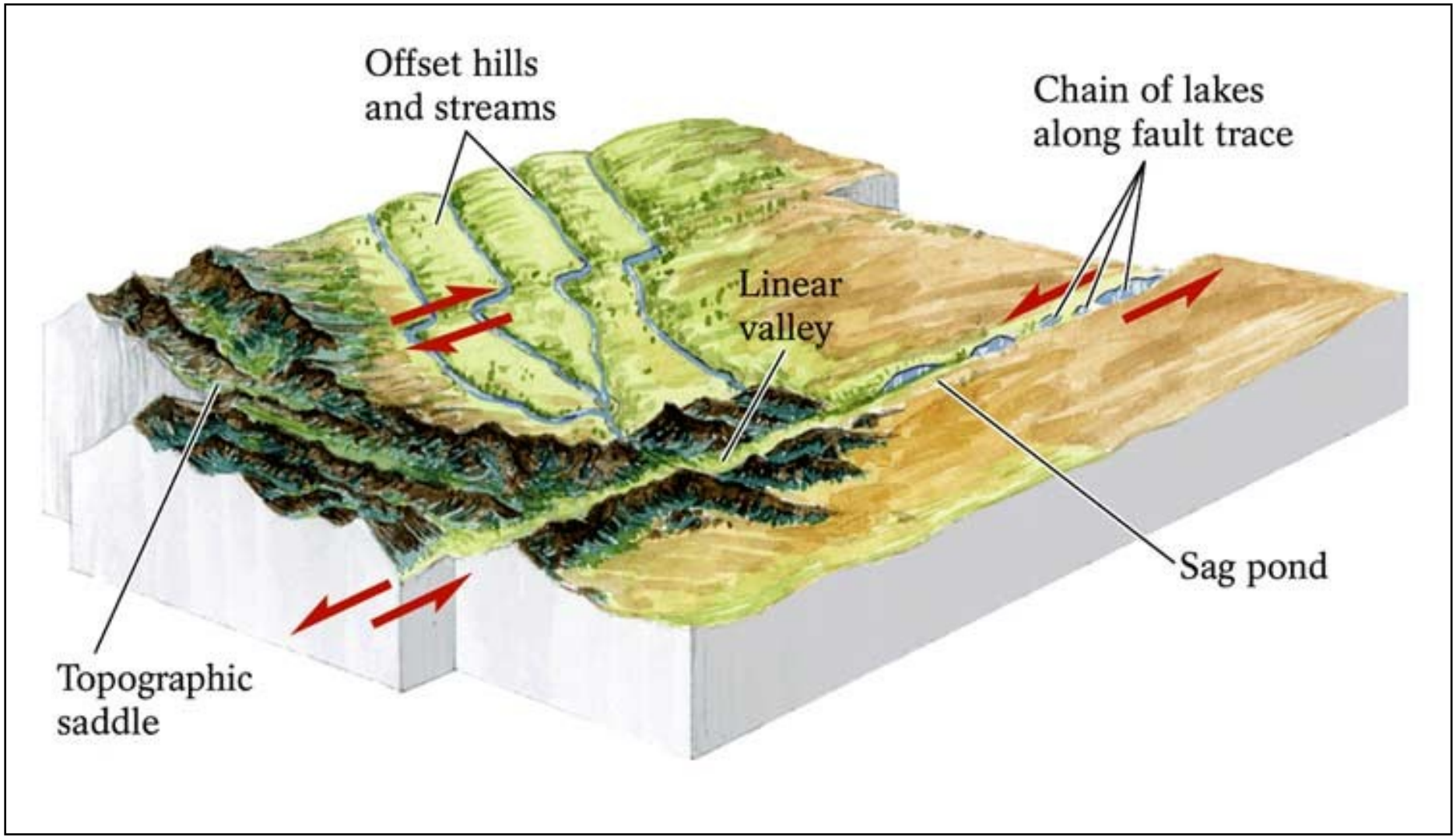
Lewis Thrust Fault (cont'd)



Source: Breck P. Kent

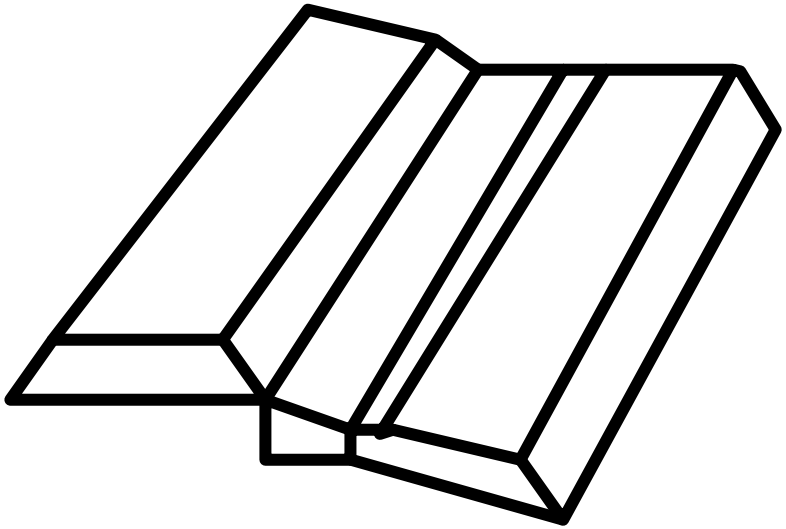
PreCambrian Limestone over Cretaceous Shales

Horizontal Movement Along Strike-Slip Fault

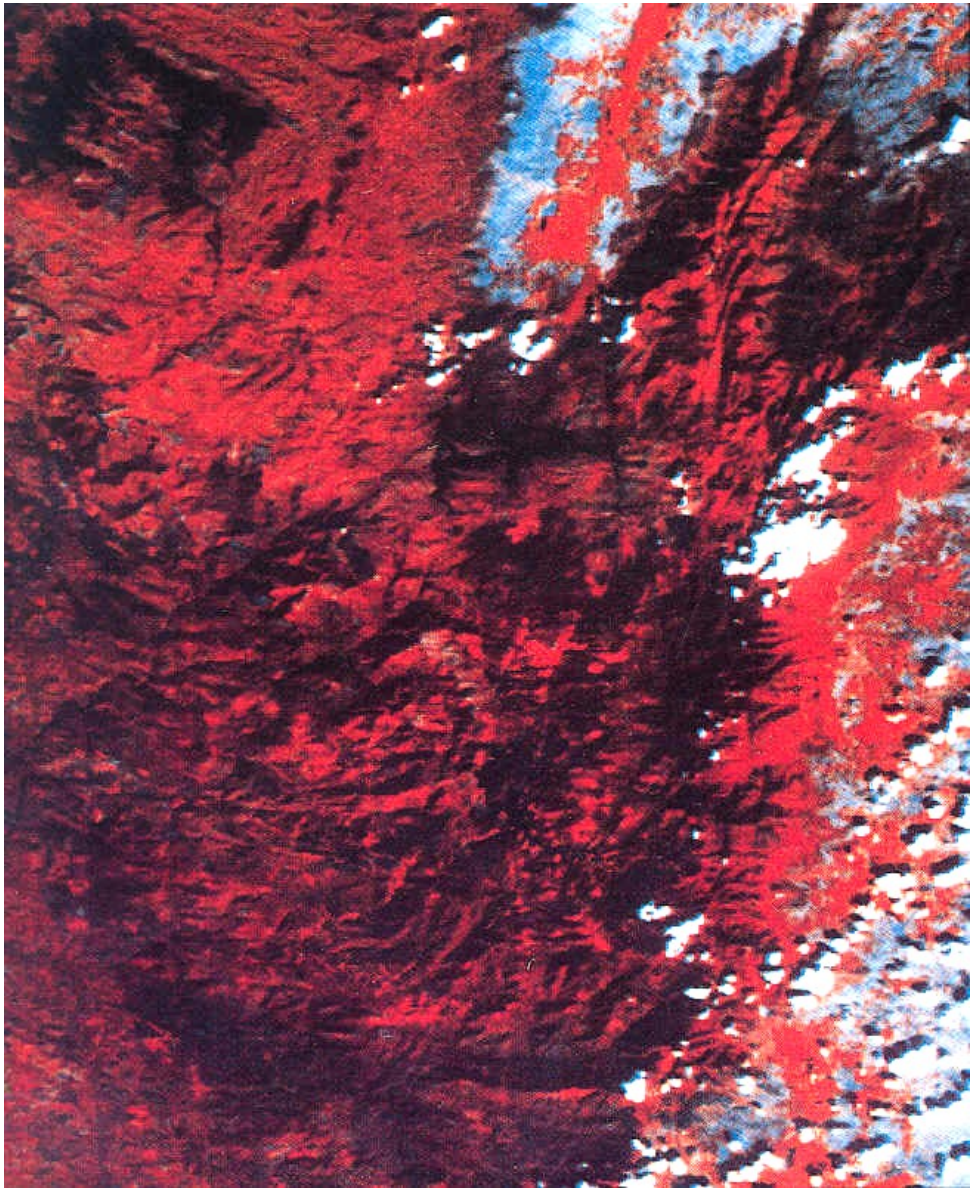


Fault valleys

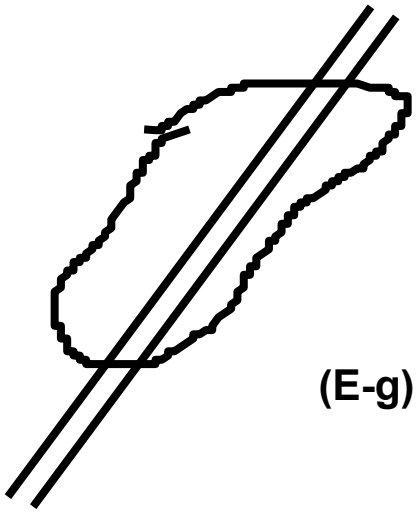
➡ *seismic prone*



CUMBUM TECTONIC VALLEY



<u>Fracture valleys:</u> Valley developed by the erosion along the faults, fracture, lineaments is called fracture valleys

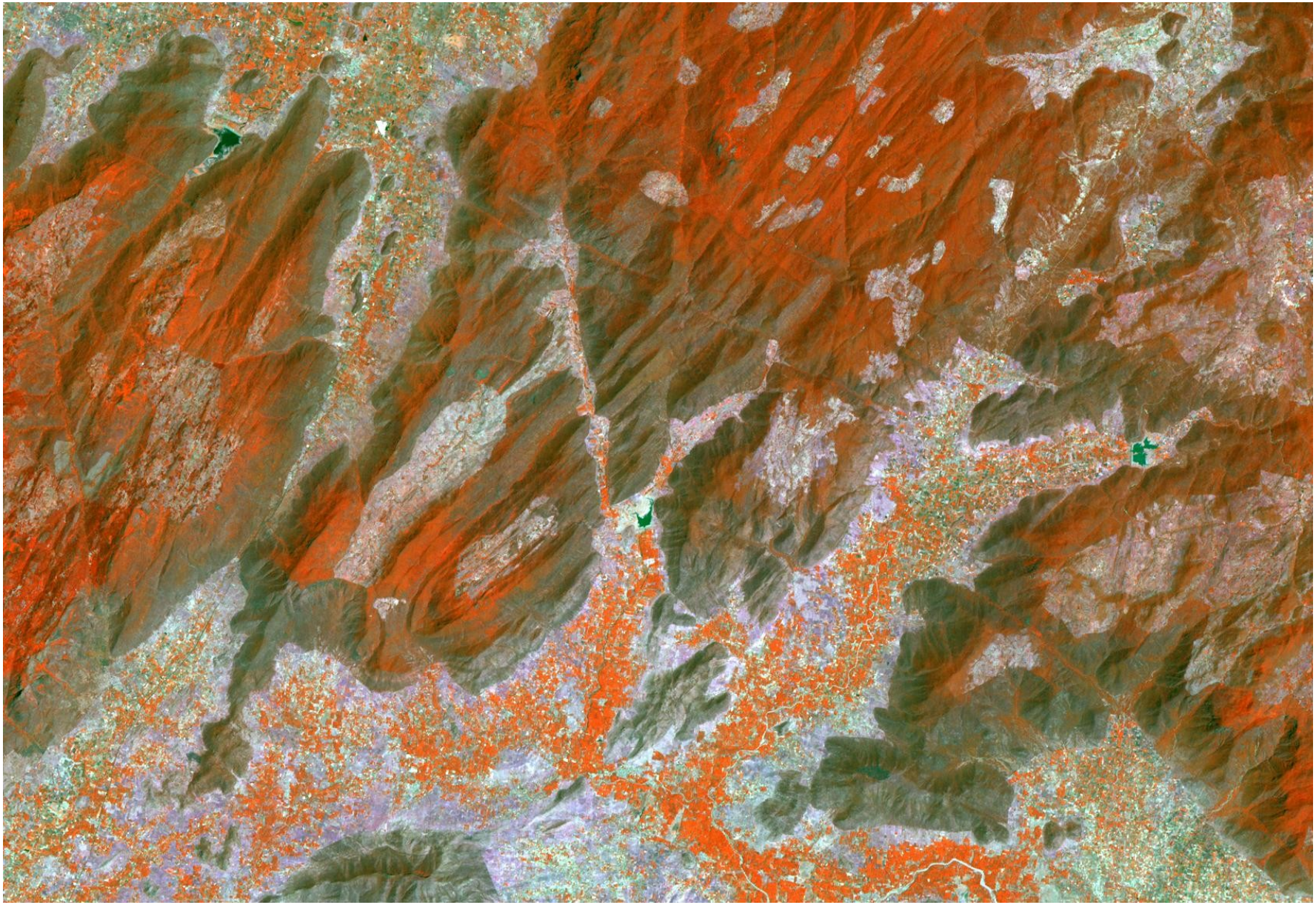


Further, may classified into filled fracture valleys or barren fracture vallys

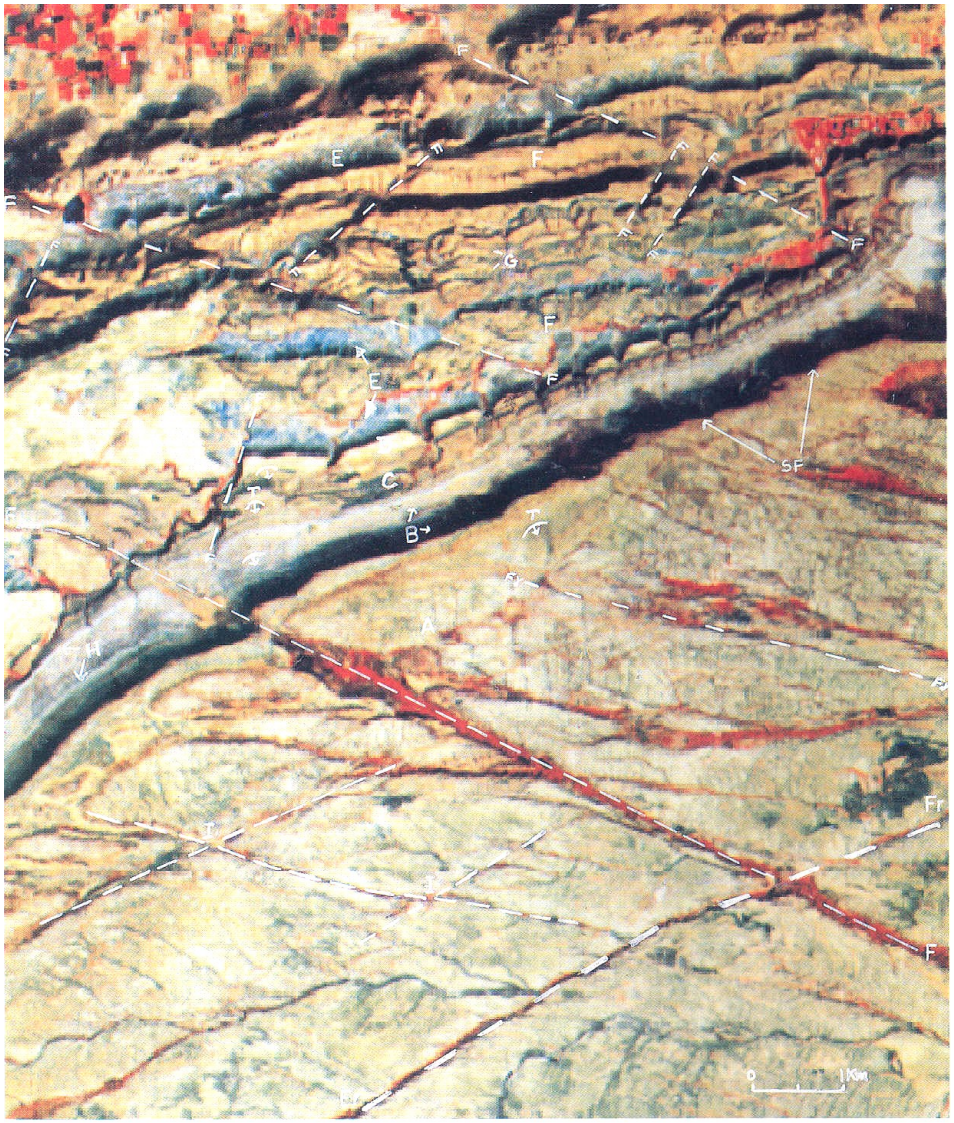
(E-g) Javadi, Shevroy, Chitteri hills

- ***metallogeny***
- ***erosion prone***
- ***groundwater flow***
- ***pollutant migration***

BARREN FRACTUTRE VALLEY



CUDDAPAH BASIN



Tectonic Pediments

If pediments dissected by the fractures are called tectonic pediments

Joints: Fractures – with no movement

http://www.pbase.com/dougsherman/image/93468807