

TECTONIC GEOMORPHOLOGY

(TECTONIC LANDFORMS)

Unit-2

Dr.J.Saravanavel, Assistant Professor, Department of Remote Sensing,
Bharathidasan University, Email: saravanavel@bdu.ac.in

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 (Vindhya)
- ⊕ Minerals in Strain maxima zones in folds
- ⊕ Remobilised deposits in fractures / maxims

(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:



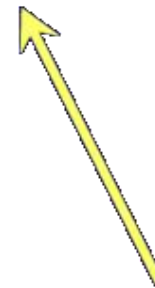
Pre-Cordillera: Patagonian Andes, Argentina

Structural Hills:



Aerial view,
Himalayan Foothills,
northern Pakistan

Plunging folds



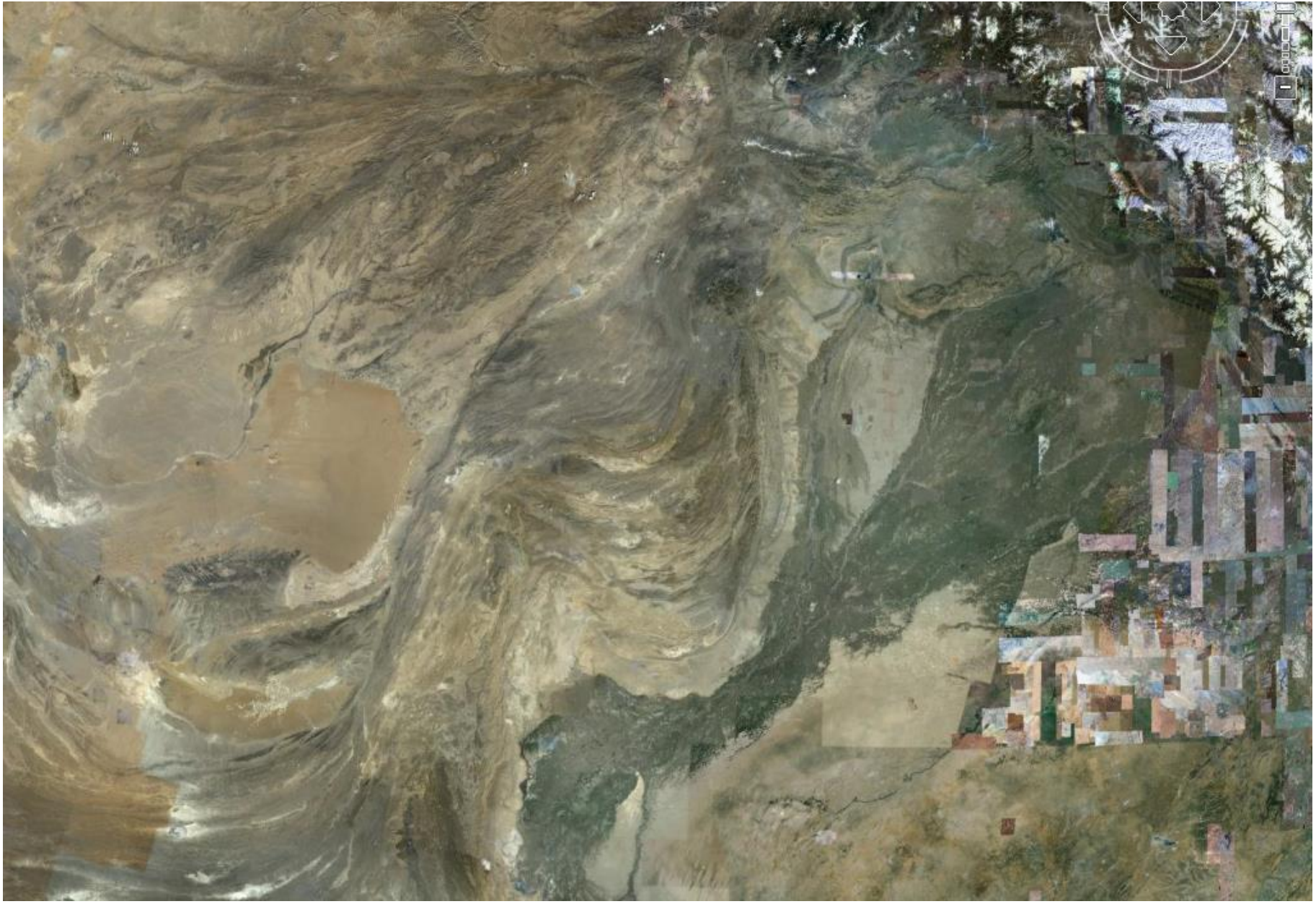
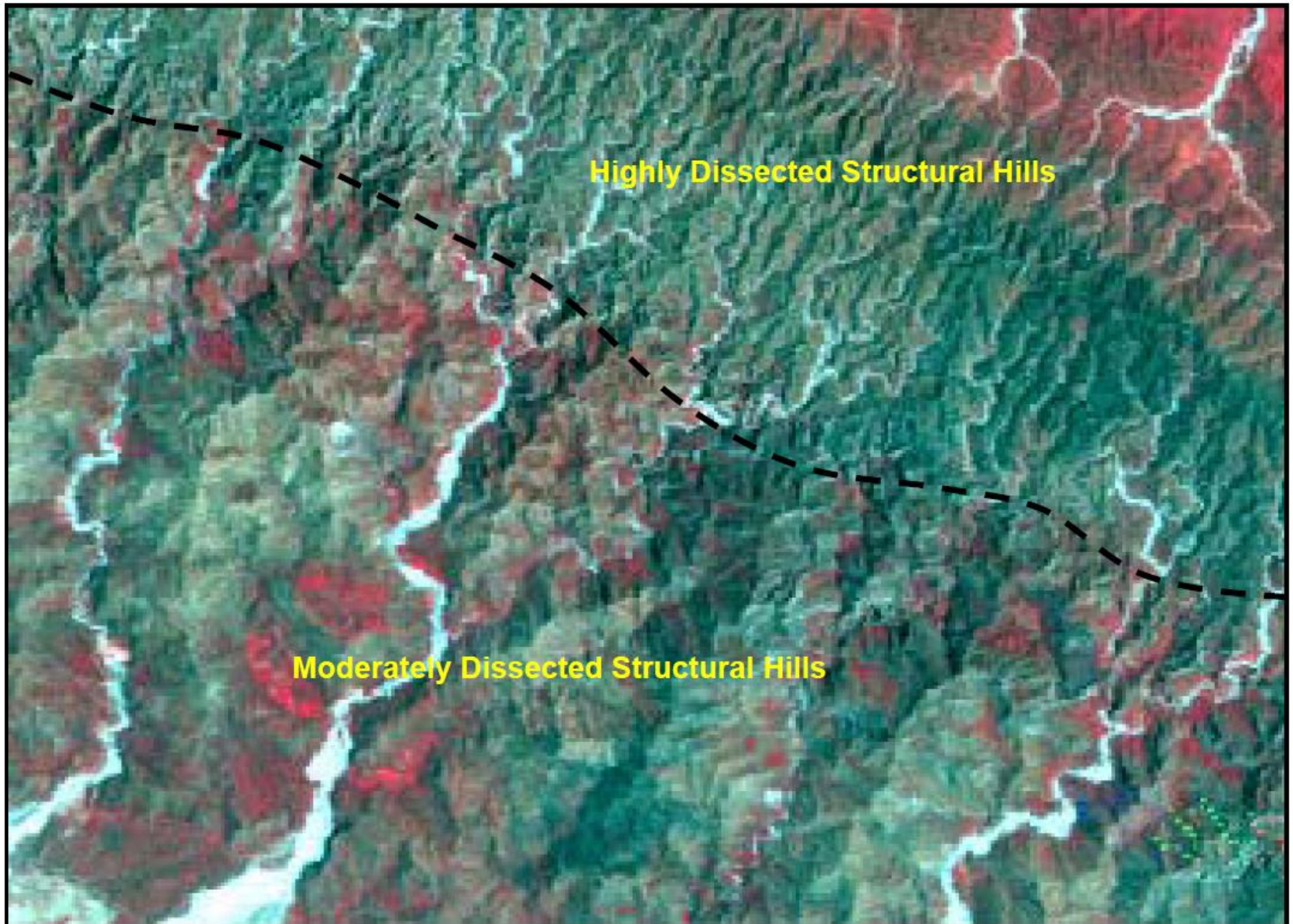


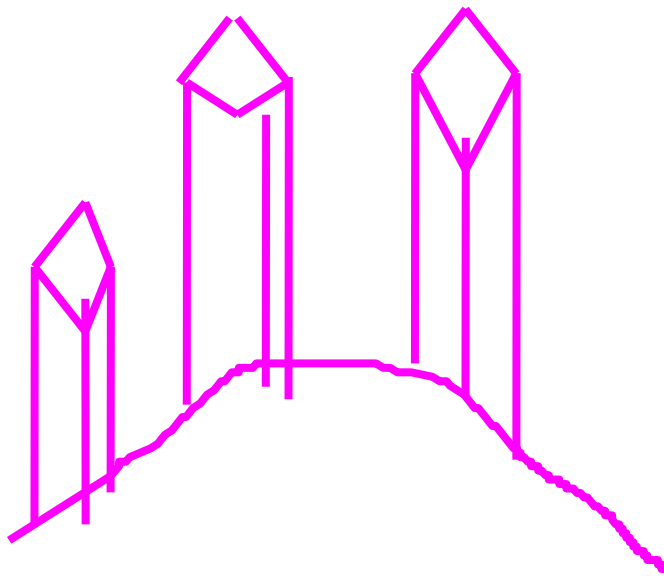
Fig. 4.26: Satellite image of Himalayan region showing dissected structural hills.



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.

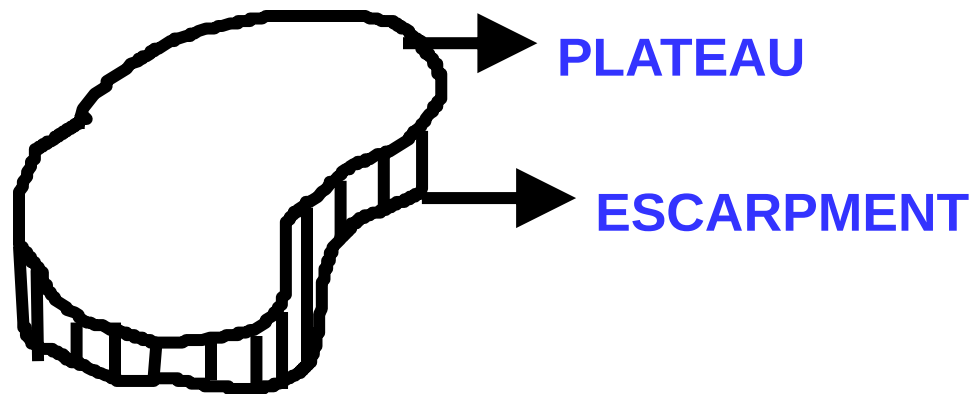
- No heavy metal segregate in the foot.
- Less reservoir siltation in the foot hill reservoirs



Courtesy of William Allen Hammer, Jr.
 EAGLE'S HEAD, FORT LEE, N. J., 1946
 The photograph shows the original amount of weathering along both points, except for the complete

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 - Vindhya*
 - 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

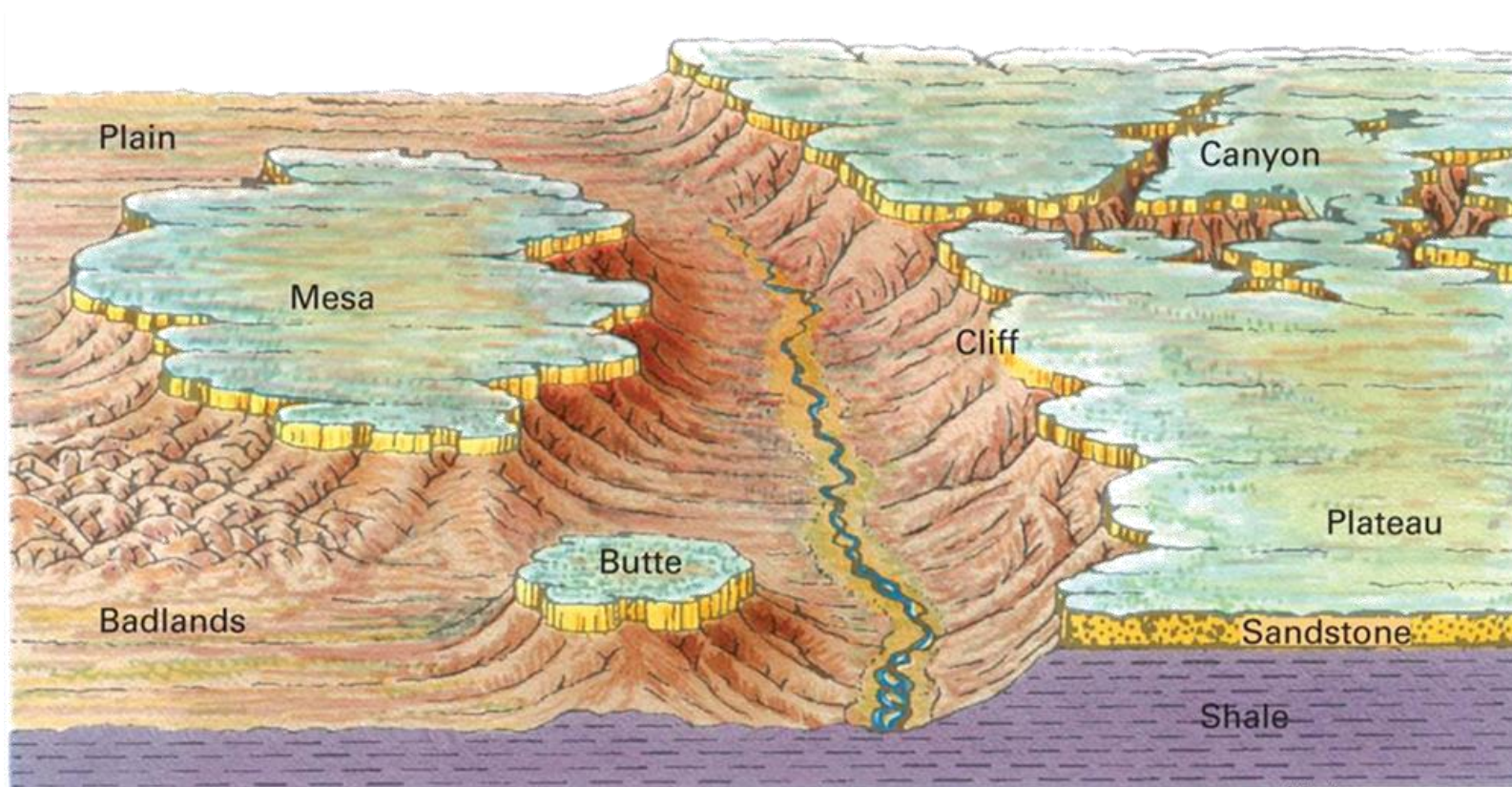
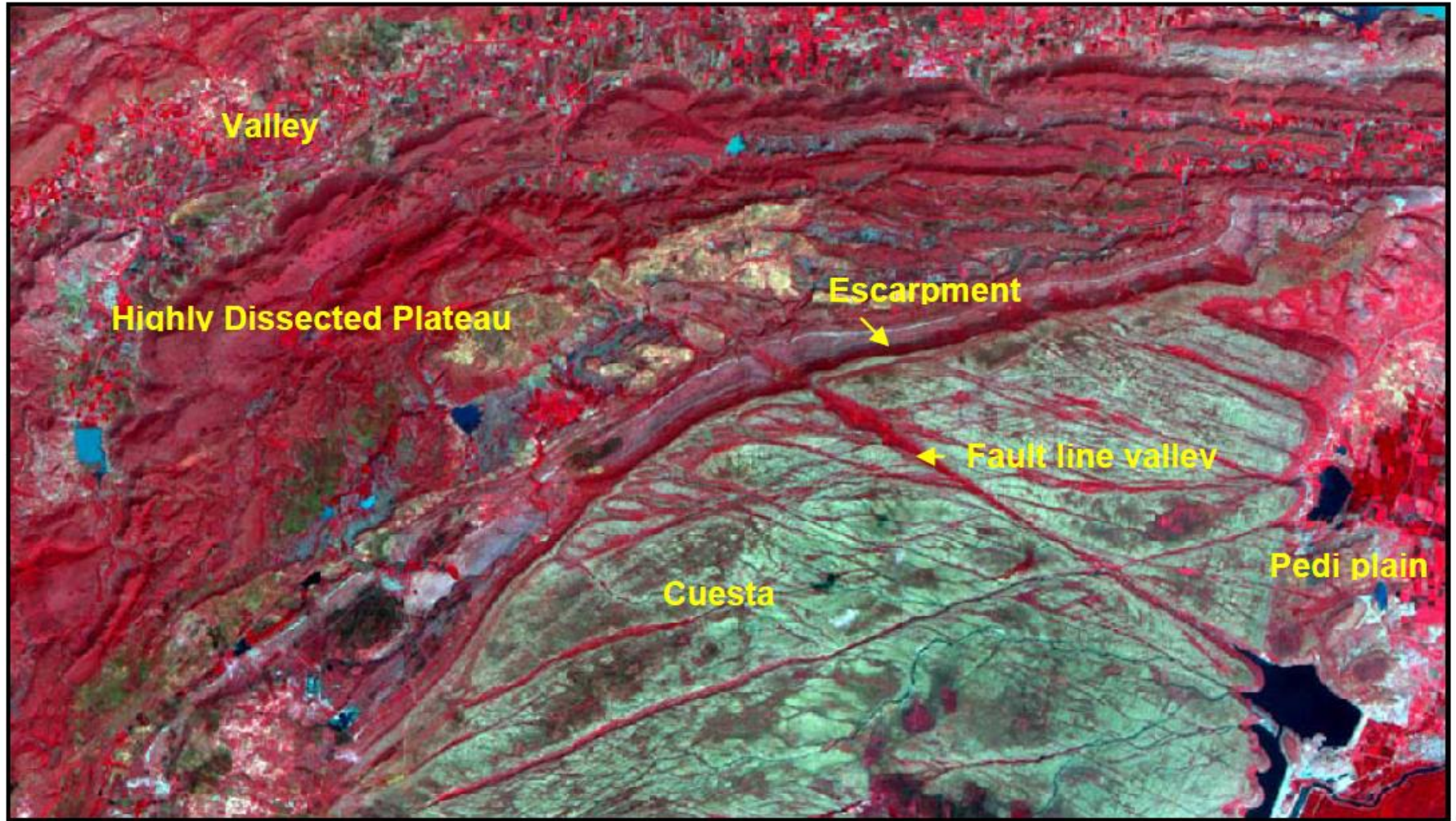
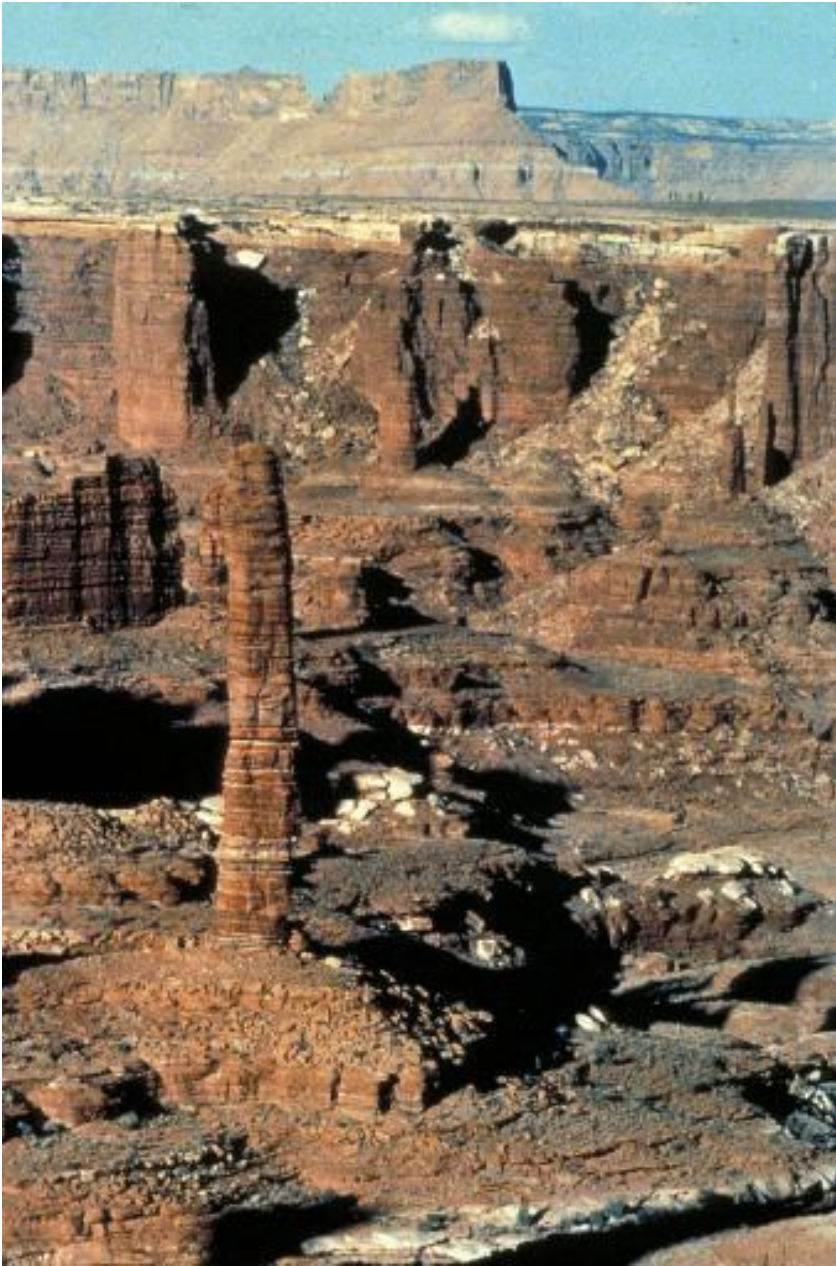


Fig. 4.21: Satellite image of Cuddapah basin showing the Structural landforms.







Cedar Mesa Sandstone;
Colorado Plateau;
Erosional Features;
Geomorphology

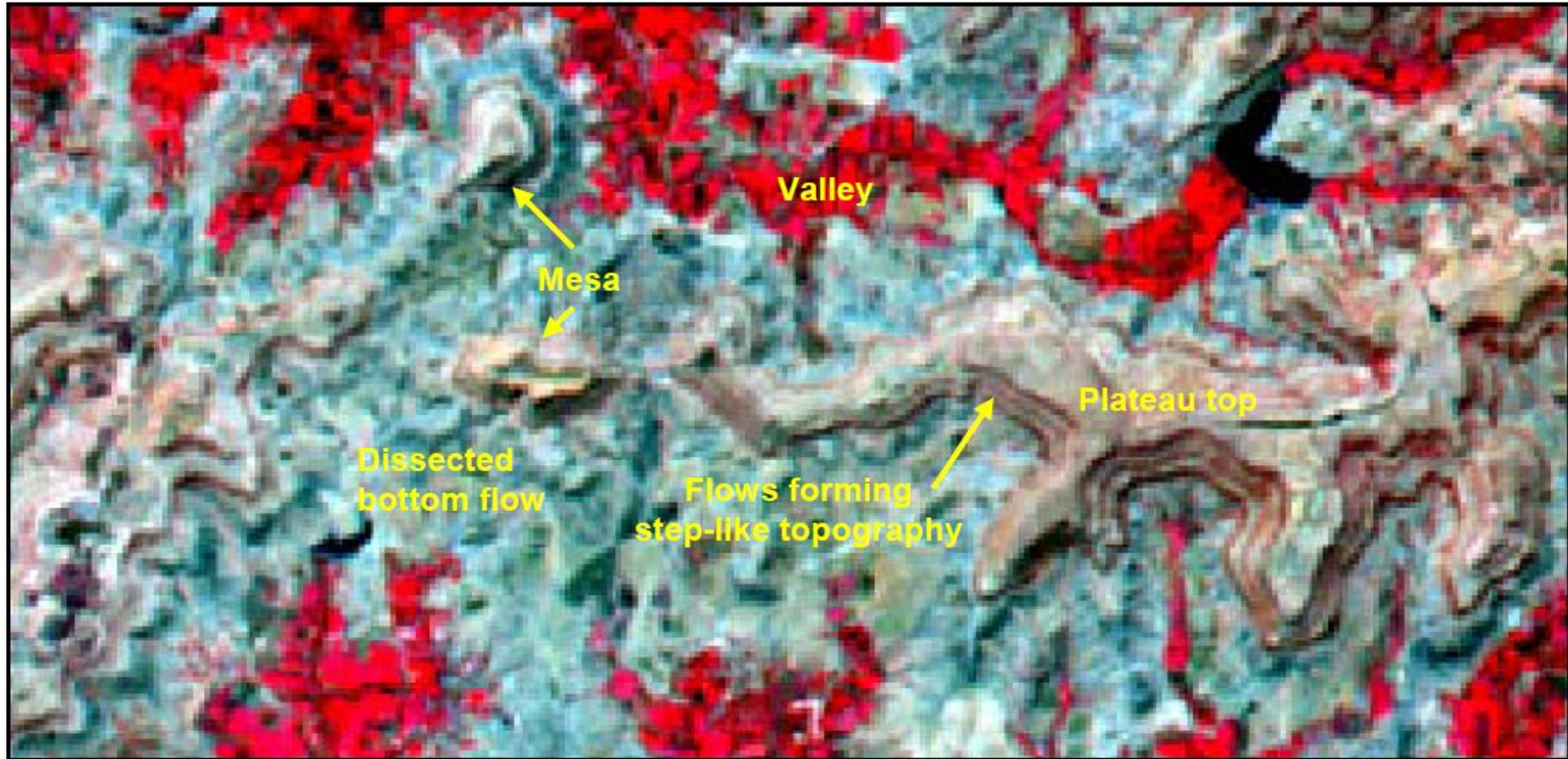
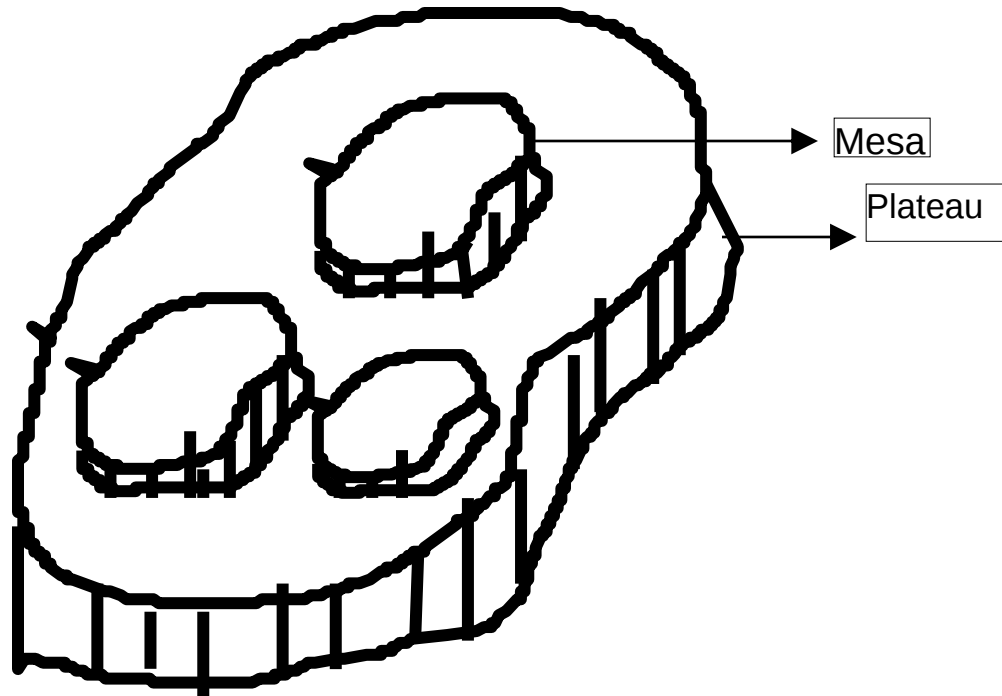


Fig. 4.7: Satellite image of Deccan trap area showing a pile of basalt flows forming step like topography

Mesa: *Plateau of small aerial extent*

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



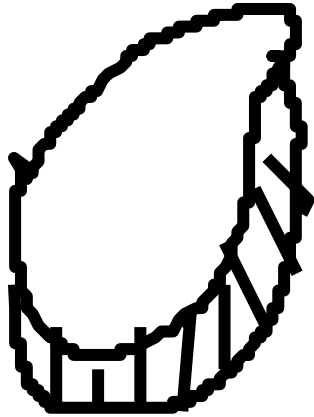
Mesas and buttes

- **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

Copyright © Alan Arbogast 2002

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

In horizontal beds, rocks outcrops
would follow contours

Tablelands: note horizontal layers,
differential erosion

Butte

chimney

mesa

Inselberg

Pediment (gentle slope $< 5\%$,
erosional concave up surface
w thin veneer of gravel etc.)

Dry Climate, intermittent strong storms

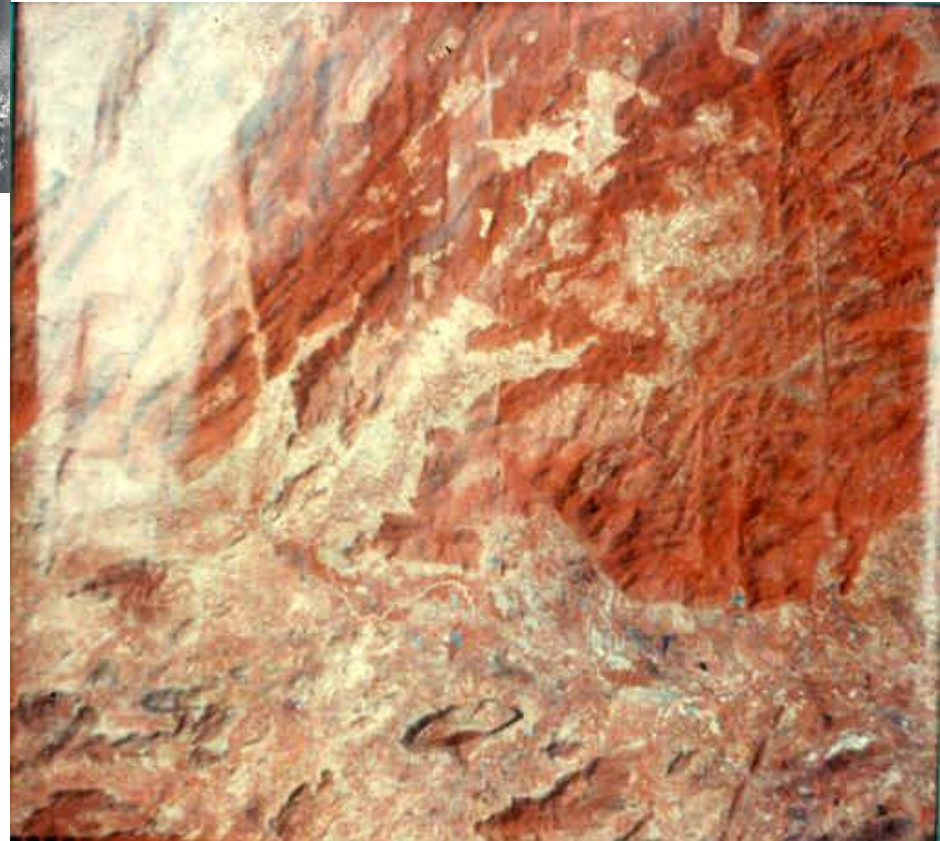
- Plateau > mesa > butte > chimney
- Ratio surface area of top to height



Dry Climate, intermittent strong storms



PLATEAU - HIGHLY DISSECTED

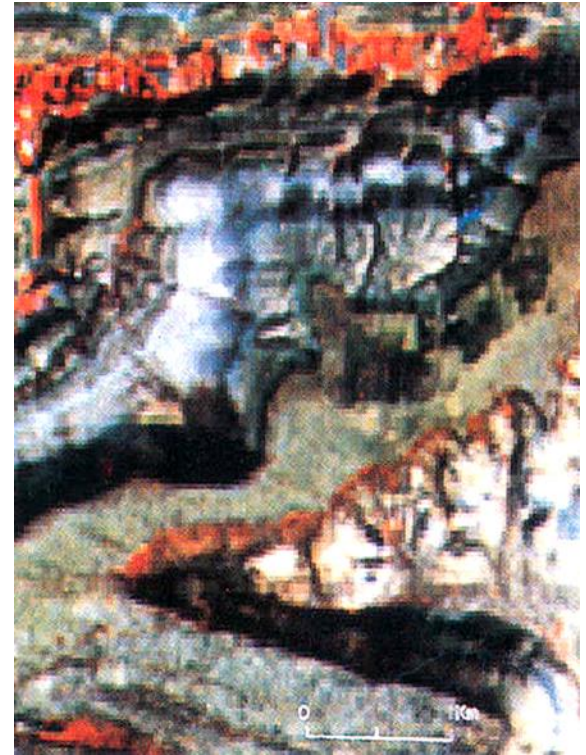
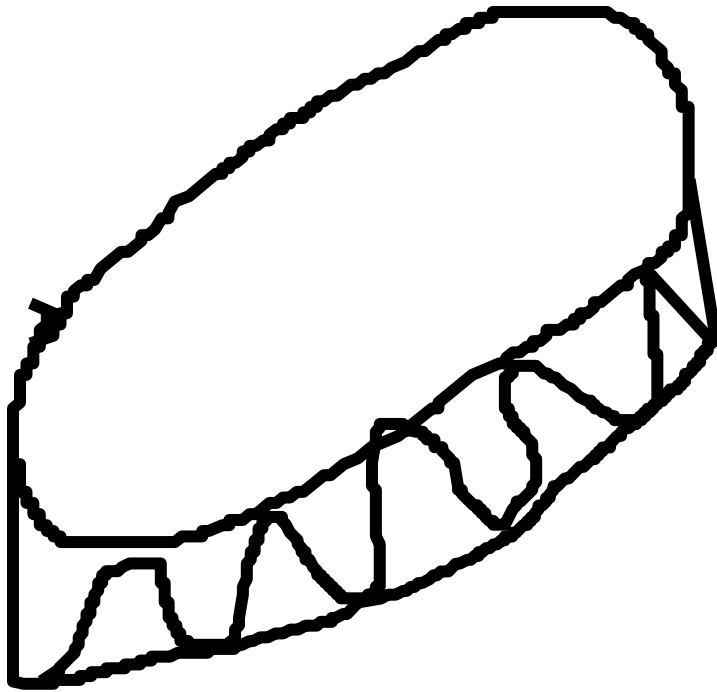


HIGHLY DISSECTED PLATEAU

(Tower View, Bryce, Canyon)



Plateaus in the folded basement

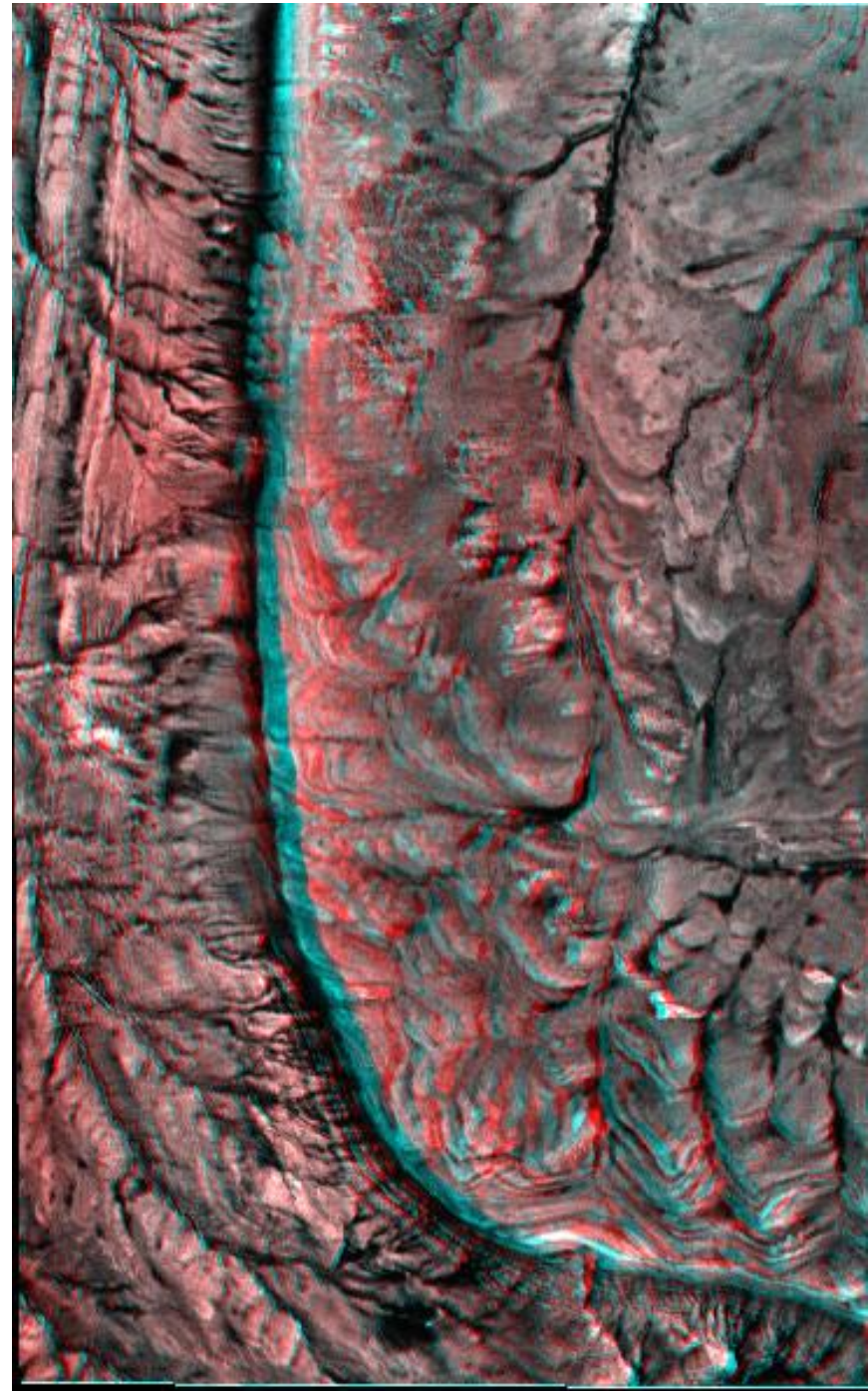
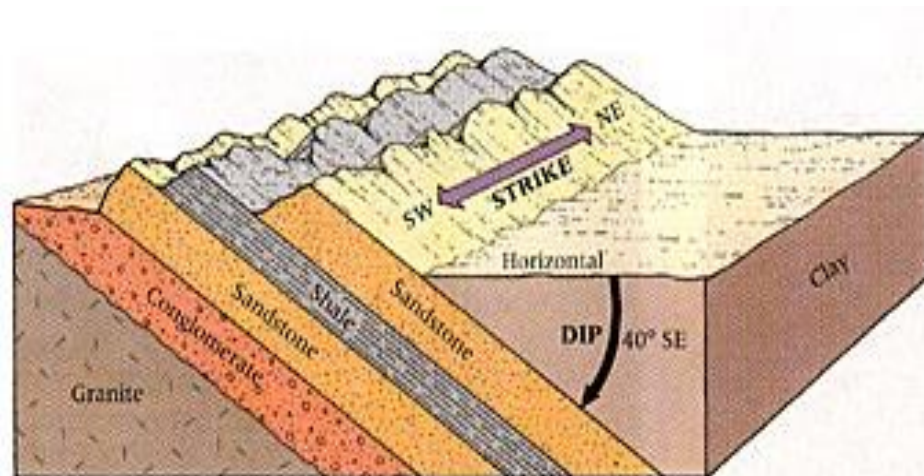


- ➡ better groundwater prospects in axis
- ➡ groundwater heterogenous in metamorphic plateau
- ➡ sheet flow in volcanic plateau
- ➡ erosion generally less, except in metamorphic plateau

LANDFORMS IN marginally DEFORMED ROCKS

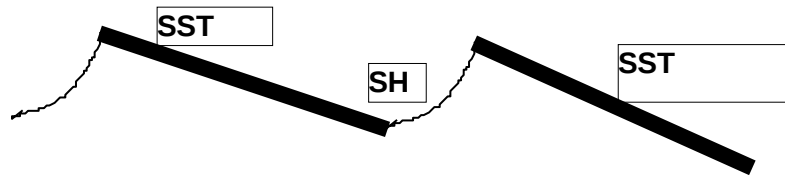
Tilted Strata

- 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 outcrop of the resistant rocks, the formation of the ridge being controlled by the differential erosion of the gently inclined strata.

- ➡ dip less than 25°
- ➡ cap or sheet rock at top
- ➡ obsequent slope by shale
- ➡ runoff area
- ➡ valleys better for reservoirs / storage

Cuestas - $<30^\circ$ dip
Hogbacks - $>30^\circ$ dip

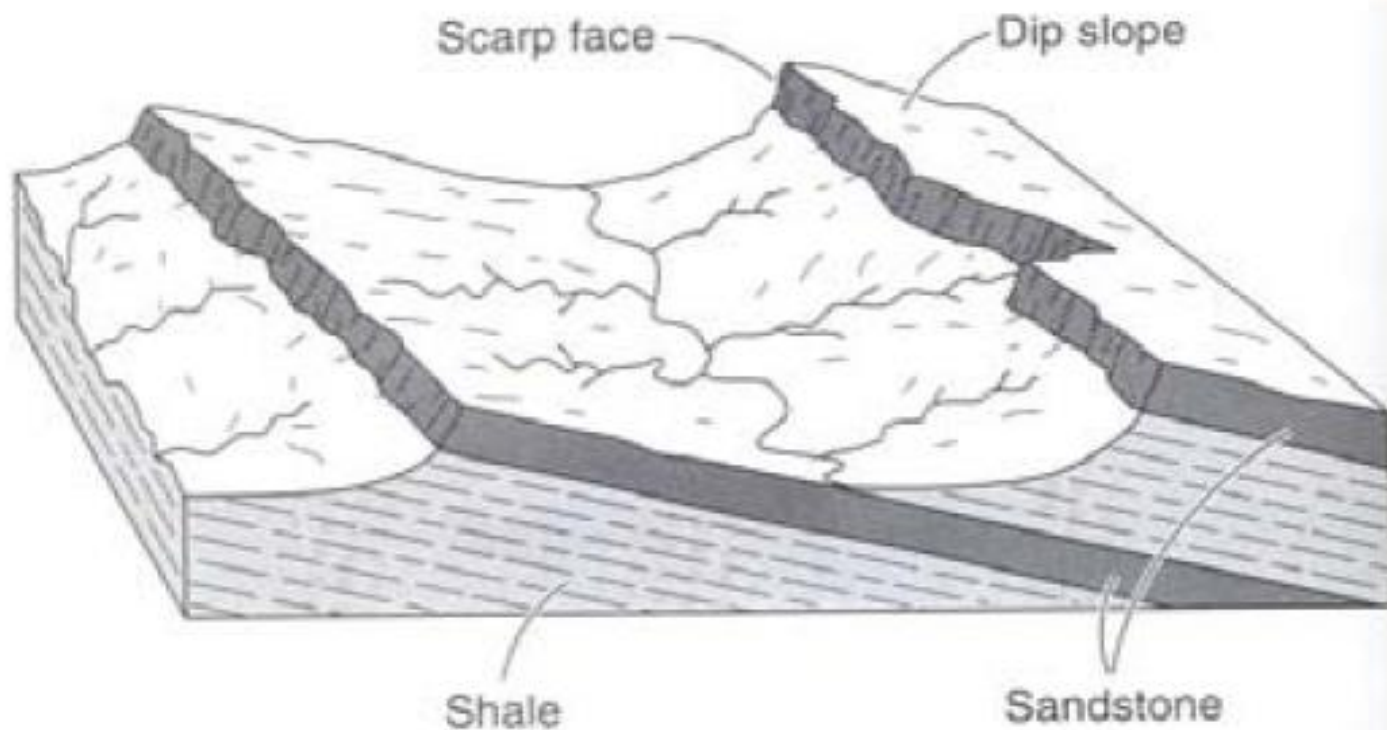


FIGURE 9-6

Adjustment of topography to geologic structure.

TECTONIC CUESTA

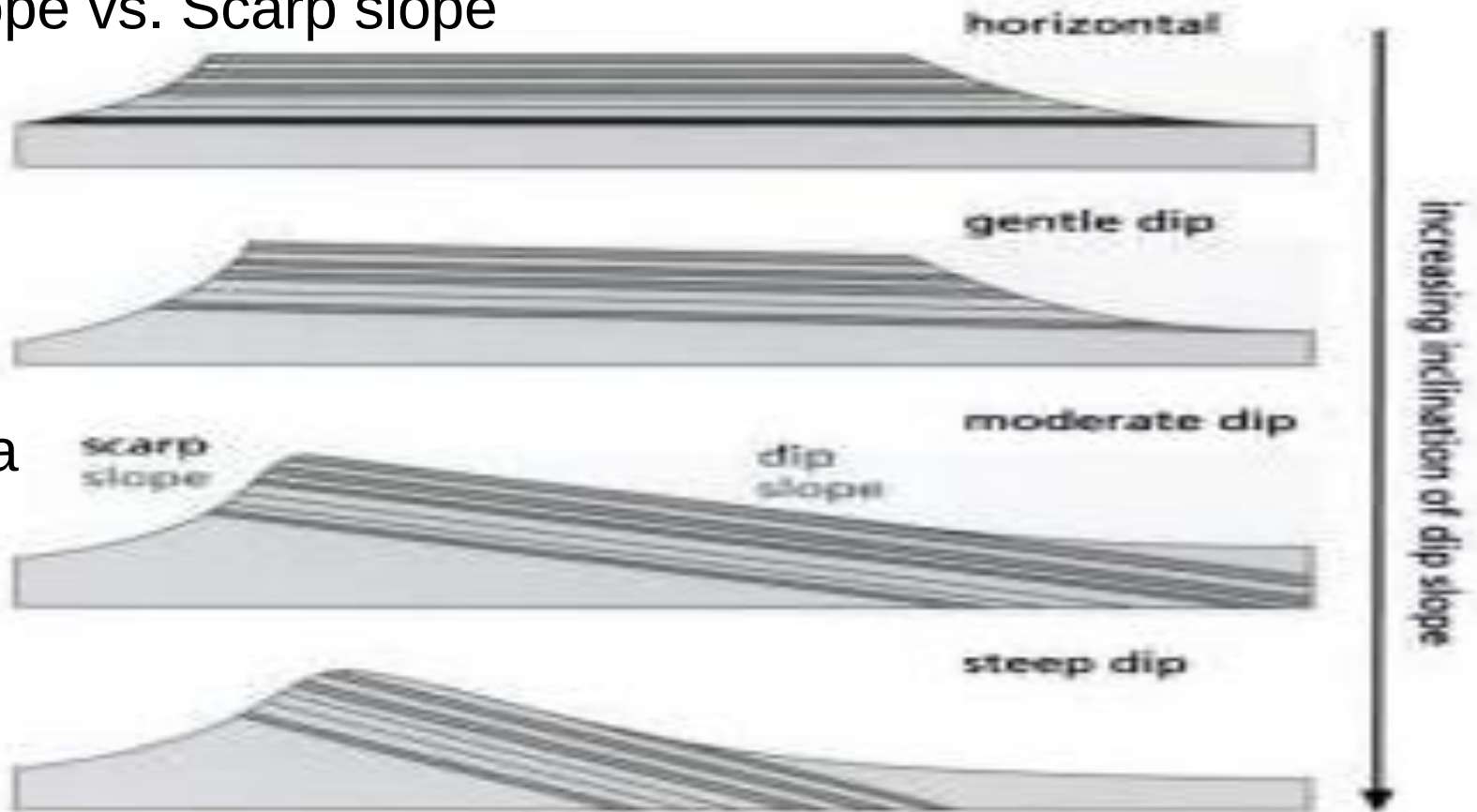
PASSIVE DIP SLOPE



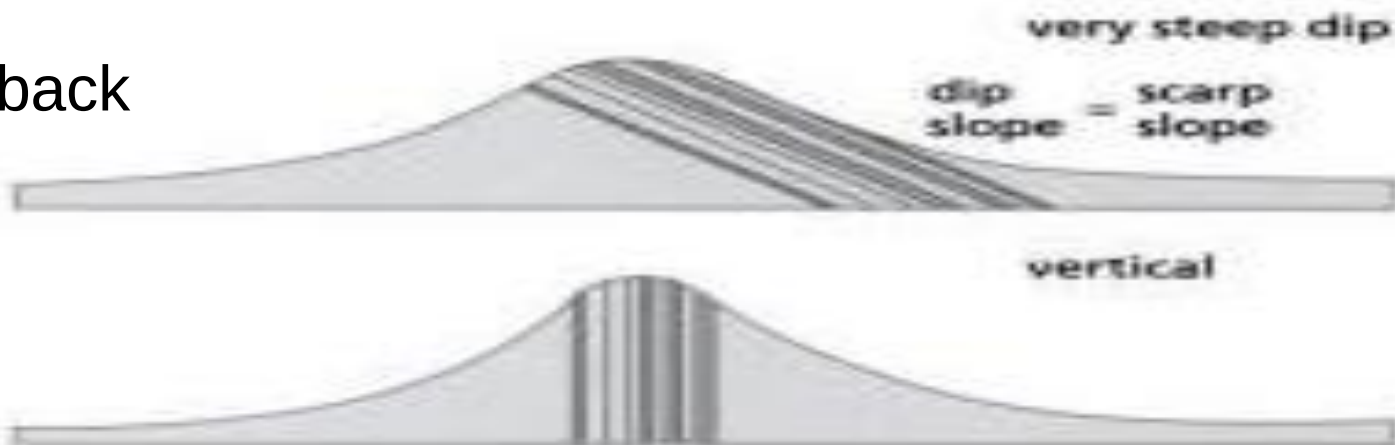
CUESTA SCRAP PASSIVE
OBSEQUENT SLOPE

Dip Slope vs. Scarp slope

Cuesta

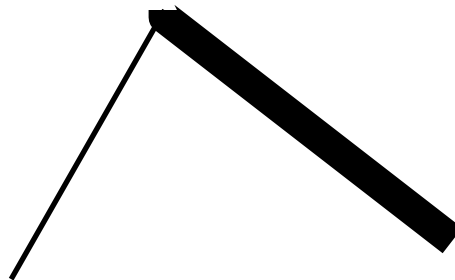


Hogback



Hogbacks

- ➔ *dip more than 25°*
- ➔ *dip and obsequent slope will look almost similar in expression*
- ➔ *dip and obsequent slopes are equal*



–Flatiron remnant of dissected Hogback with triangular face

Anti-dip Side of Hogbacks, Flinders Range, Australia



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

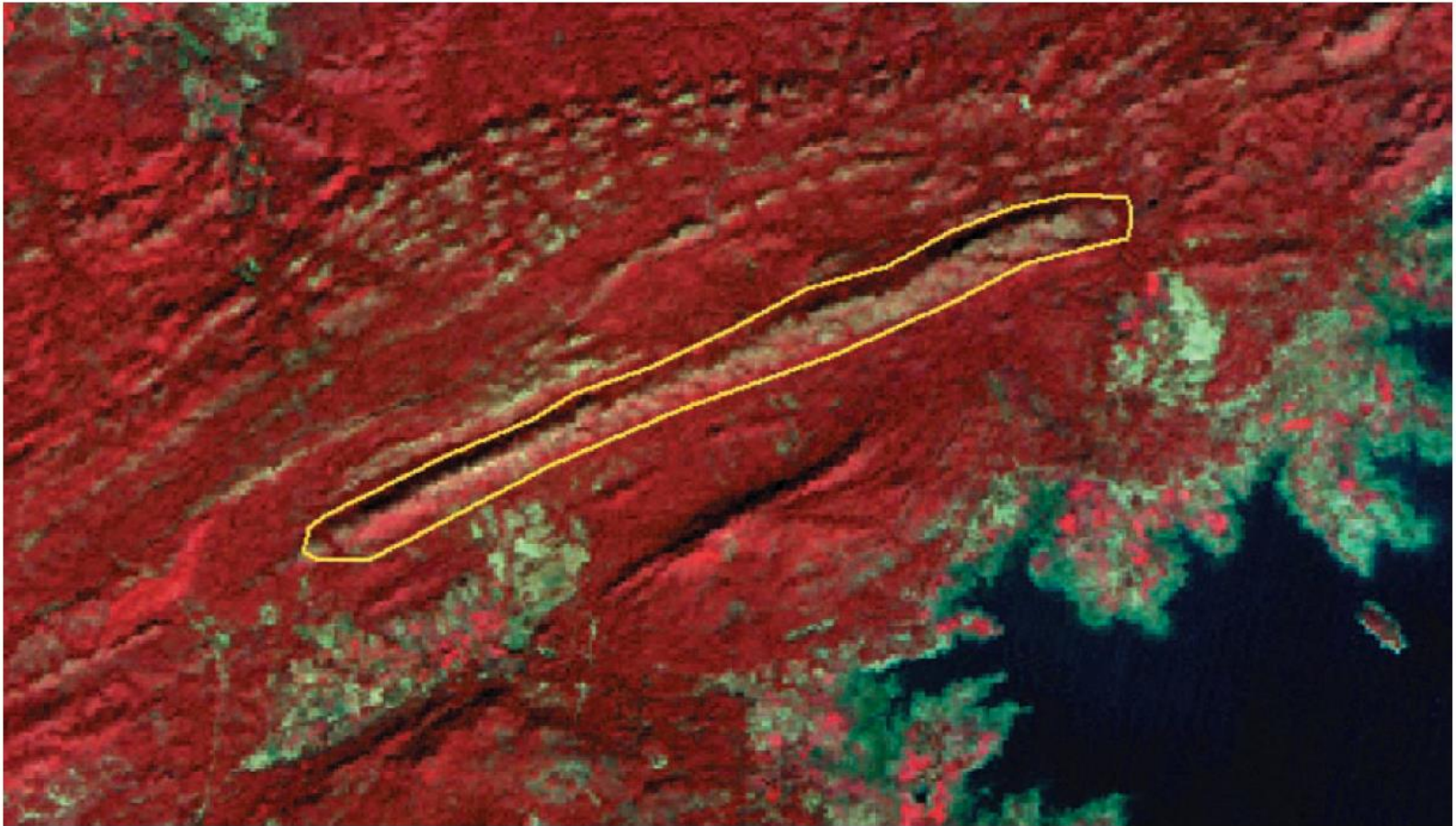


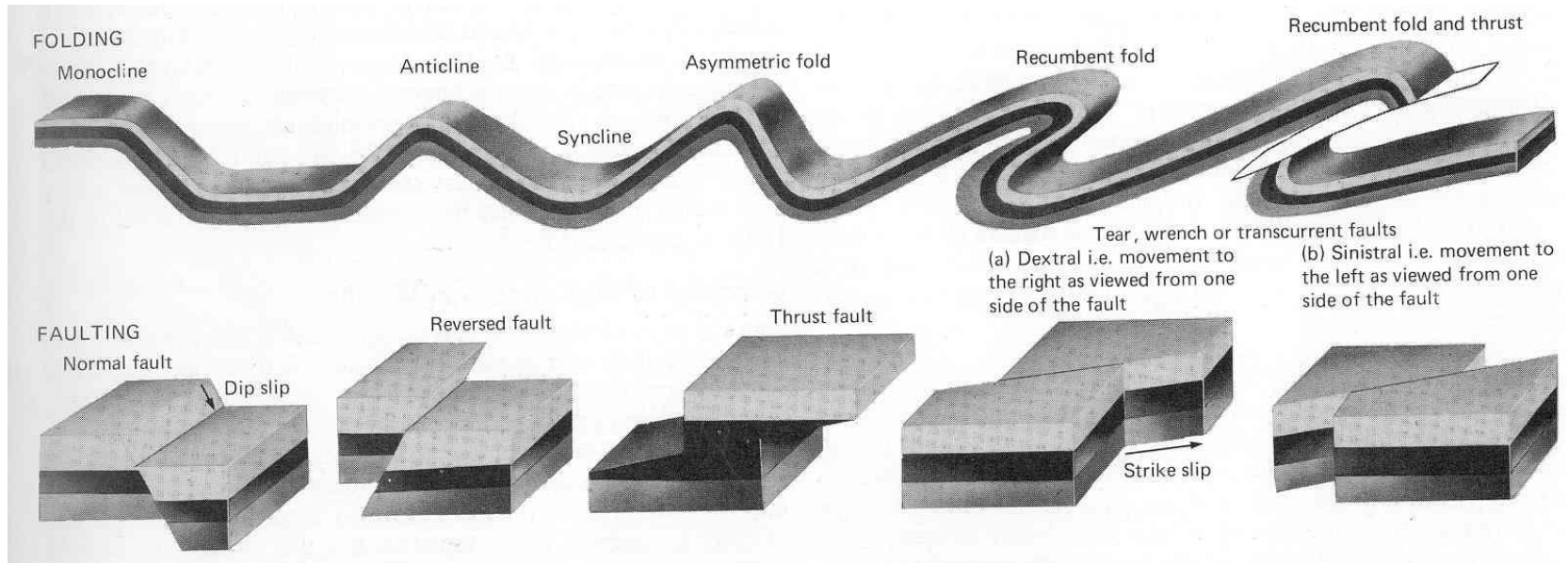
Fig. 2.1 Hogback in the Low dissected structural hills and valleys in Hoshangabad district, Madhya Pradesh state. Ridge with a sharp summit and steep slopes of nearly equal inclination on both flanks, and resembling in outline the back of a hog.

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



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

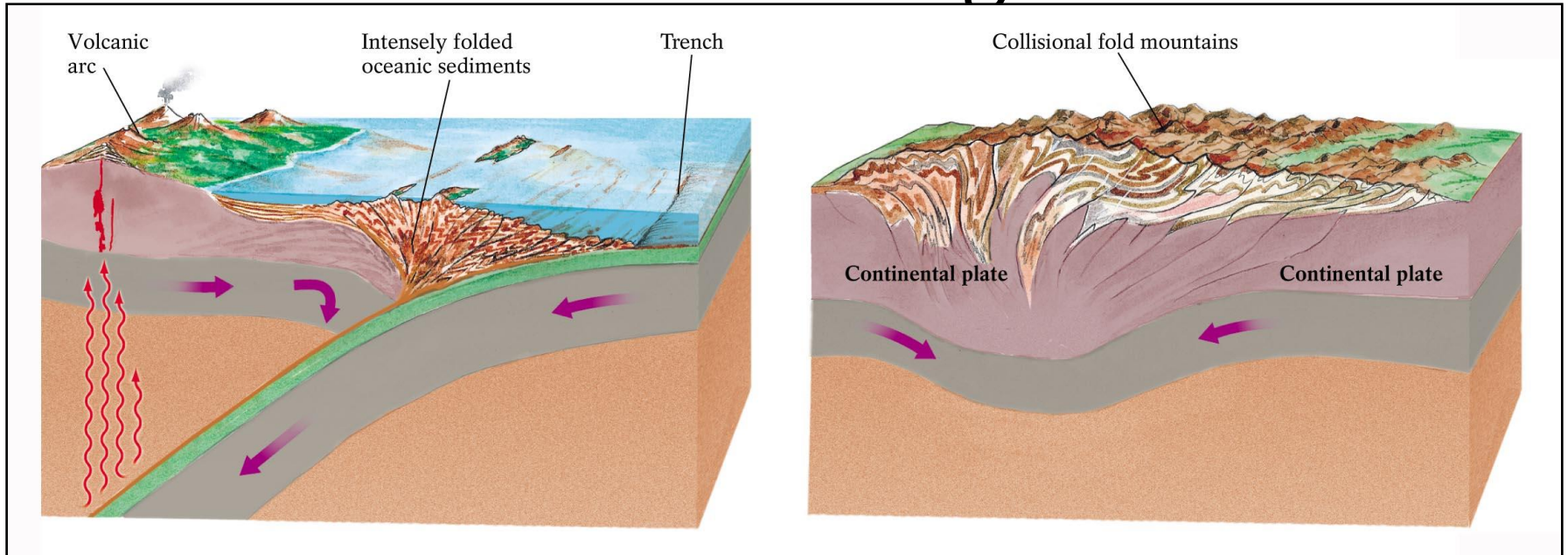
Homoclinal valley

Synclinal Ridges

Folded mountains

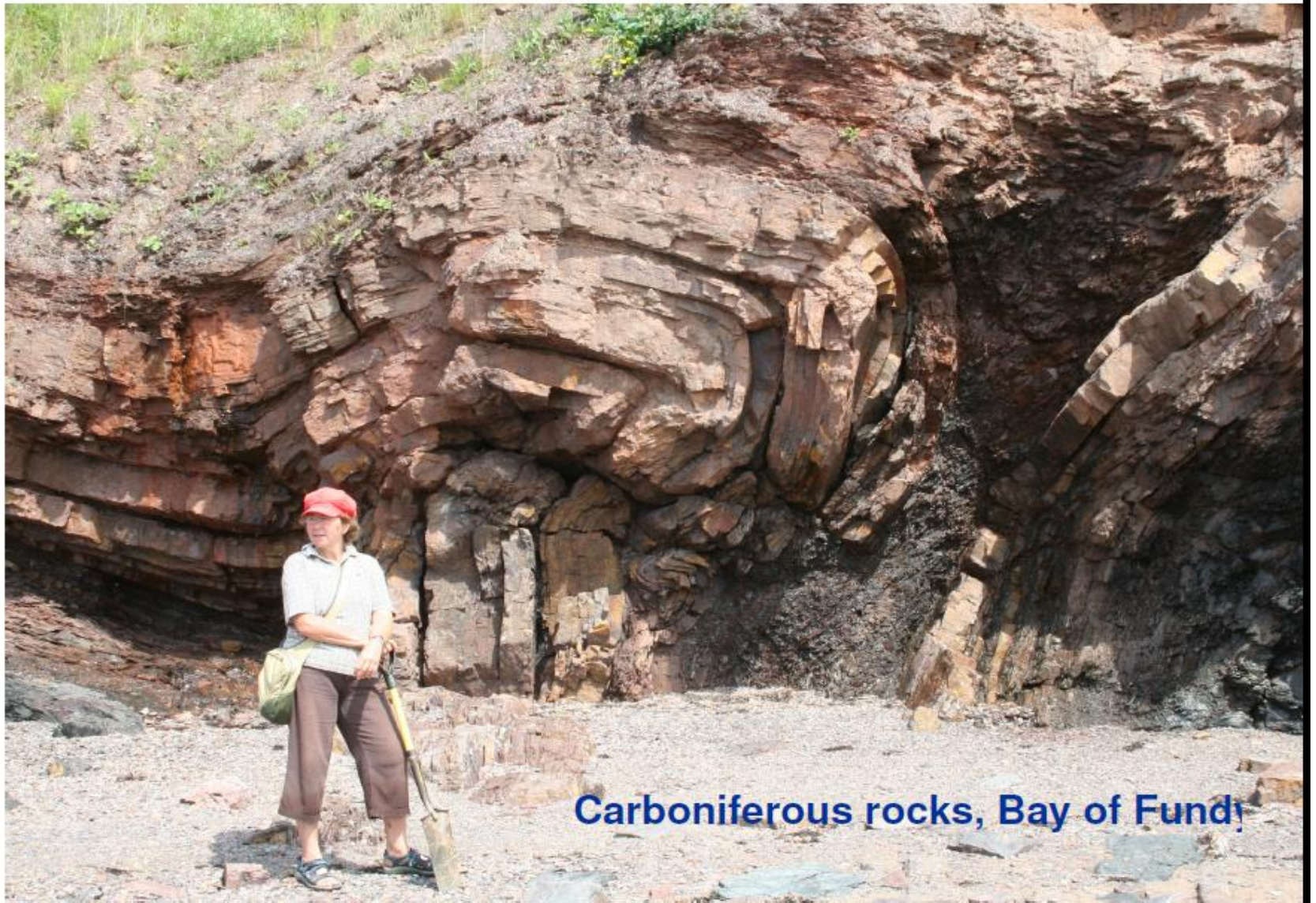
- ❖ **mountains with tight folding (E-g) Aravalli, Delhi, Bhimas, Cuddapah, himalayas**
- ❖ **contour in curved pattern**
- ❖ **curved ridges and valleys**
- ❖ **images, show curvilinear and contoured & vegetation banding radial, annular, drainage anomalies**

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



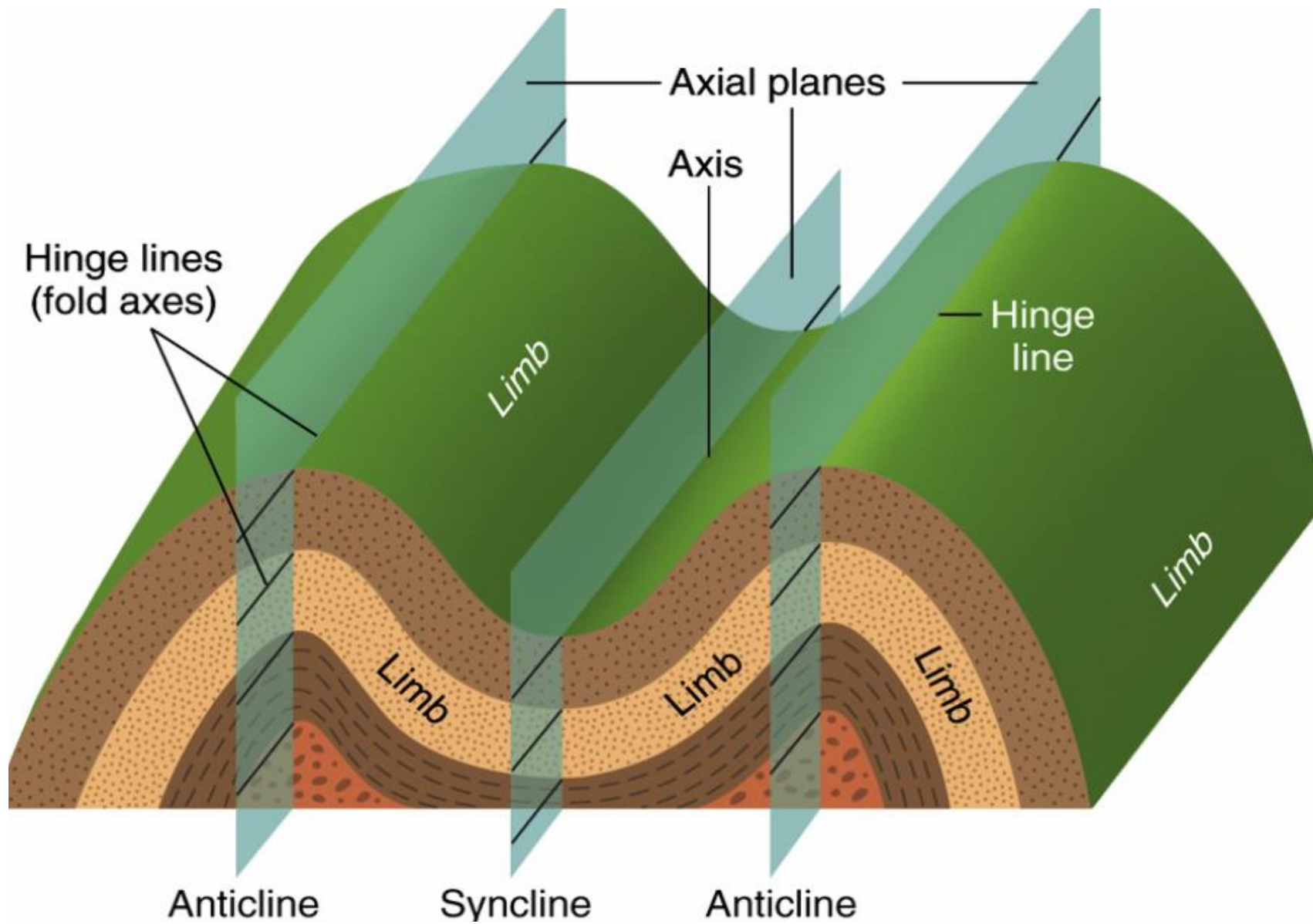
Carboniferous rocks, Bay of Fundy

Landforms : Anticline and Syncline

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

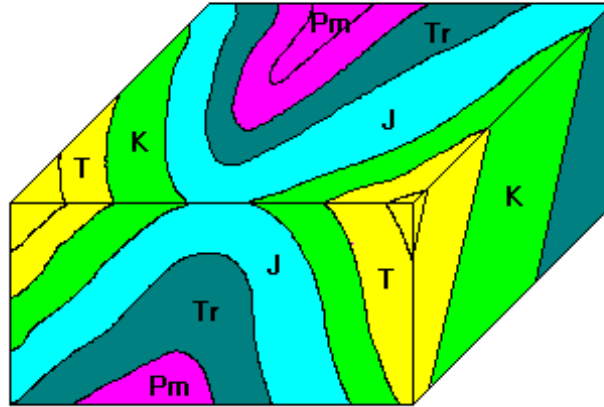
Antiform/Anticlinal ridge : A breached/unbreached uplift, where the structure is shown directly in the topography and perhaps by drainage pattern. In case of the presence of older rock in the core of the uplift the antiform is called as anticline.

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

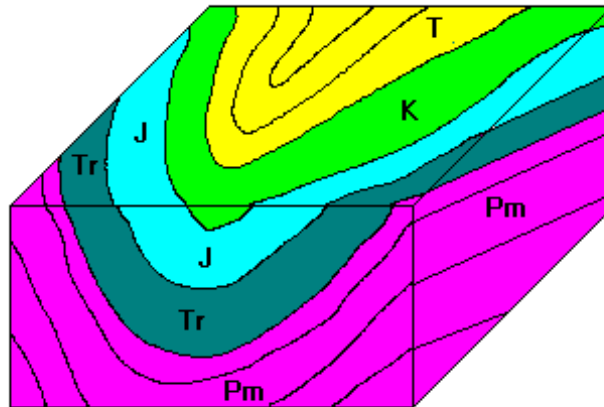


Folds and Block Diagrams

- Anticline = oldest rocks exposed in the center.

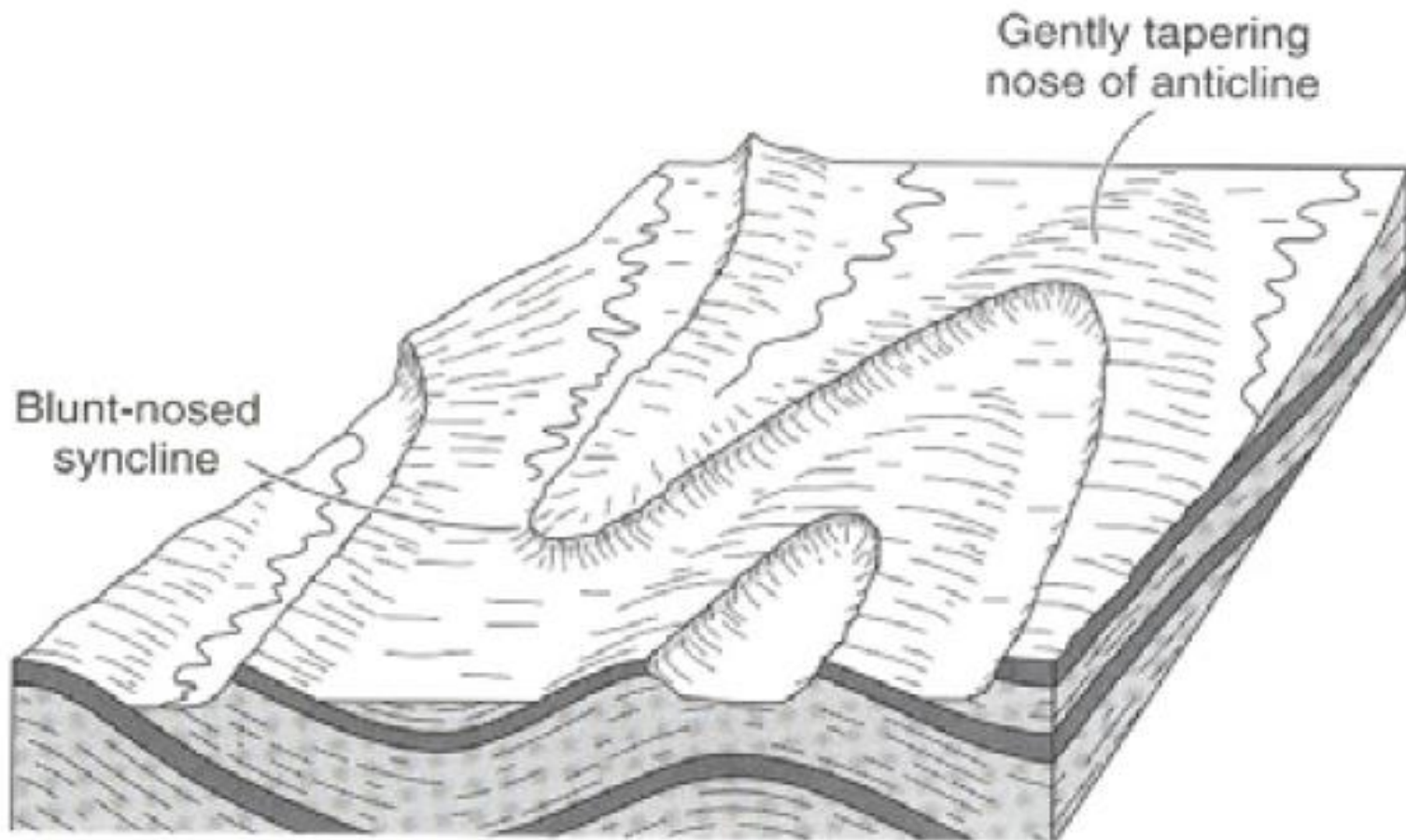


- Syncline = youngest rocks exposed in the center



AGE	ERA	PERIOD
		QUATERNARY (beyond project scope)
50	CENOZOIC	TERTIARY
100		CRETACEOUS
150	MESOZOIC	JURASSIC
200		TRIASSIC
250		PERMIAN/ PENNSYLVANIAN
300		MISSISSIPPIAN
350		DEVONIAN
400	PALEOZOIC	SILURIAN
450		ORDOVICIAN
500		CAMBRIAN
550		
600		PRECAMBRIAN

Apex of the outcrop pattern: Anticline or syncline?





Sheep Mountain, Wyoming.

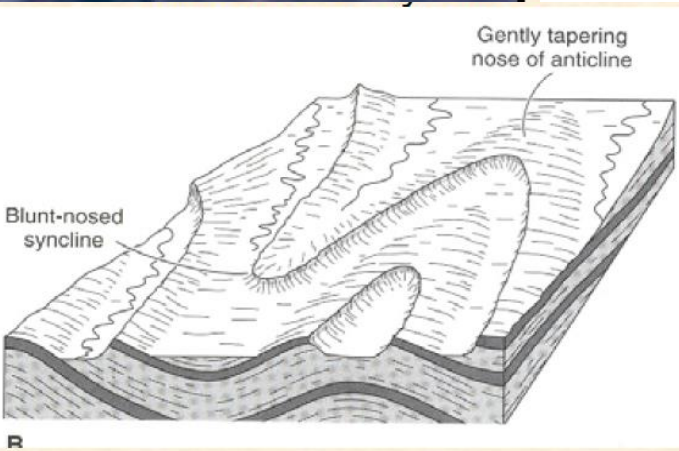
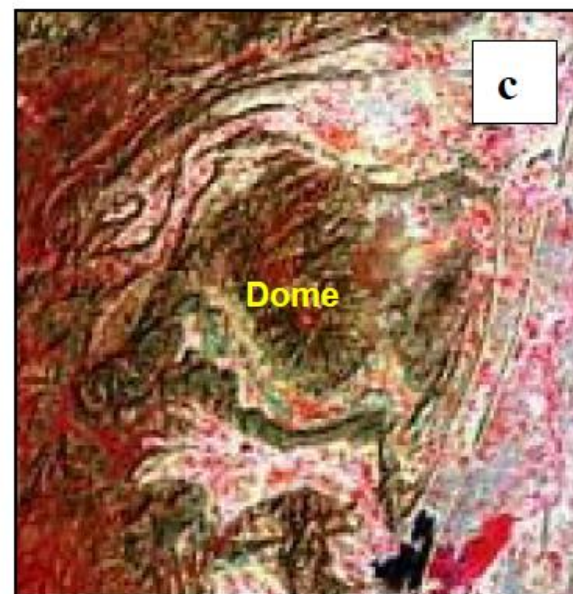
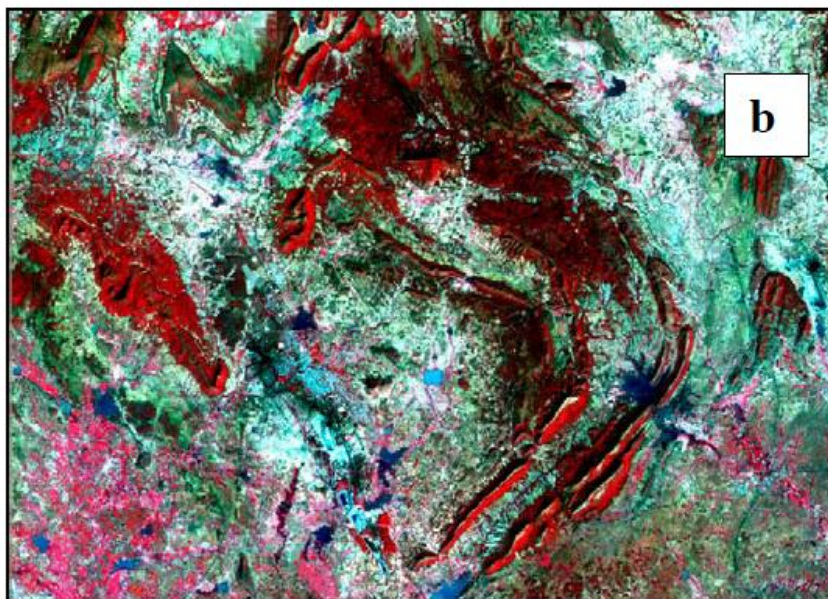




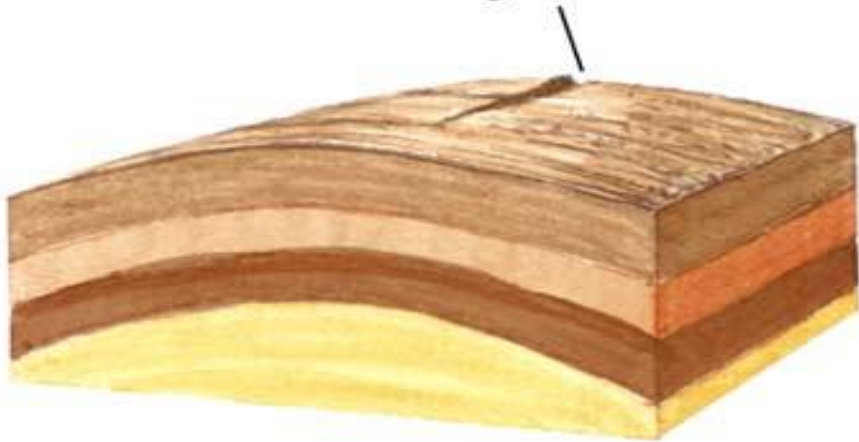
Fig. 4.15: Satellite image of a) Northeastern region b) part of Madhya Pradesh and c) Cuddapah basin showing folds



ANTICLINAL VALLEY

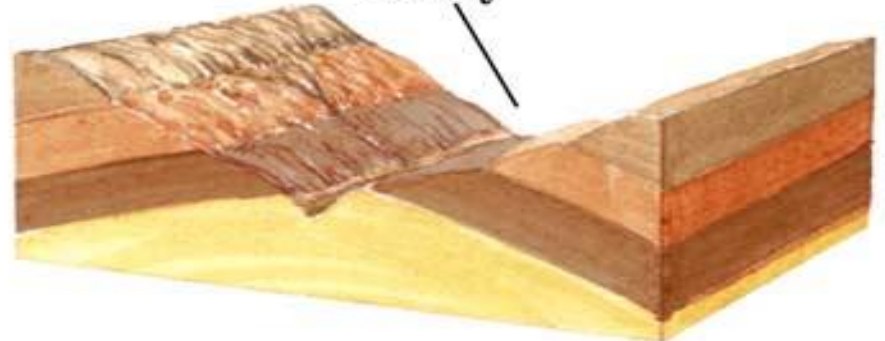
Topography may be opposite of Structure
Anticline Before/After Erosion

Stream erosion
begins near
ridge crest



1 Before erosion

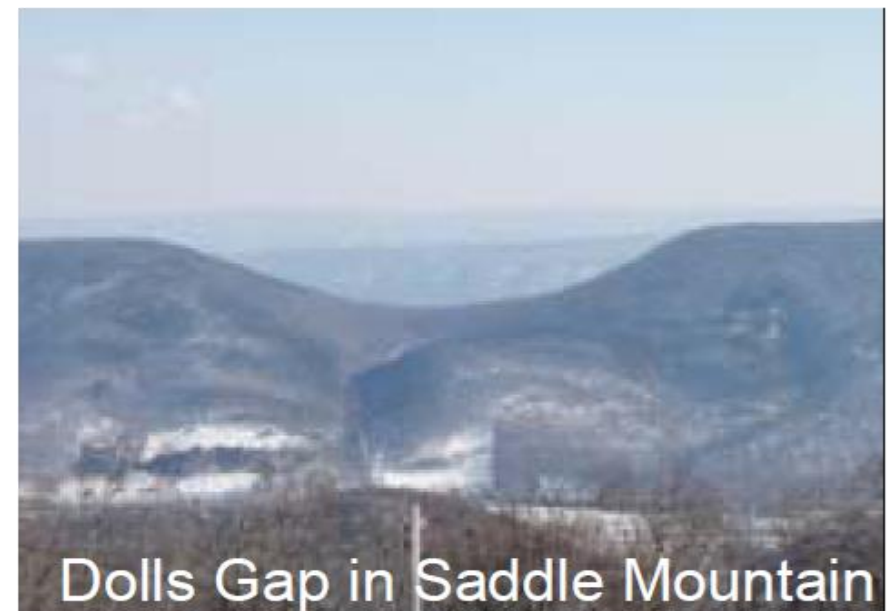
Anticlinal
valley



2 After erosion

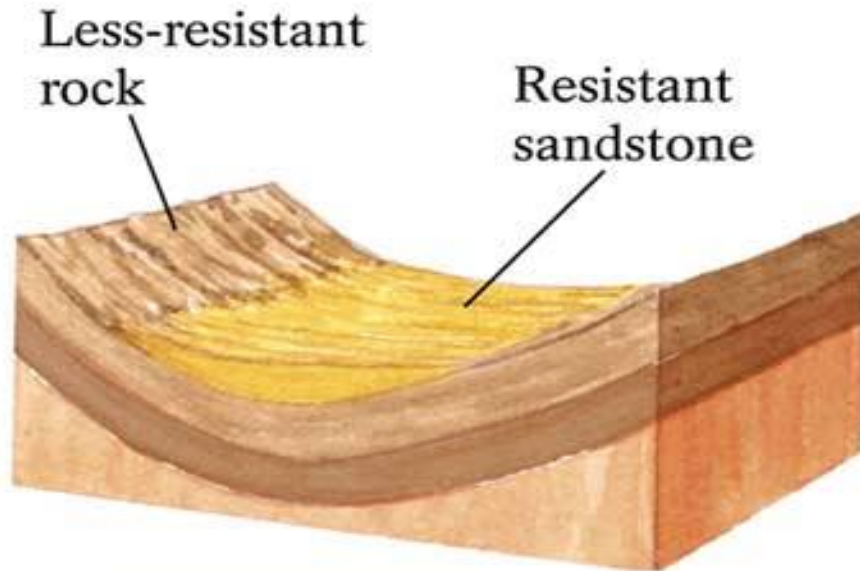
(a) Anticline with highly erodible surface Notice center rock oldest

Wills Mountain (Breached) Anticline

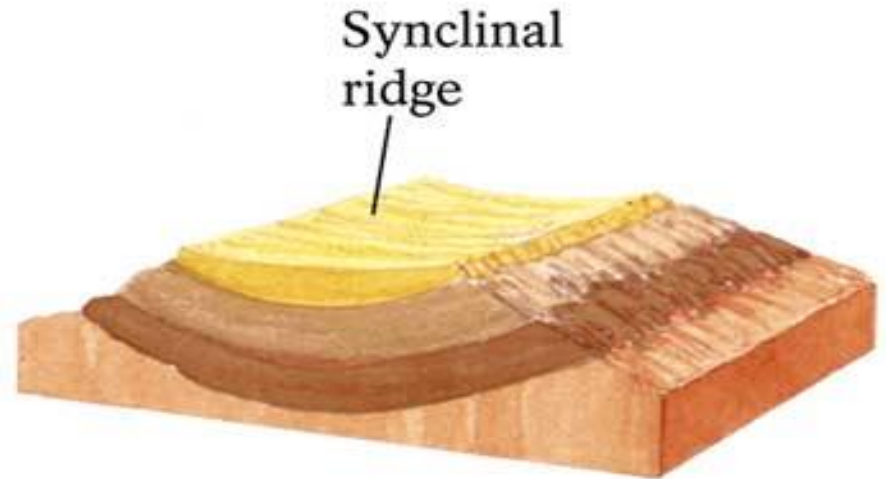


Topography may be opposite of Structure

Syncline Before/After Erosion



1 Before erosion



2 After erosion

(b) Syncline with resistant rock at axis

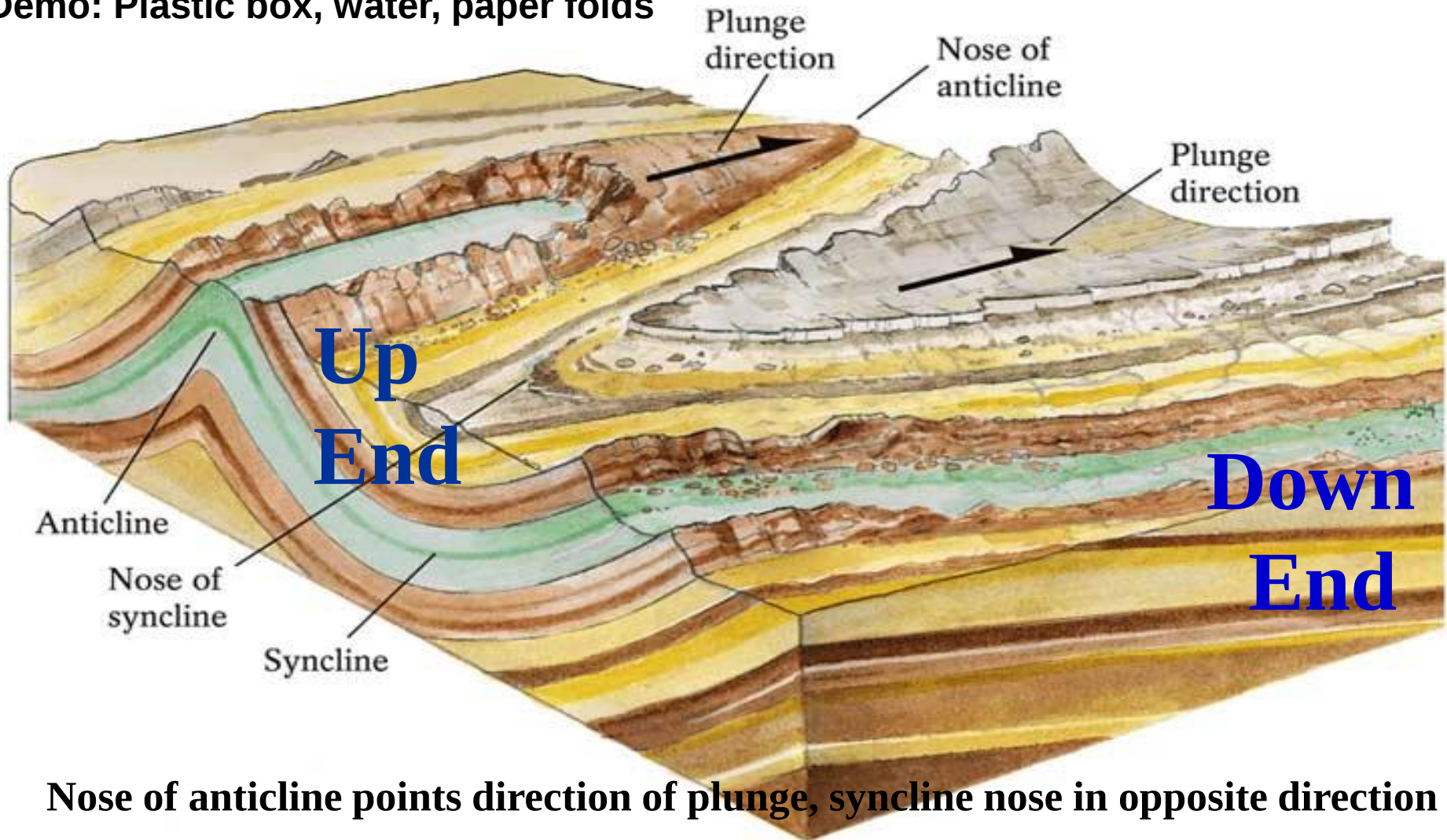
Notice center rock youngest

Sideling Hill, MD-WV-PA, Synclinal Ridge



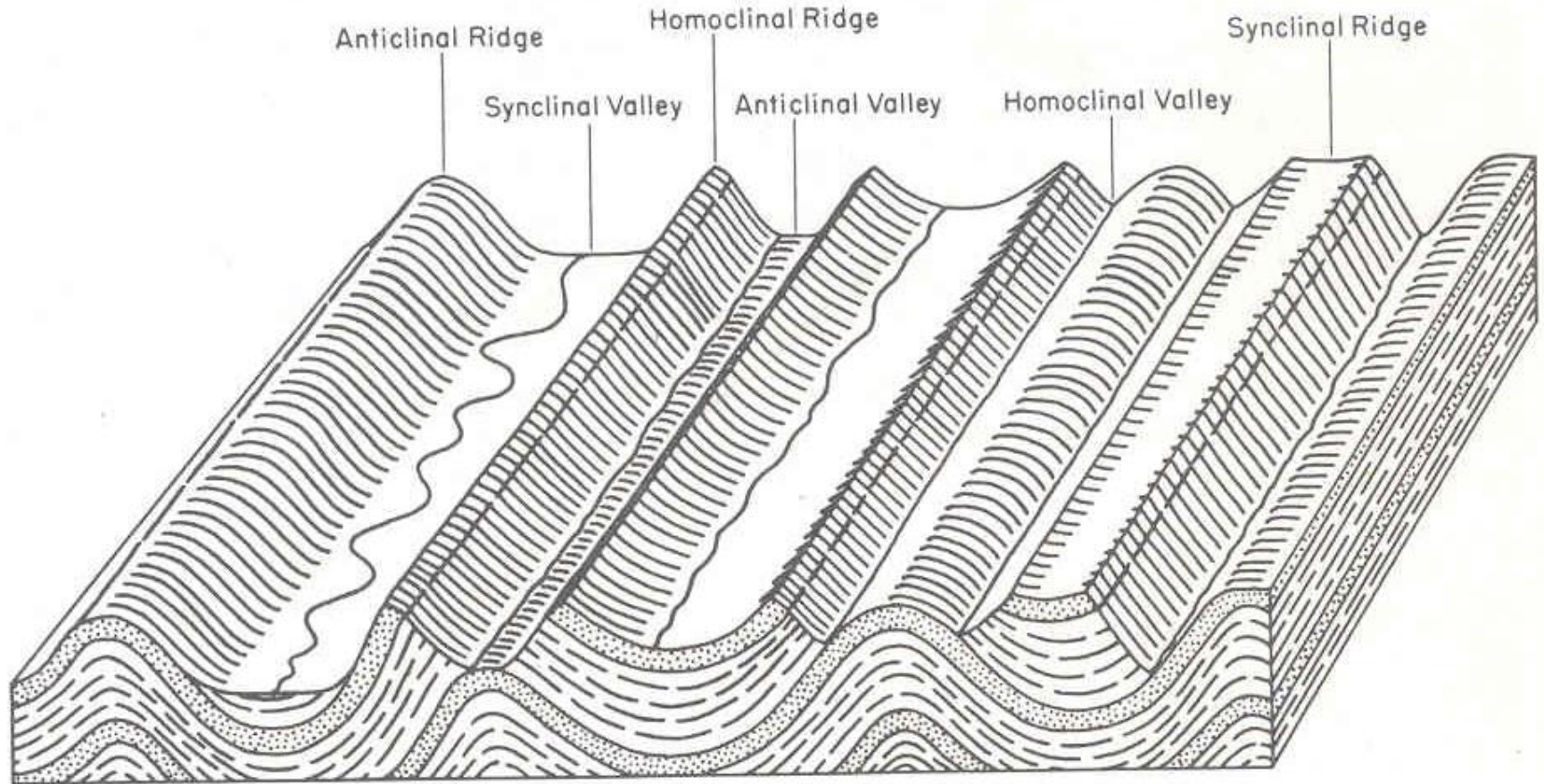
Plunging Folds and Nose Rules

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

Live Anticline, Breached by Water Gap



**Live Folds -
Consequent Drainage**

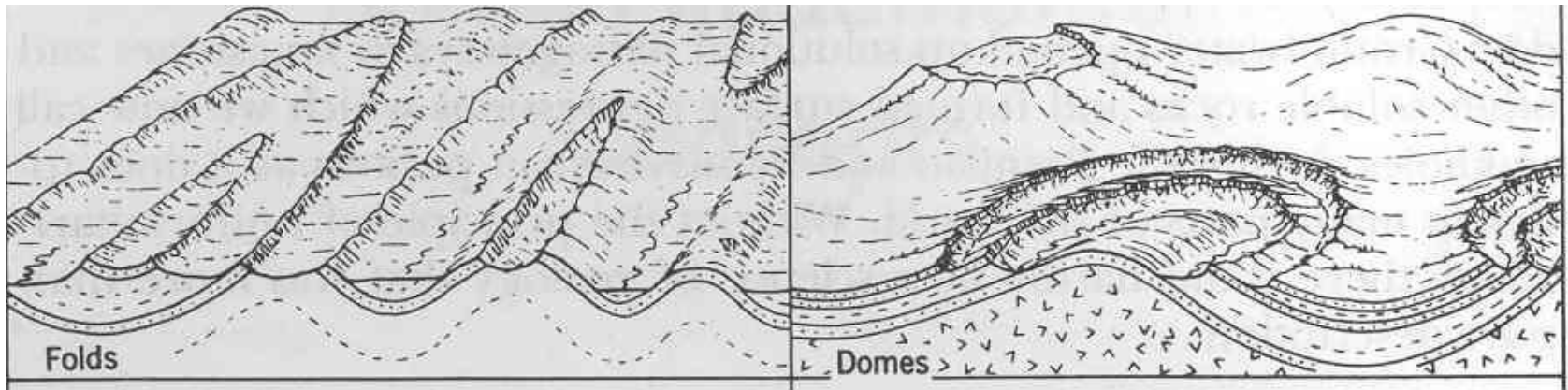
**Short, N. M., and Blair, R. W., 1986, Geomorphology from Space, NASA
[daac.gsfc.nasa.gov/DAAC_DOCS/geomorphology/
GEO_2/GEO_PLATE_T-42.HTML](http://daac.gsfc.nasa.gov/DAAC_DOCS/geomorphology/GEO_2/GEO_PLATE_T-42.HTML)**

Homoclinal Ridges, near Rawlings, Wyoming

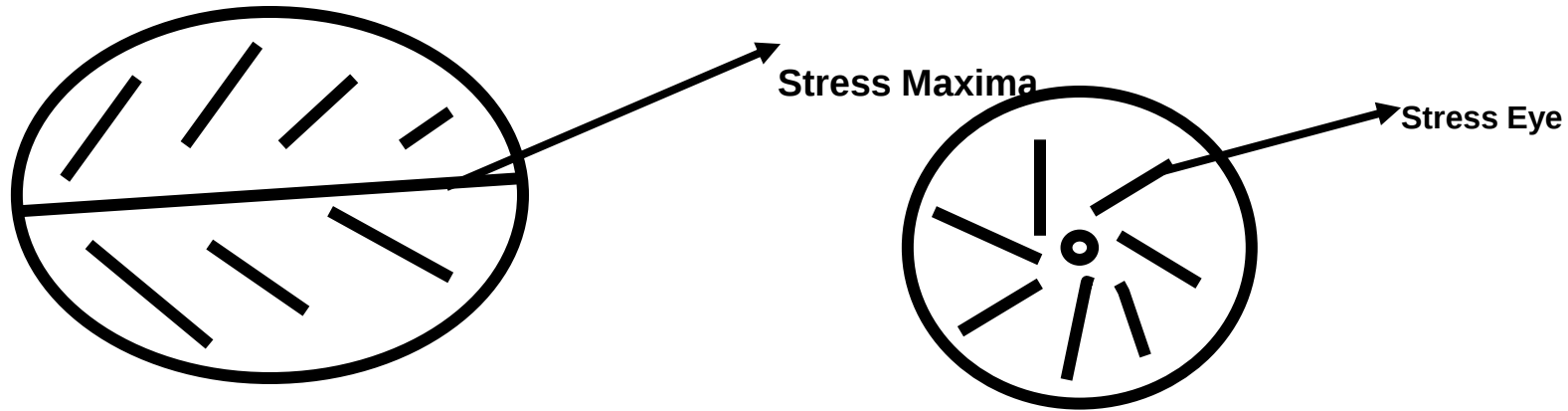


Short, N. M., and Blair, R. W., 1986, Geomorphology from Space, NASA
daac.gsfc.nasa.gov/DAAC_DOCS/geomorphology/

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.

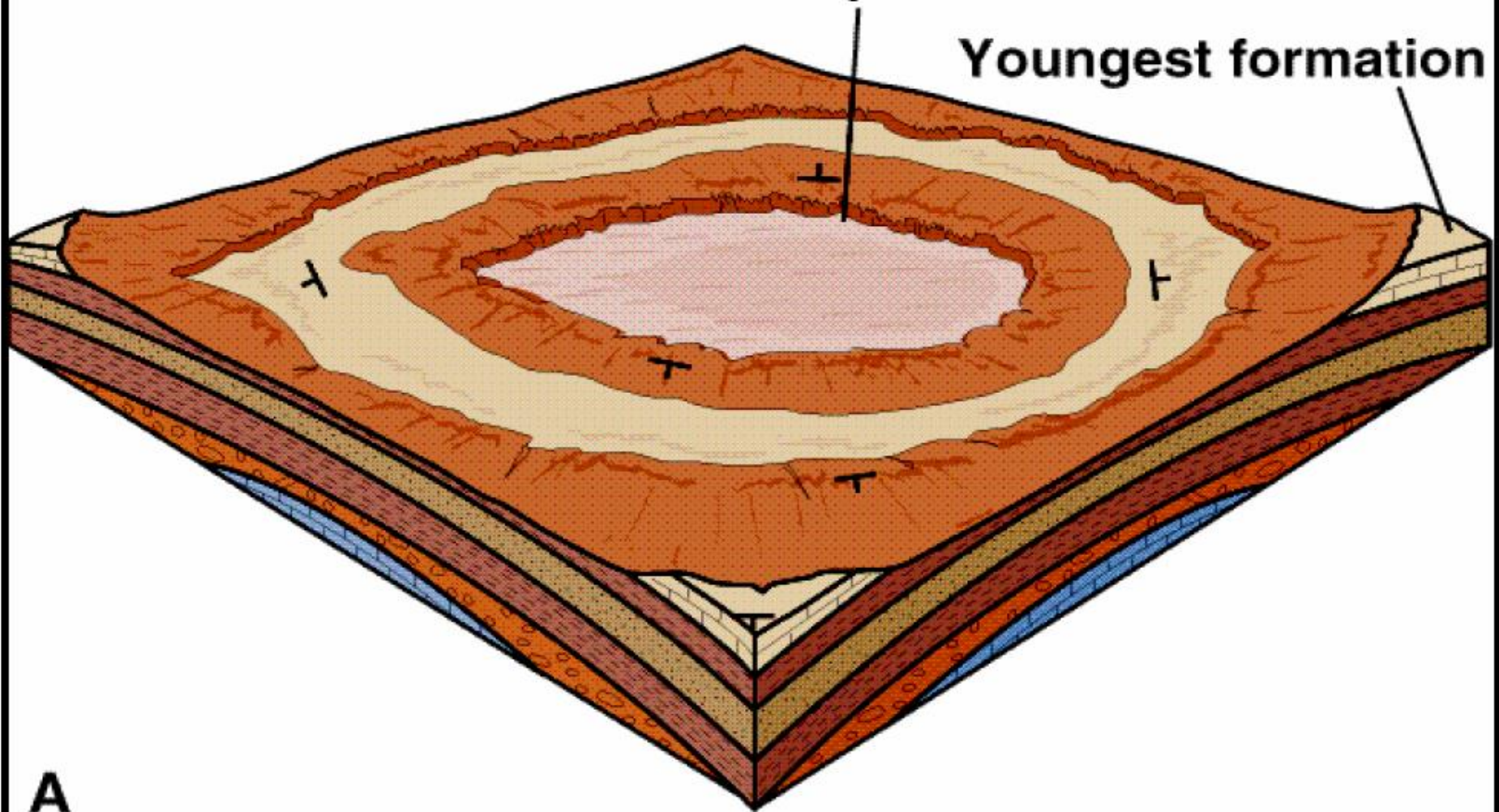
Sedimentary Basins

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

Structural Dome

Oldest formation exposed on the surface

Youngest formation



A

Richât Structure, Mauritania

Surface Expression of a Dome

**Beds dip
away from
center.**

**Note
Fractures.**



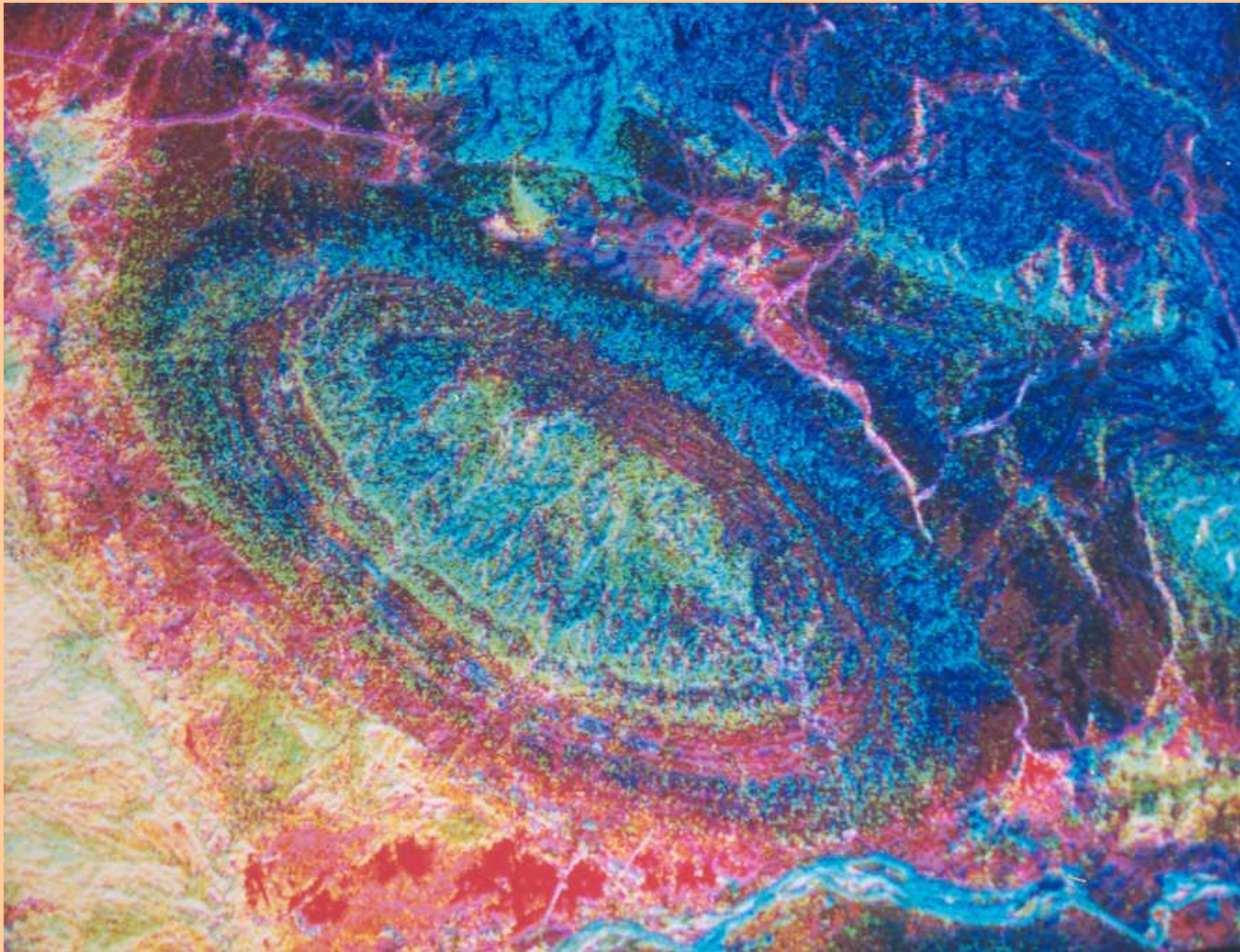
http://daac.gsfc.nasa.gov/DAAC_DOCS/geomorphology/GEO_2/GEO_PLATE_T-31.HTML

Grenville Dome, Wyoming



Shelton

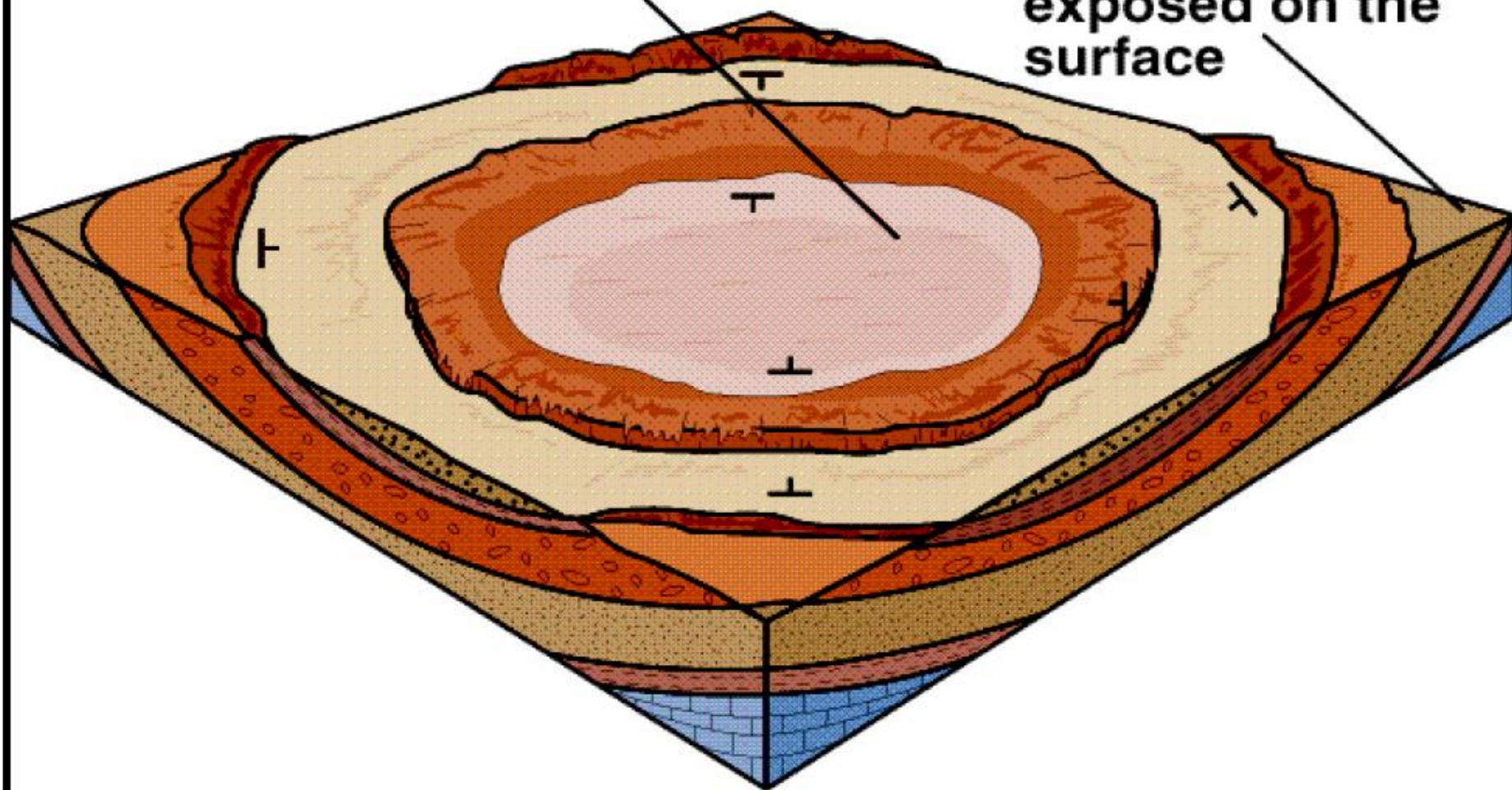
DOMES - IRAN



Structural Basin

Youngest formation

Oldest formation
exposed on the
surface



BASINAL HILLS or Synclinal Mountains



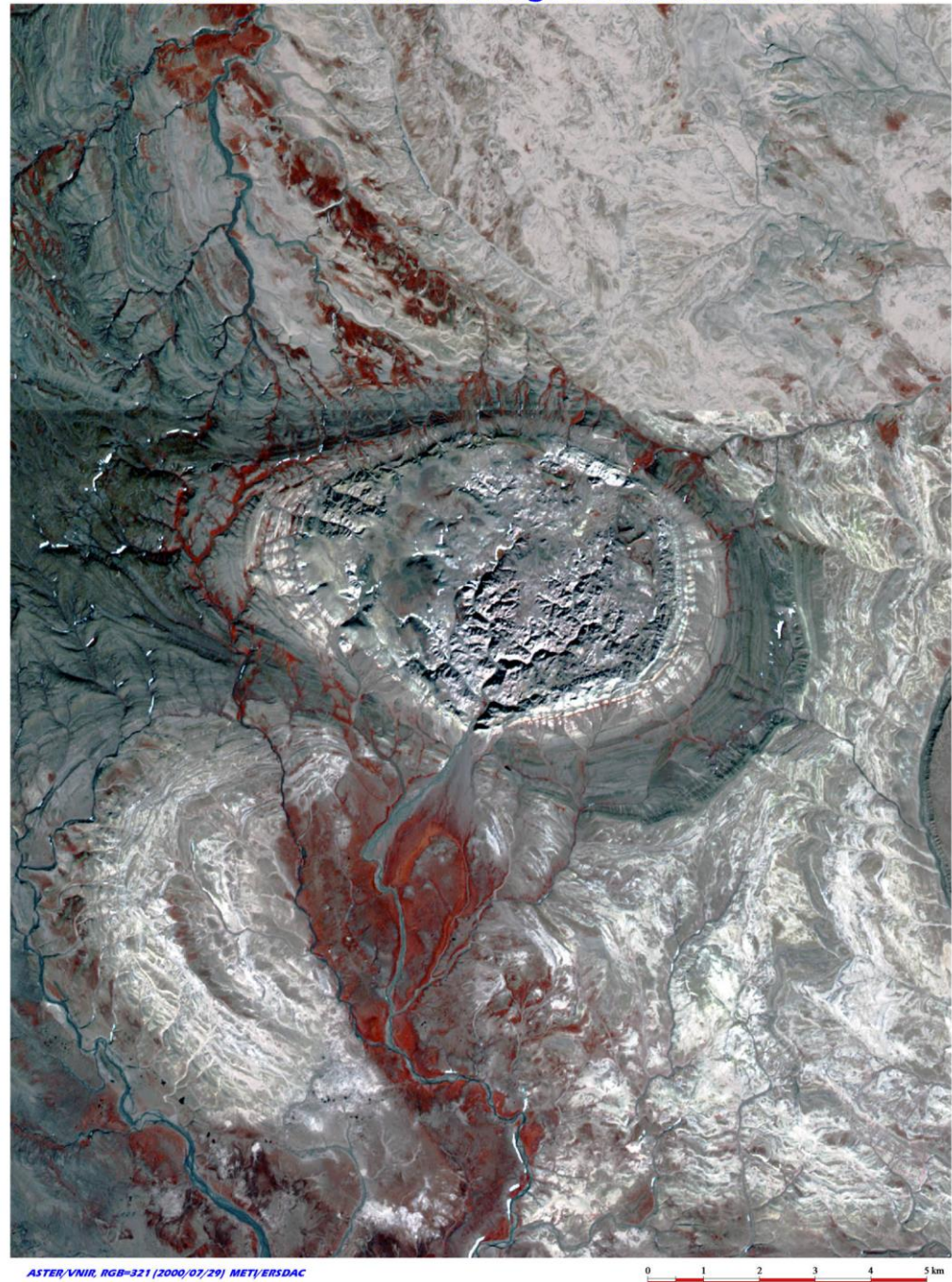
Synclinal mountains may vary from elongate narrow ridges to broad plateau like expanses, but typically they are broader than anticlinal mountains

Salt Dome

Low density
Buoyant
Diapirs

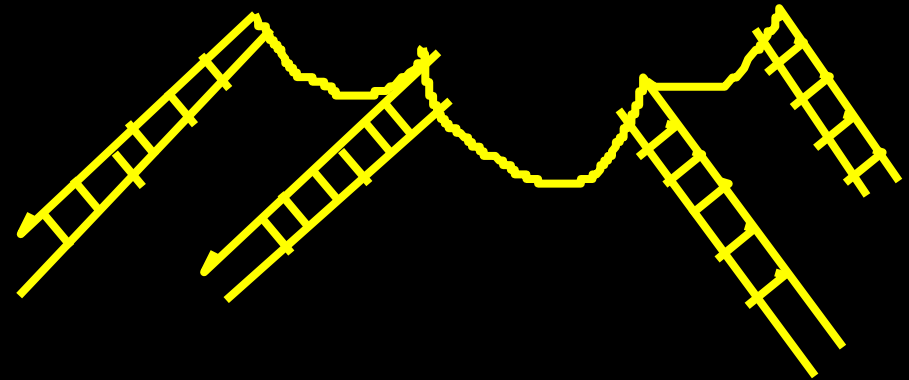
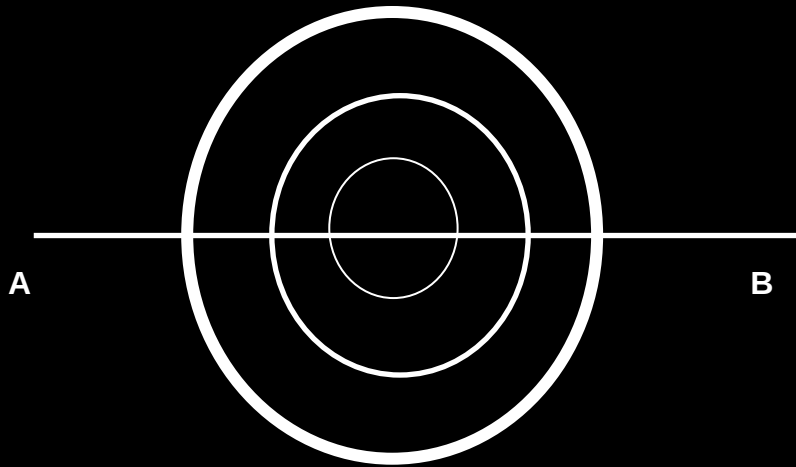
Surrounding
sediments
upwarped

Petroleum exploration





Annular Hills

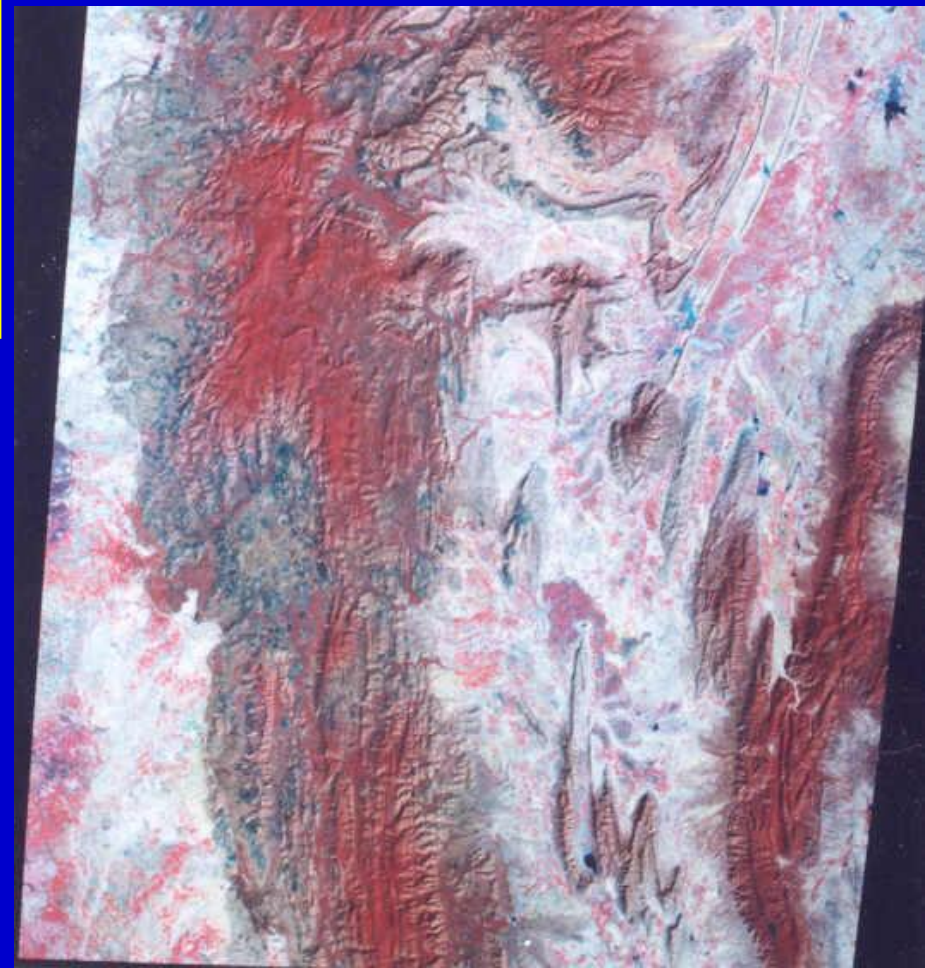


➔ circular ridges & valleys

➔ radial annular centrifugal / centripetal drainage

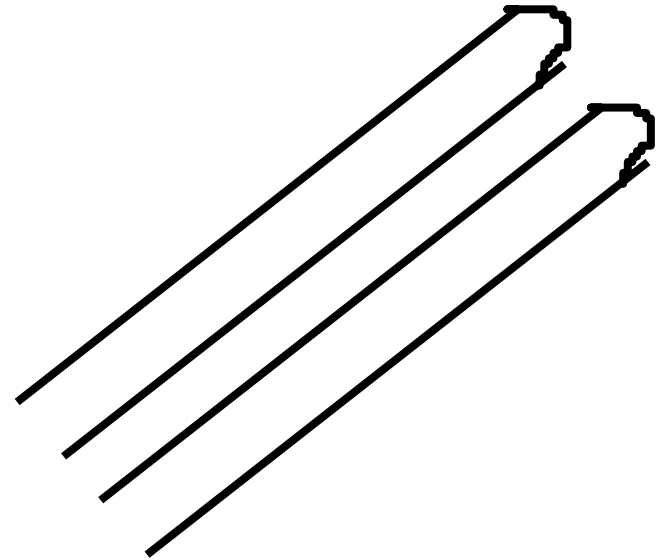
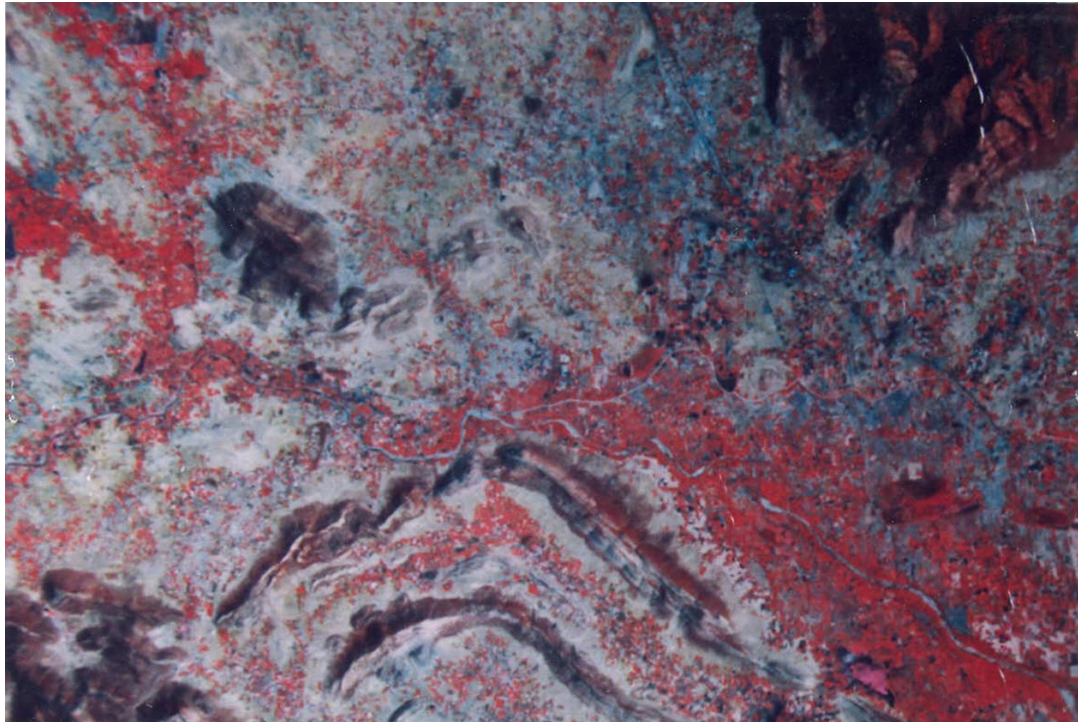
(E-g) Ramgarh dome, Ishwarakuppam dome

ANNULAR HILLS & VALLEYS



Linear Ridges

- steep dipping hills form ridges
- no debris slope
- least erosion



LANDFORMS IN FAULTED ROCKS

Demo: Cardboard Models

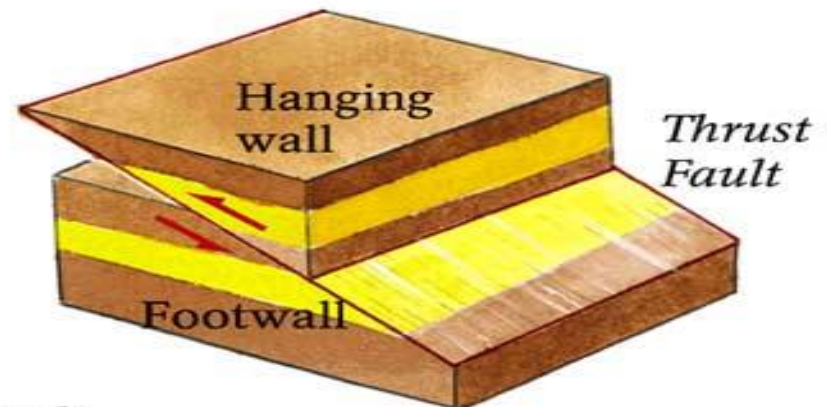
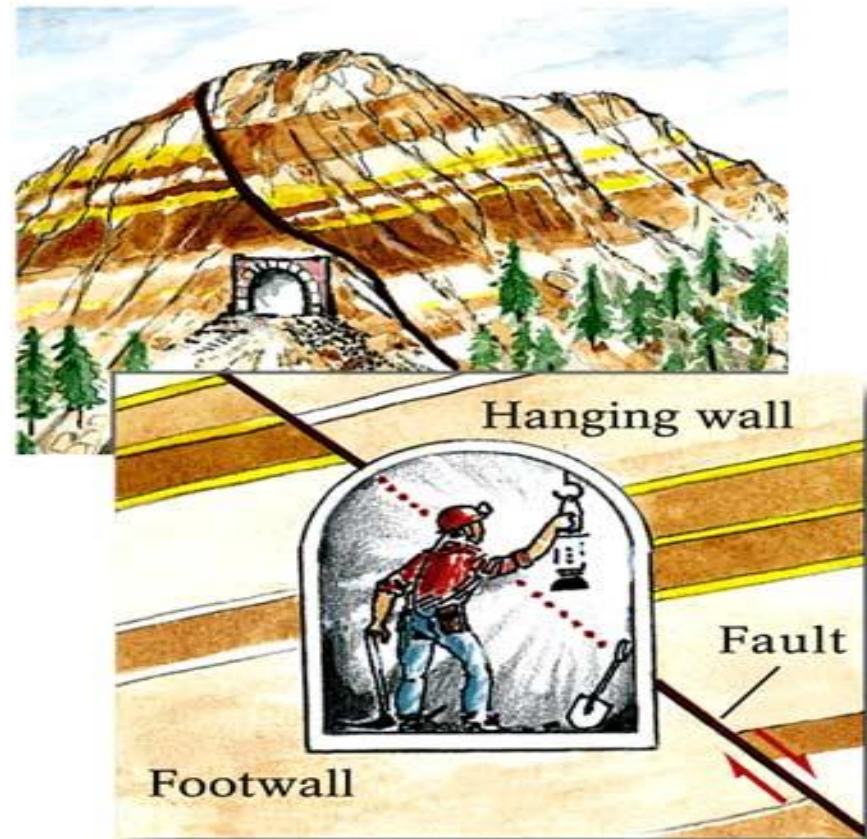
Dip-Slip Faults



Normal Fault



Reverse Fault

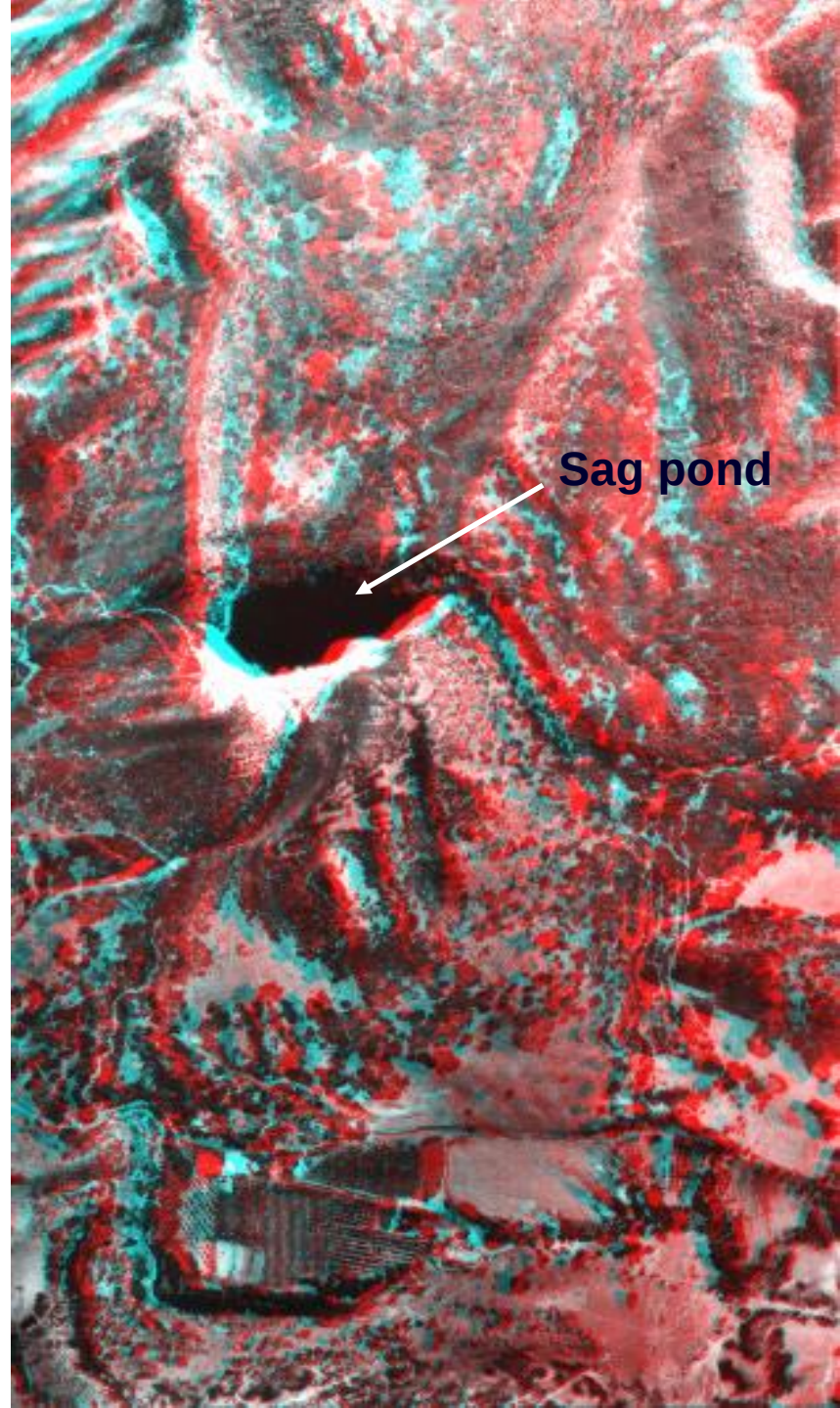


Faults 1: Normal Faults

- 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

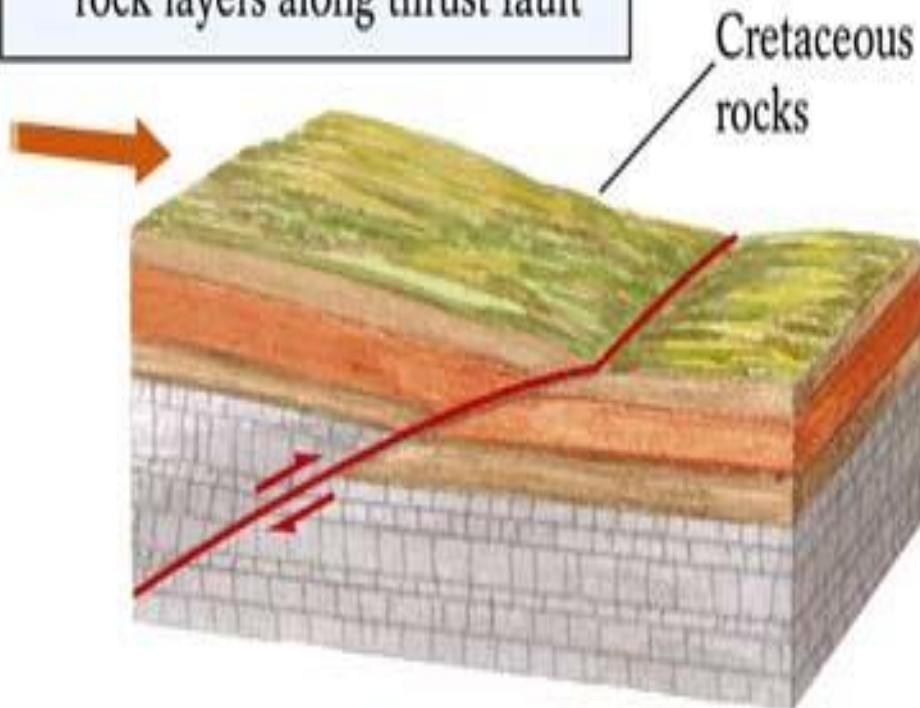
- Typical of Convergent Margins
- E.g. Accretionary Wedges (Santa Catalina Island) and Fold and Thrust Mountains (Himalayas, Alps, Appalachians)
- Often low-angle thrusts
- Hanging wall is up



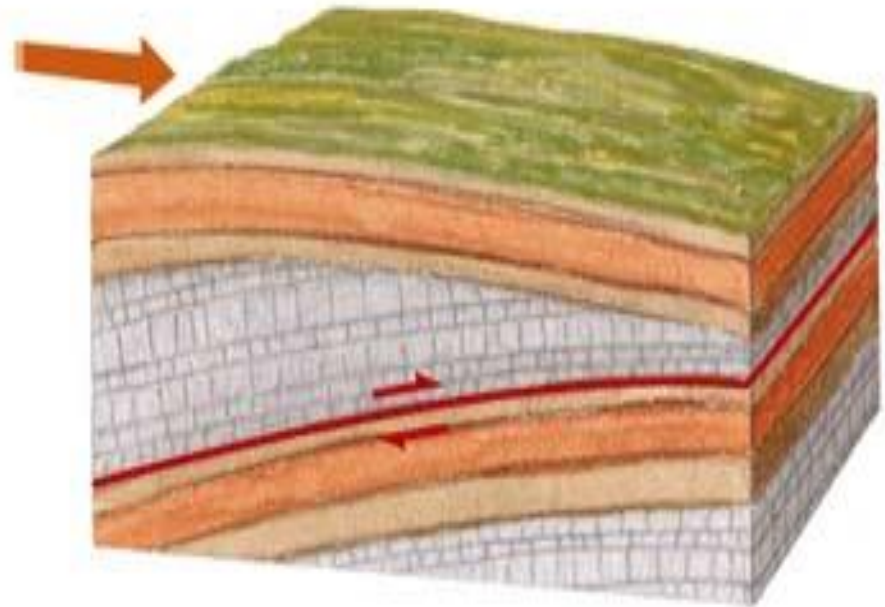
http://rst.gsfc.nasa.gov/Sect2/05-01_reverse_fault-iyougashima_DSC8766.jpg

Shallow Reverse Fault = Thrust Fault

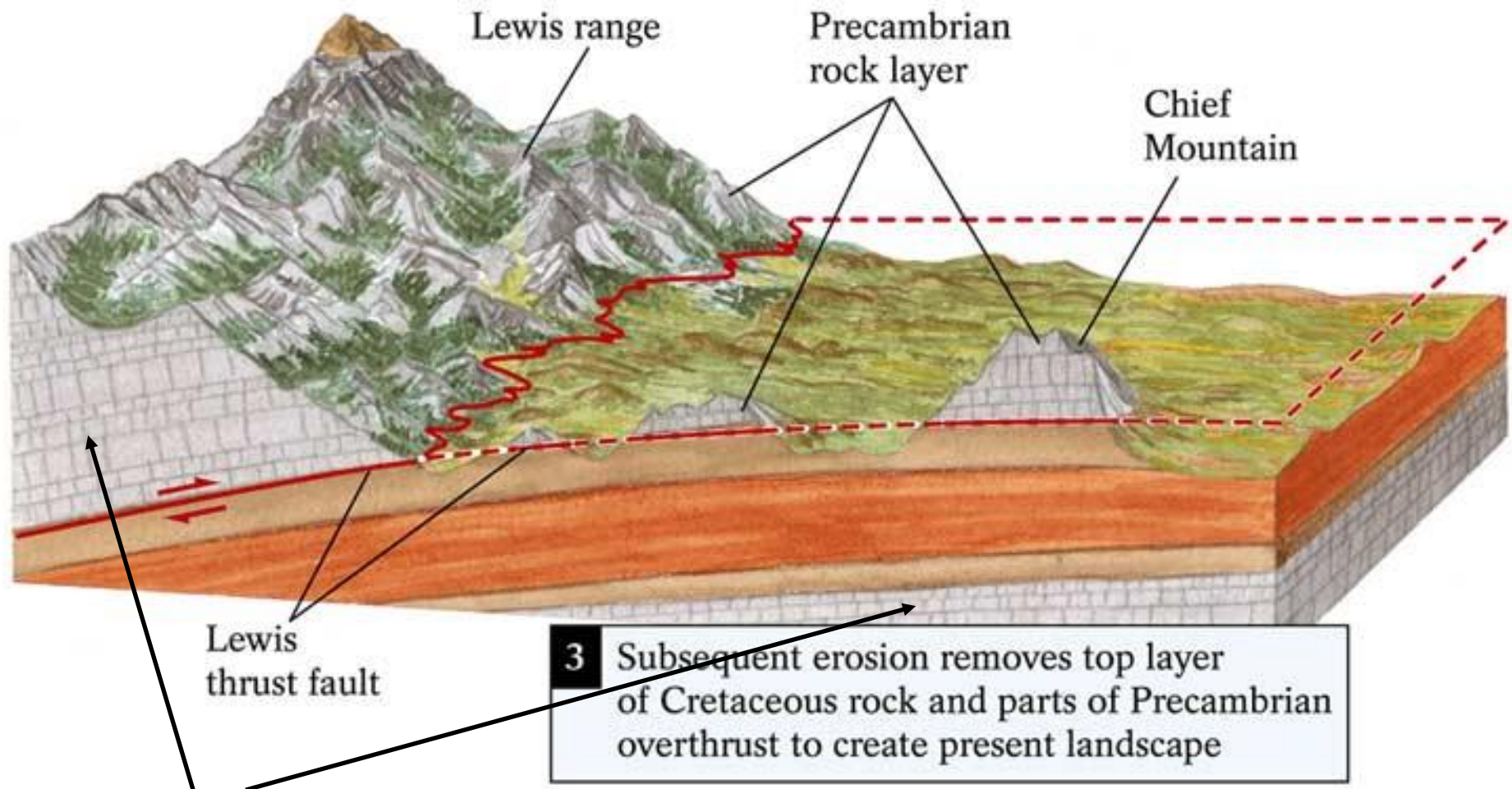
1 Precambrian rock layer begins to move on top of Cretaceous rock layers along thrust fault



2 Overthrust of Precambrian rock



Lewis Thrust Fault (cont'd)



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

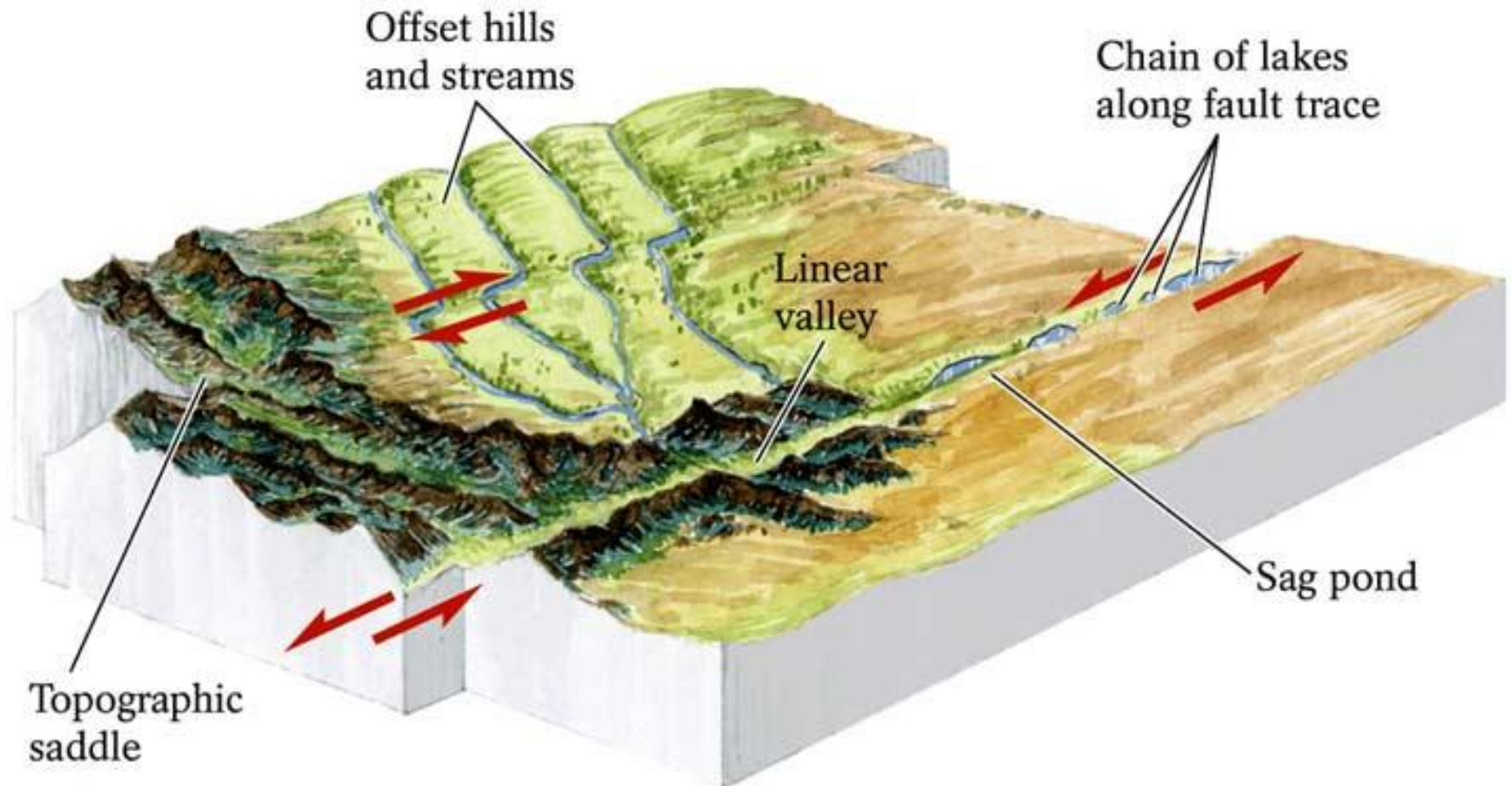
Lewis Thrust Fault (cont'd)



Source: Breck P. Kent

**PreCambrian Limestone over
Cretaceous Shales**

Horizontal Movement Along Strike-Slip Fault

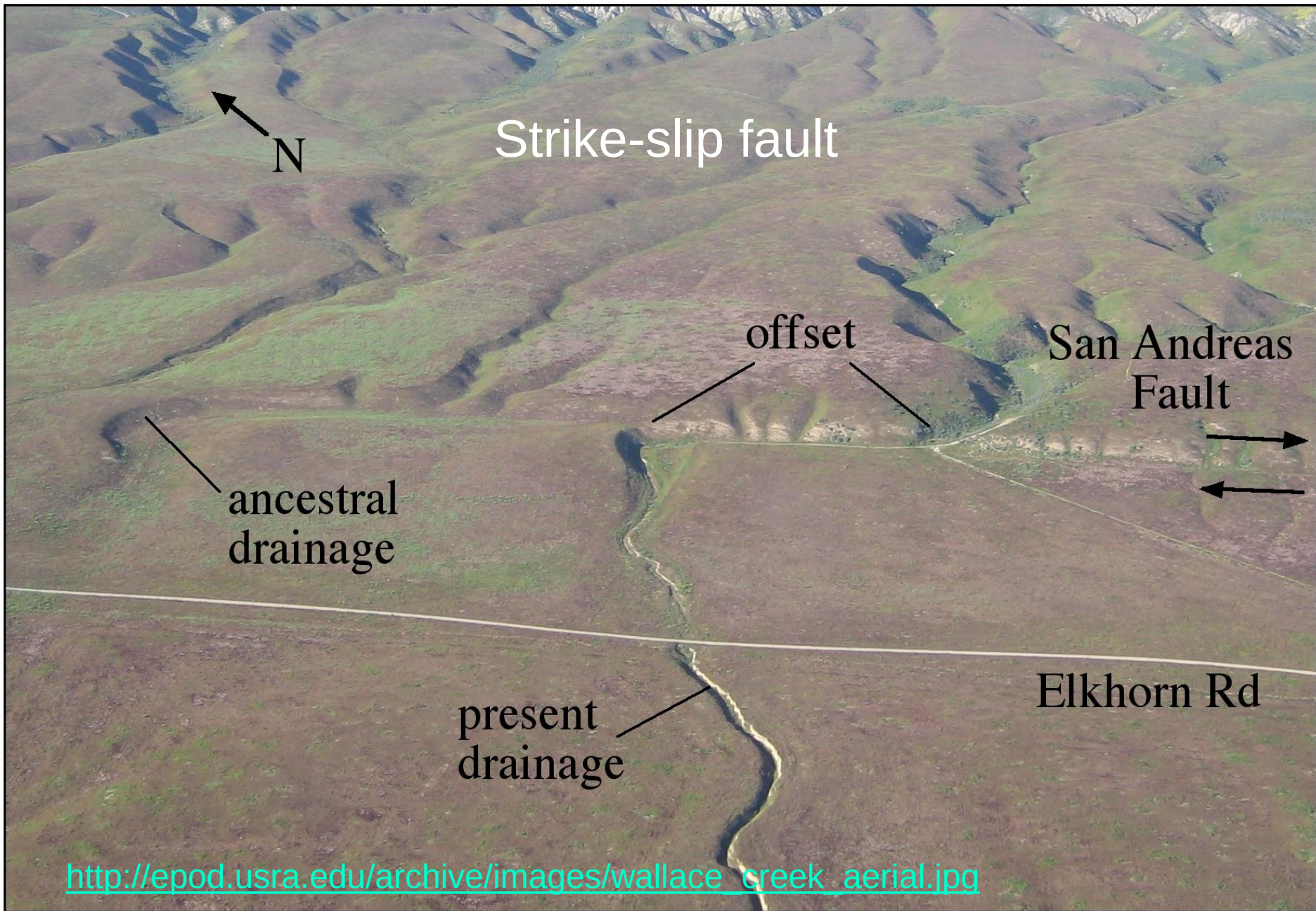


Tectonic Landforms

Faults and Fault Landforms

The East African Rift Valley is a graben





Strike-slip fault

N

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



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

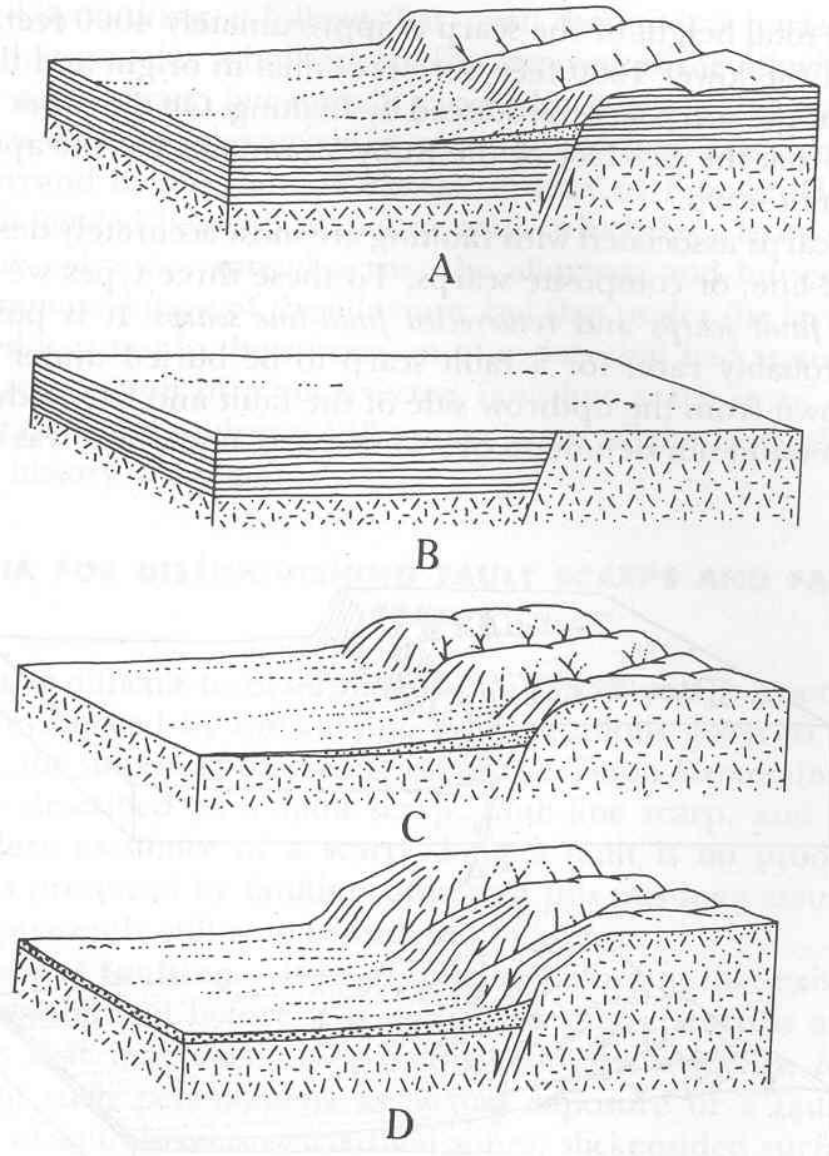
Filled

Barren

Fault valleys

Rift valleys

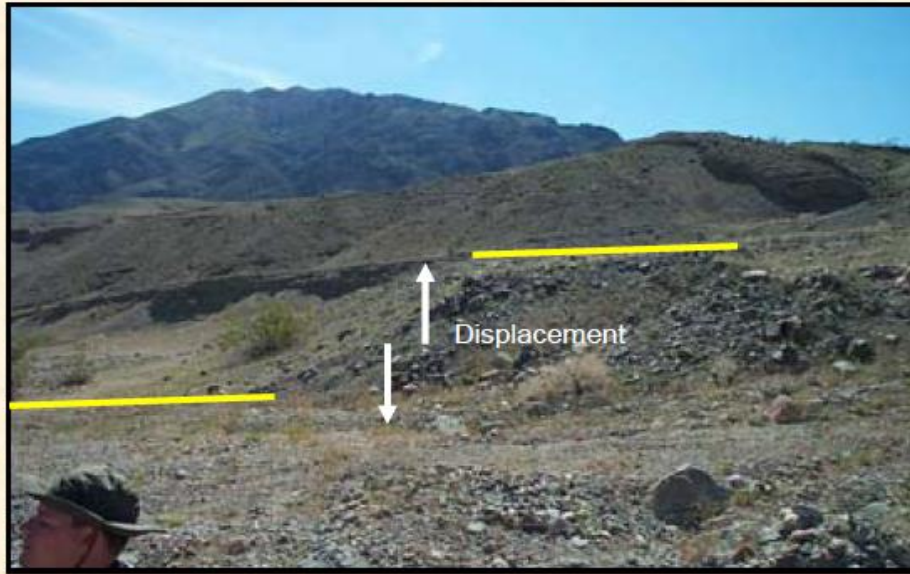
FAULT SCARP: The scarp produced directly by the faulting is called fault scarp



Different stages in the formation of the scarps

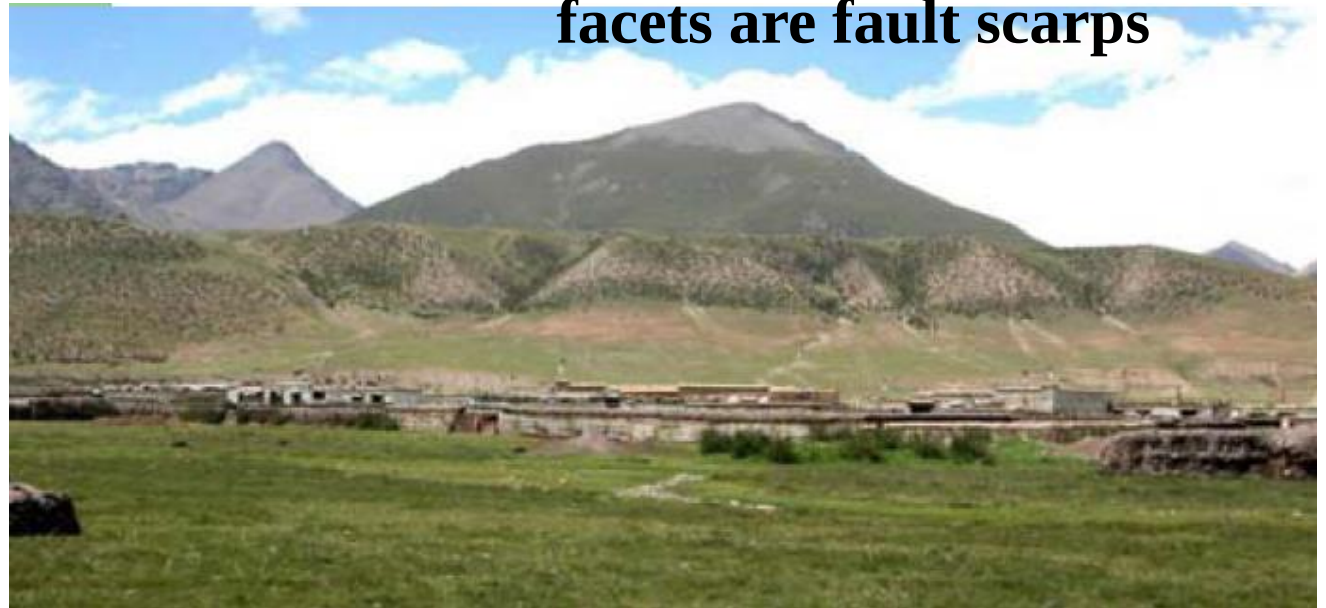
- A) Formation of Fault Scarp**
- B) Destruction of fault scarp by erosion**
- C) Renewal of erosion, following upliftment, with development of fault line scarp**
- D) Renewal of faulting with composite scarp, whose upper part is of erosional and lower part of fault origin**

Fault scarp on alluvial fan



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

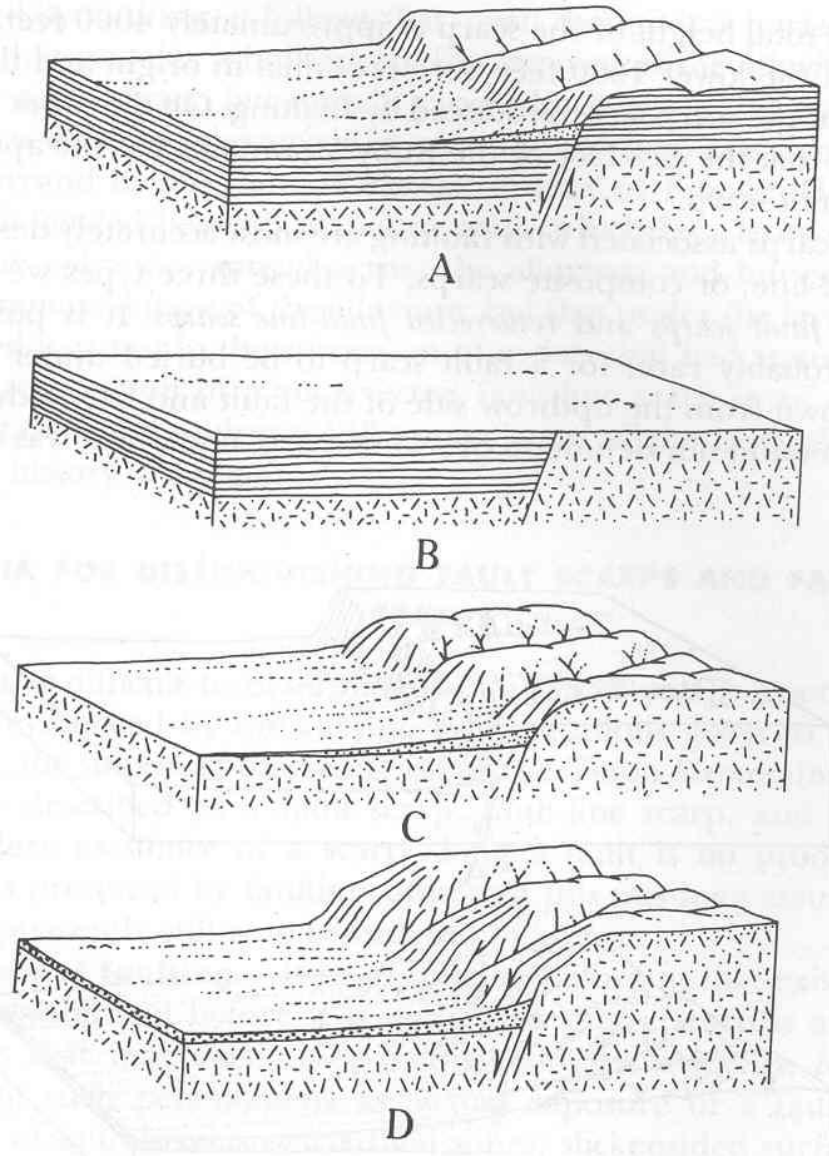
Northern Tibet: Triangular facets are fault scarps



Fault Scarp



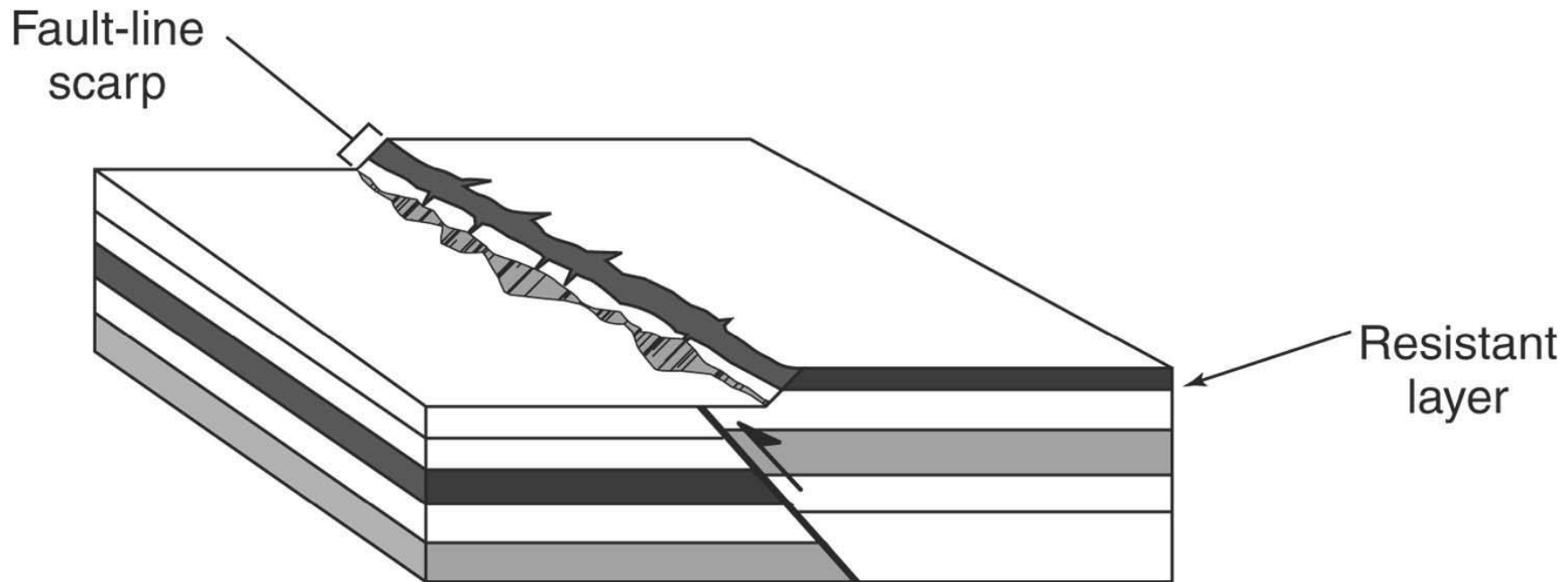
FAULT LINE SCARP: Fault line scarp produced by the differential erosion along the fault line



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**

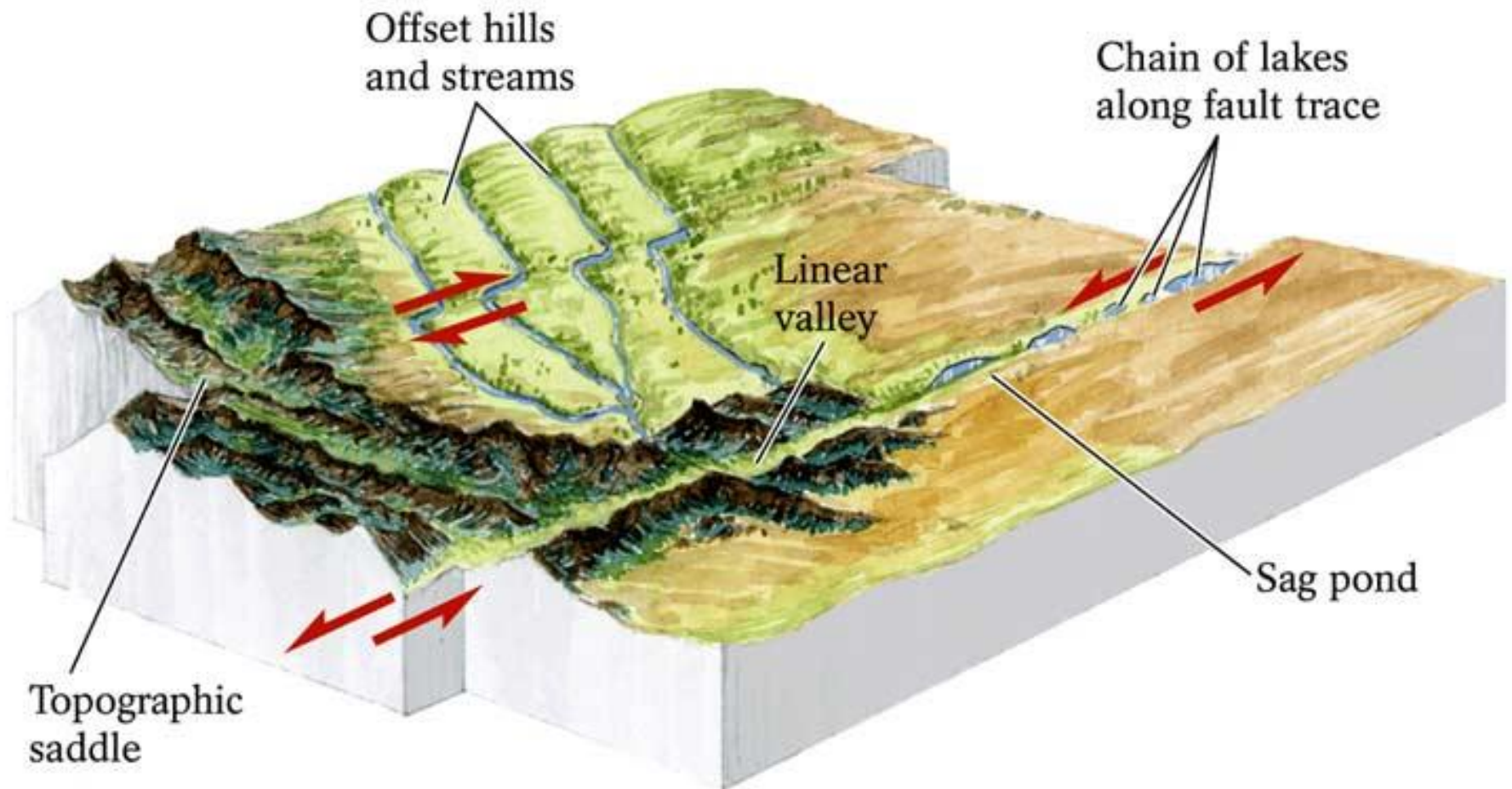
Fault-line scarp caused by faulting of a resistant layer



Fault Line scarp
(High-angle
Normal Fault)



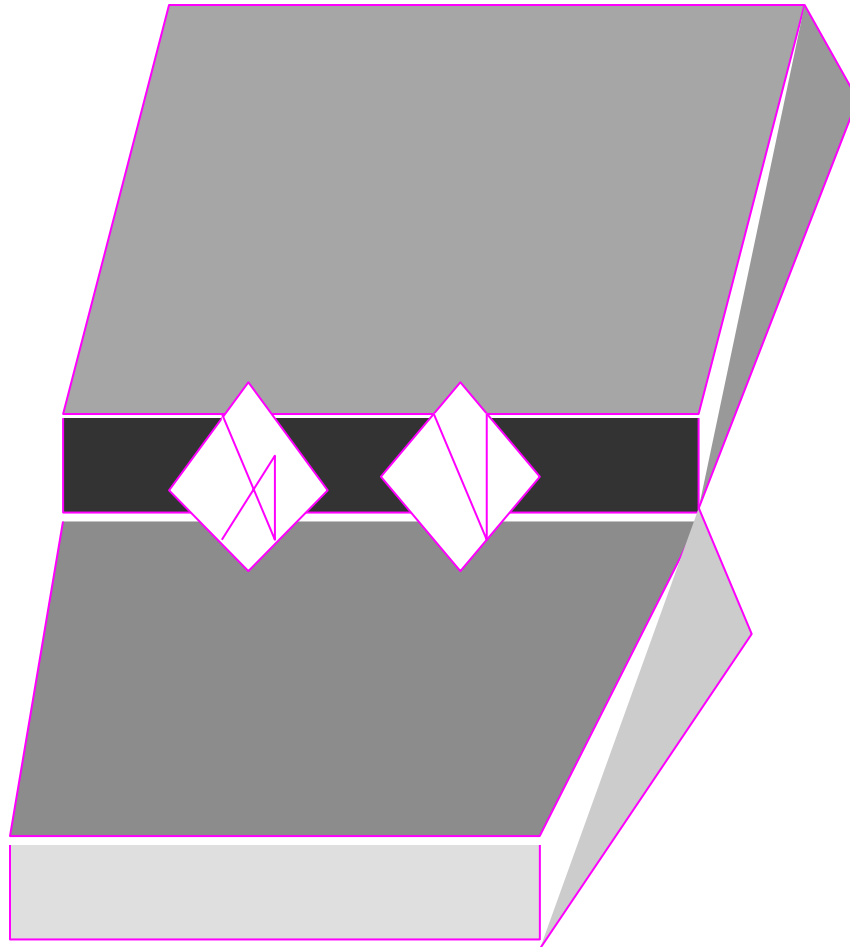
Sag Pond: Chain of lakes formed in fault line is called Sag pond





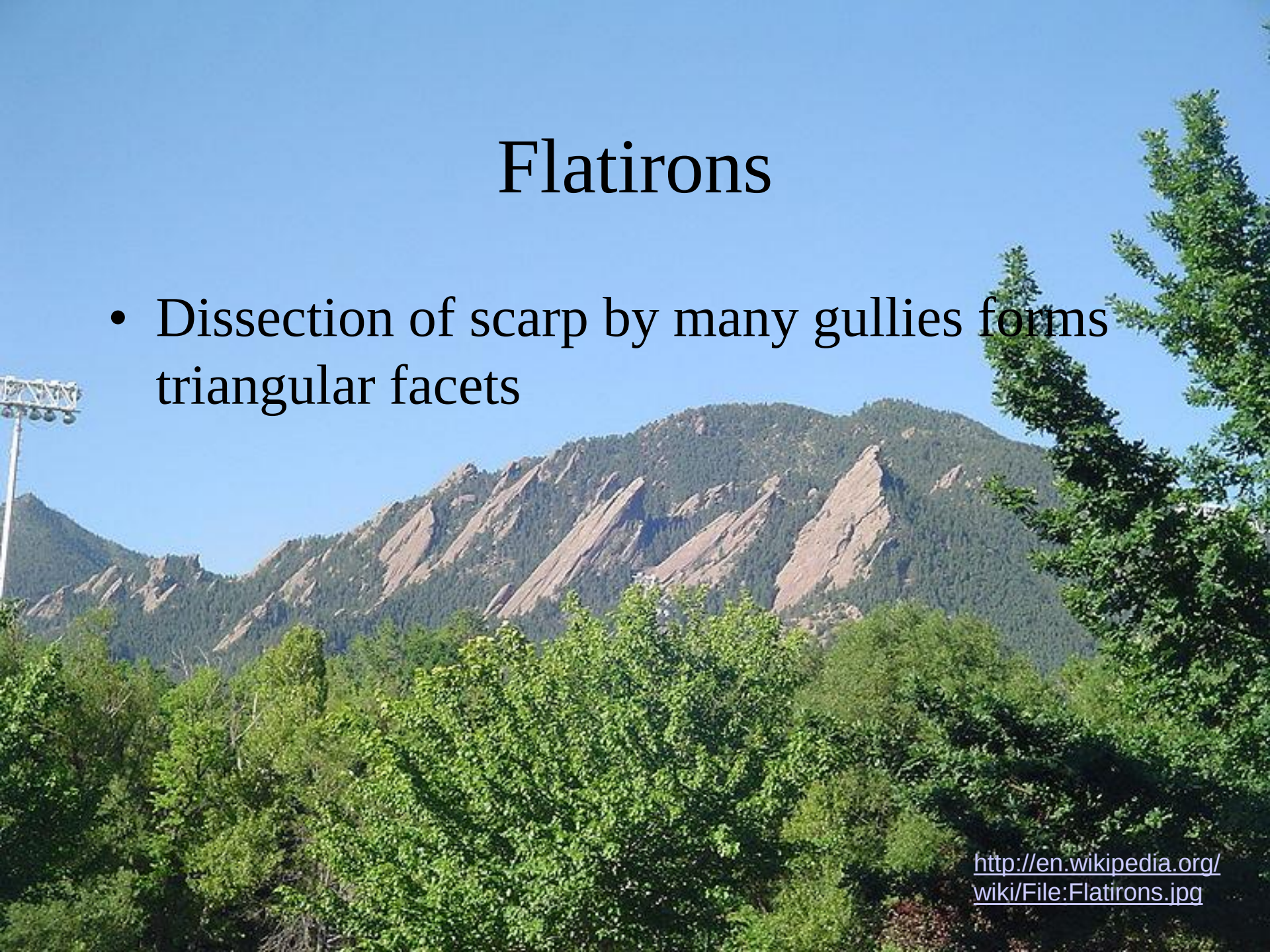
Sag pond on trace of 1906 break along San Andreas fault. California

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



TRIANGULAR FACETS

(Jagged, Cappadocia, Turkey)



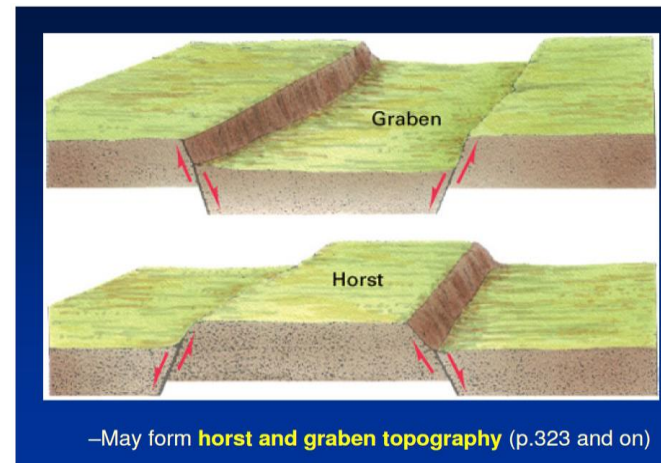
Horst and Graben

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

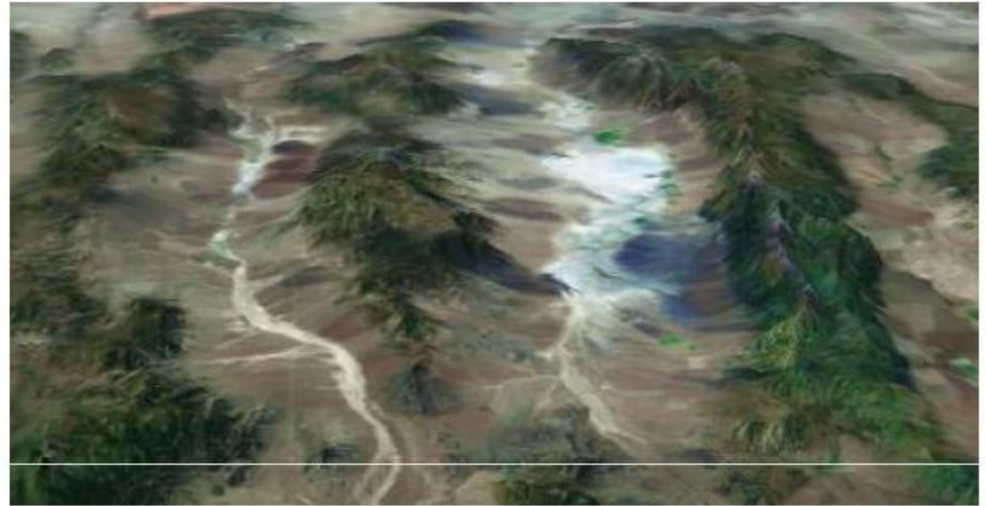
The Jordan-Dead sea depression, Death valley, the Rhine graben, the rift valleys of east Africa - GRABEN

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



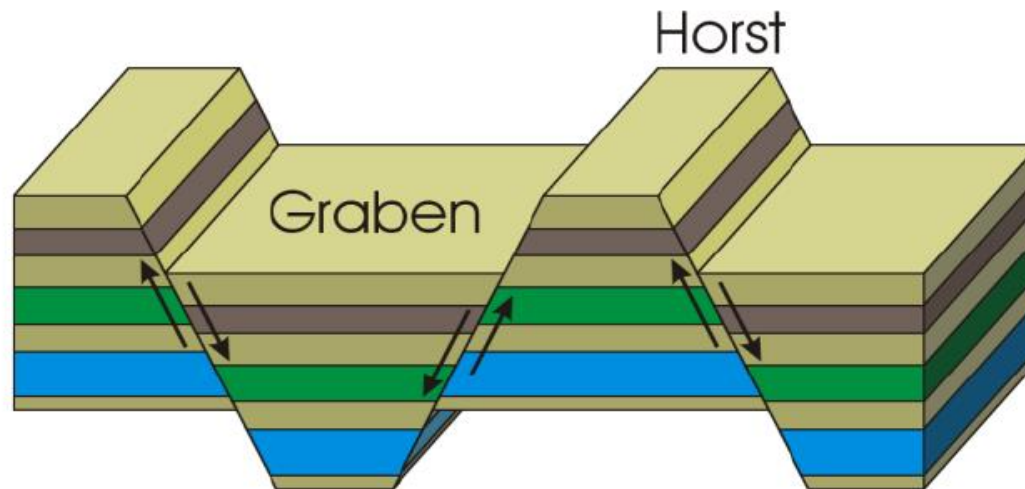
Graben

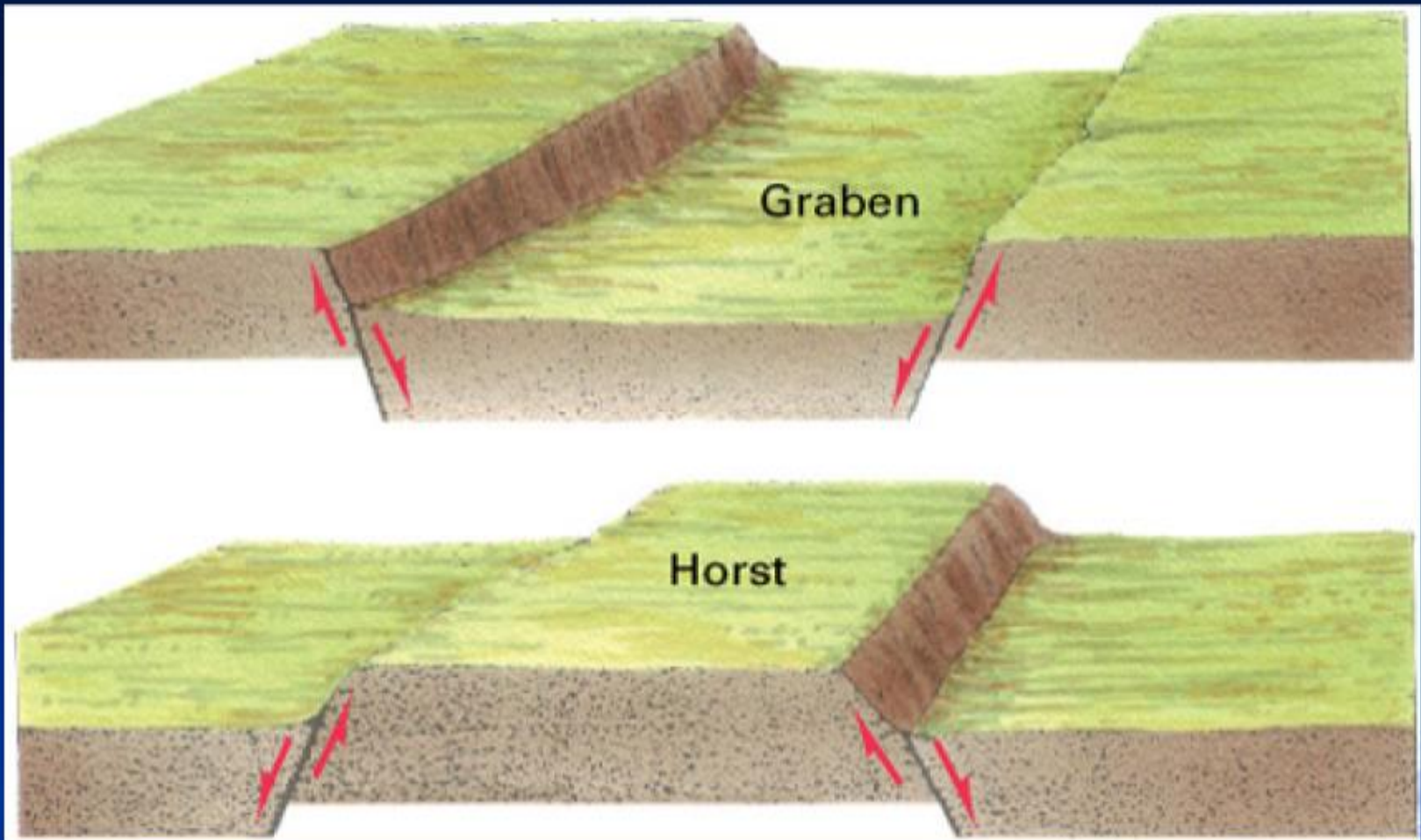
- As the crust is stretched, a block called a **graben**, which is bounded by normal faults, drops down. Graben is a German word for ditch or trench.



Horsts

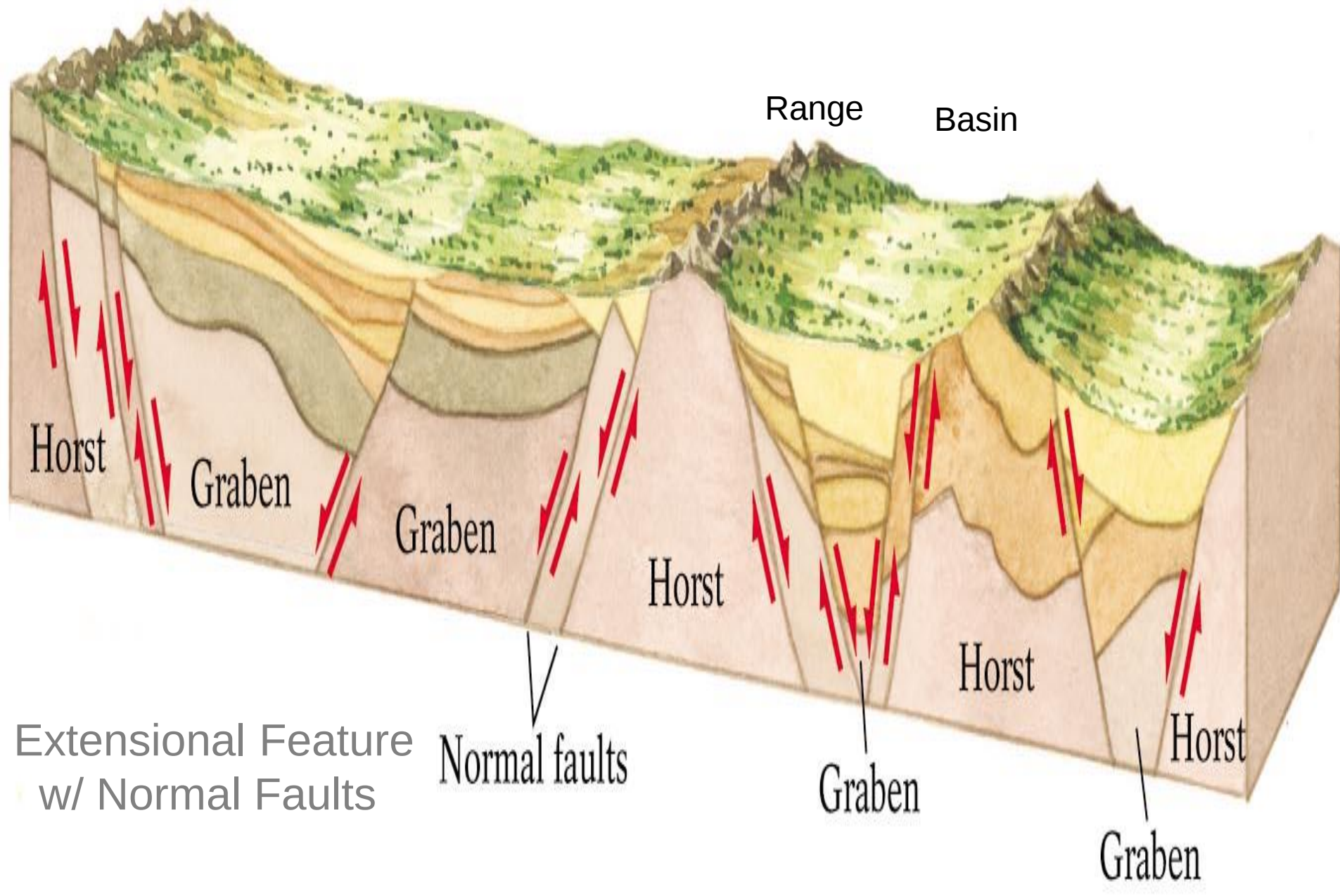
- Grabens produce an elongated valley bordered by relatively uplifted structures called **horsts**.





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

Horst and Graben





Graben

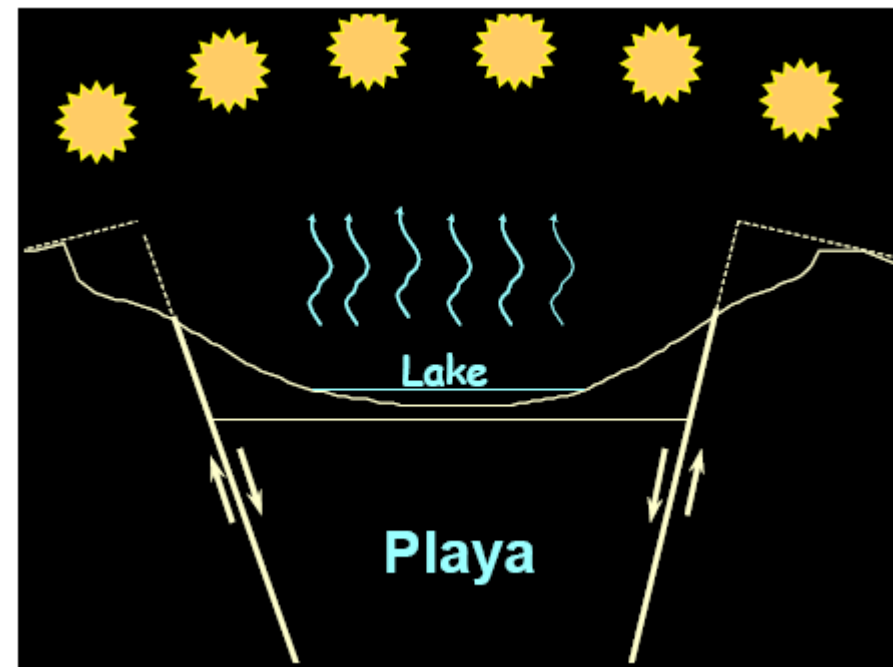
Fault block mtn. alluvial fan, pediment, basin, playa, fault block mtn.

Erosion

Erosion

Depositional
Basin

Playa Lake



"Salt Flat"

Playa

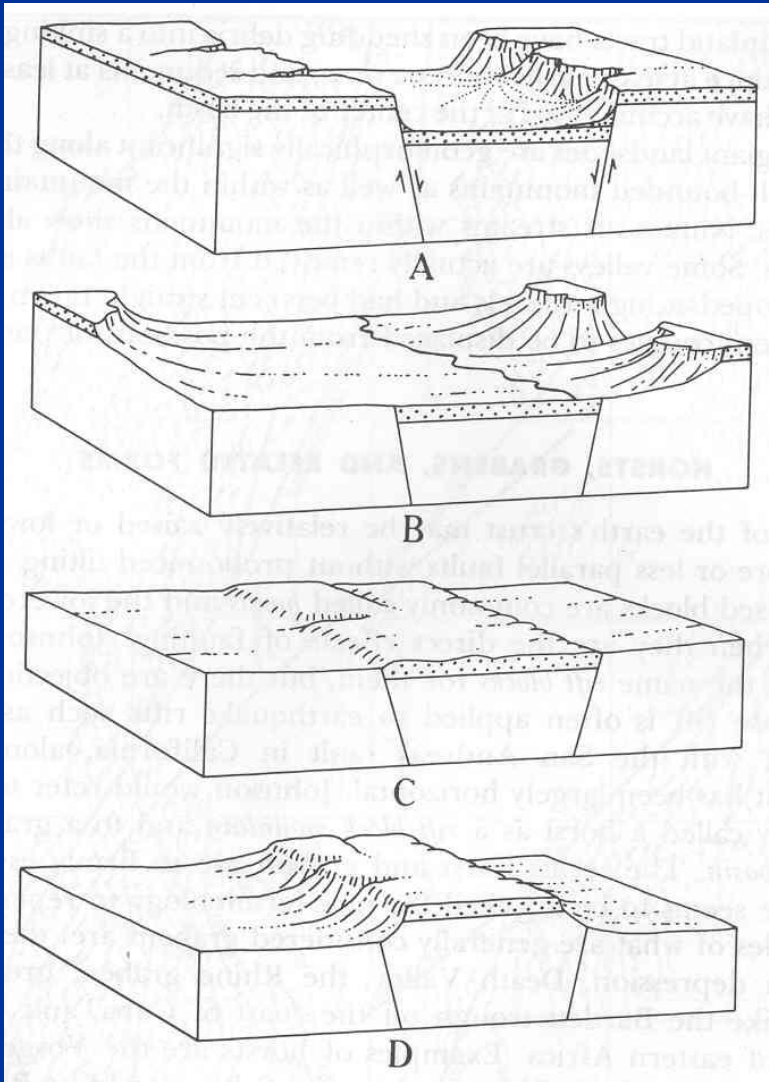
Salt Pan, Death Valley

Martin Miller Photo



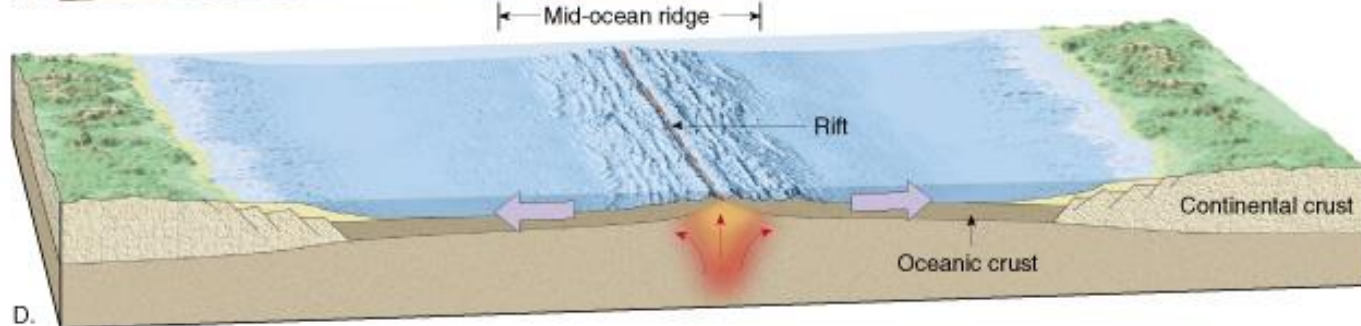
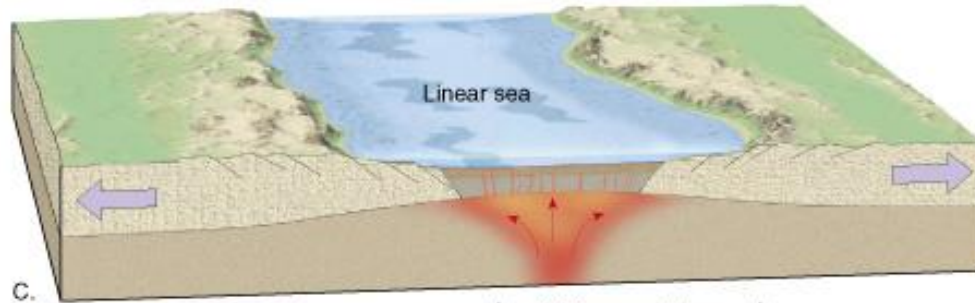
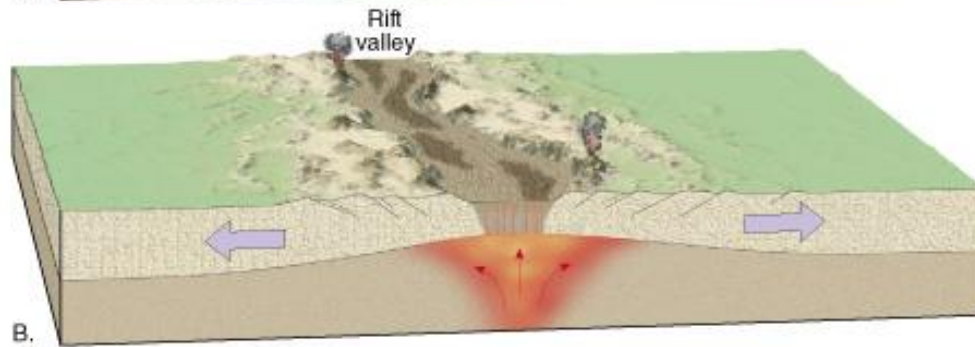
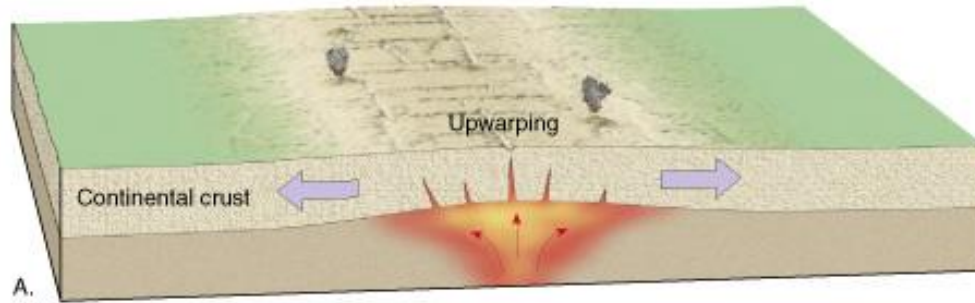
INVERSION OF TOPOGRAPHY

Stages of development of inversion topography upon a graben



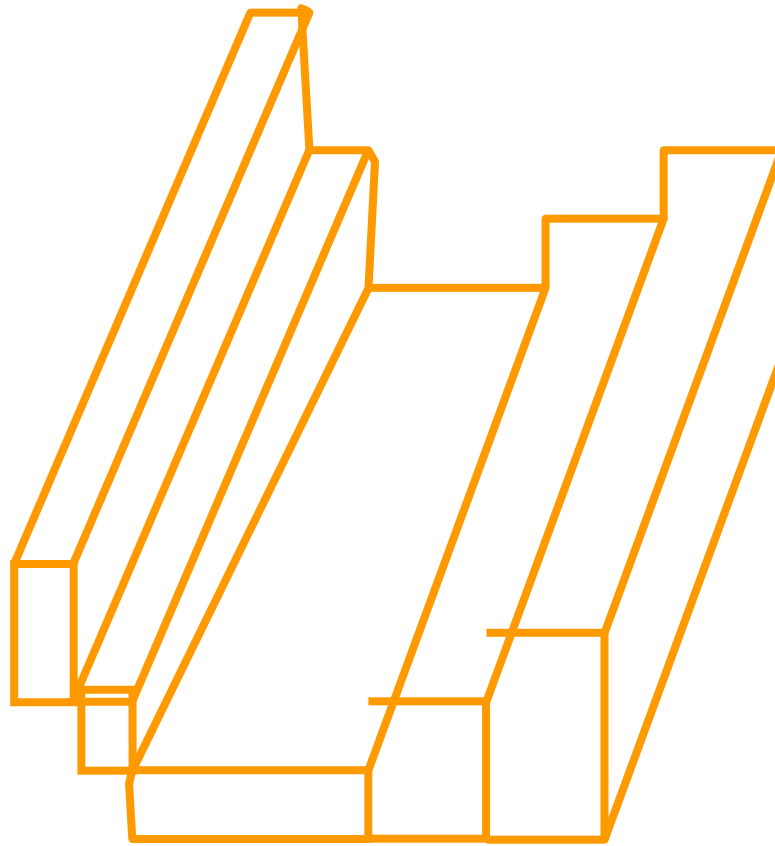
- A) Formation of graben by faulting
- B) Destruction by erosion of the fault produced topography
- C) Renewal of erosion accompanying uplift
- D) Development of an obsequent rift block mountains where the originally graben exits

Continental Rift into Ocean Basin - Tension => Divergence

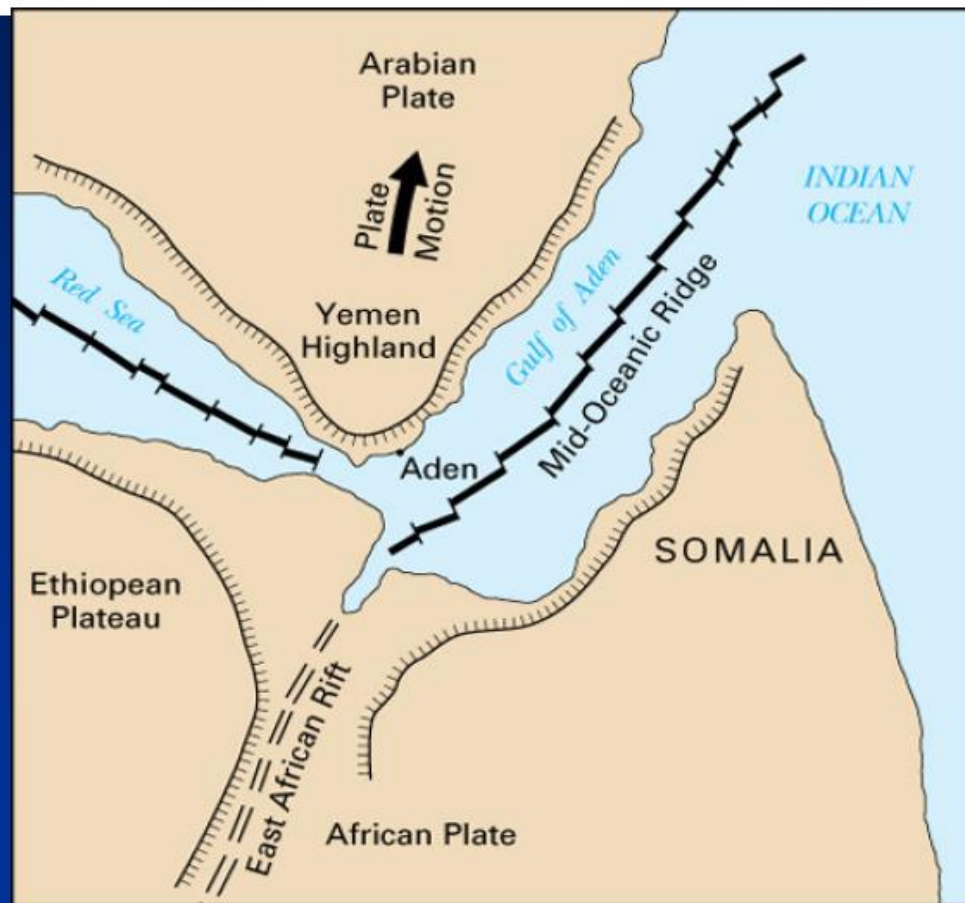
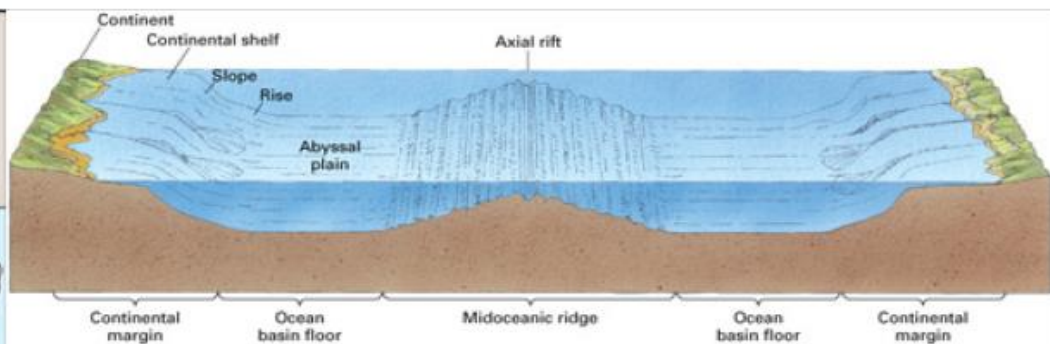


Rift Valleys and
Oceans are the
same thing

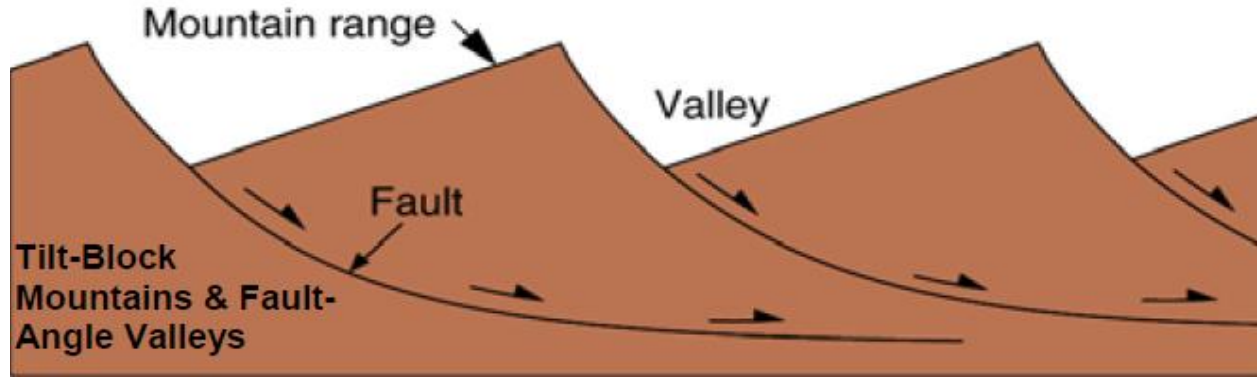
Rift valleys: The term rift valley applied to the great trough or great grabens of East Africa and elsewhere. Rift valley may develop on a block of weak rock bounded by parallel faults. Such feature is called as rift block valley



- ➔ seismic prone
- ➔ hot water / geothermal



Basins and Range Topography



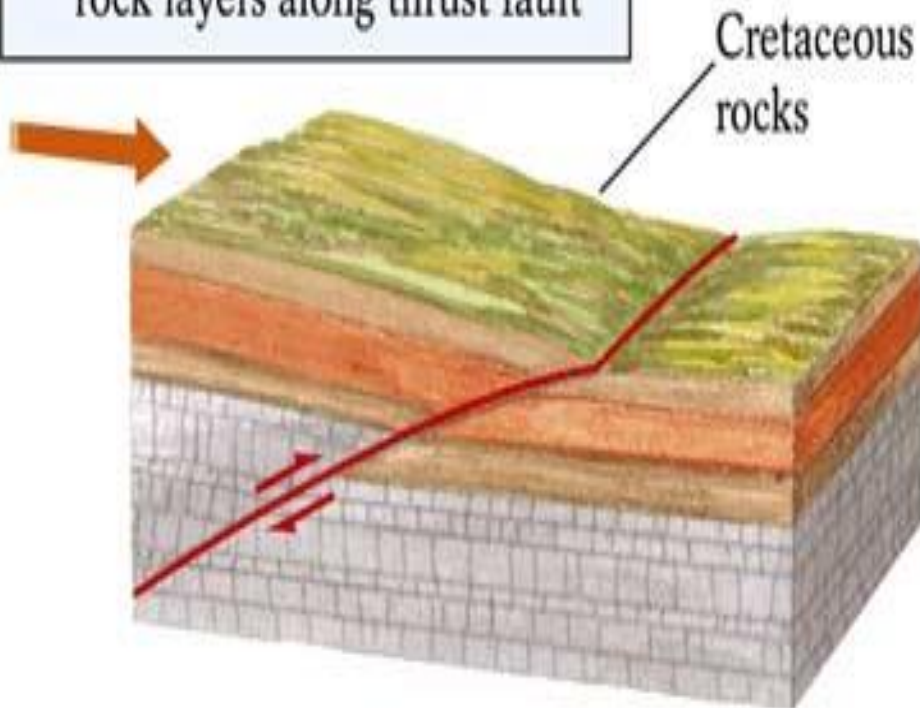
Faulted and tilted monoclinal blocks that had been raised above the adjacent basins along range-front fault

Basins and Range Topography – Western United state

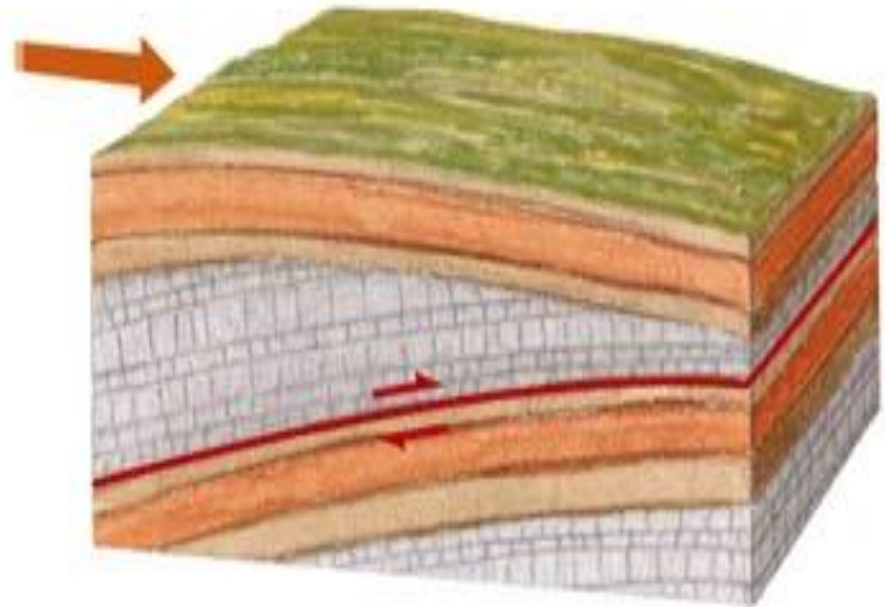


Shallow Reverse Fault = Thrust Fault

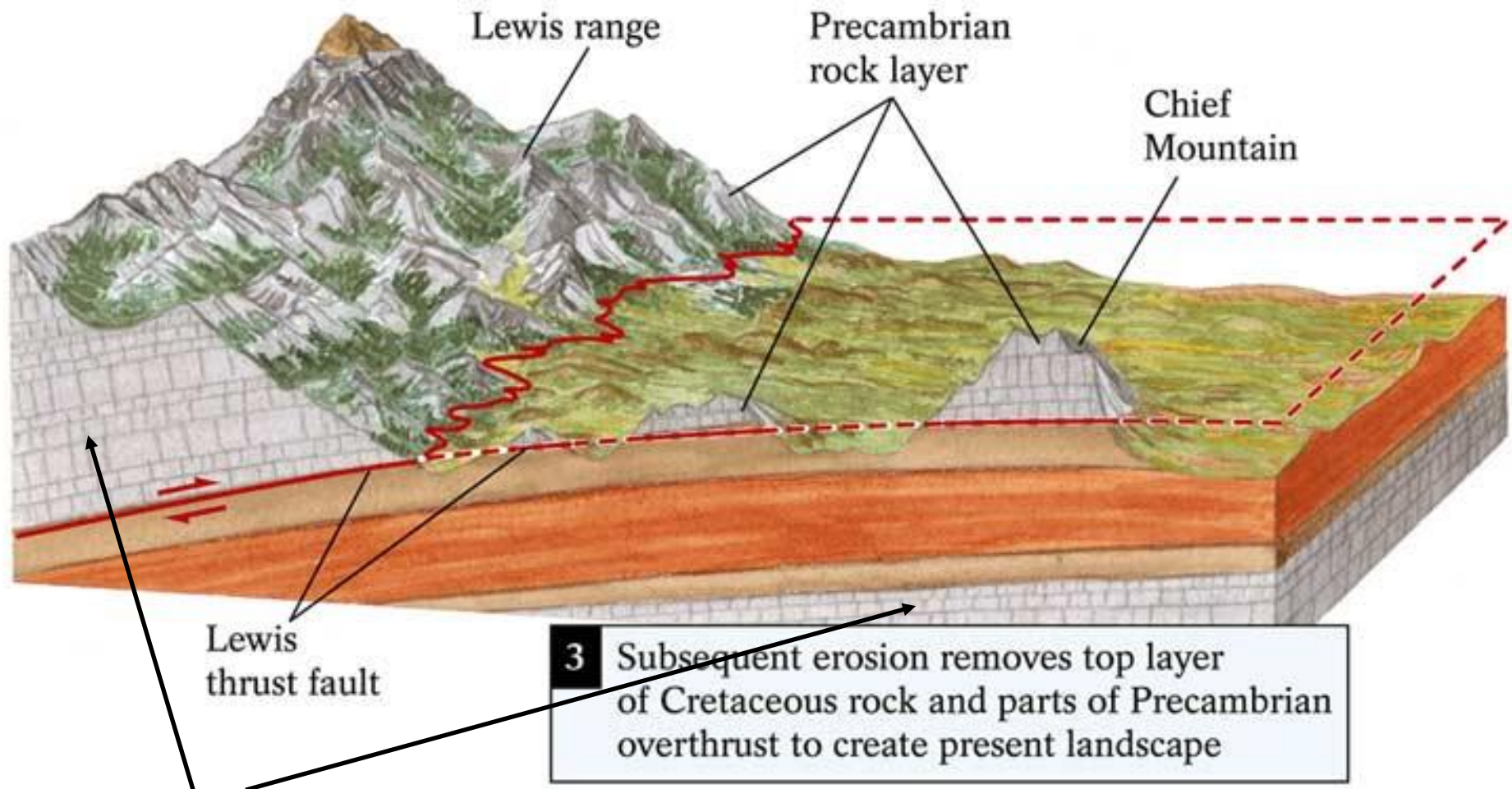
1 Precambrian rock layer begins to move on top of Cretaceous rock layers along thrust fault



2 Overthrust of Precambrian rock



Lewis Thrust Fault (cont'd)



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

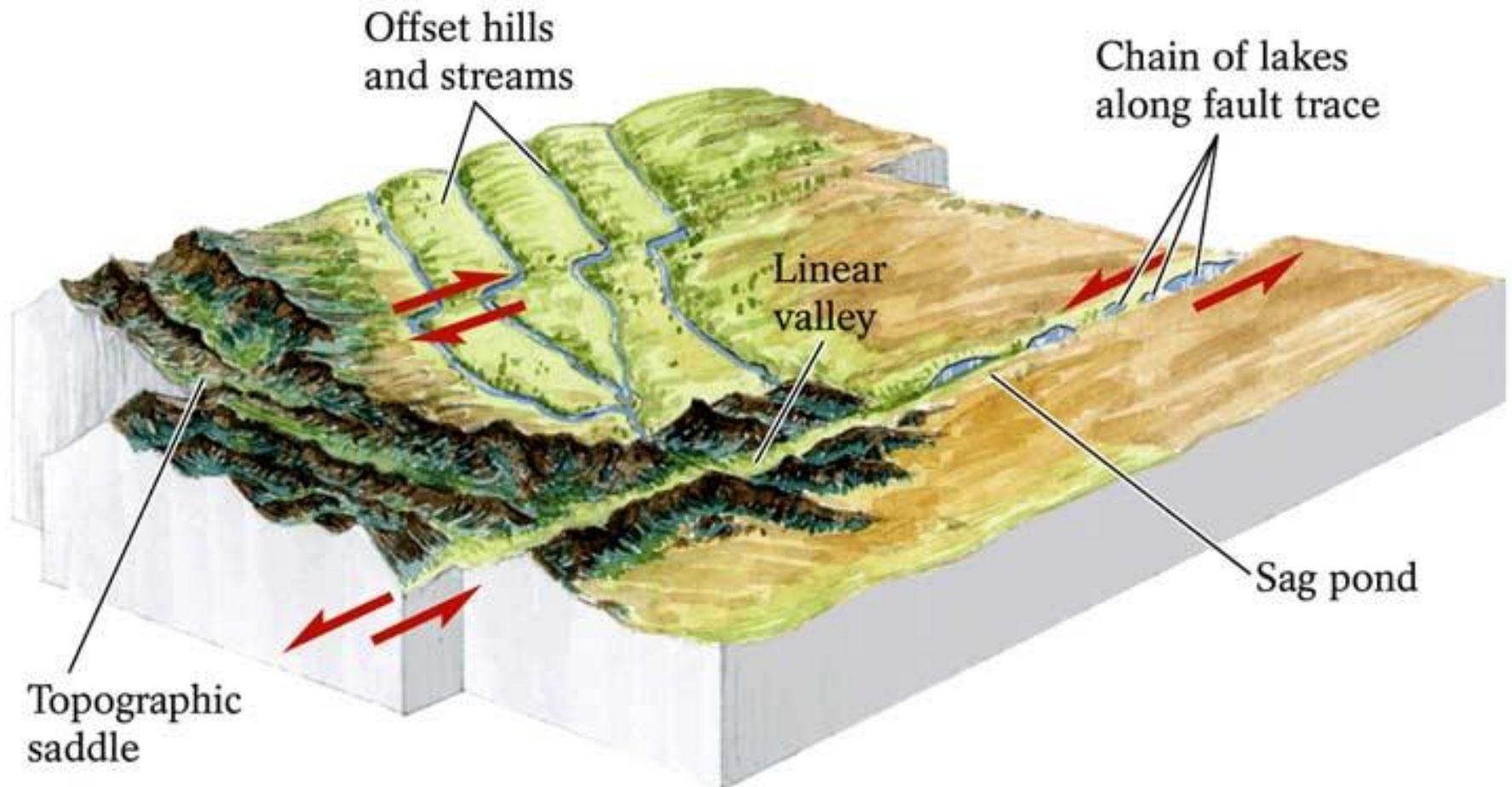
Lewis Thrust Fault (cont'd)



Source: Breck P. Kent

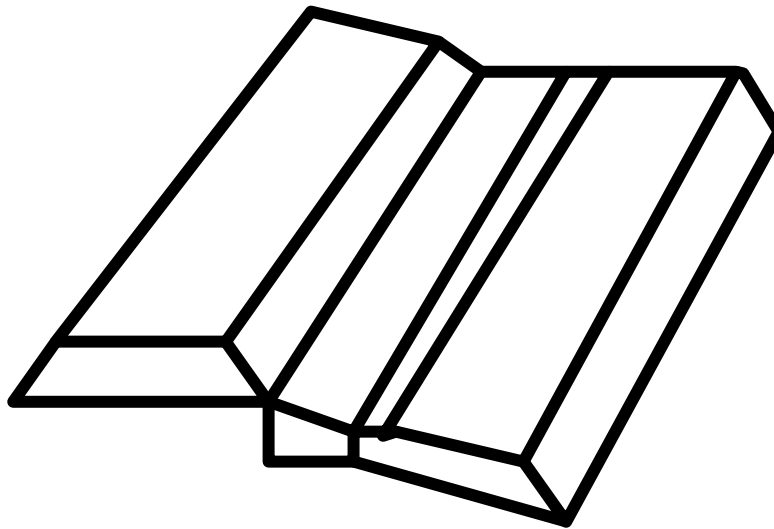
**PreCambrian Limestone over
Cretaceous Shales**

Horizontal Movement Along Strike-Slip Fault

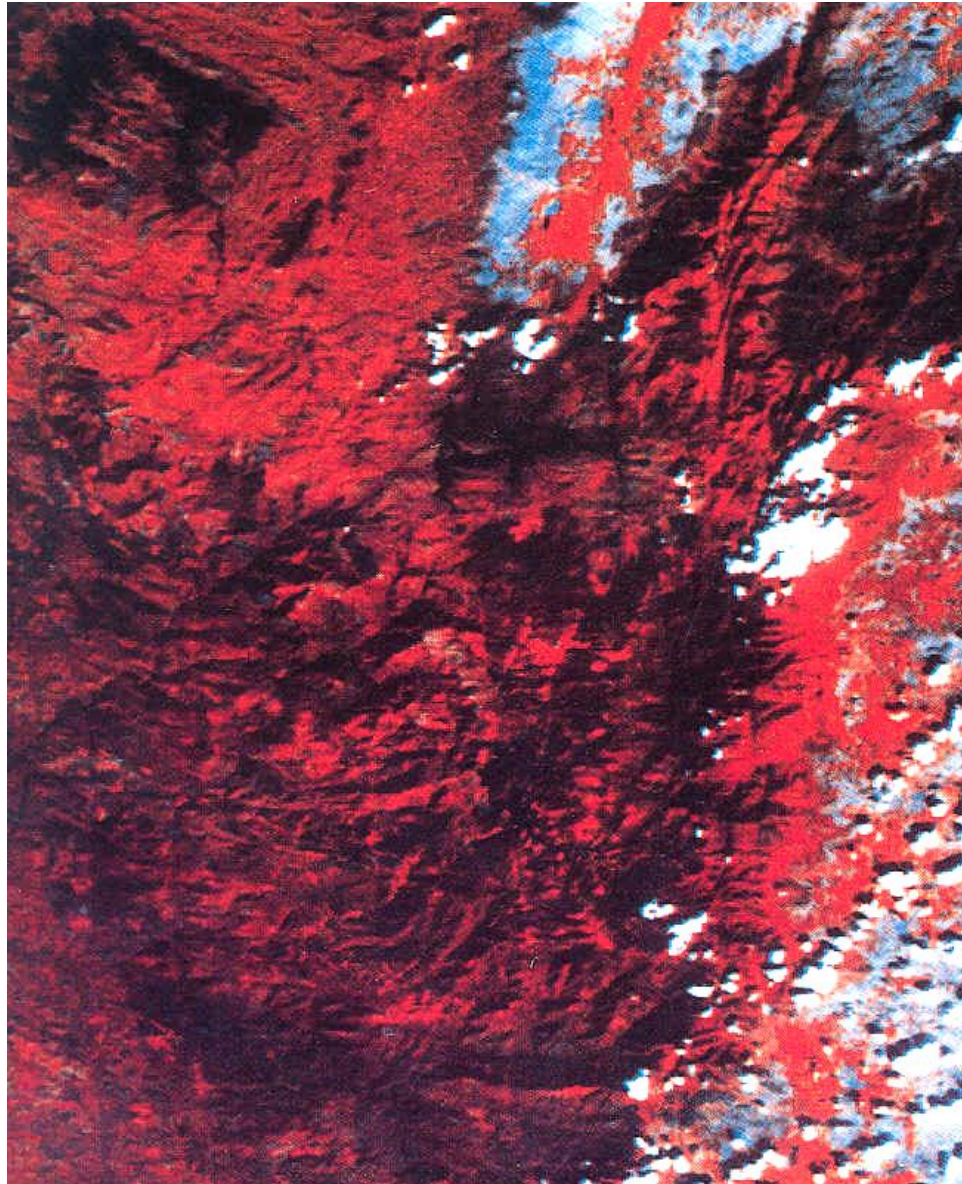


Fault valleys

➡ *seismic prone*

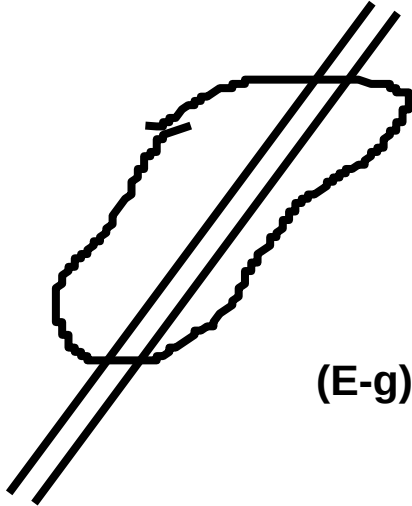


CUMBUM TECTONIC VALLEY



Fracture valleys: Valley developed by the erosion along the faults, fracture, lineaments is called fracture valleys

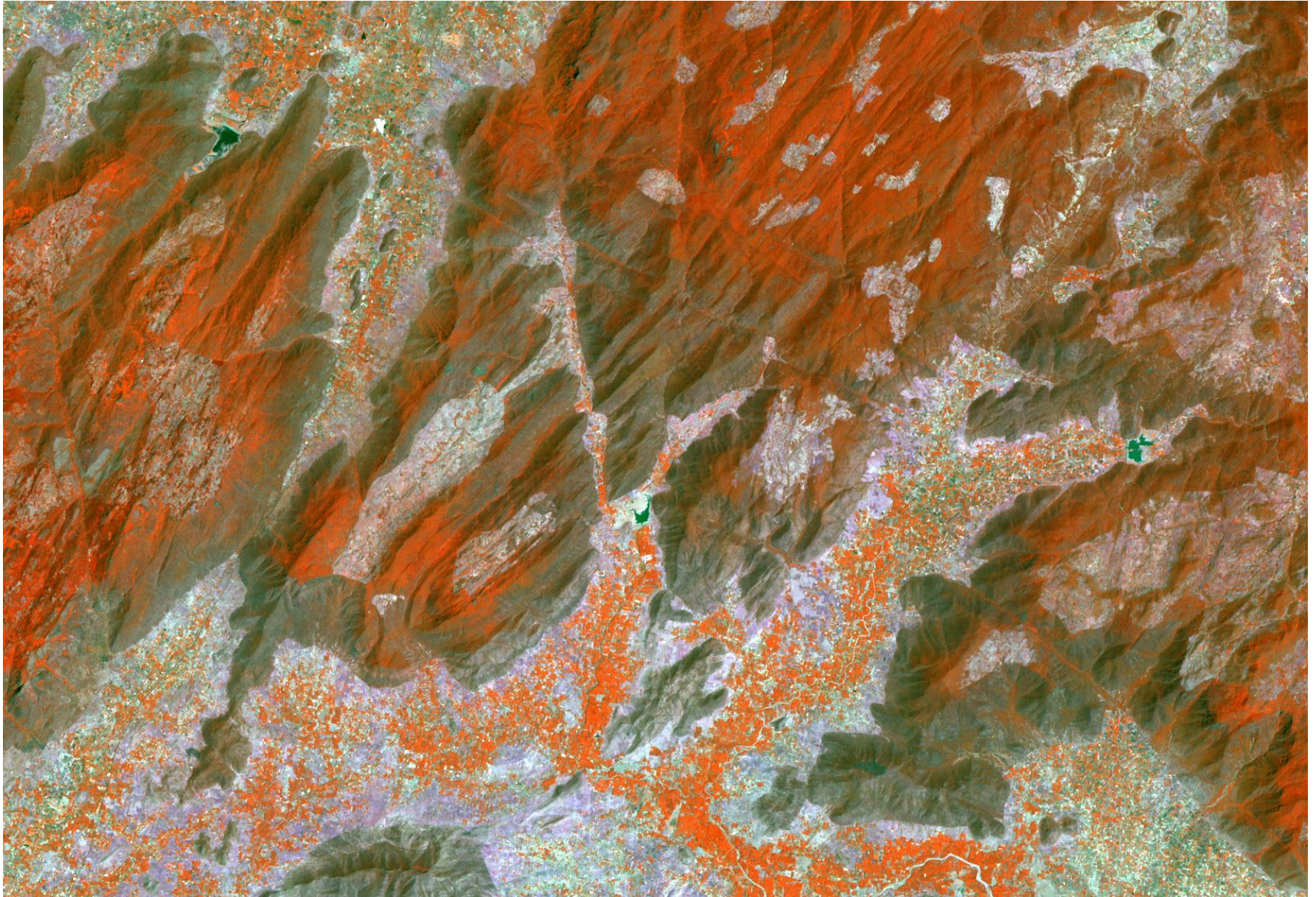
Further, may classified into
filled fracture valleys or
barren fracture valleys



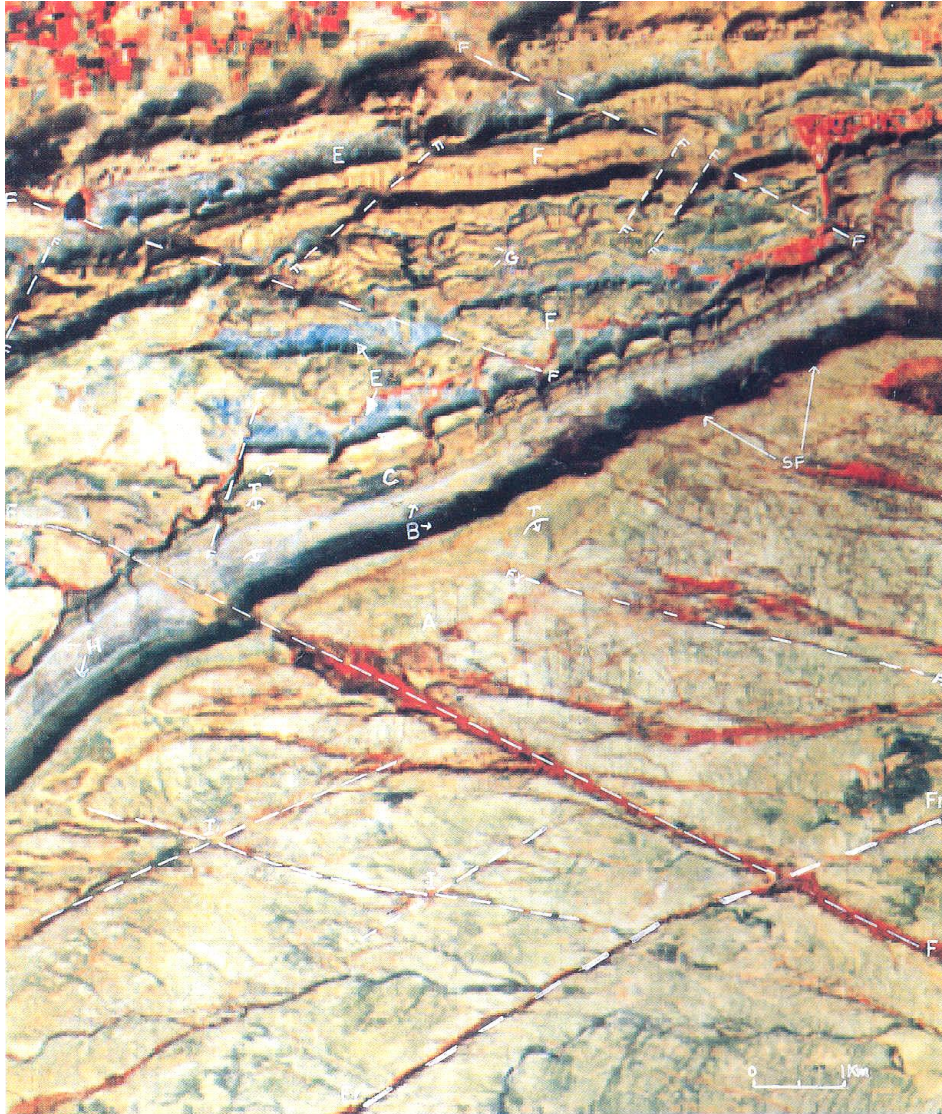
(E-g) Javadi, Shevroy, Chitteri hills

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

BARREN FRACTURE 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>