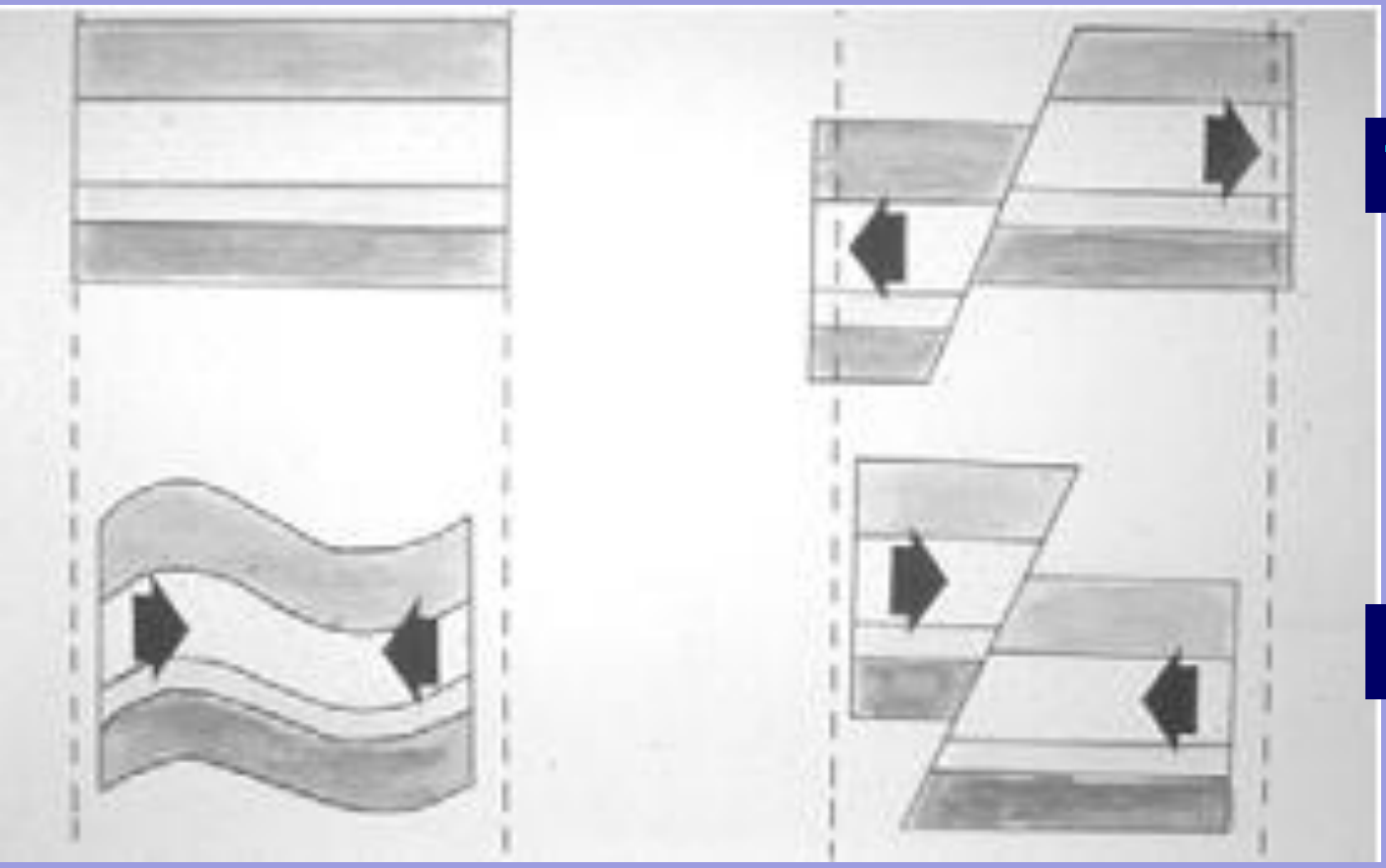
Introduction to Folds



TENSION

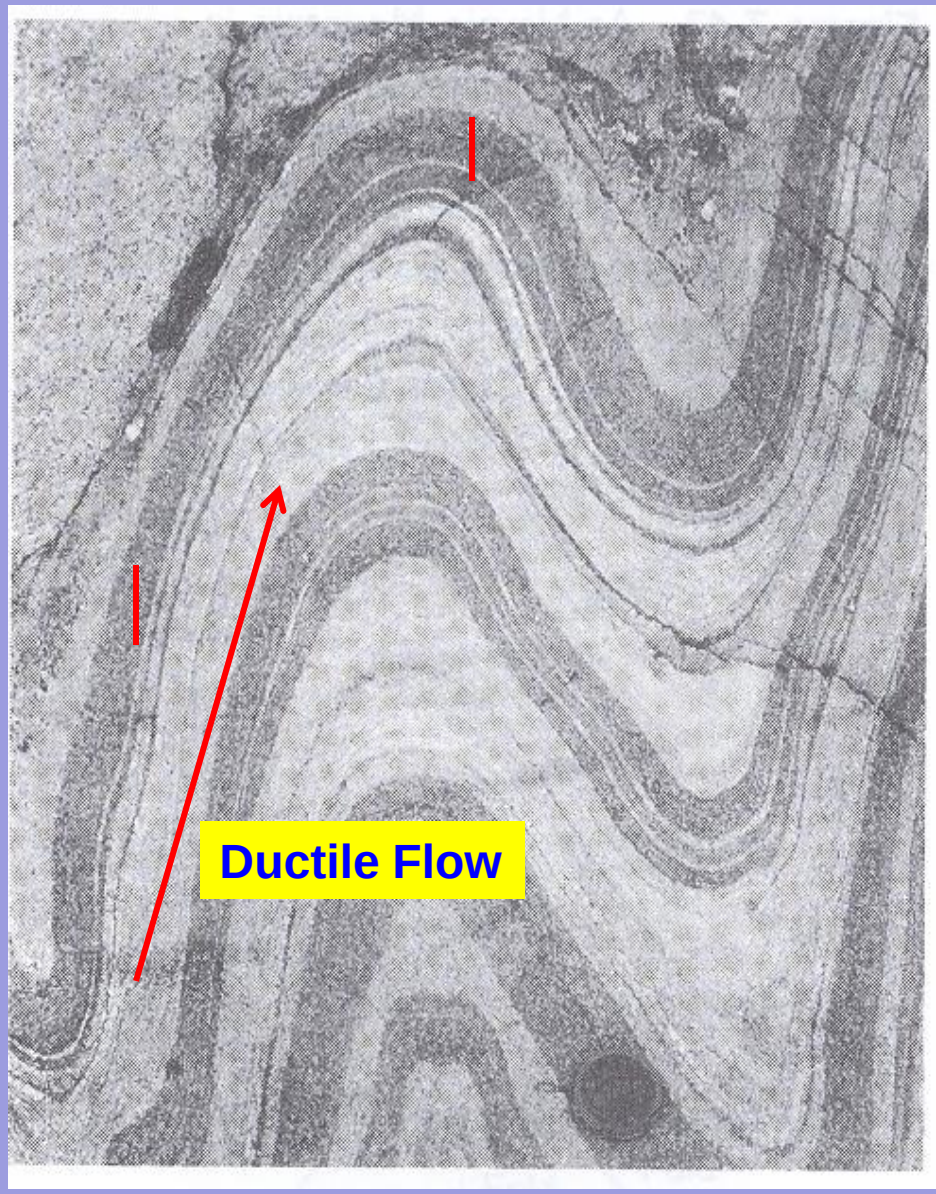
COMPRESSION

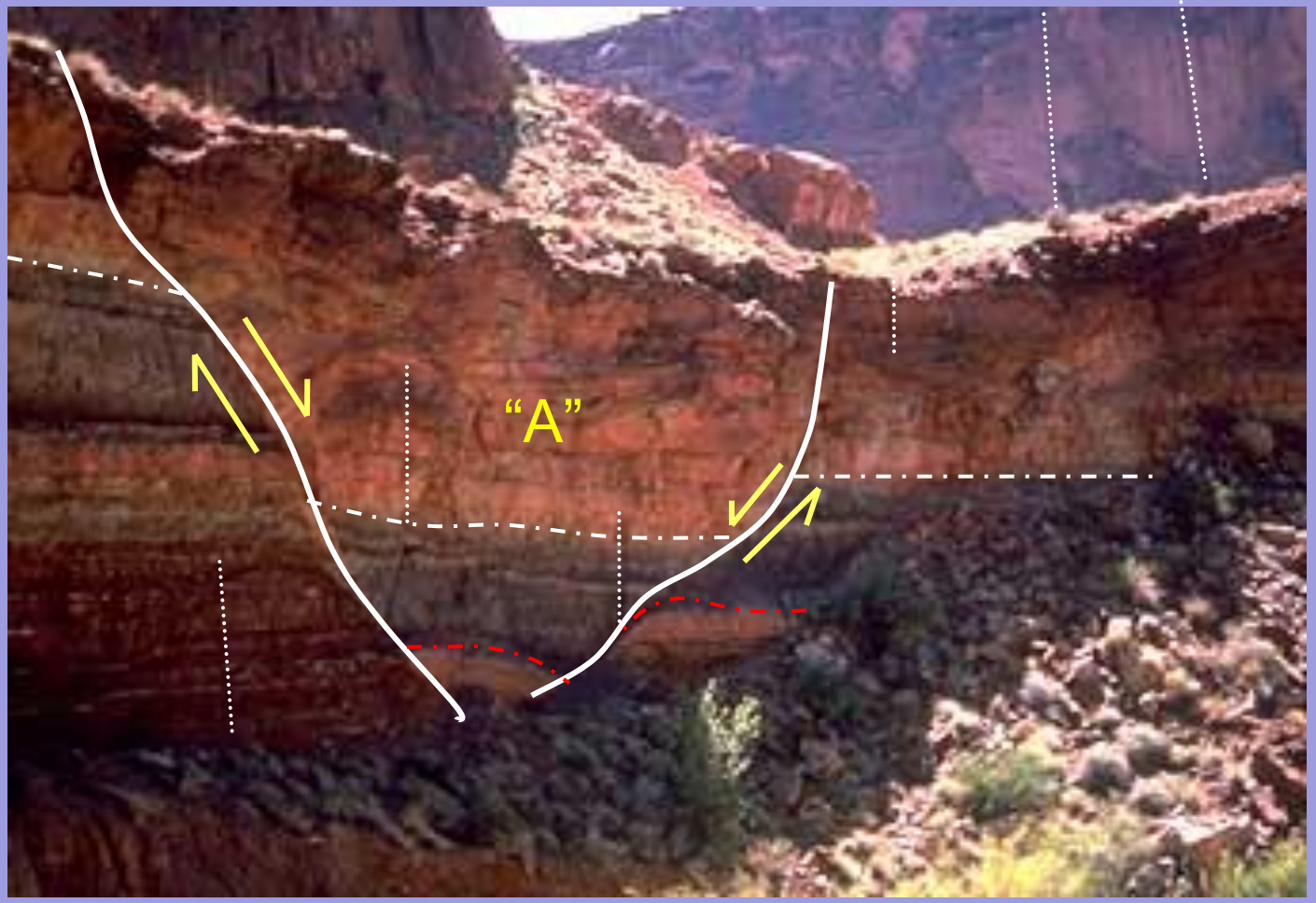
Plastic (Ductile) Deformation of Rocks: **Permanent solid-state deformation in which there is no loss of cohesion at the scale of crystals and larger**

- **Due to flow at the atomic scale**
- **Favored by higher temperature and lower strain rate**

FOLD: A wavelike undulation that develops due to ductile deformation of layered rock.

Folds are curves, which are like an alternation of convex and concave waves. For geometrical point of view, the concave areas are called *synclinal* and the convex areas *anticlinal.*





What is it?

(1) Is "A" in the hanging wall or footwall of the faults (bold white lines)?

(2) What types of faults are the bold white lines?

(3) Do the faults accommodate shortening or lengthening?

(4) What structures do the dotted lines represent?

(5) What kind of folds do the red dash-dot lines represent?

Why are folds important?

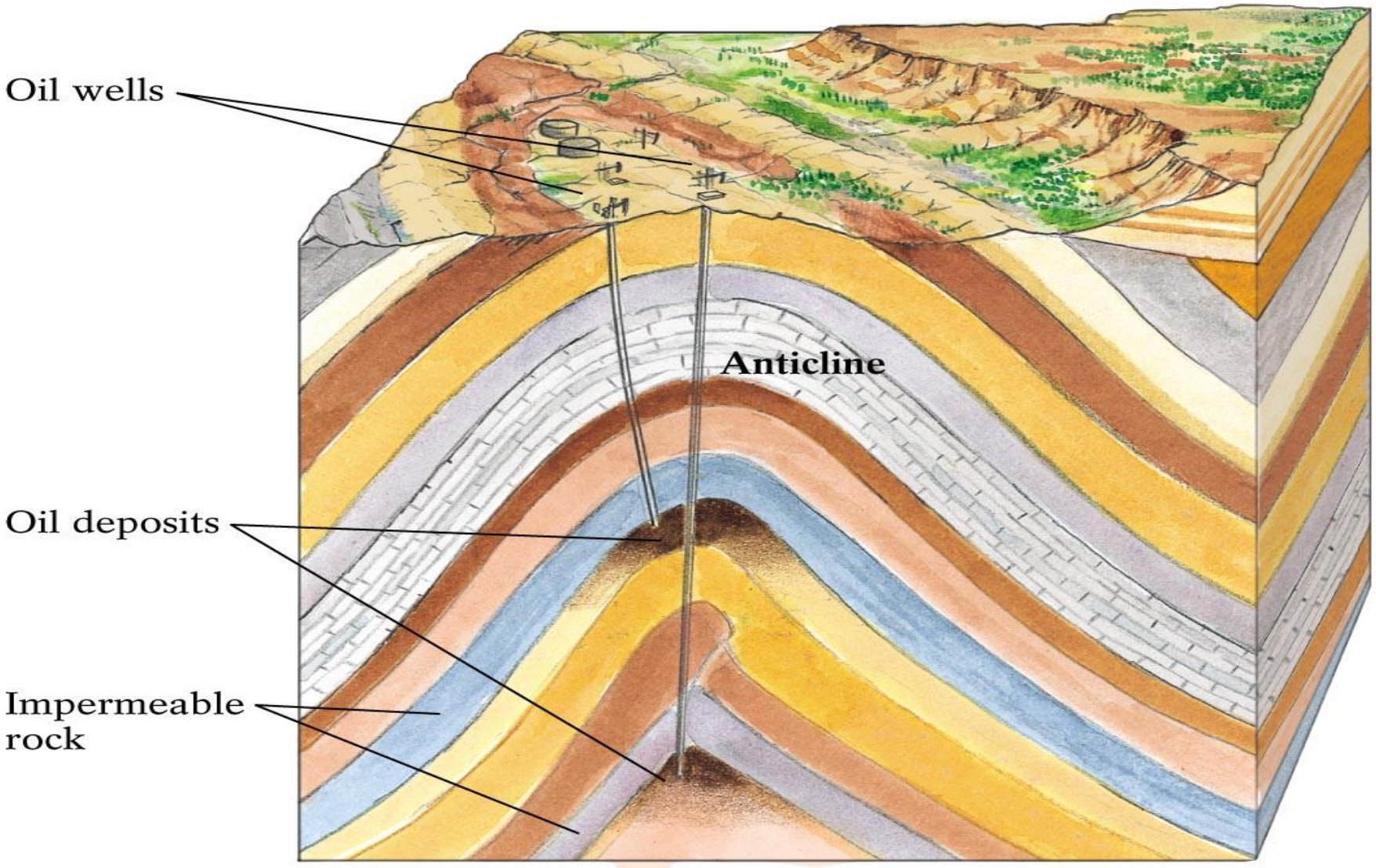
Fundamental to deformation of the Earth's crust

- **The shape, orientation and extent of folds can be of critical importance in finding economically valuable deposits and In predicting continuations of known deposits.**

Why are folds important?

- **Oil and gas are commonly trapped in the up-bowed parts of folds. Ore deposits may be concentrated in the most sharply curved areas of folds (in hinge zone) or located in *particular layers* that have been folded.**

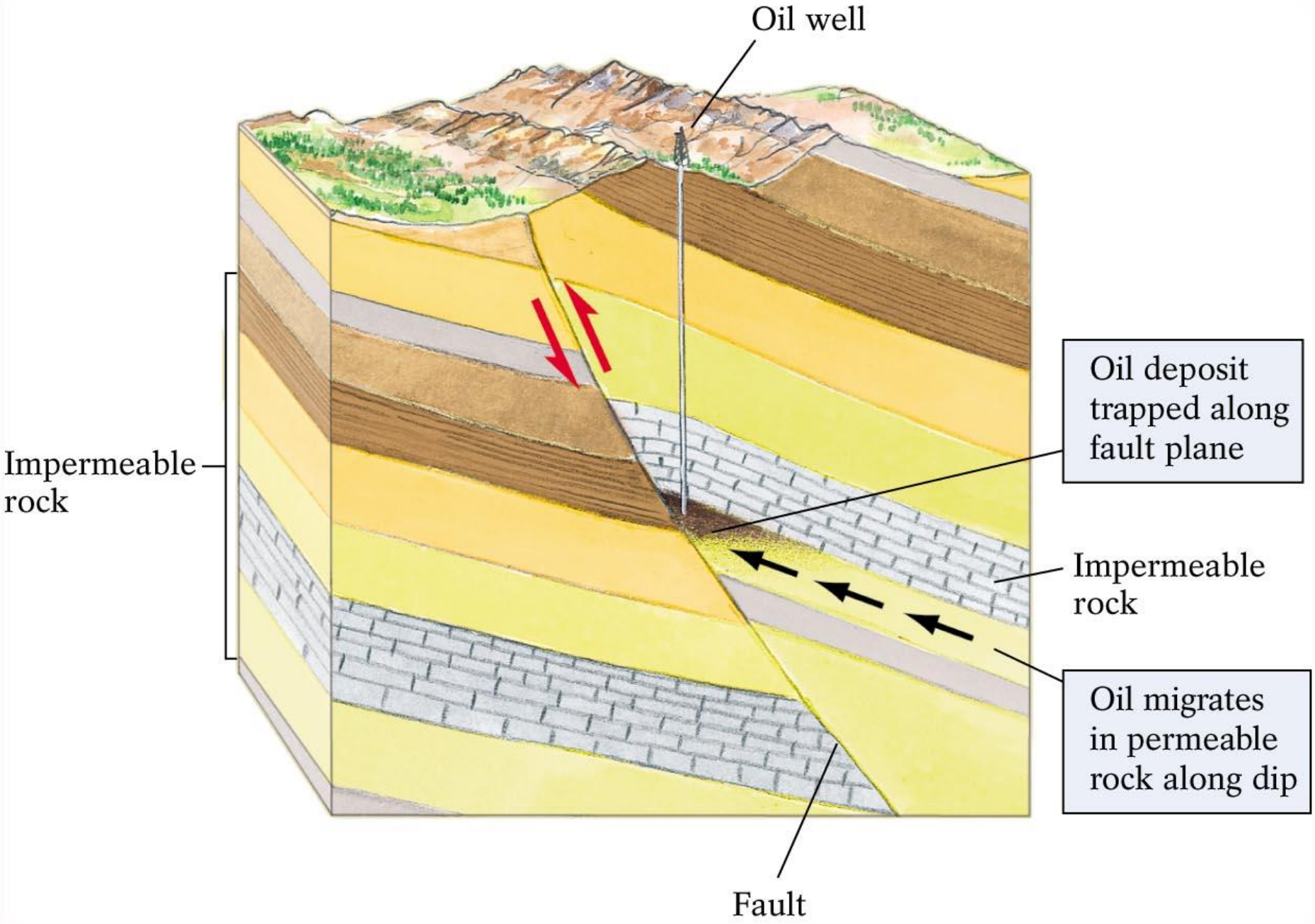
- **Beyond their economical importance, however, folds provide a record of tectonic processes in the earth and explain *the deformation of earth crust*. (i.e.** Fundamental to deformation of the Earth's crust)


Oil wells
Anticline
Oil deposits
Impermeable rock

Structural traps for oil

Controls ore geometry in strata-bound deposits

Faults and Oil



Geometric analysis

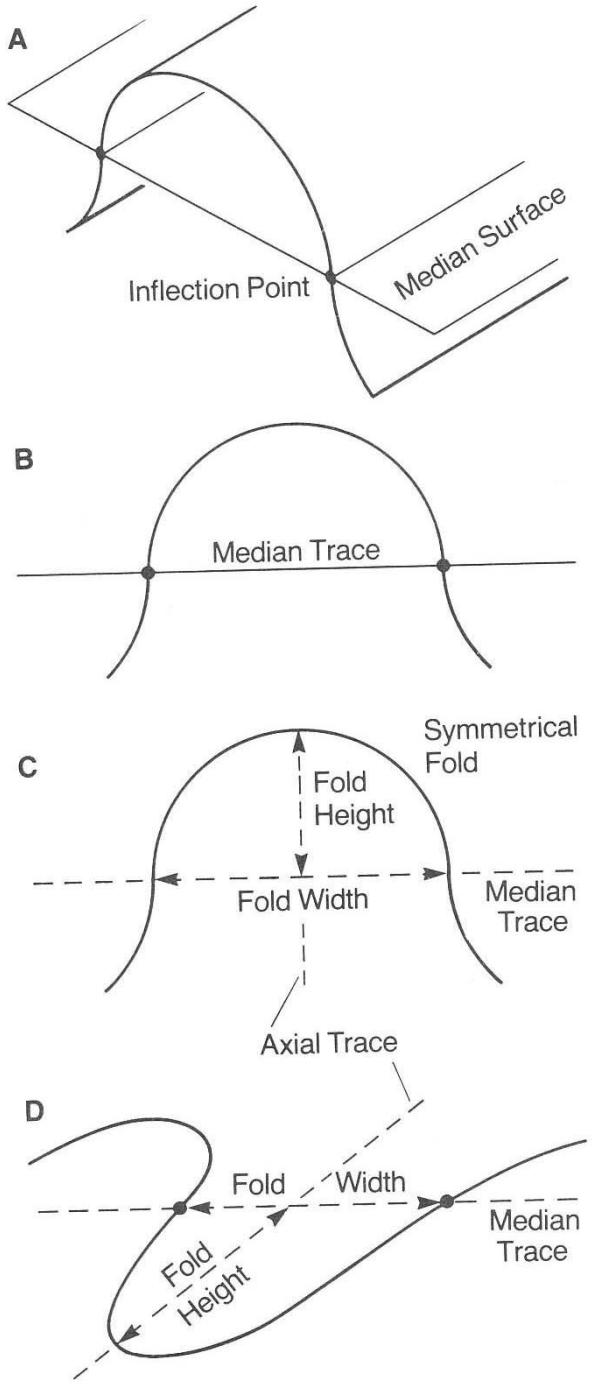
Folds are 3-dimensional structures

inflection point: point of opposing convexity

median surface: imaginary surface connecting inflection points

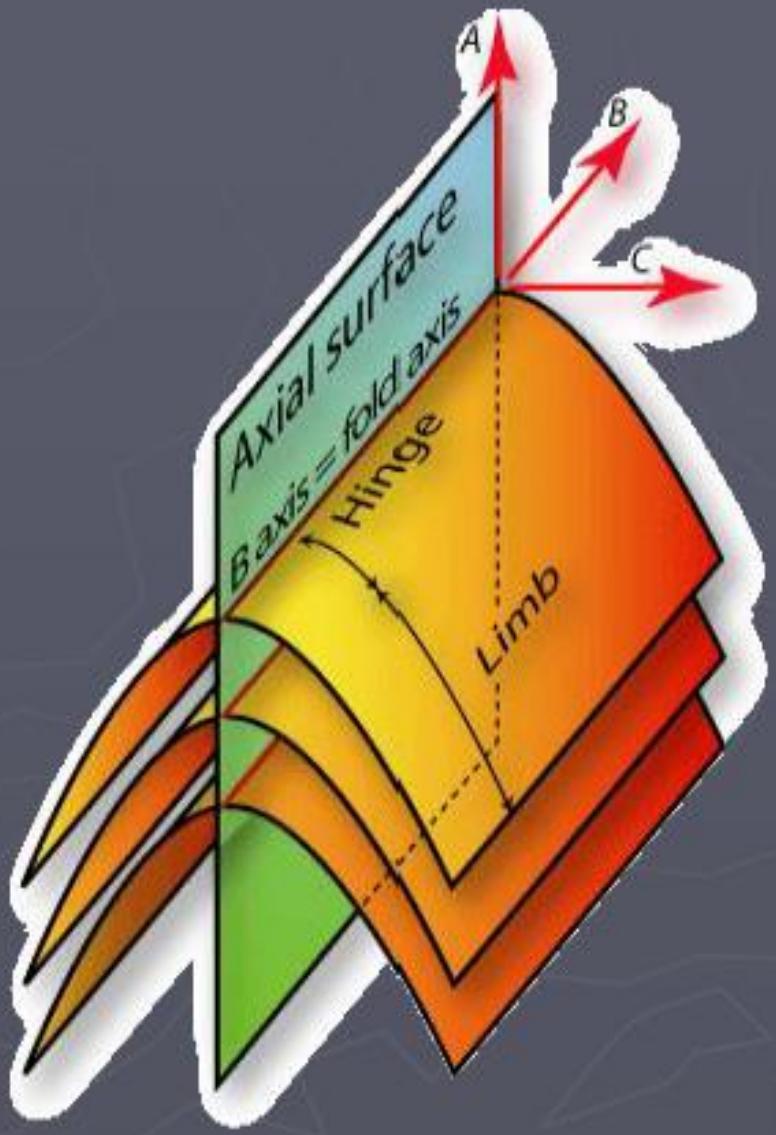
fold width, fold height

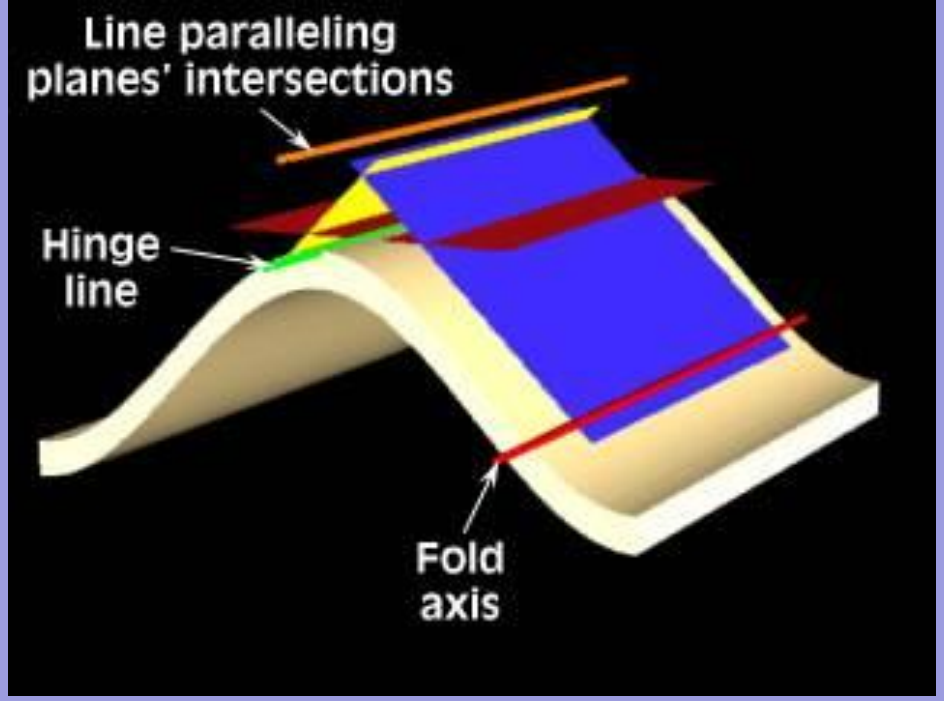
symmetrical vs. asymmetrical



BASIC FEATURES OF A FOLD

- HINGE: The zone of maximum curvature in a fold
- LIMB: the relatively planar segment between hinges
- AXIAL SURFACE/PLANE: the plane that bisects a fold
- FOLD AXIS: The line that is defined by the intersection of the folded surface and the axial plane





axial surface: surface that passes through successive hinge lines

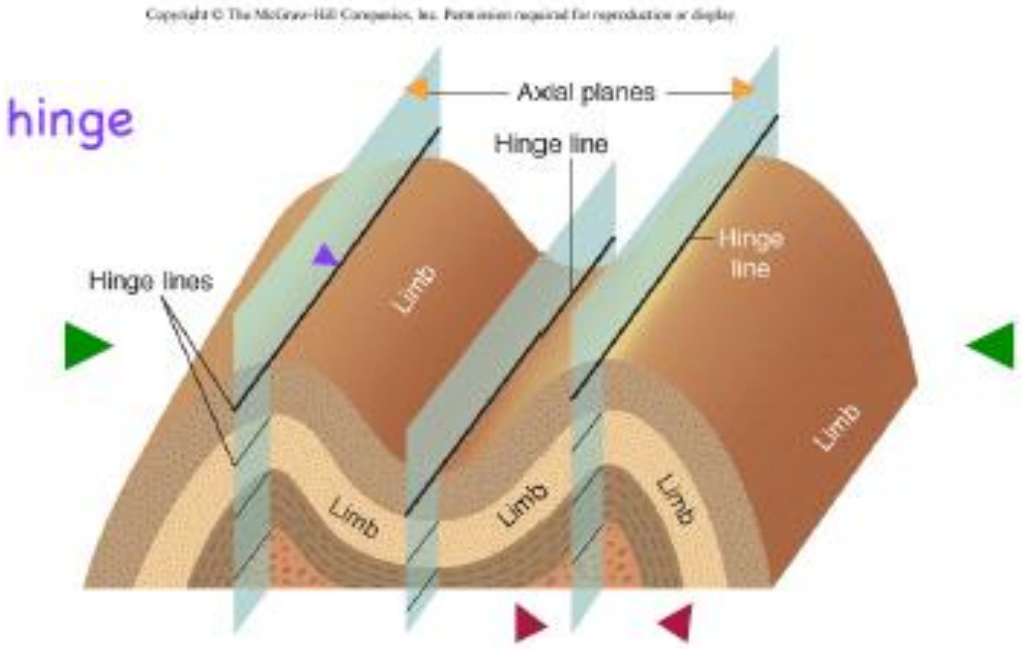
axial trace: line of intersection of axial surface and ground surface

symbology: anticline, syncline, antiform, synform

folds

wavelike bends in layered rock

- represent ductile deformation
- form during compression



fold divided into two limbs by its axial plane

hinge is where fold curves

axial surface: surface that passes through successive hinge lines

axial trace: line of intersection of axial surface and ground surface

symbology: anticline, syncline, antiform, synform

Classification of Folds

❑Based on Curvature

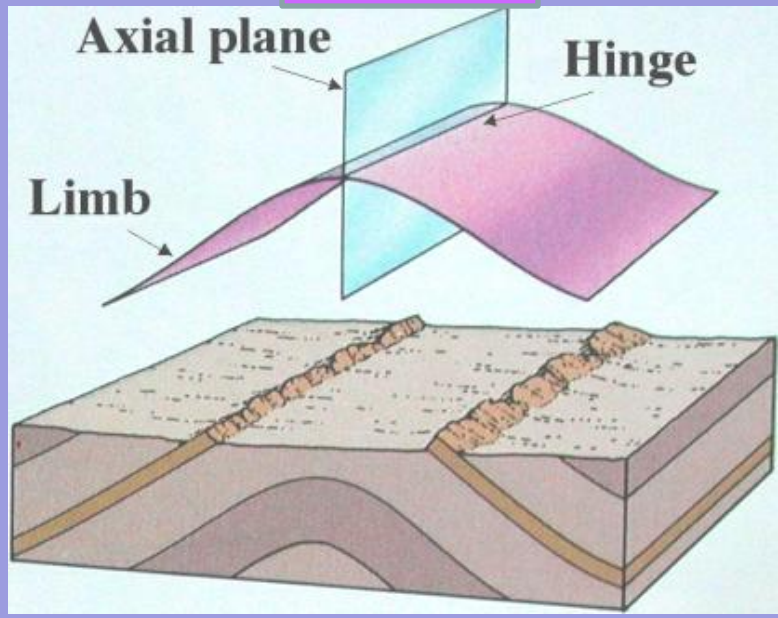
Antiform & Anticline:

- Folds that open downward are called antiforms.
- An anticline is a specific type of antiform in which the oldest beds are in the center of the fold.

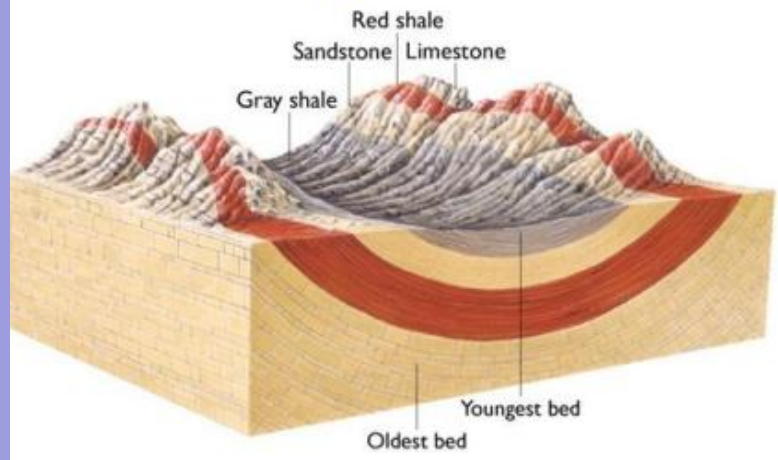
Synform & Syncline:

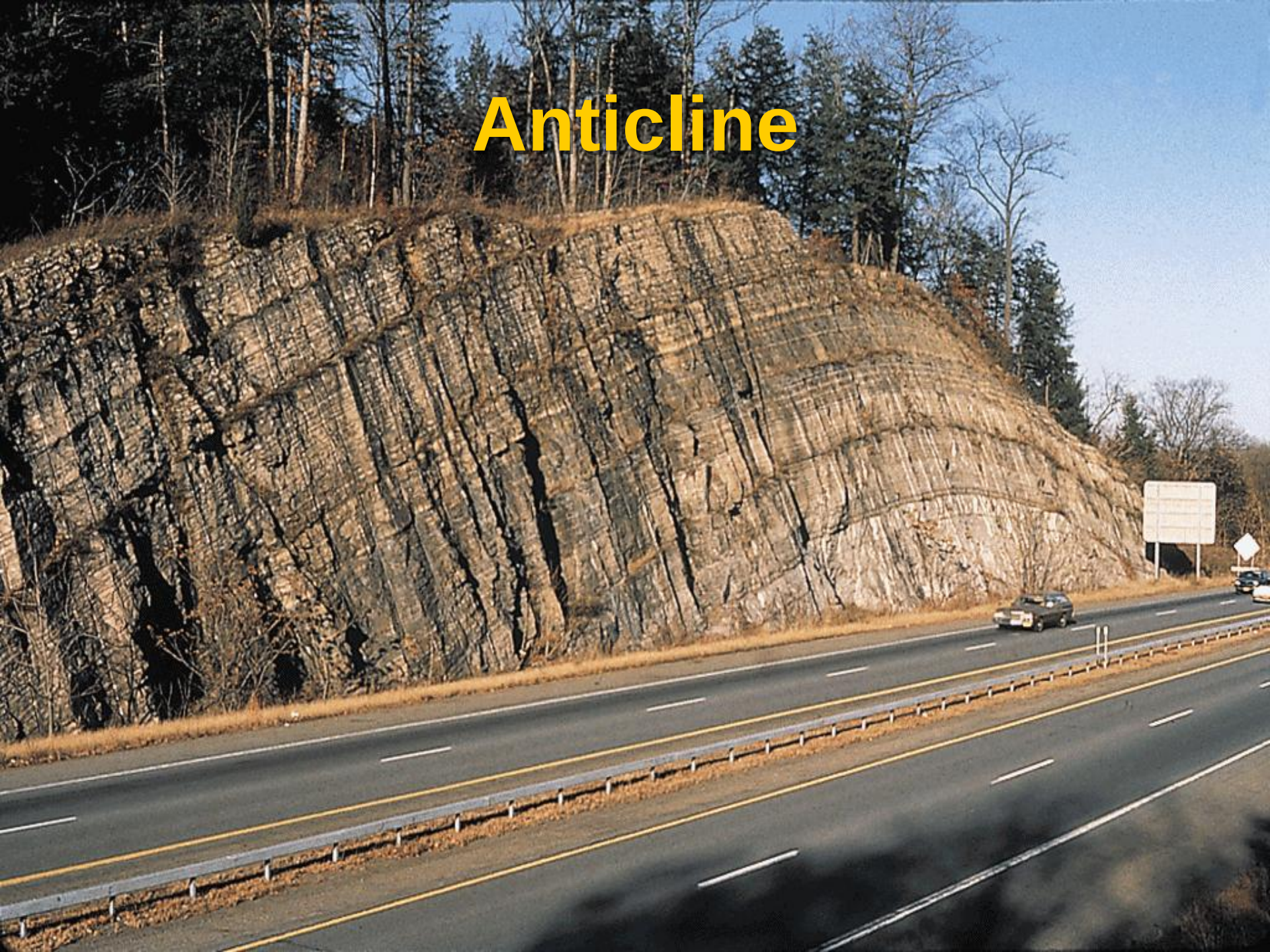
- Folds that open upward are called synforms
- A syncline is a specific type of synform in which the youngest beds are in the center of the fold.

Anticline



Syncline

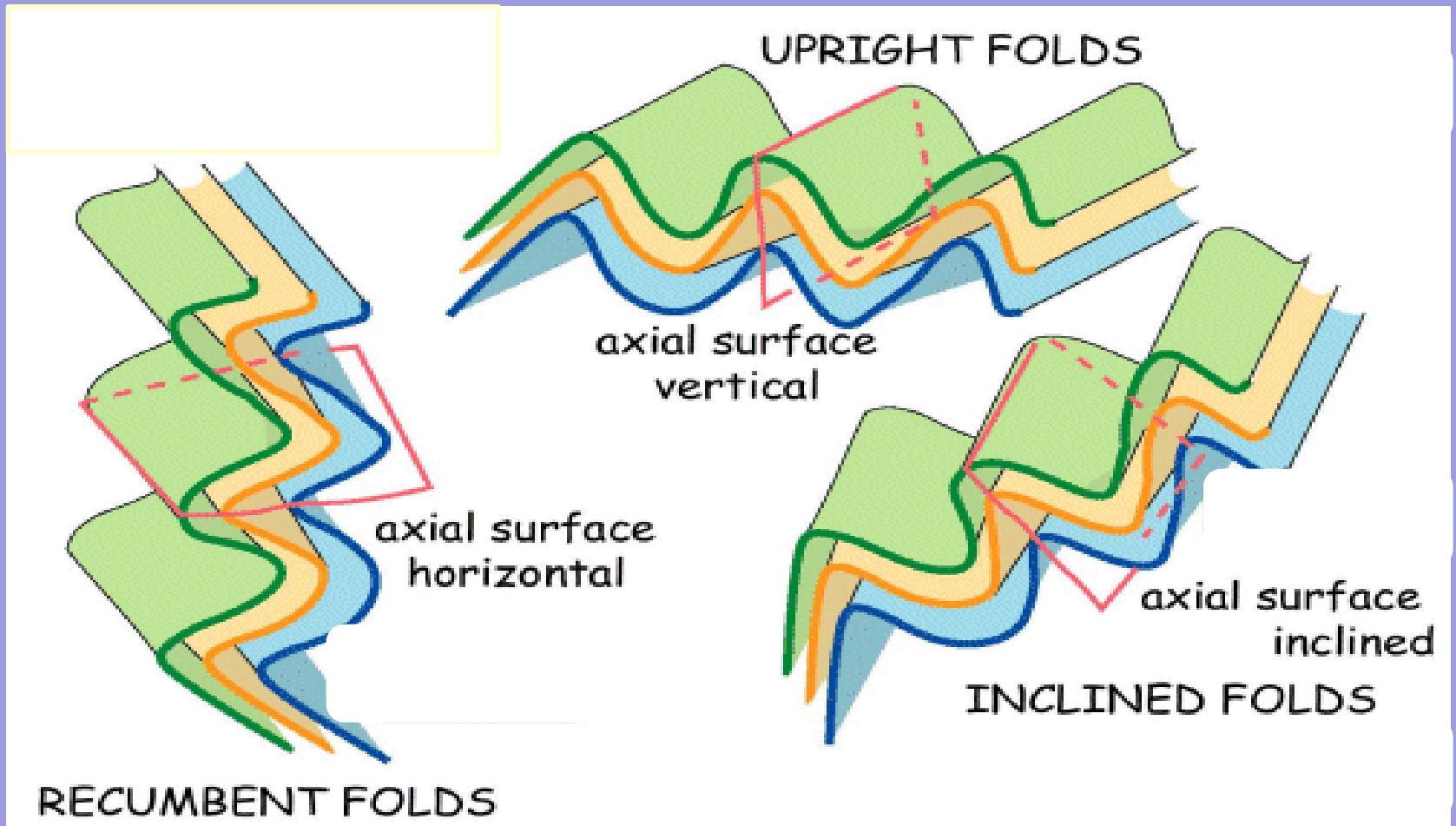



Anticline


Syncline

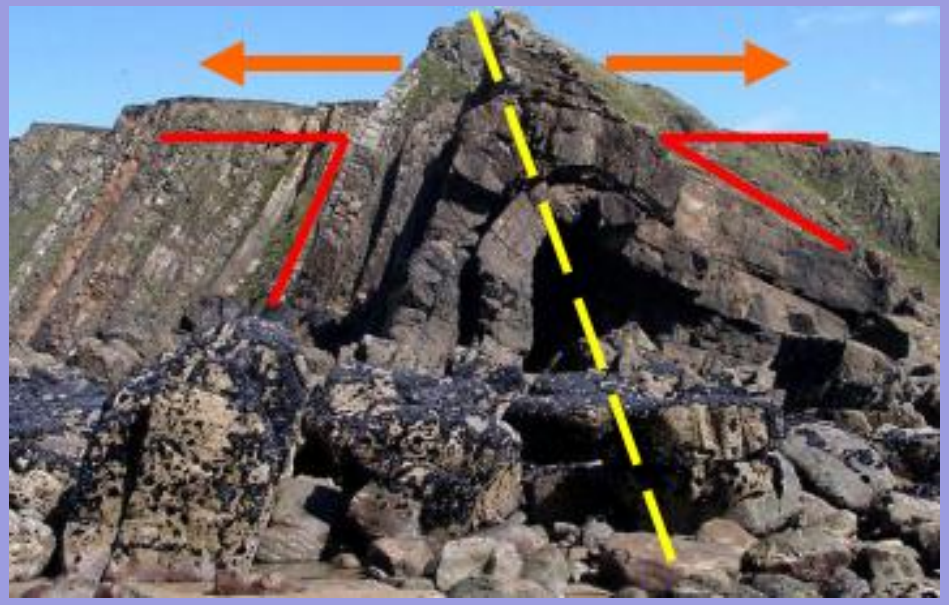
❑Based on Orientation of Axial Plane

- **Folds can be classified based on the dips of limbs and the axial plane**
- **The spectrum of fold orientations generally corresponds to a gradient in strain**

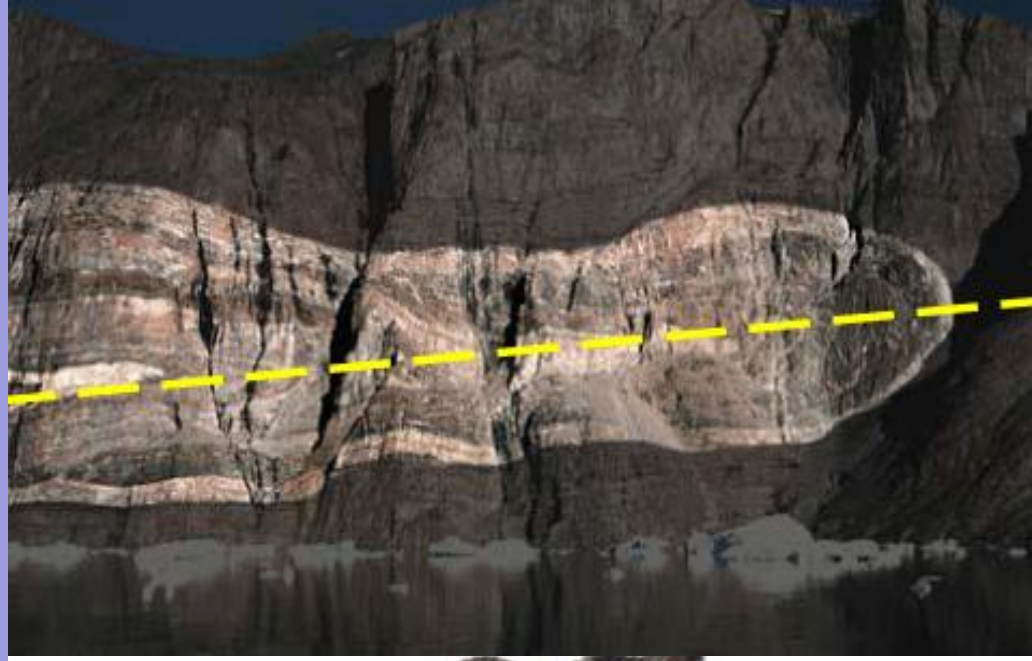


UPRIGHT FOLD: Vertical AP, Dip Direction of limbs are opposite but Dip Angle is equal

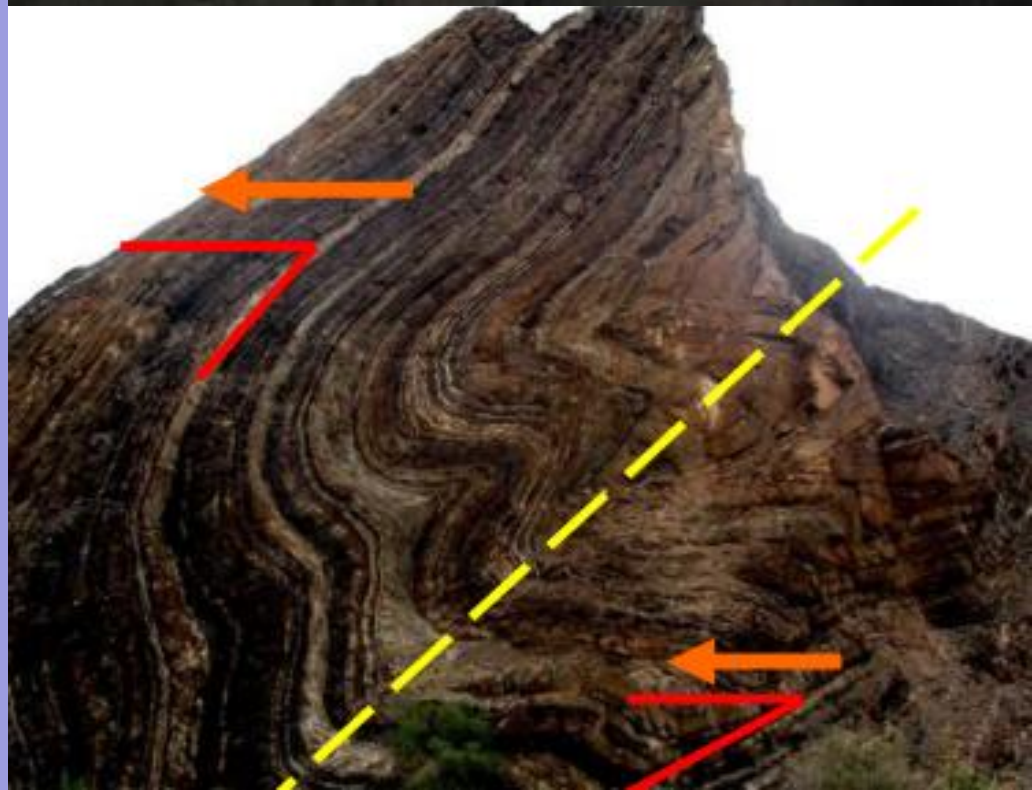
INCLINED FOLD: Non-vertical AP, Dip Direction of limbs are opposite, Dip Angles are different, both limbs are upright



RECUMBENT FOLD: Horizontal AP, one limb is upside-down



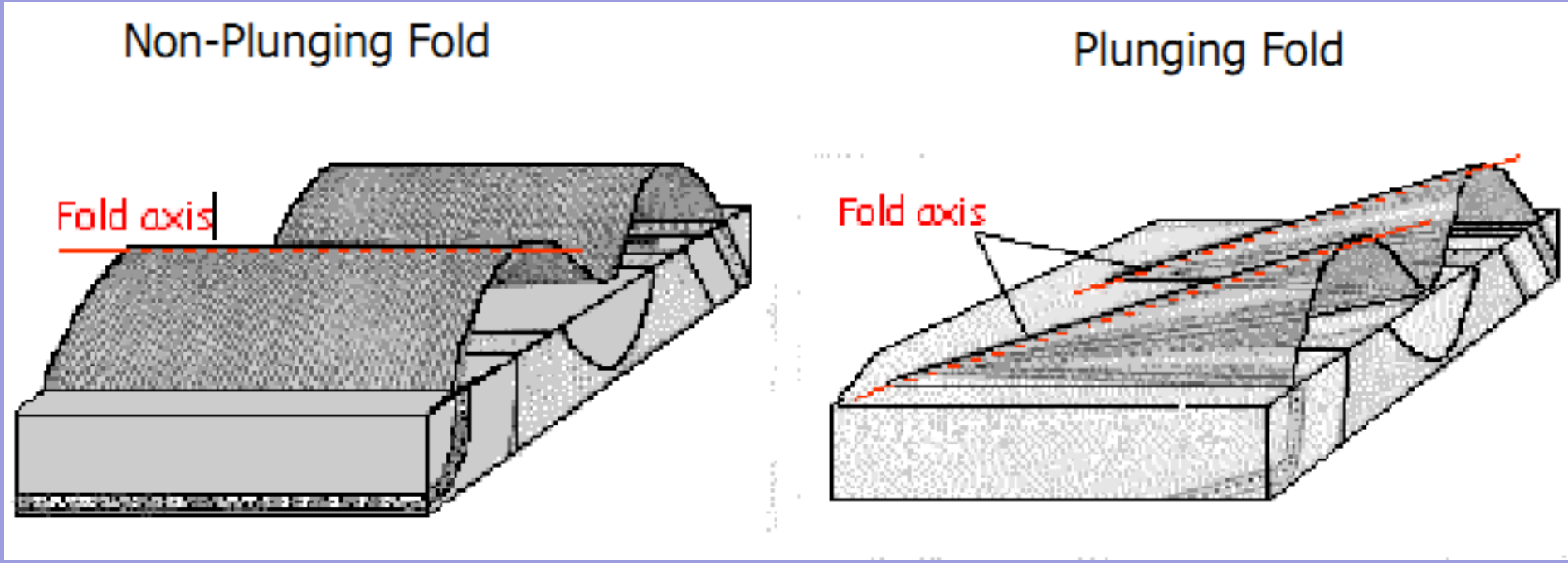
OVERTURNED FOLD: Non-vertical AP, Dip Direction of limbs are the same, Dip Angles are different, one limb is upside-down



❑ FOLD CLASSIFICATION BY FOLD AXIS

Folds can be classified based on the orientation of the fold axis

- Horizontal or Non-Plunging
- Plunging(Shallow, Moderate, Steep, Vertical, North, South, East, West, etc)



TREND and PLUNGE

►Strike and dip define the orientation of planar features (e.g., fault, axial plane)

►Trend and plunge define the orientation of linear features (e.g., fold axis)

- Trend is measured as azimuth (0-360) pointing in the plunge direction
- Plunge is the angle measured from the horizontal to the line (0-90)

❑FOLD CLASSIFICATION BY *INTERLIMB ANGLE*

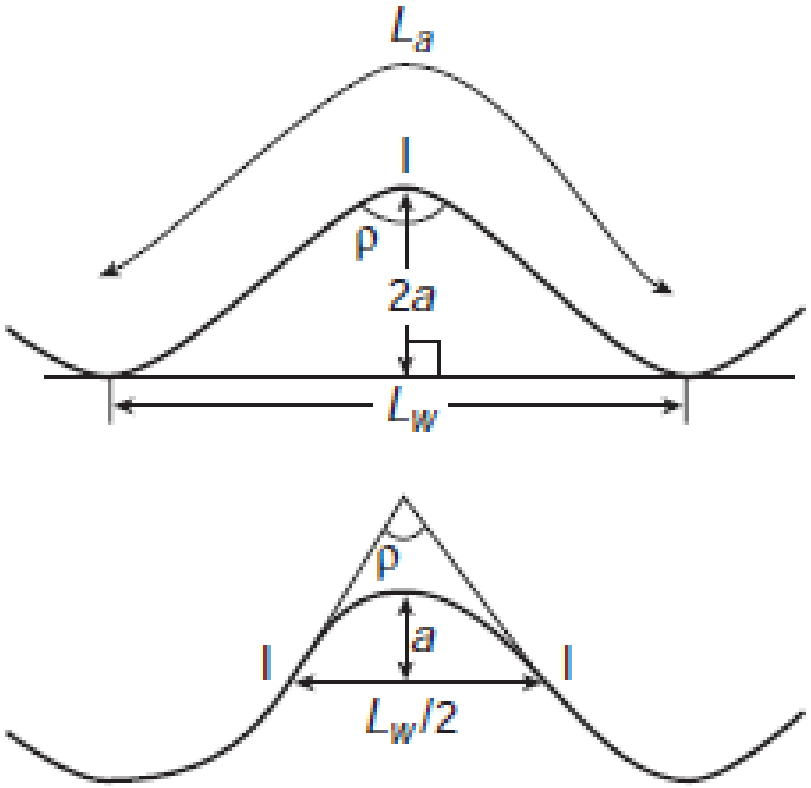


FIGURE 10.4 The interlimb angle (ρ), the wavelength (L_w), the amplitude (a), and the arc length (L_a) of a fold system in profile.

Gentle: 120-180

Open: 60-120

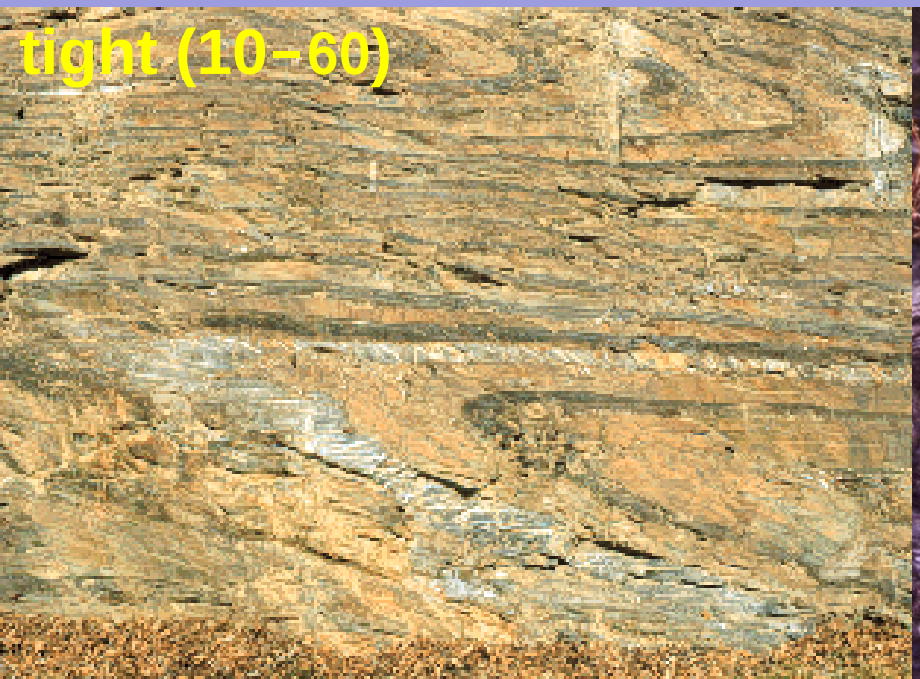
Tight: 10-60

Isoclinal: 0-10

- **Folds can be classified based on the angle from limb to limb**
- **Decreasing interlimb angle corresponds to an increase in strain**


gentle (>120)

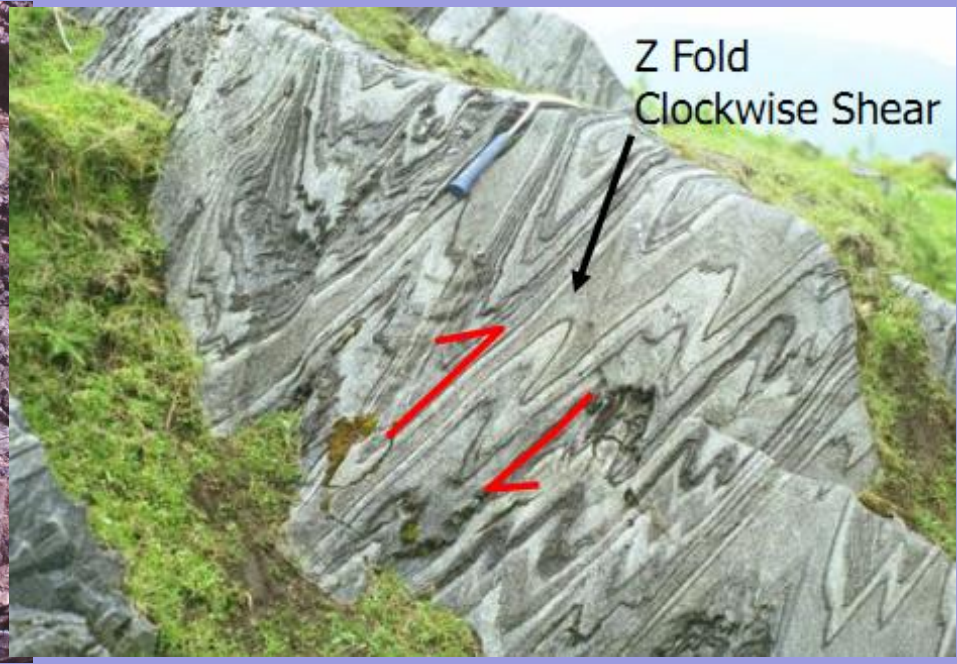

open (60-120)


tight (10–60)


isoclinal (0~10)

SPECIAL FOLDS: ASYMMETRIC FOLDS

- **One limb is longer than the other**
- May be described as S-folds or Z-folds, or as counterclockwise and clockwise vergence
- Asymmetric folds record the sense of shear



SPECIAL FOLDS: CHEVRON FOLDS

- Characterized by planar limbs and a narrow hinge zone and symmetrical form

Chevron: planar limbs meet at discrete hinge point

SPECIAL FOLDS: PTYGMATIC FOLDS

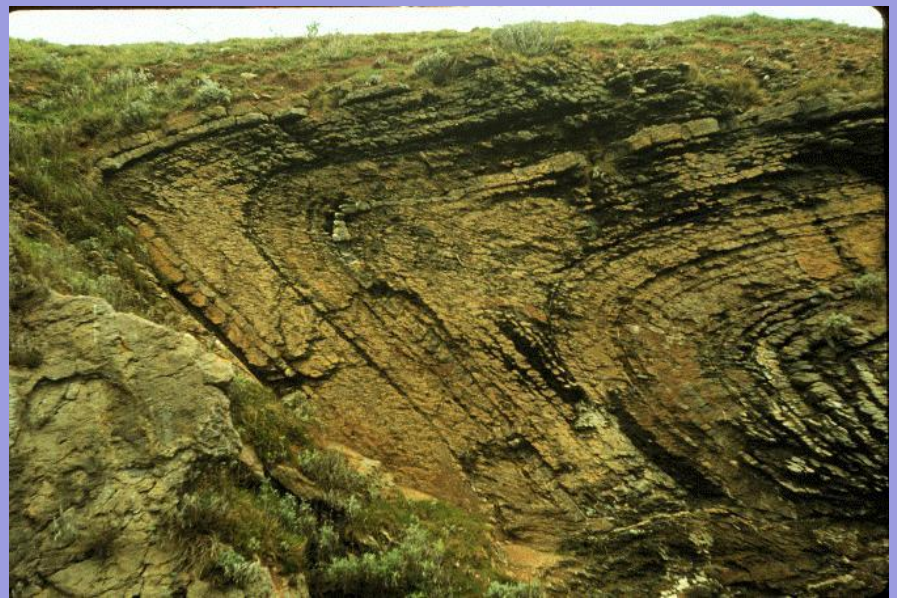
- Disharmonic in nature: Shape or wavelength changes from one layer to another

- Indicate that the viscosity of the folded layer was much greater than that of the matrix

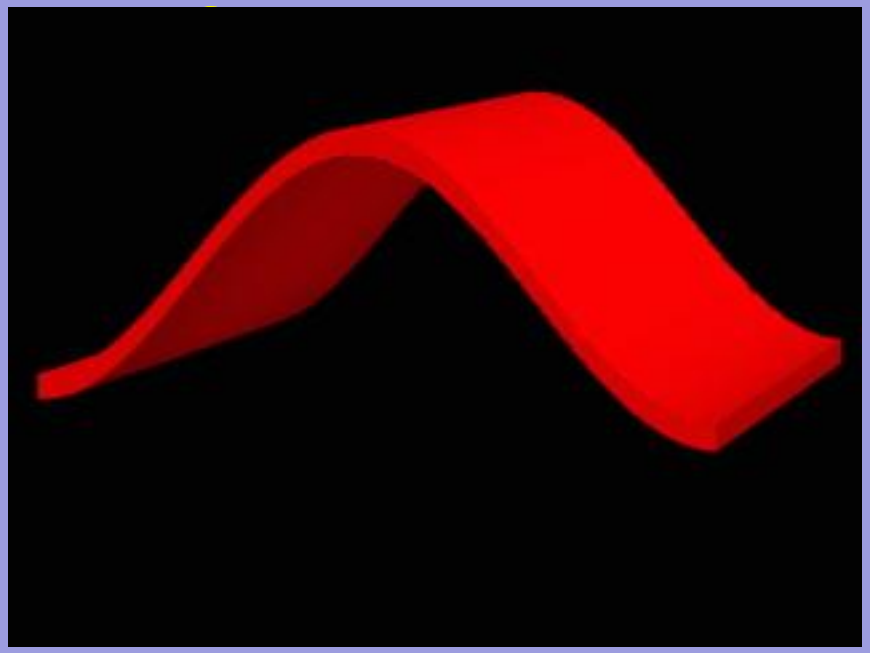
Circular fold
"lift-off" fold

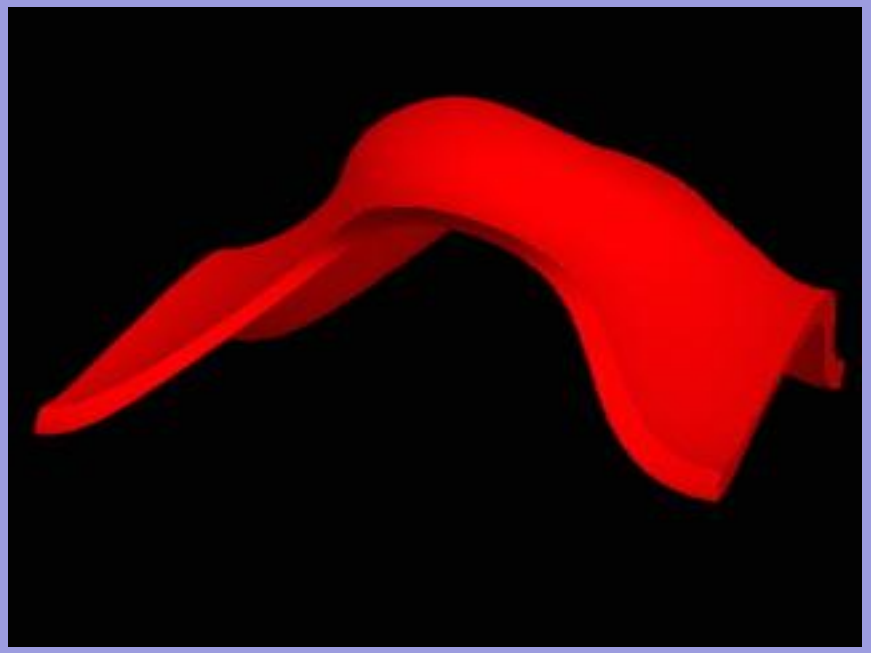
parallel/concentric folds: layer thickness does not change

similar folds: layer thickness changes; thickening in hinge and thinning along limbs



Cylindrical: well-defined axial



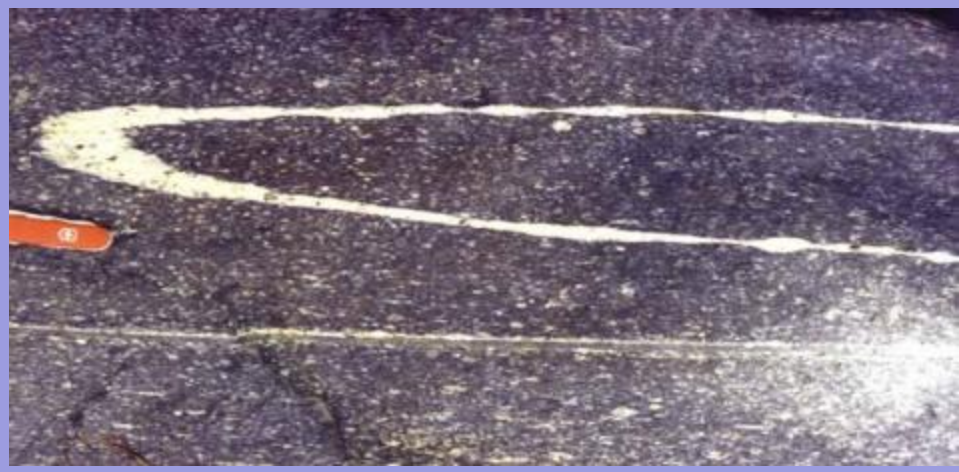


non-cylindrical: too complex to have a single well-defined axial surface

monocline: step-like fold, only one limb

PASSIVE FLOW: flow of material within layers in response to stress

- Forms in incompetent layers
- Forms similar folds

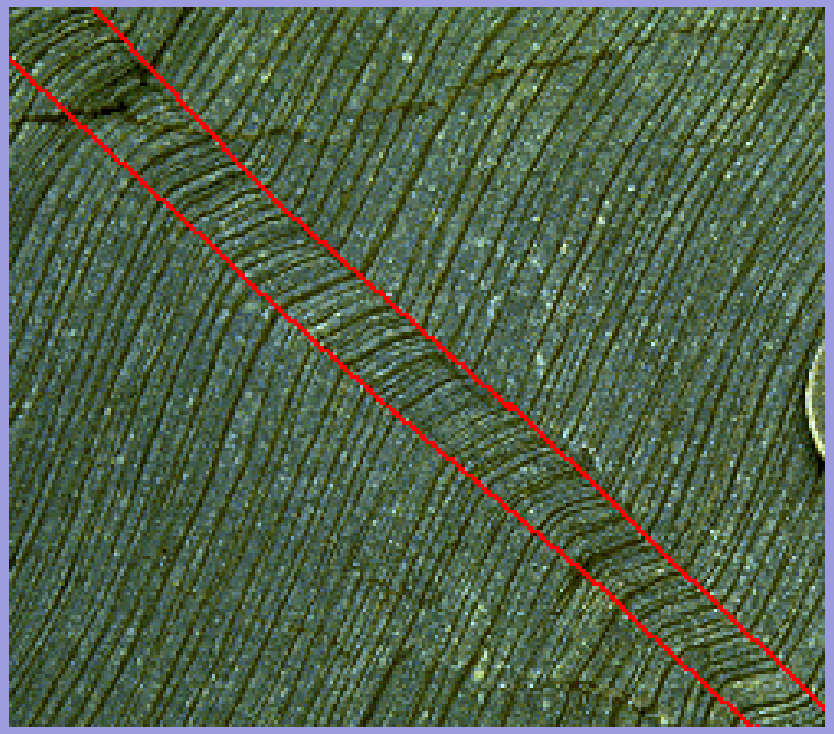


Folded folds!

Multiple episodes of deformation may result in the refolding of folds

Special Folds: Kink folding

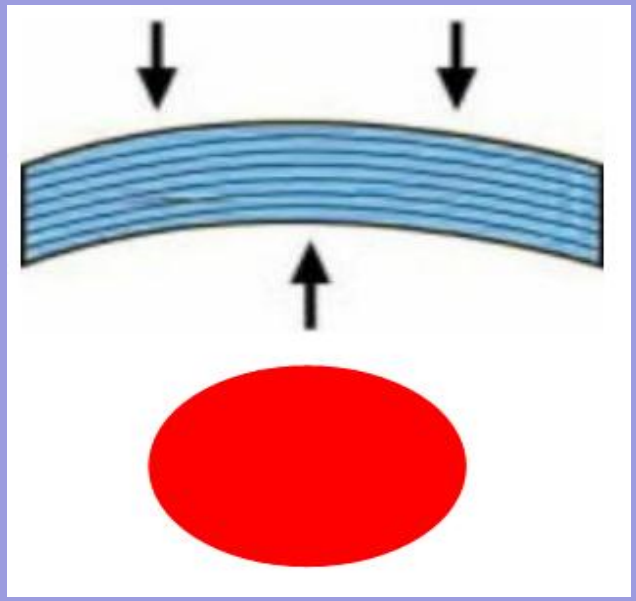
- Occurs when there is strong cohesion between layers
- Marked by sharp hinge, straight limbs (one short, two long)



FOLDING MECHANISMS

BENDING: folding that occurs when pairs of forces are applied to a layer

- For example, regionally gravity provides a downward force, but above a rising pluton there is an upward force
- Produces a bend



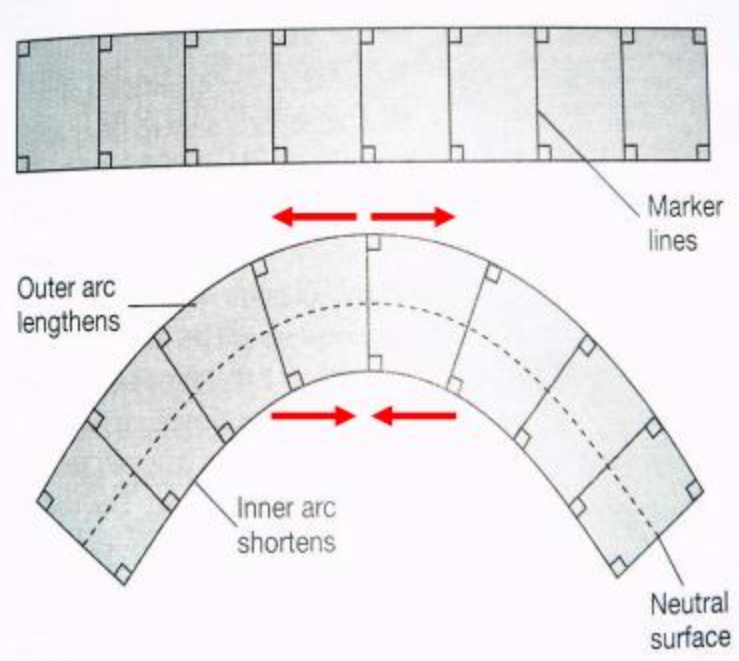
BUCKLING: Folding that occurs when compression is applied perpendicular to a layer

- Regional horizontal compression forms such folds

FOLDING MECHANISMS

ORTHOGONAL FLEXURE: the lines that were perpendicular to the layer before folding remain perpendicular after folding

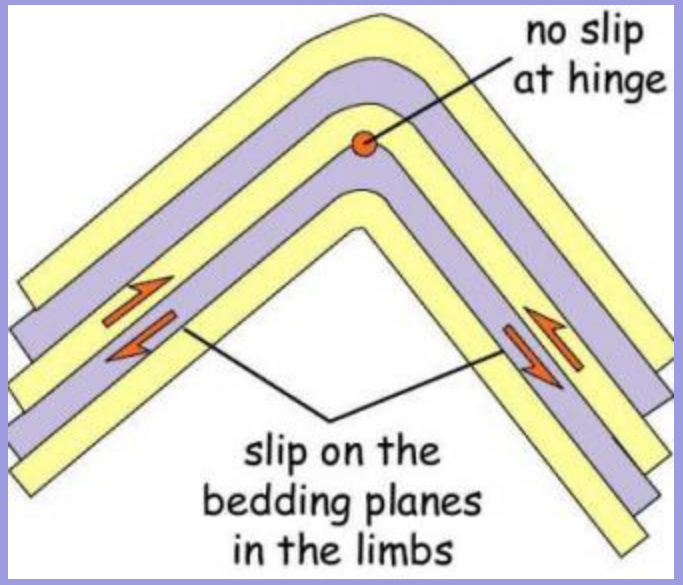
- The inner arc shortens (compression)
- The outer arc lengthens (extension)
- Forms low curvature folds
- Forms parallel folds
- Associated with competent layers



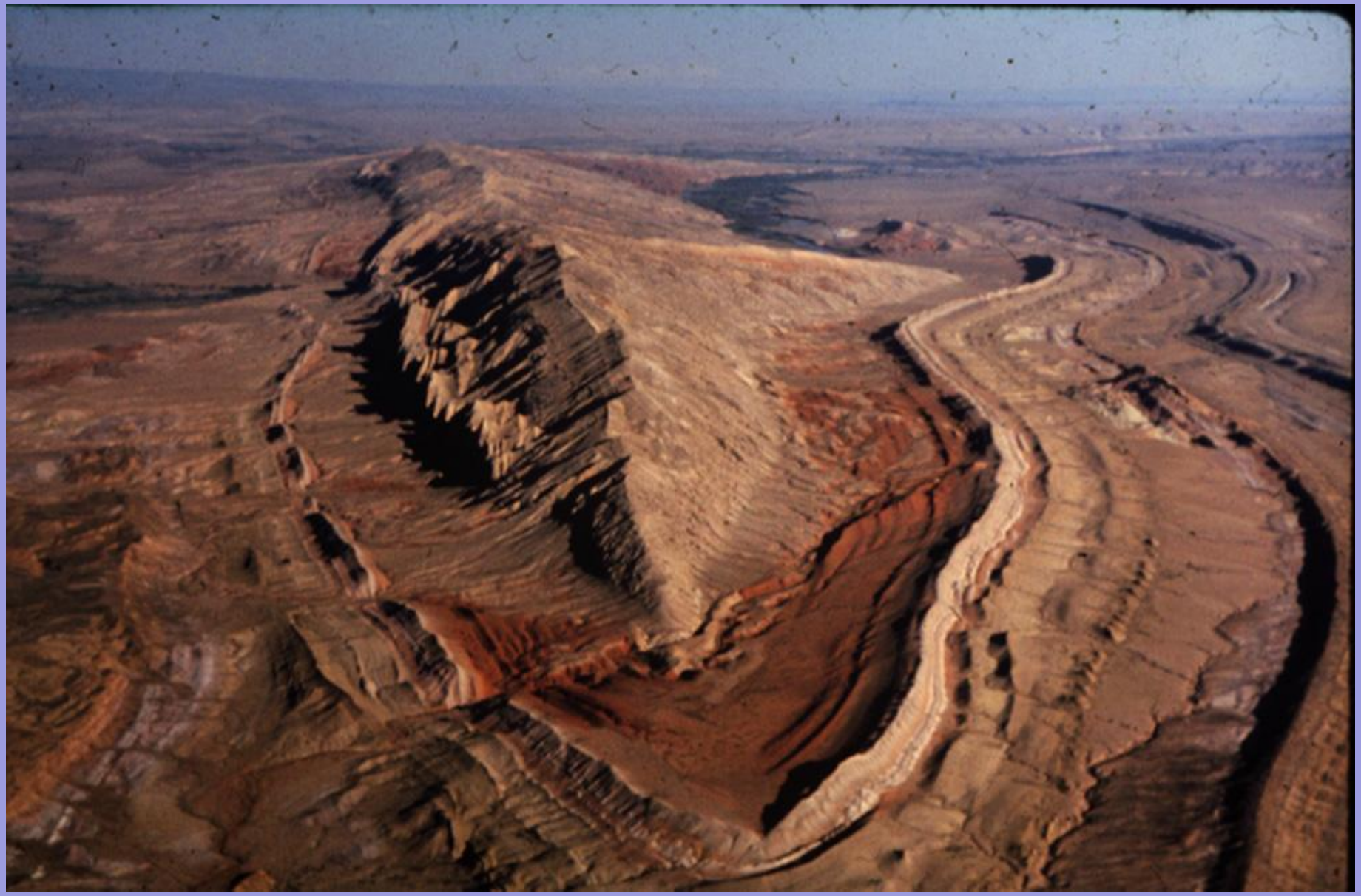
FLEXURAL SLIP:

Layers in a fold slip past each other

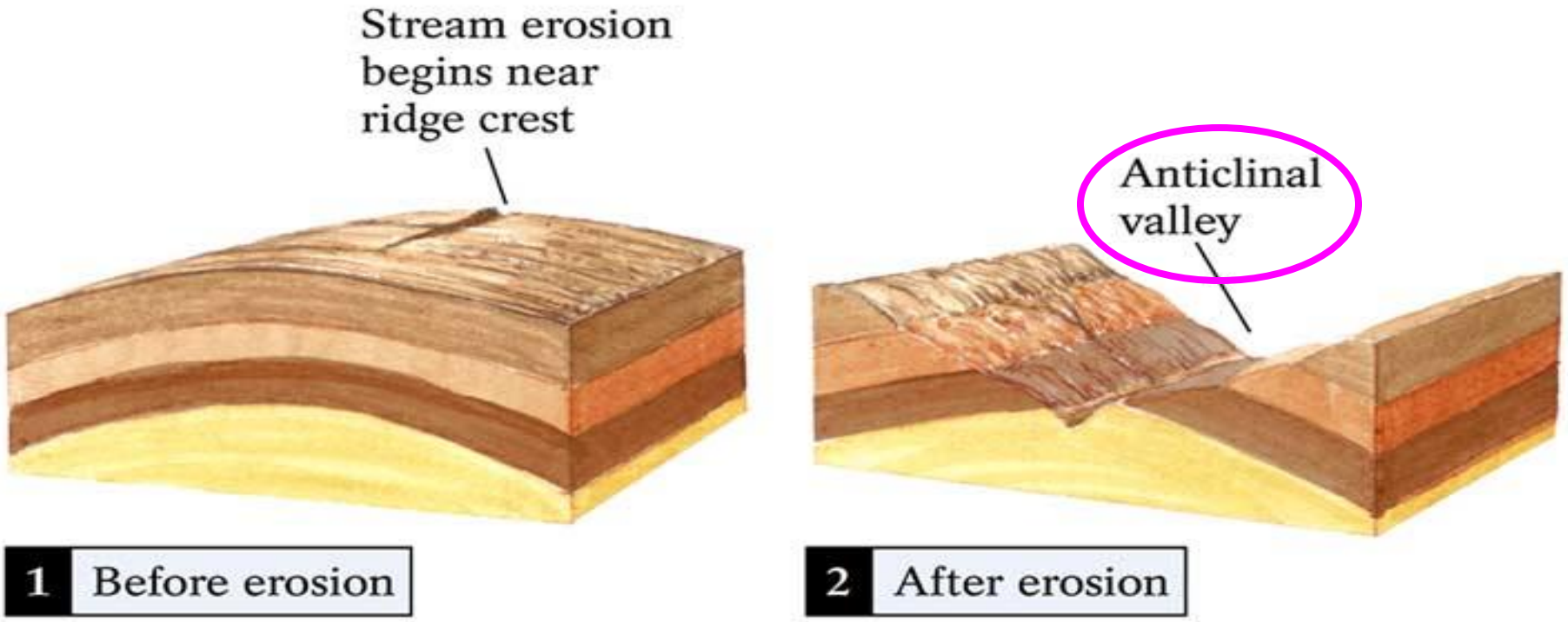
- Like folding a deck of cards
- Individual layers remain the same length
- Movement between layers along each limb
- Occurs in interbedded strata where the layers have differing competence



Topography



Topography may be opposite of Structure Anticline
Before/After Erosion

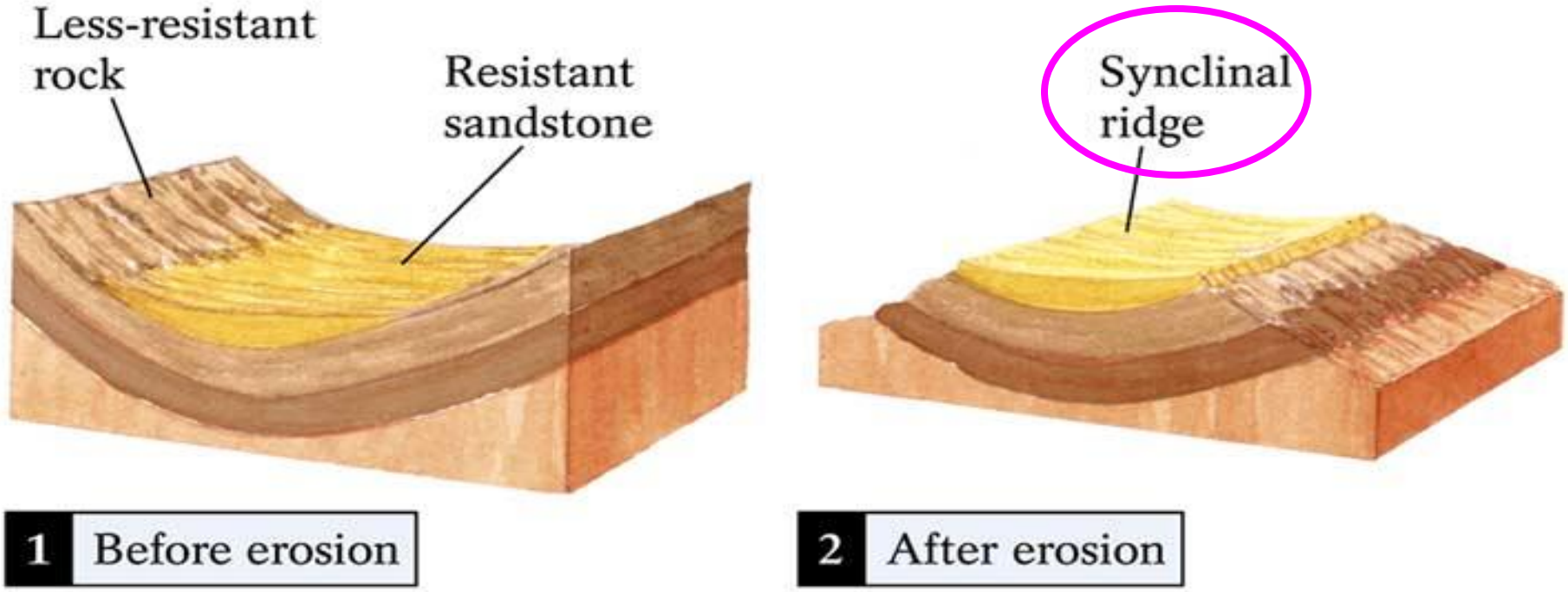


(a) Anticline with highly erodible surface

Notice center rock oldest

Topography may be opposite of Structure

Syncline Before/After Erosion



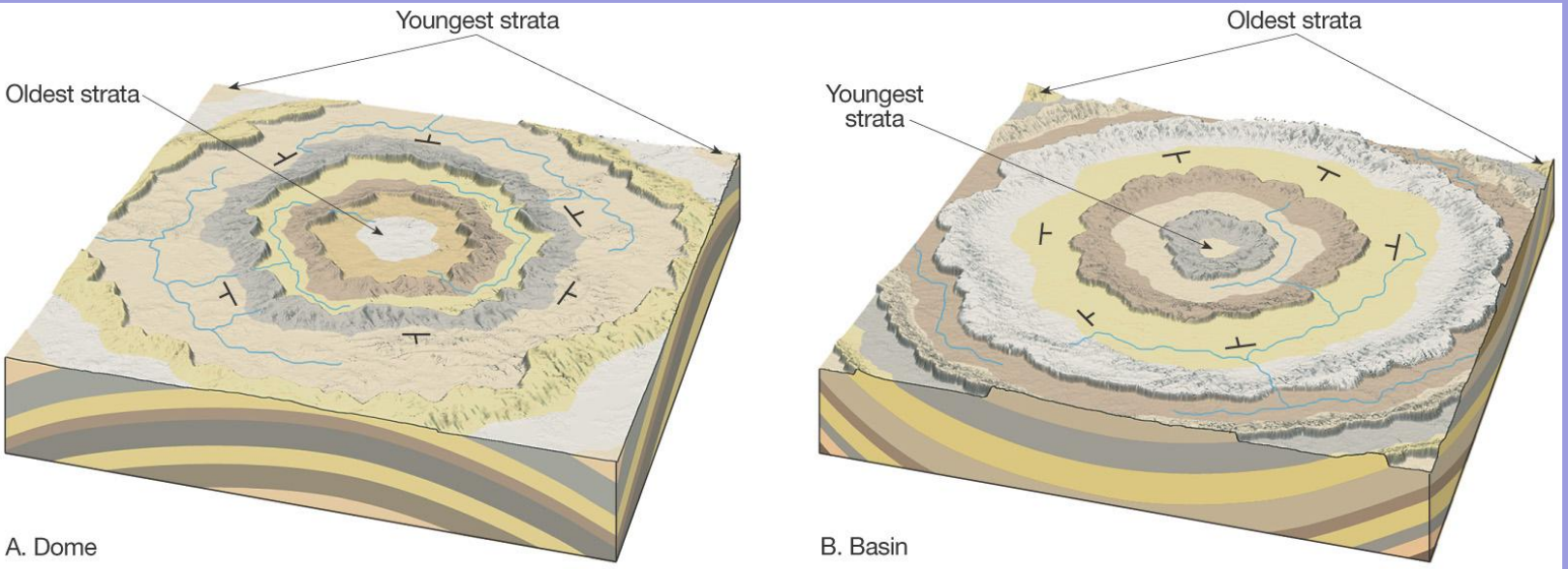
(b) Syncline with resistant rock at axis

Notice center rock youngest

Dome and Basin

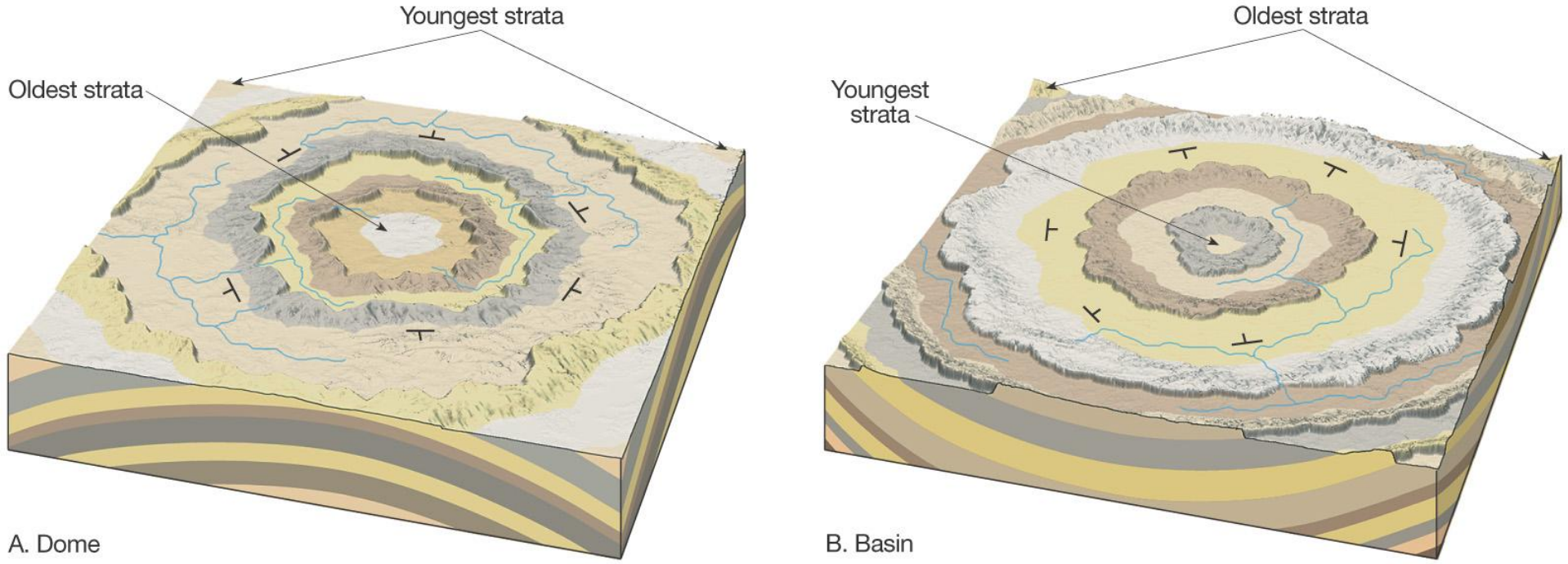
Dome is an up-arched series of strata with beds on all sides dipping away from the center ***throughout 360 degrees***--an eroded surface indicates the rocks become progressively younger away from the center of the structure

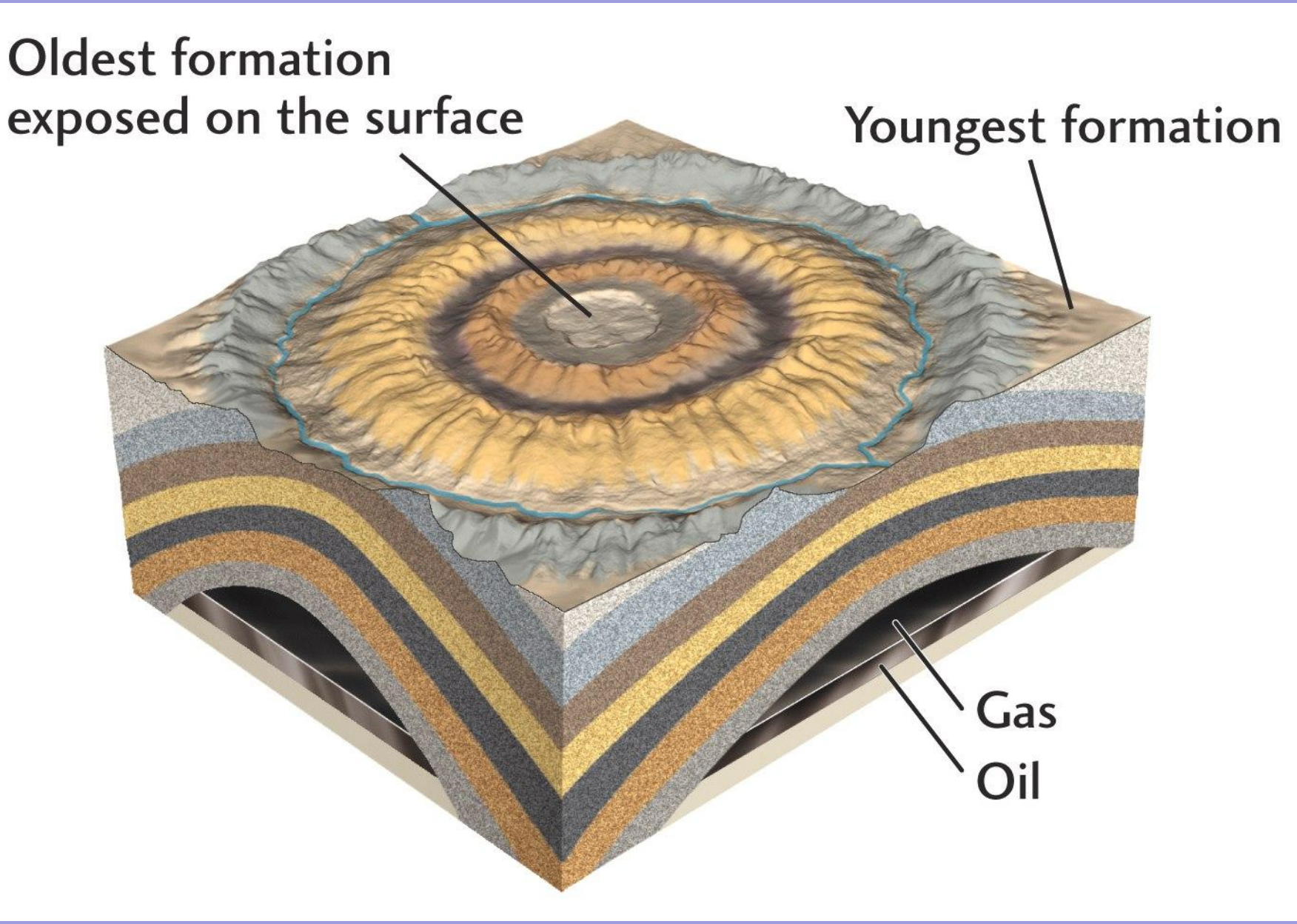
Basin is a down-arched series of strata with beds on all sides dipping in towards the center throughout 360 degrees--an eroded surface indicates the rocks become progressively older away from the center of the structure



Domes are like circular anticlines with the oldest strata exposed inthe middle.

Basins are like round synclines, with the youngest strata ex posed in the core.




Oldest formation
exposed on the surface
Youngest formation
Gas
Oil

Important terminology/concepts

- anticline
- syncline
- antiform
- synform
- anticlinorium
- synclinorium
- inflection point
- hinge line
- fold axis
- symmetrical vs. asymmetrical
- axial plane and trace
- chevron fold
- ptygmatic fold
- circular fold
- fold tightness
- recumbent fold
- box fold
- parallel/concentric vs. similar folds
- cylindrical vs. non-cylindrical folds
- monocline
- flexural-slip folding
- parasitic folds
- kink folding
- buckling instability