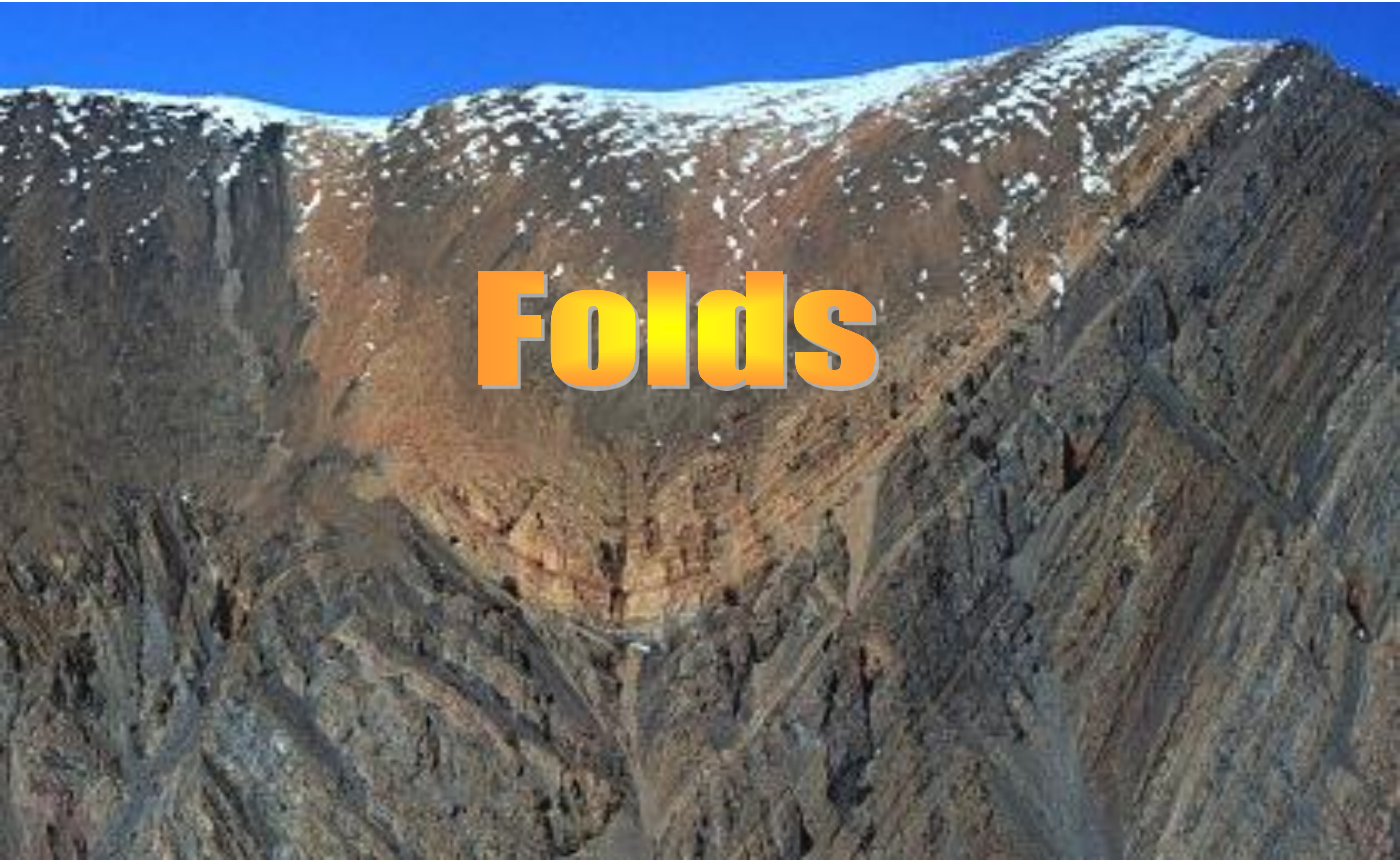
Folds



STRUCTURAL GEOLOGY

(Geological Structures: Classification of geological structures)

Structural geology deals with the study of the architecture of rocks insofar as it has resulted from deformation.

Structural geology deals with:

1. **ways in which rocks respond to the application of deforming forces and,**
2. **the structure that resulted from deformation**

The ultimate aim of structural geology is to establish the history of displacement, stress, strain rates, temperature and pressure that the crust and associated upper mantle of the earth have experienced.

FOLD

When rocks deform in a ductile manner, they may bend or fold, and the resulting structures are called *folds*.

Folds result from compressional stresses acting over considerable time. Because the strain rate is low, rocks that we normally consider brittle can behave in a ductile manner resulting in such folds.

Fundamental Structures

1. **Contacts**
2. **Primary Structures**
3. **Secondary structures**
    - Fractures (Joints, Shear Fractures)
    - Vein - Precipitated minerals from fluid flowing through fractures
    - Fault
    - Fold
    - Foliation - Preferred orientation of planar rock bodies and/or minerals
    - Lineation - Preferred orientation of linear minerals and rocks
    - Shear Zone: Zones of deformed rock that have accommodated movement

ATTITUDE OF BEDS

(Orientation of planar surface in space

Attitude refers to the three-dimensional orientation of some geological features, such as a bed, a joint, a hornblende needle, or a fold.

The attitude of planar features, such as beds, joints, fault planes is defined by their *strike* and *dip.*

The Strike

The *strike* of a bed is its trend measured on a horizontal surface.

It may also be defined as the direction of a line formed by the intersection of the bedding and a horizontal plane.

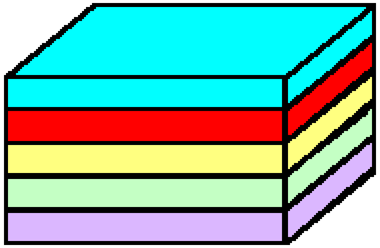
The Dip

The *dip* of a plane is the angle and direction of its inclination from the horizontal.

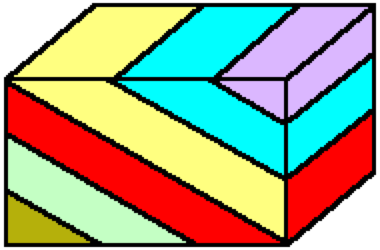
In other words it is the angle between the planar feature and a horizontal plane;

it is measured in a vertical plane that strikes at right angles to the strike of the plane.

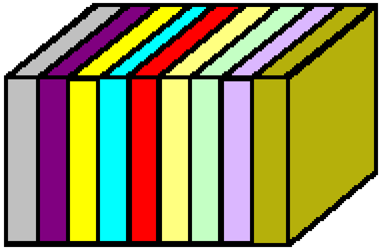
HORIZONTAL
LAYERS
Angle of dip = 0°
(No dip)

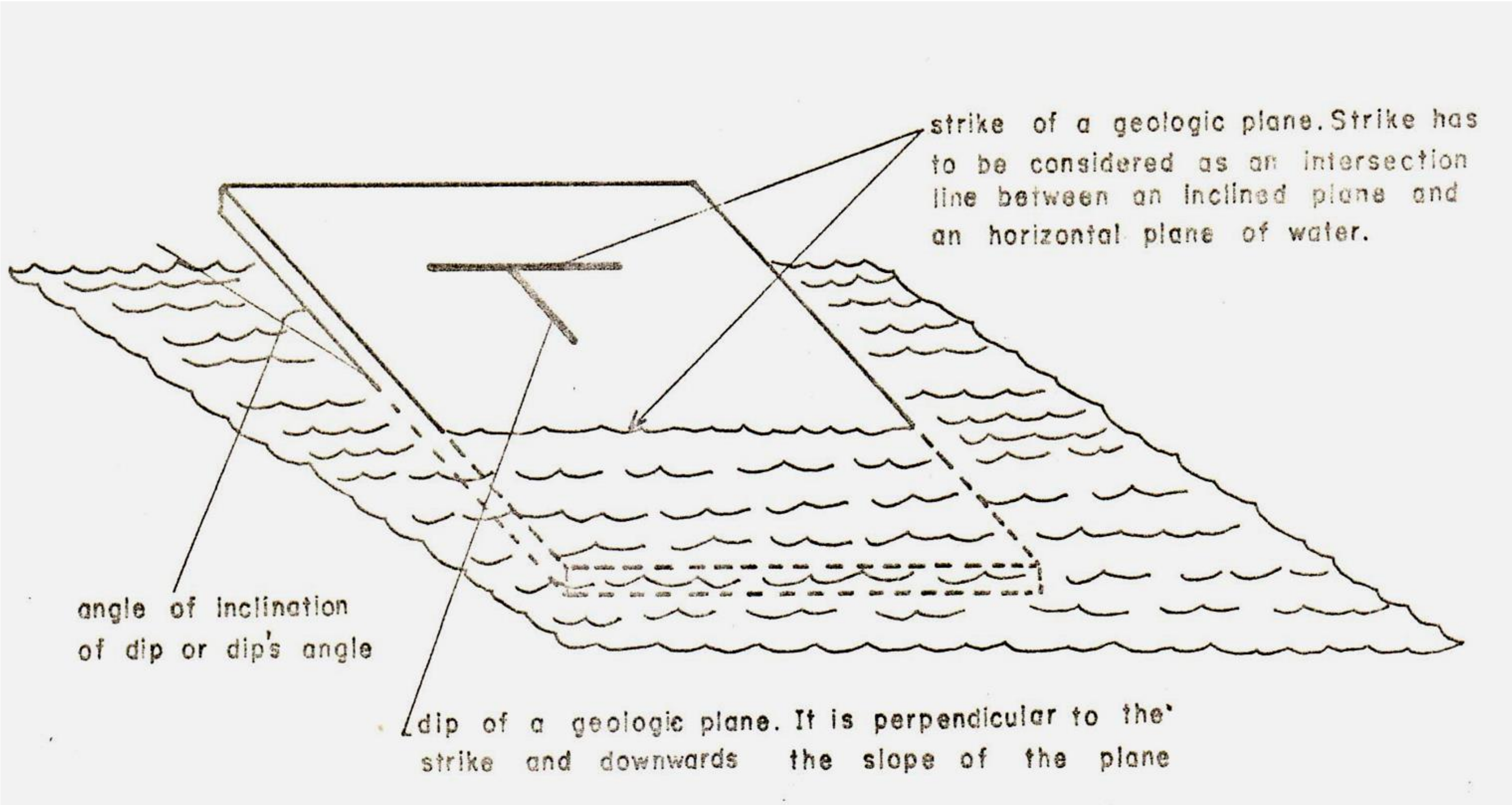


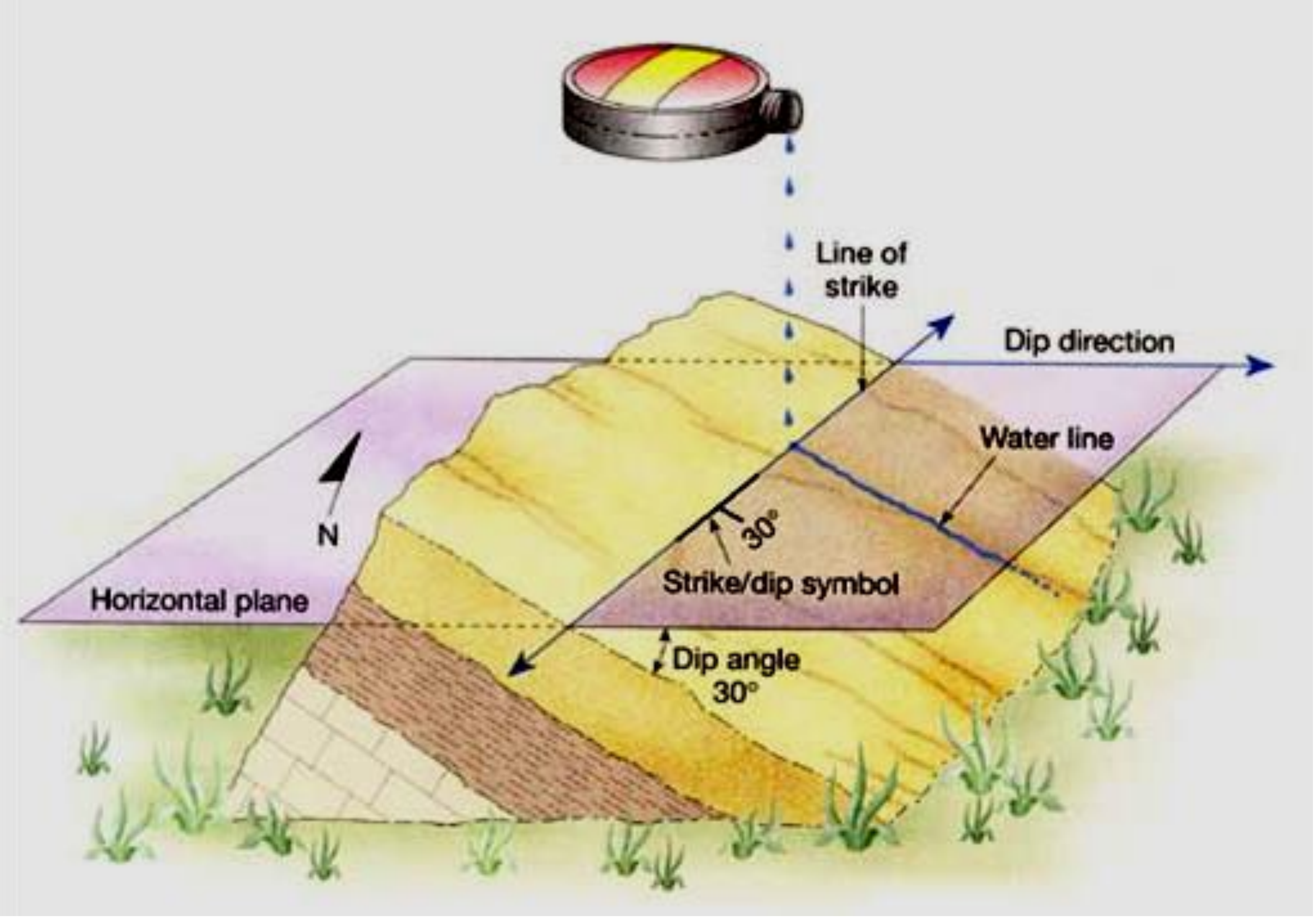
INCLINED
LAYERS
(TILTED)
Angle of dip 0°- 90°



VERTICAL
LAYERS
Angle of dip = 90°
(No dip)




strike of a geologic plane. Strike has to be considered as an intersection line between an inclined plane and an horizontal plane of water.
angle of inclination of dip or dip's angle
dip of a geologic plane. It is perpendicular to the strike and downwards the slope of the plane

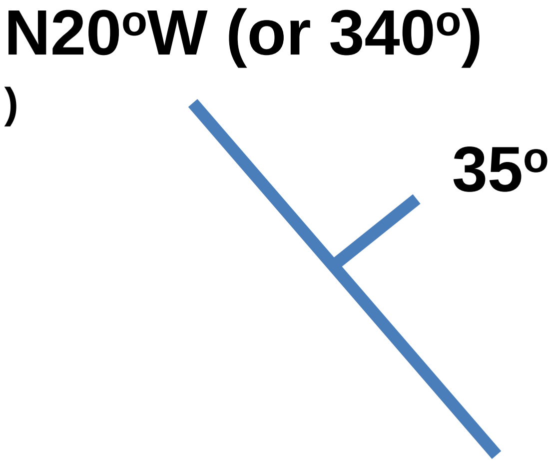


Strike and dip of a rock layer

TOPOGRAPHY and LAYERS

Rock Layers	Rock layers vs contours
HORIZONTAL LAYERS	**Contacts follow contour lines (they make Vs pointing upstream**
INCLINED LAYERS	**Contacts form Vs** The V points in the direction of dip. (Upstream or downstream)
VERTICAL LAYERS	**Contacts do not form Vs. The cut straight across contour lines**

Symbols of dip and strike of a bed used on a map



Folds

We often think of rock as hard, brittle material. Throw a rock hard enough on the ground and it will likely break into pieces.

But under the right conditions, rock can actually 'flow' in a way that keeps it from breaking.

When rock deforms in such a way that it bends instead of breaking, we call this a fold. Folds are wavelike bends in layered rock.

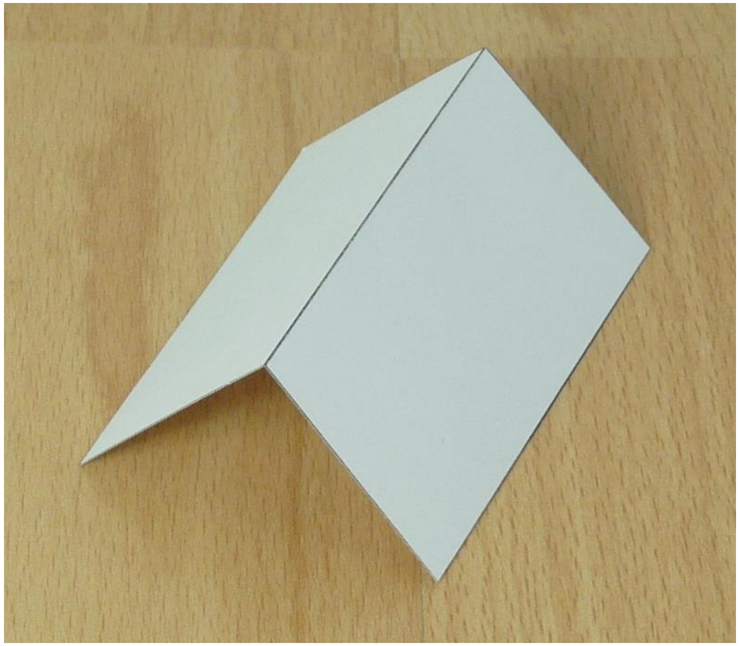
It represent rock strained in a ductile manner, usually under compression.

A Fold

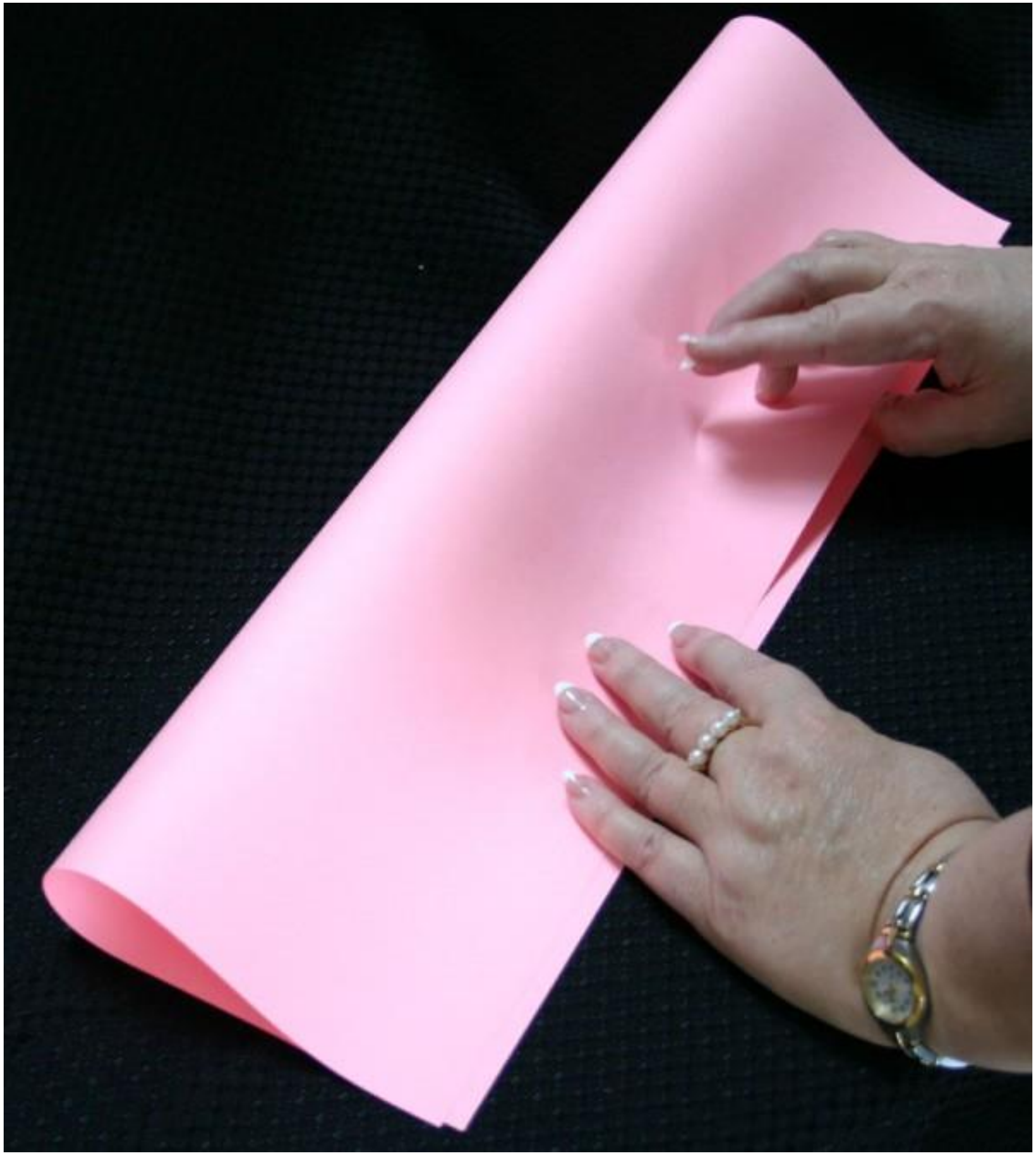
A wave-like undulation of strata, usually the result of tectonic movements is called fold.

Many parts of the earth's crust are found to be wrapped into wavy forms called folds.

Folds are permanent wavelike bends or distortions in the planer features of rocks, such a in sedimentary strata and the foliations of metamorphic rocks.



A Fold



A Fold

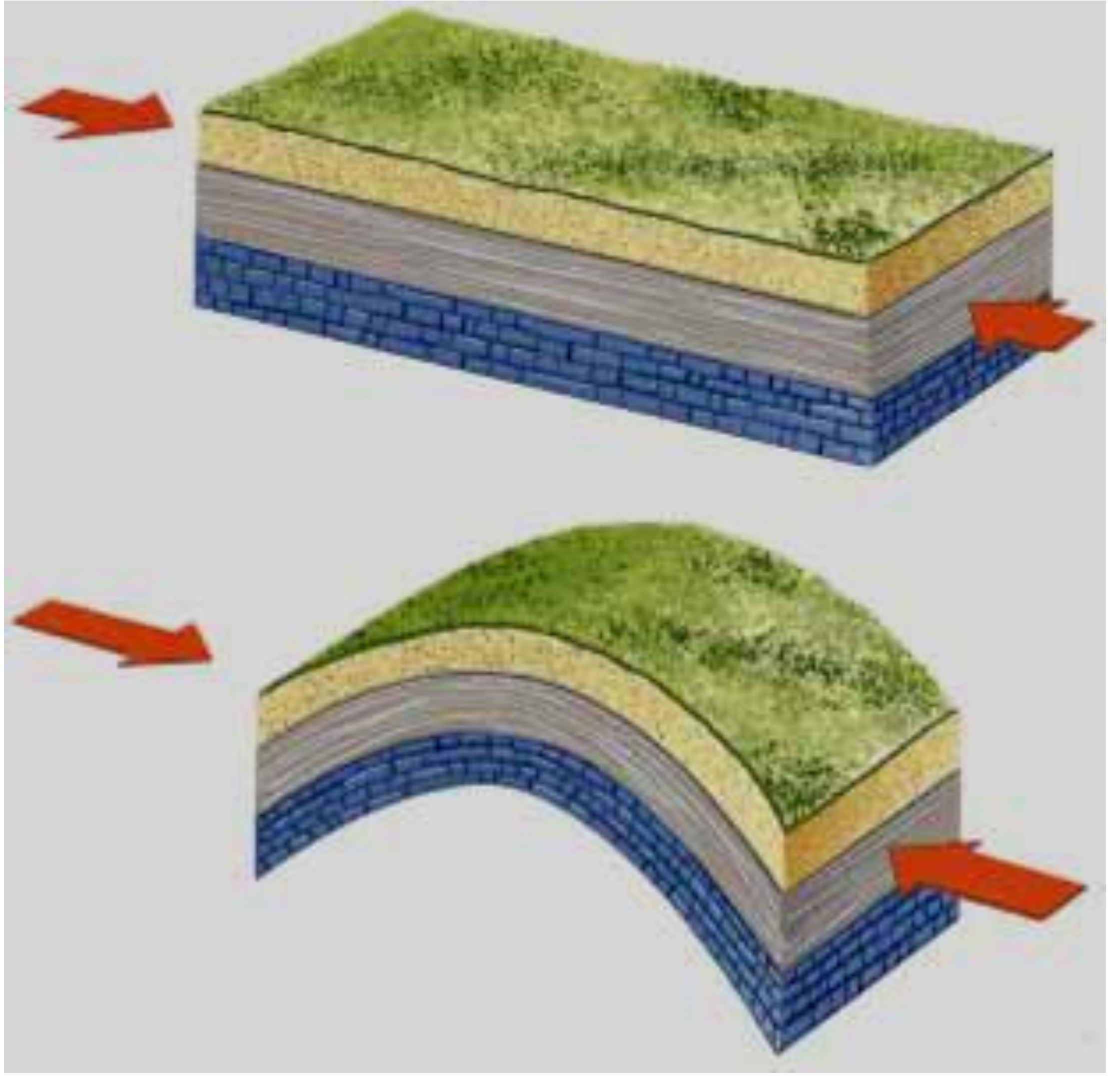


Figure 12–5 (a) Horizontally layered sedimentary rocks.(b) A fold in the same rocks. The forces that folded the rocks are shown by the arrows. Notice that points A and A′ are closer after folding.

A Fold

Figure 12–6 (a) An anticline, a syncline, and the parts of a fold. (b) A plunging anticline. (c) A syncline in southern Nevada.

Figure 12–7 A syncline lies beneath the mountain peak and an anticline forms the low point, or saddle, in the Canadian Rockies, Alberta.

Folds **are wavelike bends in layered rock. It represent rock strained in a *ductile* manner, usually under *compression***

The *axial plane* divides a fold into its two *limbs.*

The surface trace of an axial plane is called the *hinge line* (or *axis*) of the fold

Folds are eye-catching and visually attractive structures that can form in practically any rock type, tectonic setting and depth.

They are visually the most spectacular of Earth's structures.

But they are best displayed by stratified formations such as sedimentary rocks or volcanic rocks or their metamorphosed equivalents.

Figure 12–29 Wildly folded sedimentary rocks on the Nuptse–Lhotse Wall from an elevation of 7600 meters on Mount Everest. (Galen Rowell/Mountain Light)

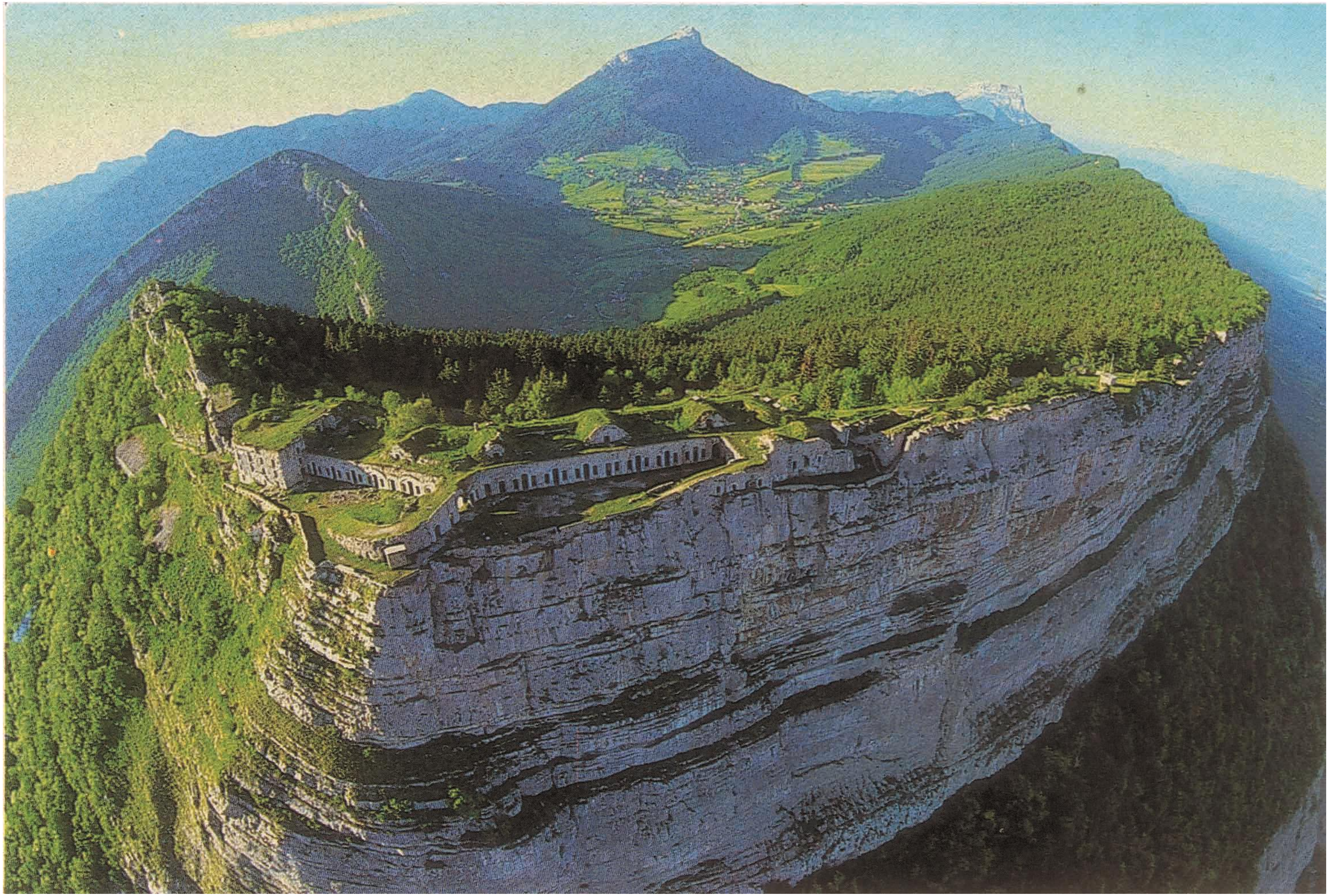


FIGURE 9–12 Recumbent non-parallel fold in gneiss, East Greenland Caledonides, Kildedalen. The relief between the top of the cliff and valley bottom is about 800 m. (Photograph courtesy of John Haller.)

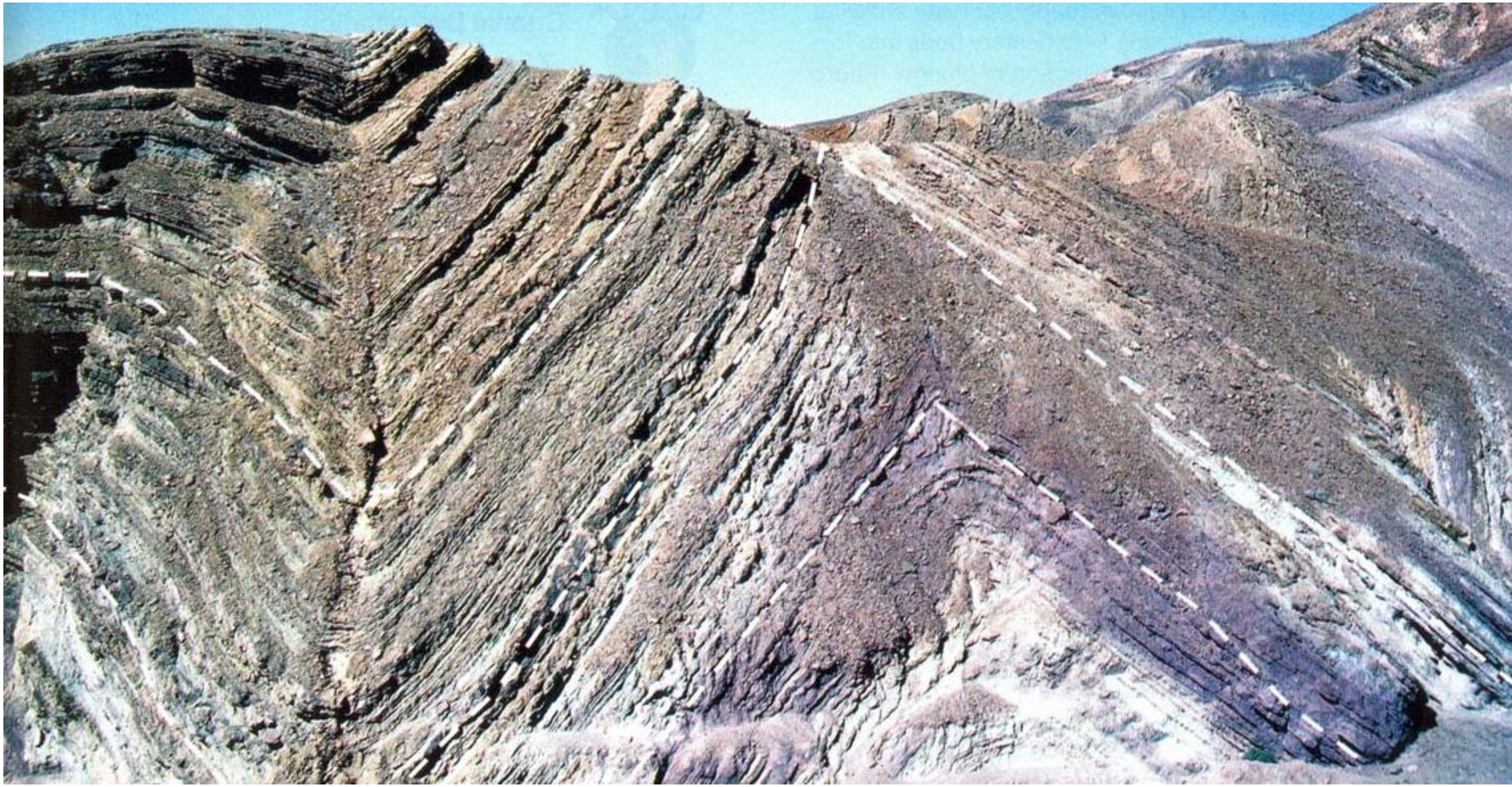


FIGURE 10.11 Syncline (left) and anticline (right) share a common limb. (Photo by E. J. Tarbuck).

Fig. 15.13: Sheep Mountain, a doubly plunging anticline. Note that erosion has cut the flanking sedimentary beds into low ridges that make a “V” pointing in the direction of plunge. (Photo by John S. Shelton).

FIGURE 9–8 Angular parallel fold within Cambro-Ordovician Taconic sequence of eastern Newfoundland, Canada.

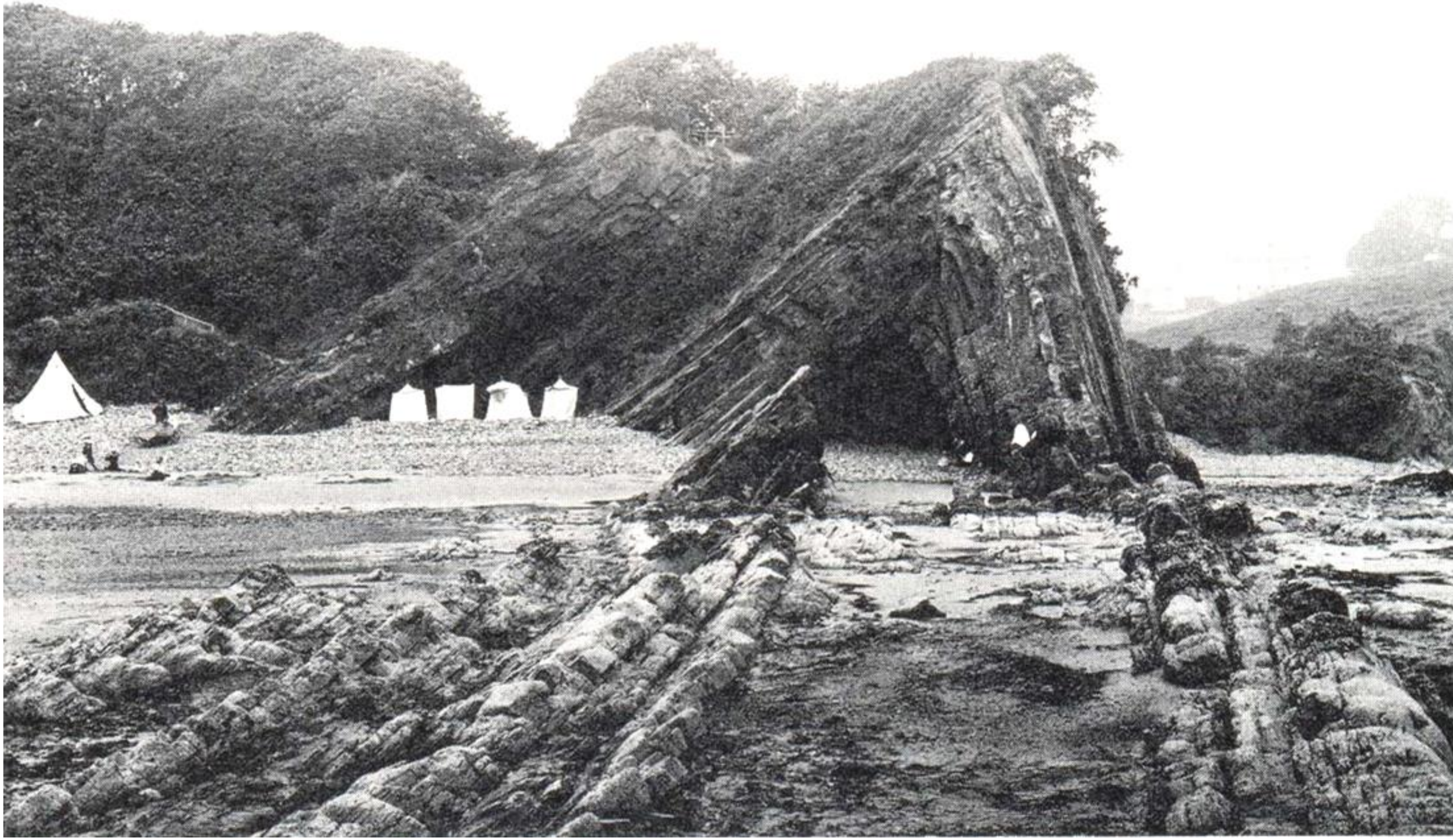


FIGURE 9–7 Angular parallel fold in coal measures, Pembroke, Great Britain; note cylindrical nature. (Photograph courtesy of Geological Survey of Great Britain.)

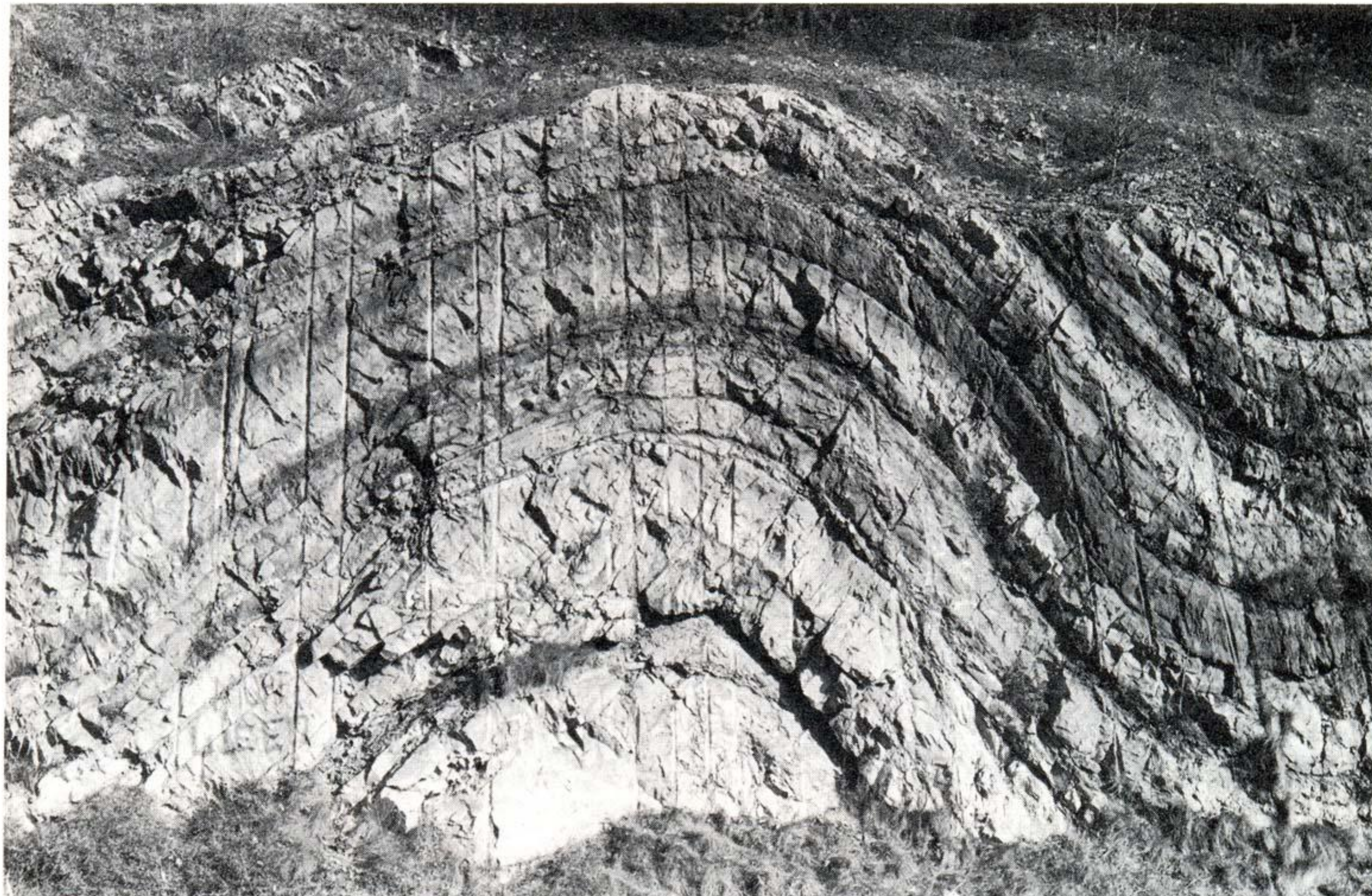


FIGURE 9–4 Curved parallel fold in Silurian sandstones in the central Appalachians near Newfoundland, New Jersey.


FOLDS
Undulation in rocks

Figure 7-1a

Understanding Earth, Fifth Edition

Rainbow Basin syncline in the Barstow Formation near Barstow, California

Folds in rocks in Crete, Greece.

Folds, whether observed on the micro-, meso- or macroscale, are clearly some of our most important windows into local and regional deformation histories of the past.

Their geometry and expression carry important information about the type of deformation, kinematics and tectonics of an area.

The physical forms and orientations of folds seem limitless.

Fold size varies too, from anticlines that fit into the palm of a hand to regional folds best seen through the eyes of a satellite (Figure 7.2).

There are practical incentives to come to know folds and their properties.

They can be of great economic importance, both as oil traps and in the search for and exploitation of ores and other mineral resources.

There is a legacy of discovery of oil and gas in structural traps created by folding (Figure 7.8).

Folds commonly serve as collection sites for oil and gas that migrate up the dip of strata from hydrocarbon source beds below.

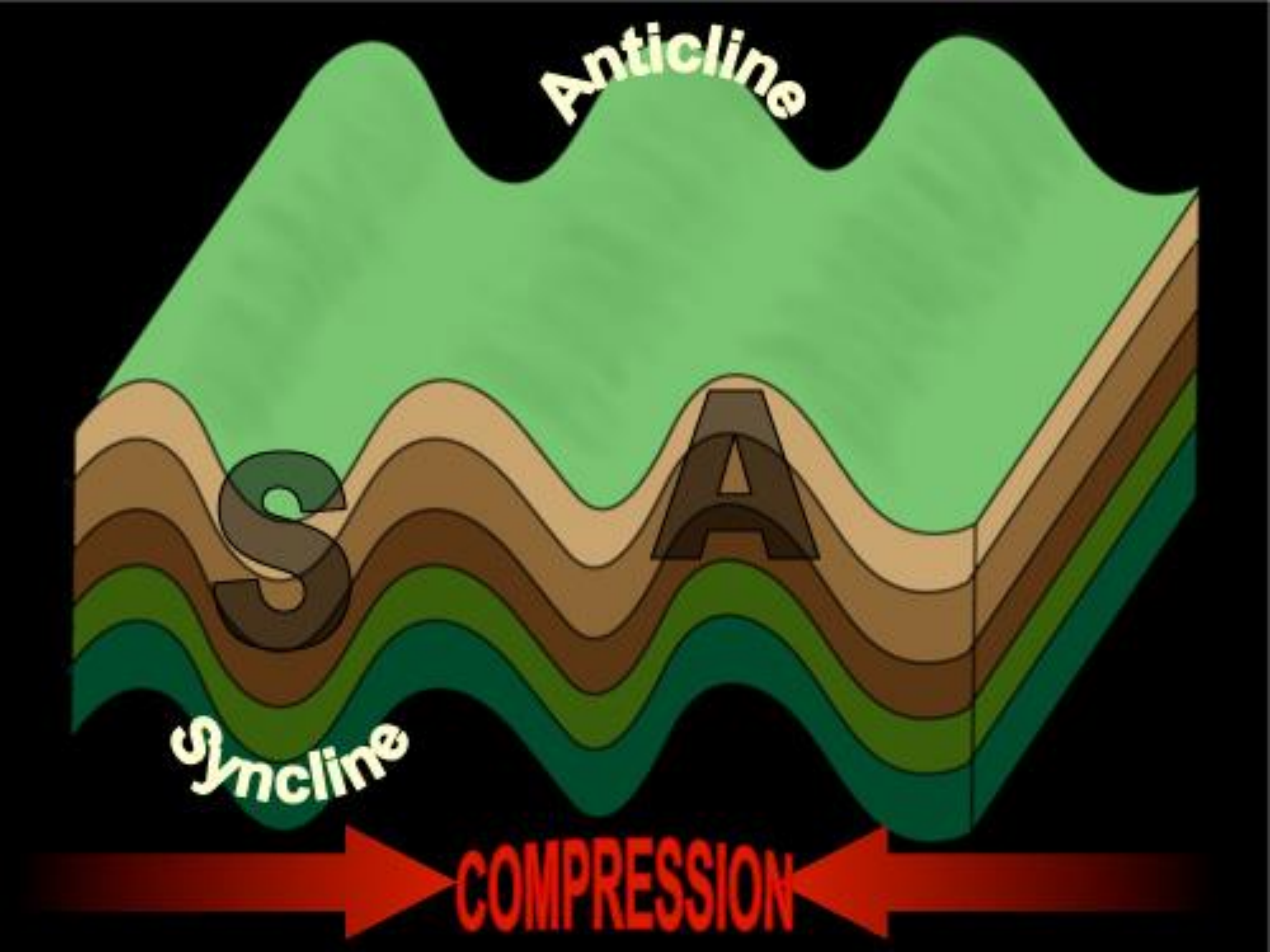
PARTS OF A FOLD

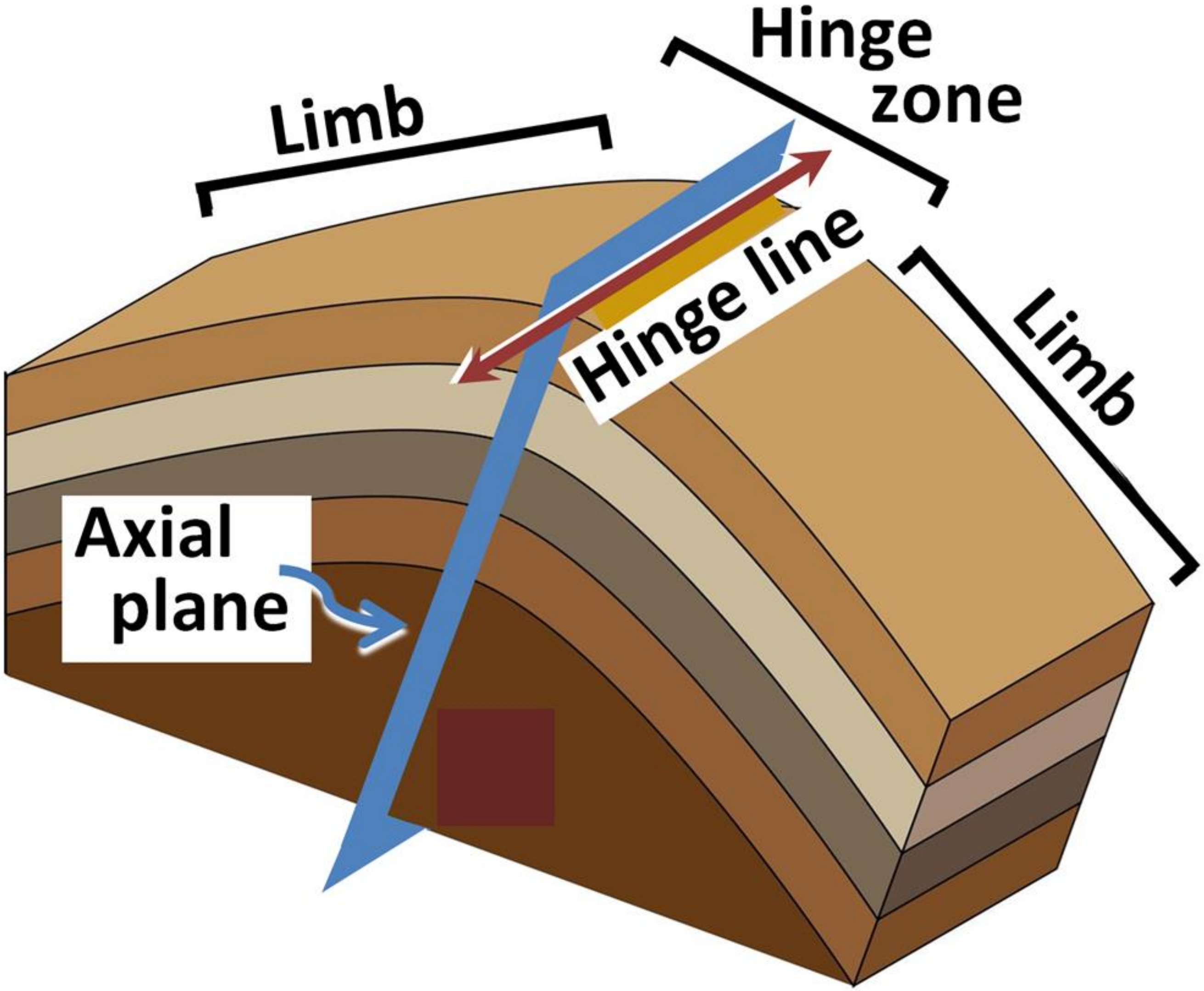
1. Hinge
2. Limbs
3. Axial surface
4. Axis
5. Crest
6. Trough

Considered two-dimensionally in normal profile view, folded surfaces can be subdivided into:

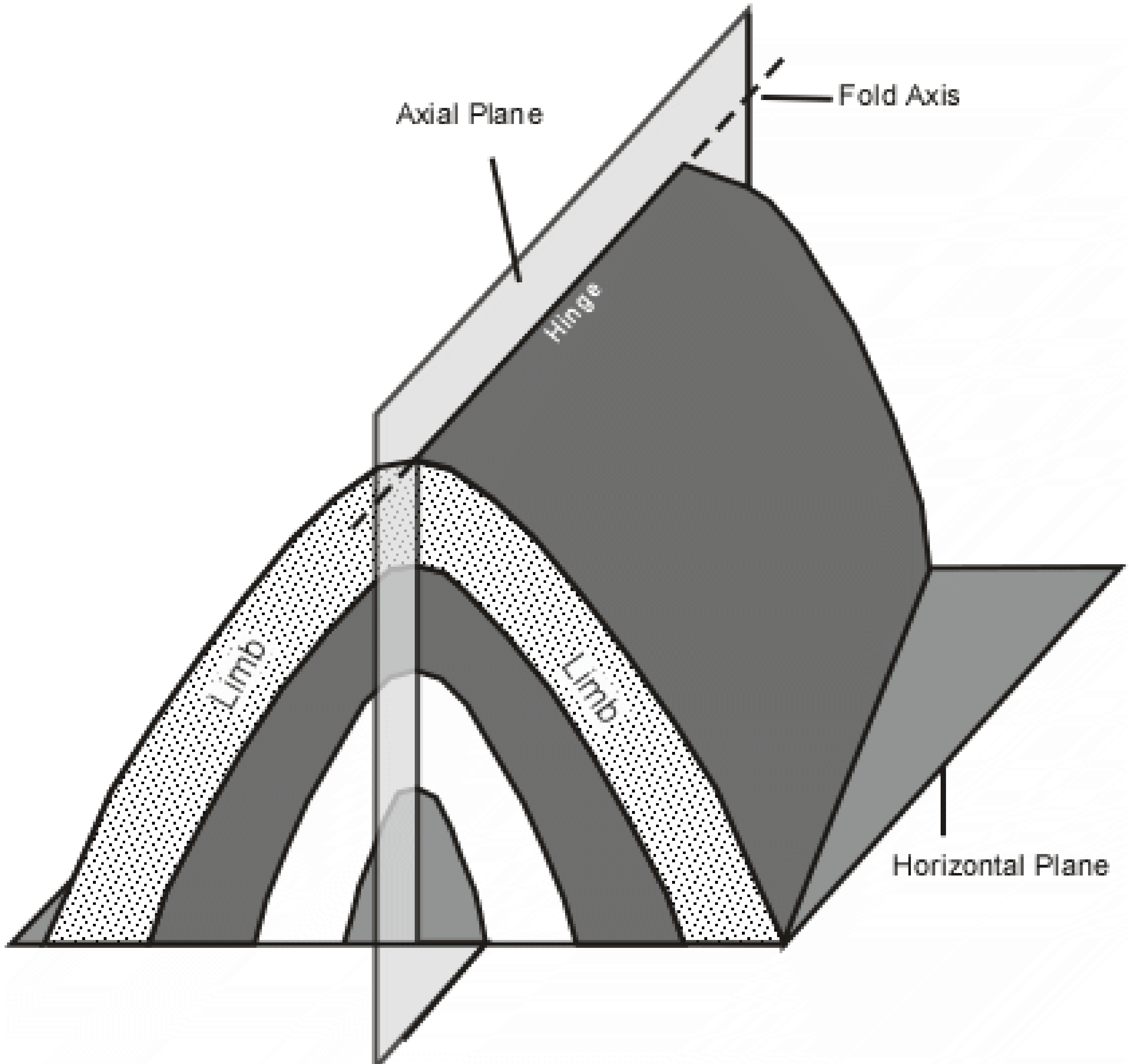
- **limbs and**
- **hinges (Figure 7.18).**

Limbs are the flanks of folds, and these are joined at the hinge. The hinge zone, is distinguished by the maximum curvature achieved along the folded surface (Ramsay, 1967).

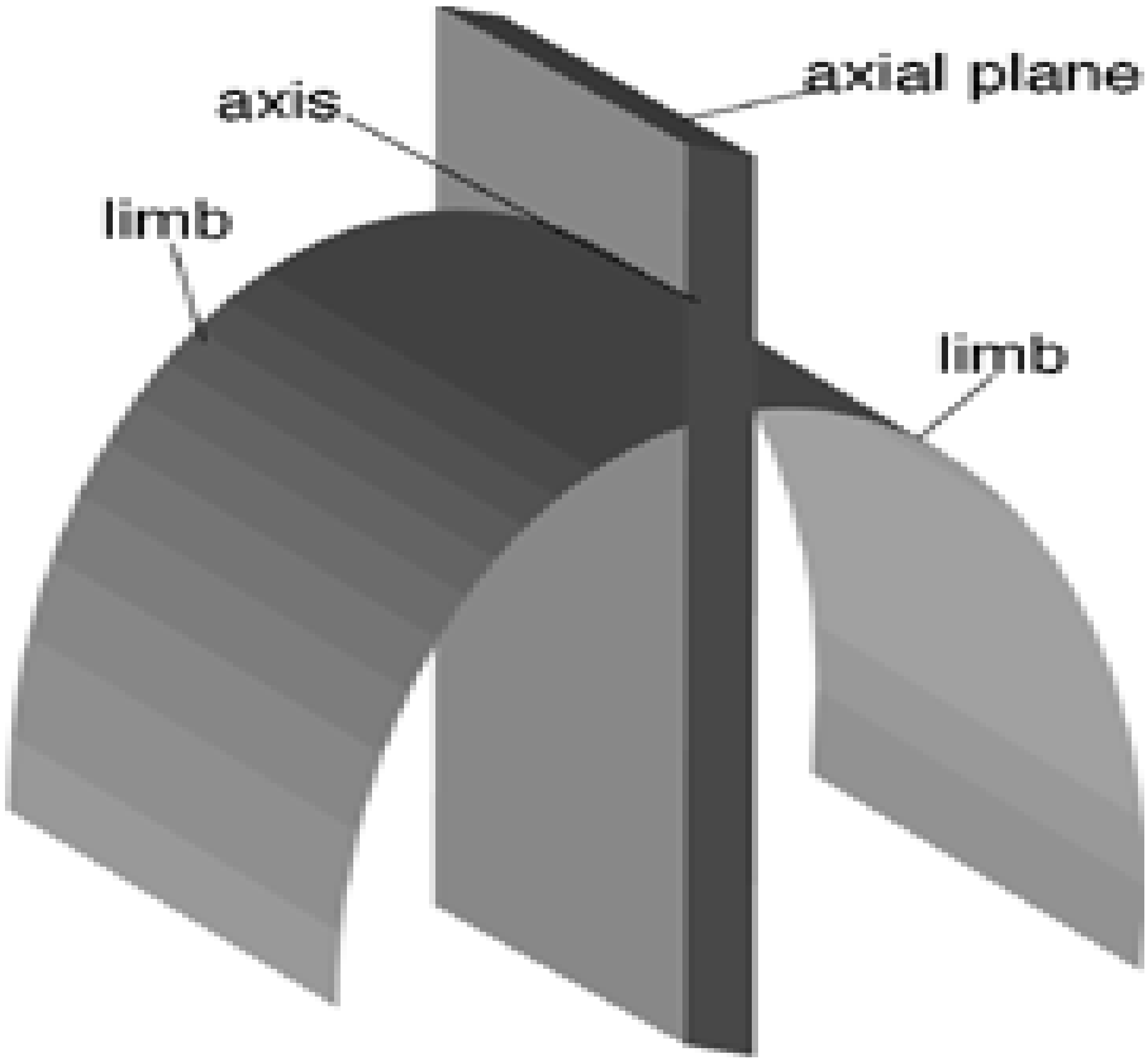

Anticline
S
A
Syncline
COMPRESSION



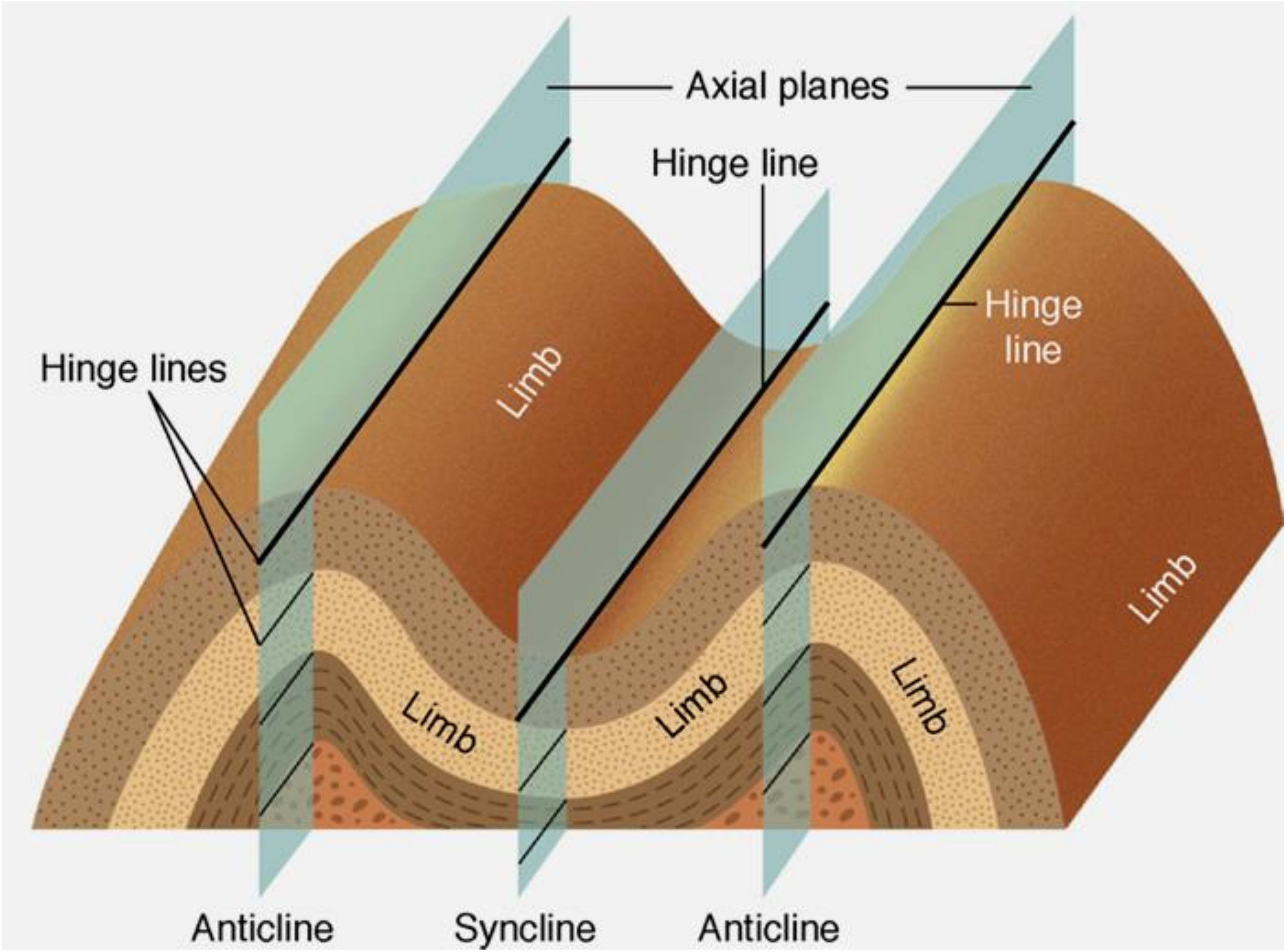
Fold terminology. For more general fold shapes, a hinge *curve* replaces the hinge line, and a non-planar axial*surface* replaces the axial plane.



Axial Plane
Fold Axis
Hinge
Limb
Limb
Horizontal Plane



axis
axial plane
limb
limb



Axial planes
Hinge line
Hinge line
Hinge lines
Limb
Limb
Limb
Limb
Limb
Anticline
Syncline
Anticline

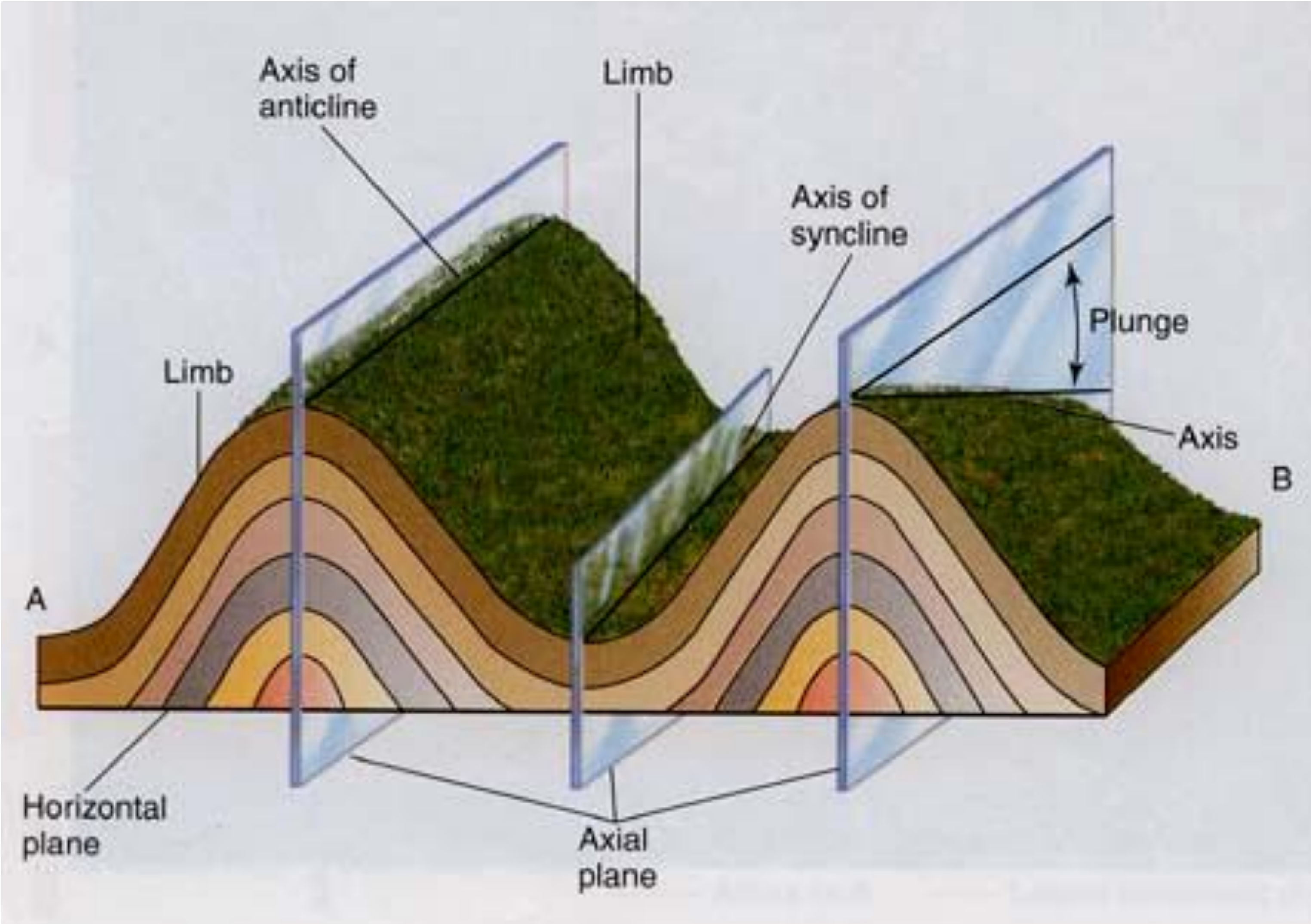


Fig. 9.21: Geometry of fold: Features of a simple fold. Note that the strata dip away from the axis of an anticline but towards the axis of a syncline. A. Fold axis horizontal. B. Fold axis plunging

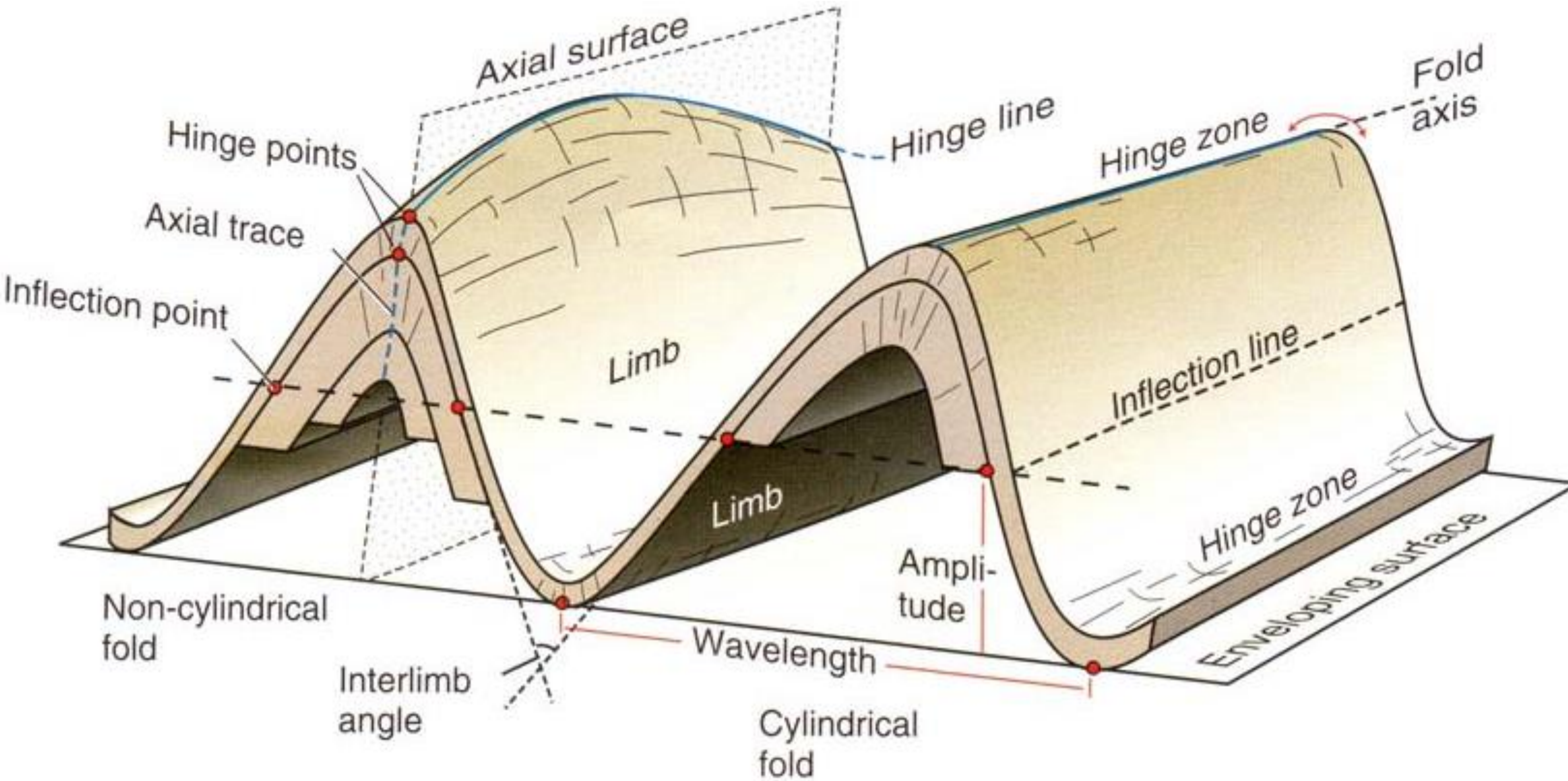


Figure 11.1 Geometric aspects of folds

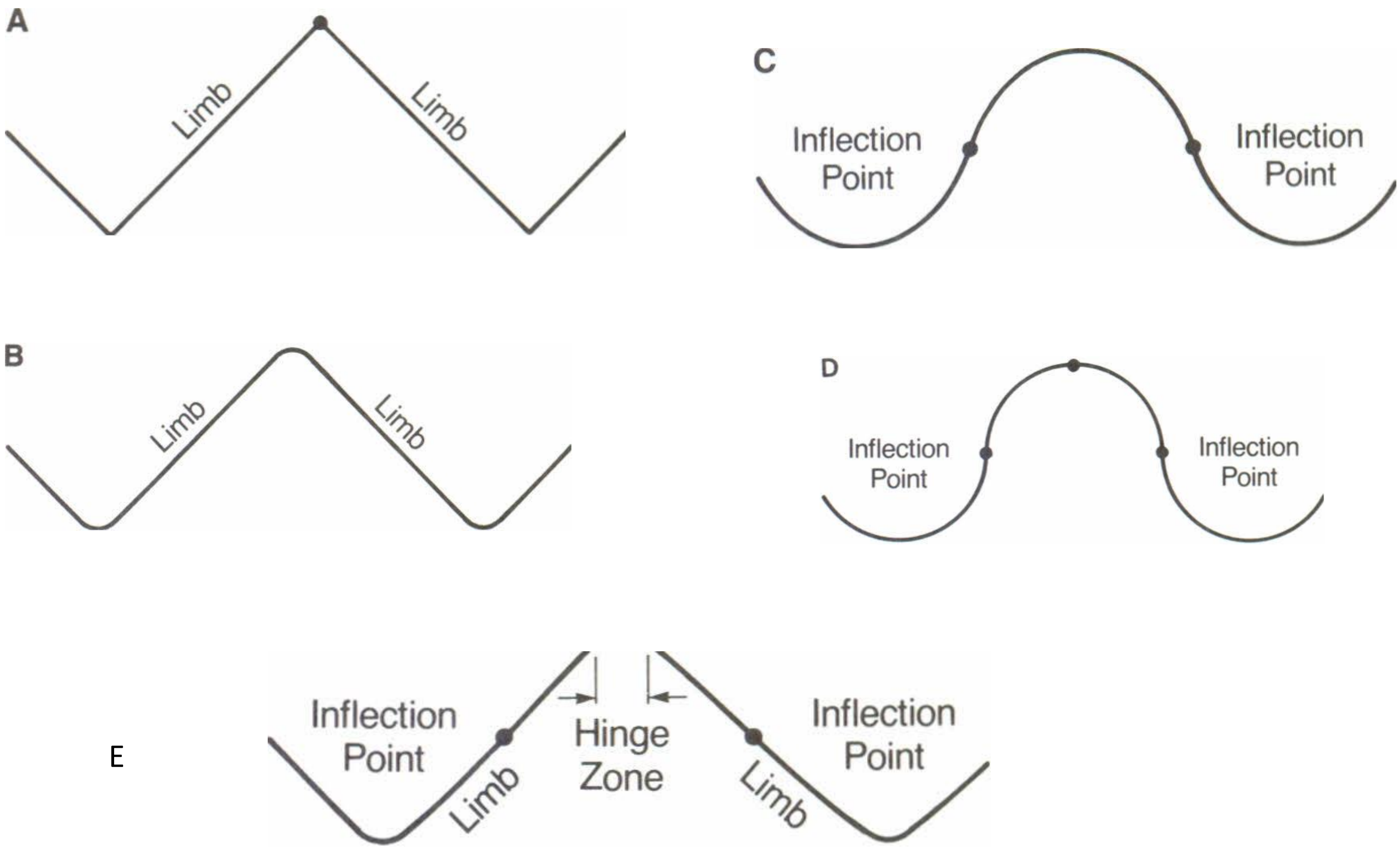


Figure 7.18 Geometric and physical elements of single folded surfaces.

Fold Symmetry

The overall symmetry of a fold can be described in terms of the angular relationship of its median trace and axial trace. Symmetrical folds are characterized by a median trace and an axial trace that are mutually perpendicular; thus fold height and fold width are measured along mutually perpendicular lines (see Figure 7.40C).

Asymmetrical folds, on the other hand, are marked by limbs of different lengths; thus the median trace and the axial trace of an asymmetric fold intersect at some oblique angle (see Figure 7.40D).

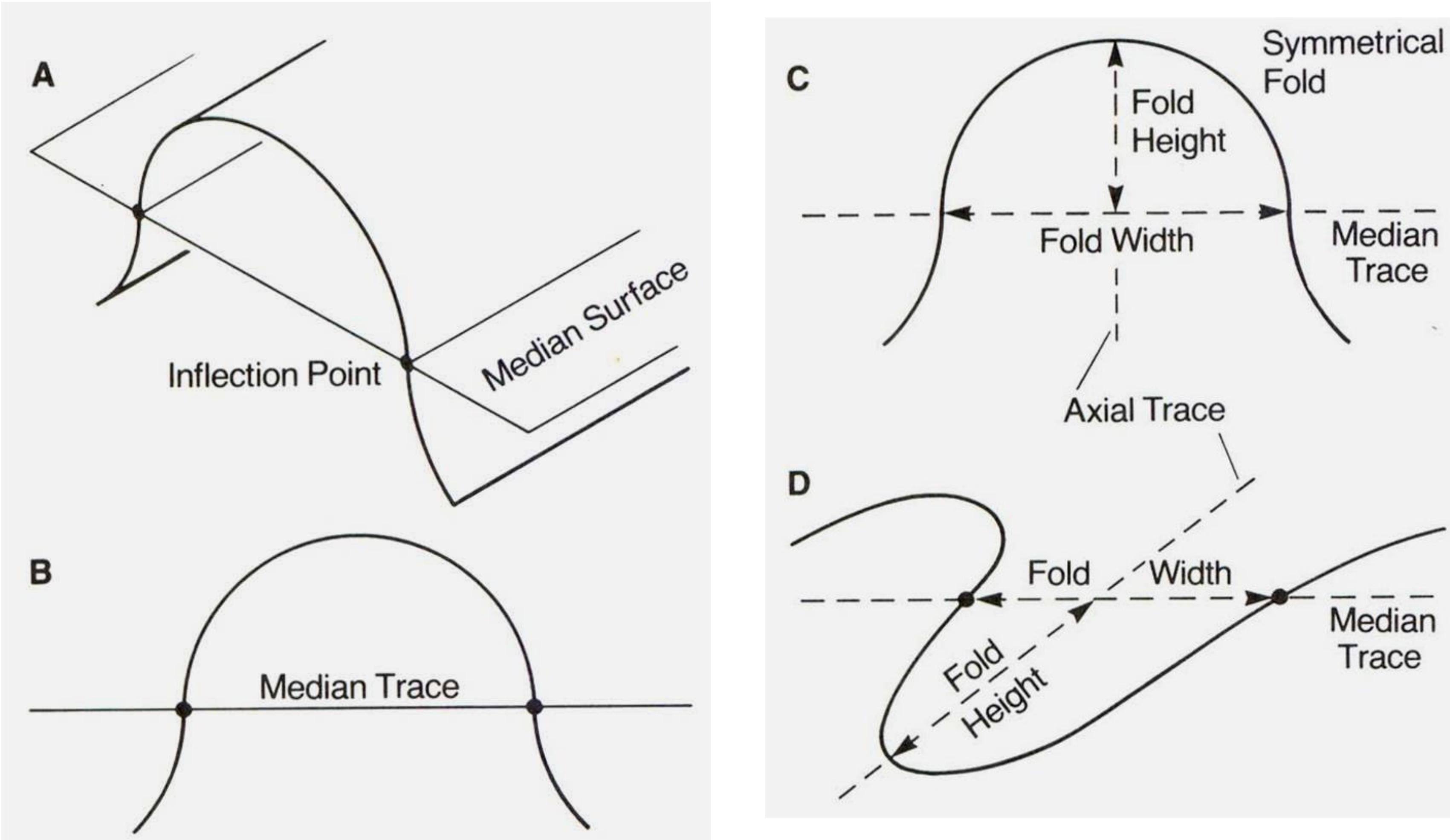
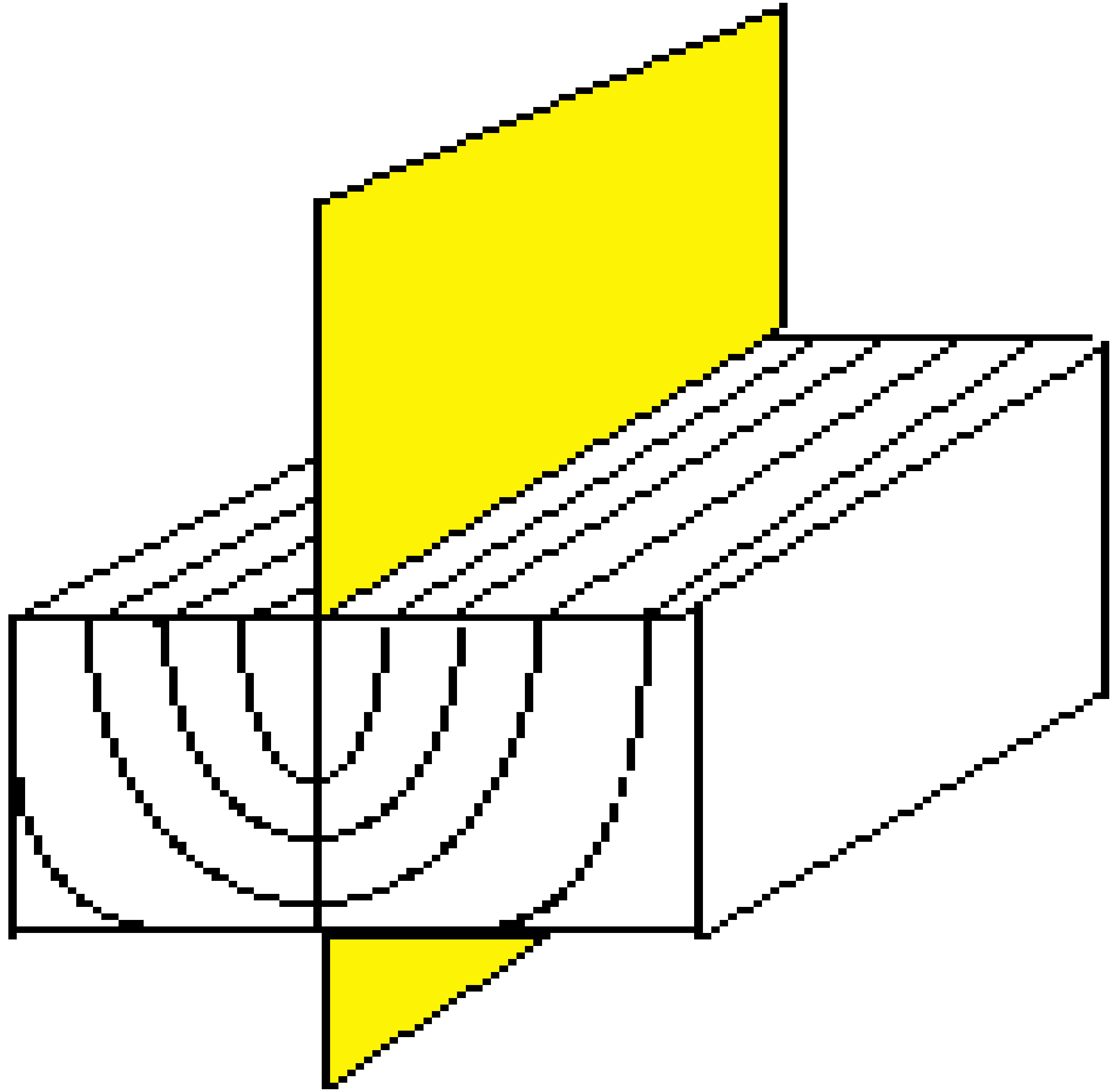
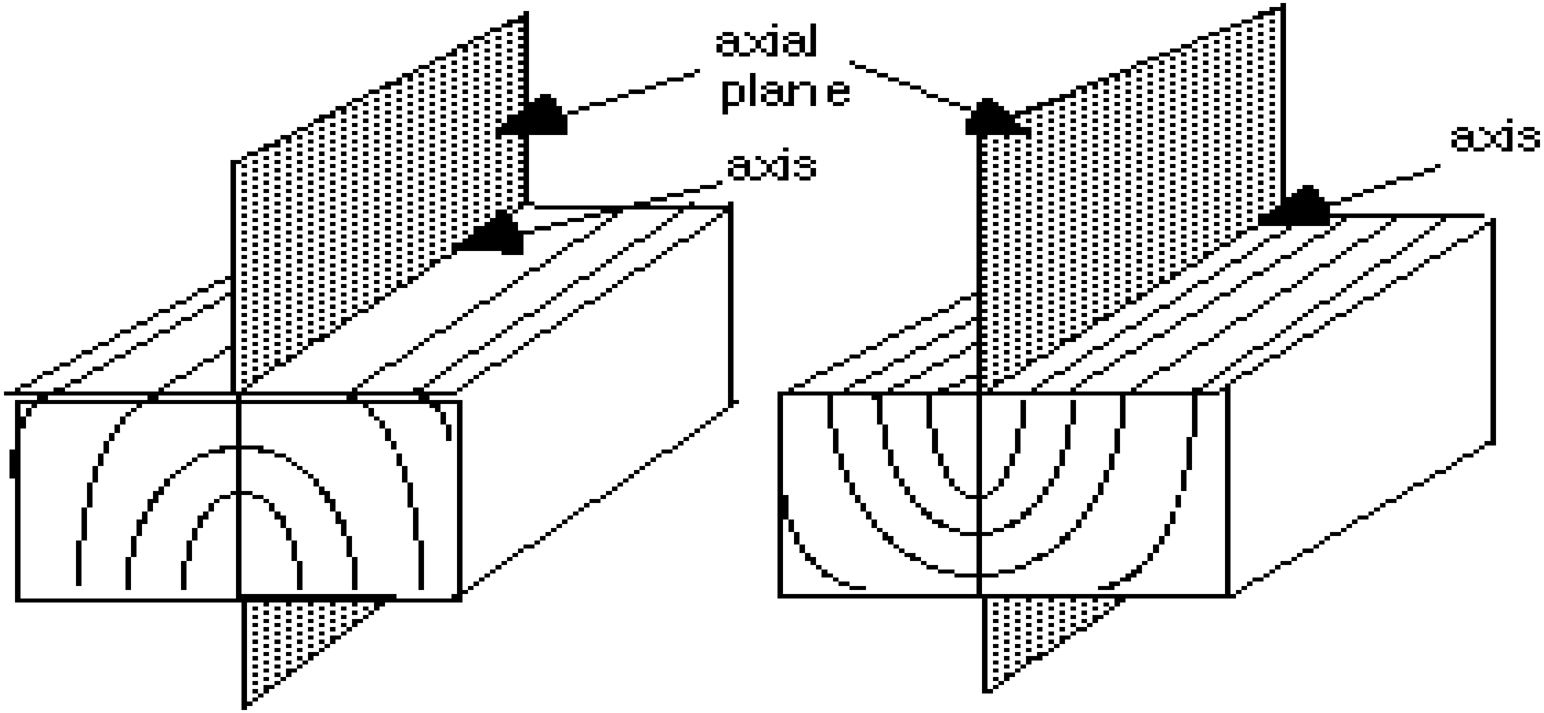
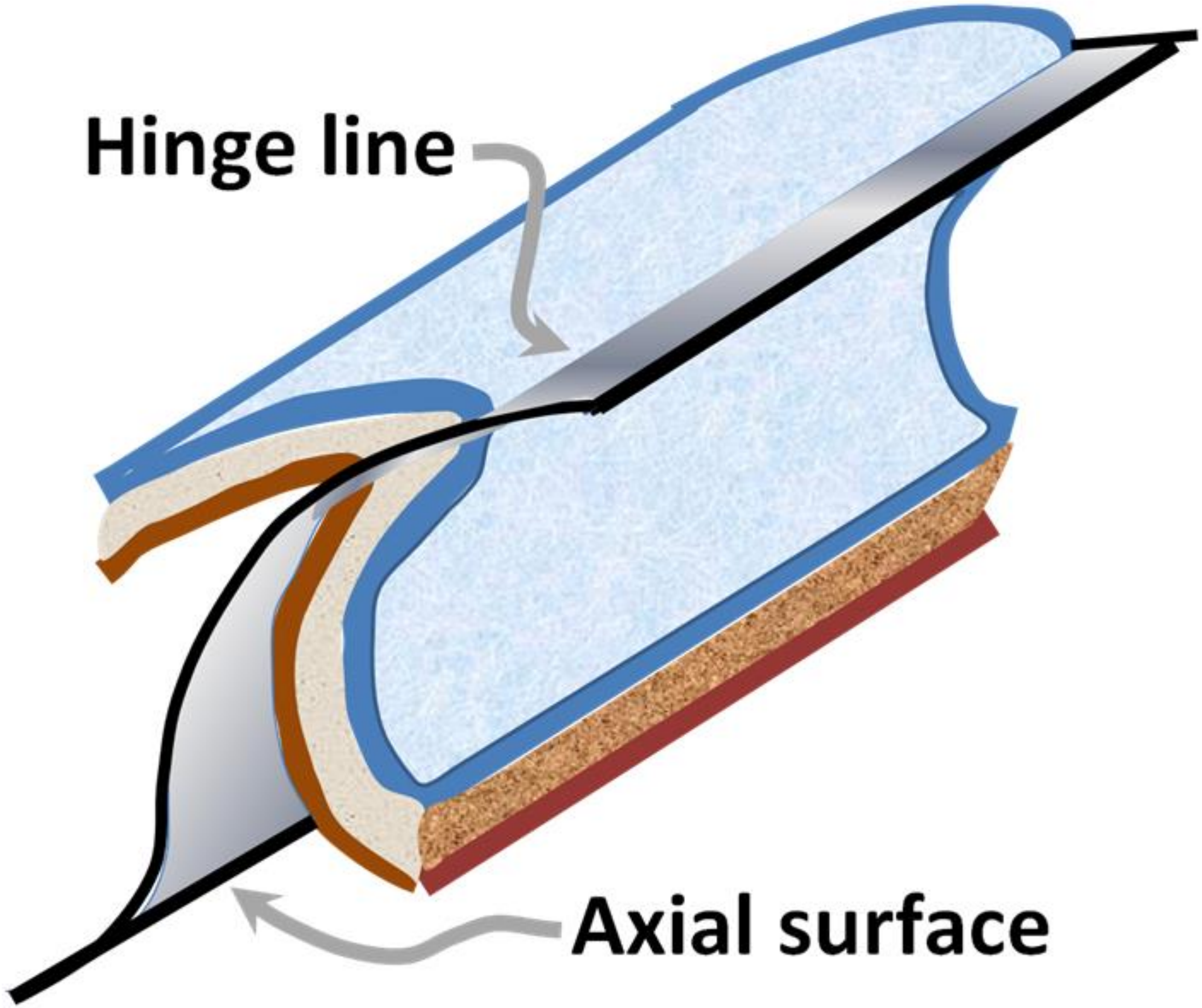


Fig. 7.40: Geometric nature of (A) the median surfrace and (B) the median trace of a fold. Convention for measuring fold height and fold width of (C) Symmetrical and (D) Asymmetrical folds.

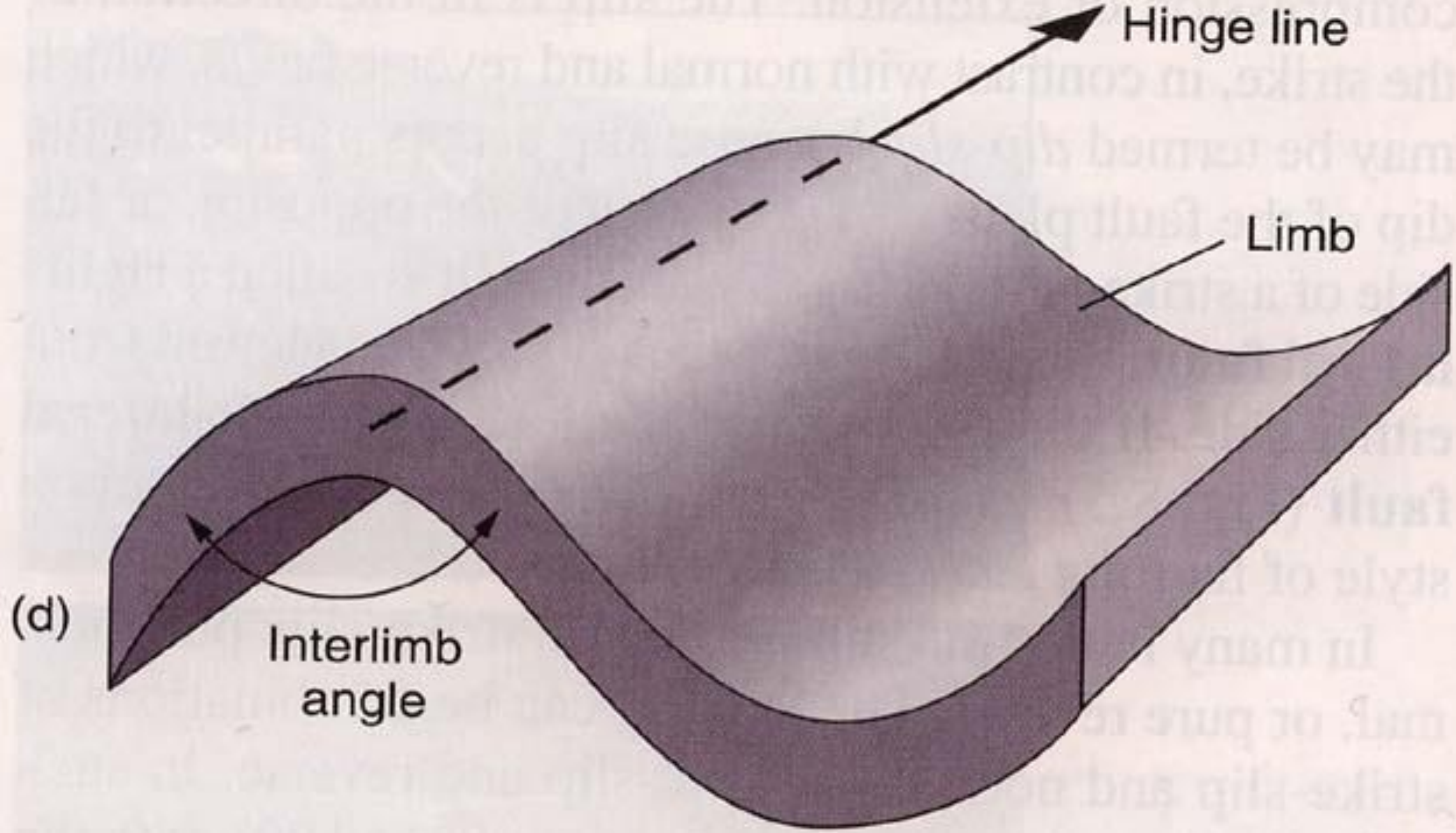




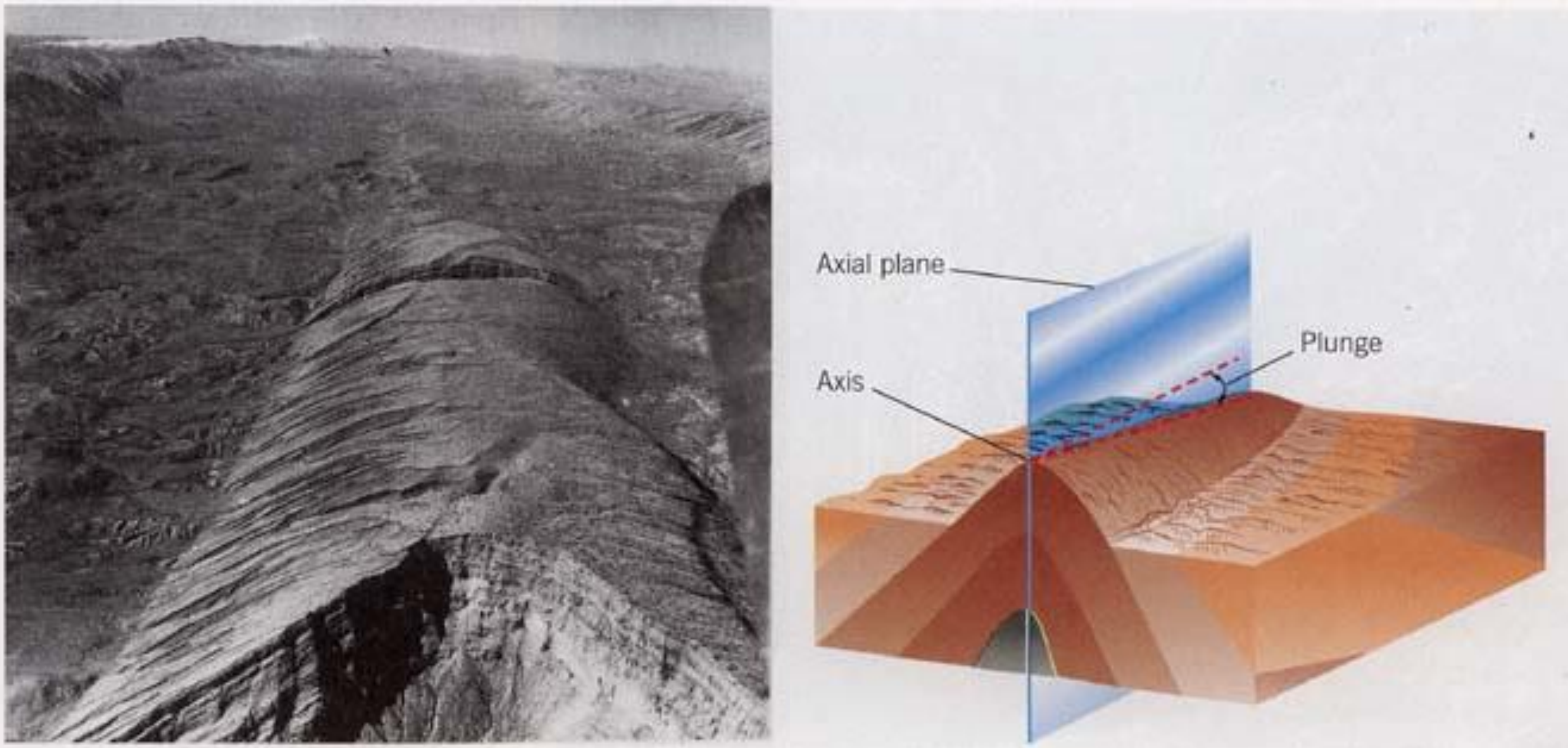
A Anticline **B** Syncline



Cylindrical fold with axial surface not a plane.



■ **FIGURE 8.7** (a) Flat-lying layers of rock before folding. (b) Anticline and syncline. (c) Eroded fold structure. (d) Fold hinge line, limb, and interlimb angle.



(a) (b)

Fig. 9.8 (a) A plunging anticline in the Zagros Mountains of Iran; the fold limbs converge in the direction of plunge. (b) the axis of the fold is inclined with respect to the Earth’s surface.

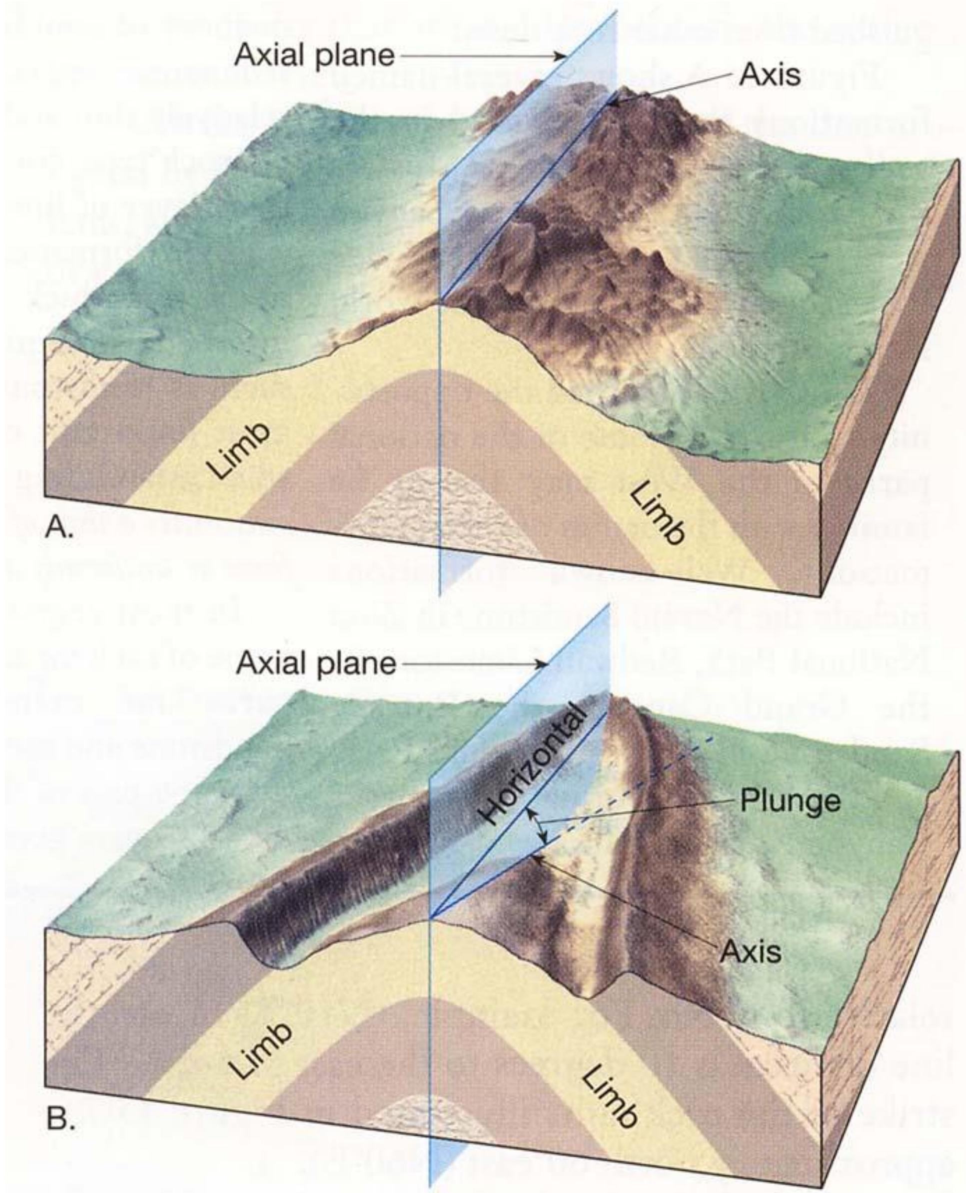
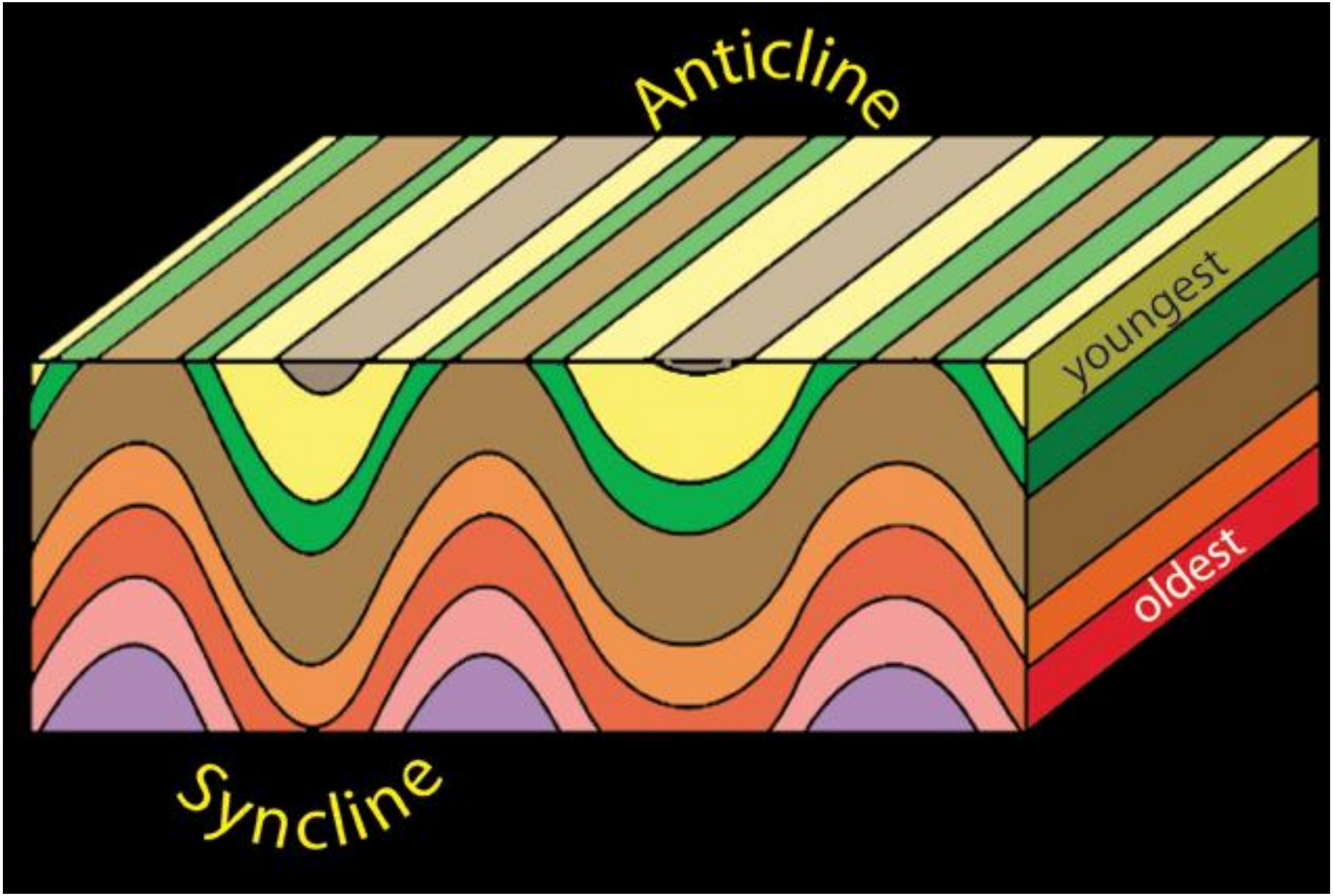
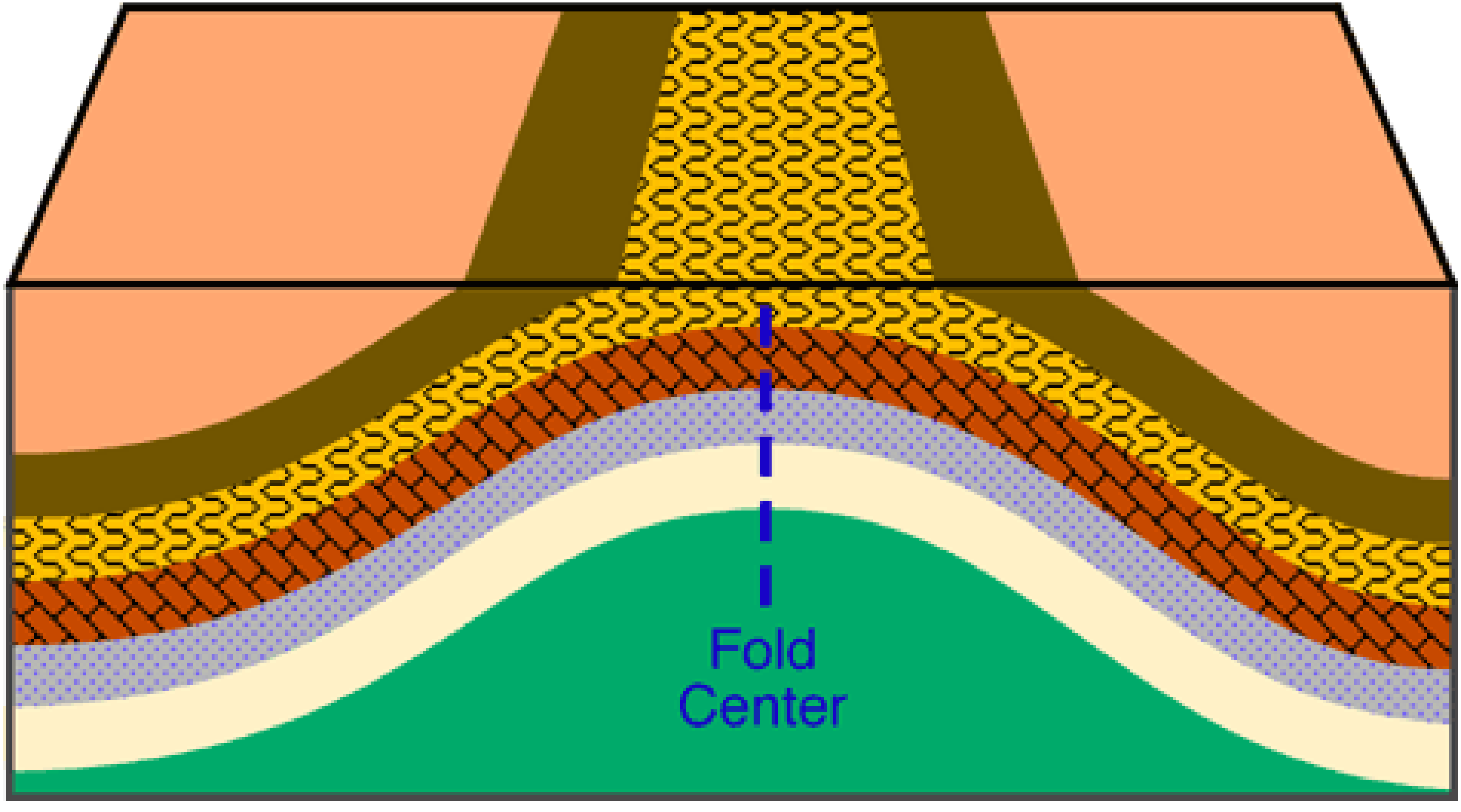


Fig. 15.9: Idealized sketches illustrating the features associated with symmetrical folds. The axis of the fold inb A is horizontal, whereas the axis of the fold in B is plunging


Anticline
youngest
oldest
Syncline



An **anticline** is a convex up fold in rock that resembles an arch like structure with the rock beds (or limbs) **dipping** way from the center of the structure (**Figure 10l-3**). **Figure 10l-3:** Anticline fold. Note how the rock layers dip away from the center of the fold are roughly symmetrical.

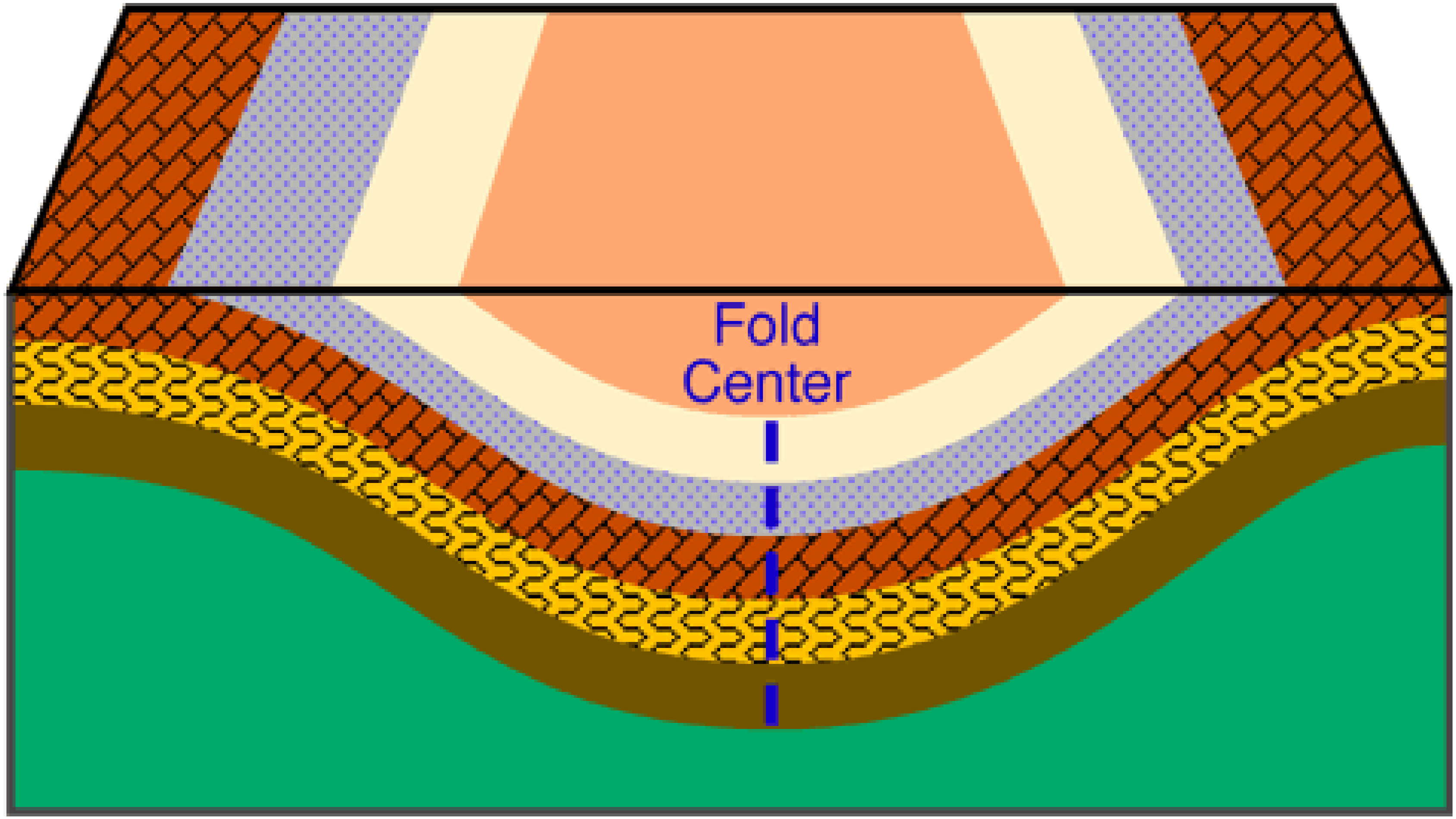


Figure 10l-4: Syncline fold. Note how the rock layers dip toward the center of the fold and are roughly symmetrical.

Figure *7.18A* shows an angular fold marked by planar limbs and an easily identifiable hinge point that separates the limbs.

Figure *7.18B,* on the other hand, pictures a fold marked by planar limbs connected by a hinge zone within which the folded surface displays uniformly high curvature.

Strictly speaking, the hinge zone of a folded surface does not possess a unique hinge point.

But for descriptive purposes a hinge point can be arbitrarily posted at the midpoint of the hinge zone.

Hinge Lines, Axial Surfaces, and Axial Traces

The three-dimensional geometric characteristics of folded surfaces invite a yet fuller nomenclature (Figure 7.19).

The hinge points along a single folded surface, taken together, define a hinge line. In some cases the hinge line of a folded surface is perfectly straight or systematically curved or, more rarely, terribly irregular (Figure *7.19A,B,C).*

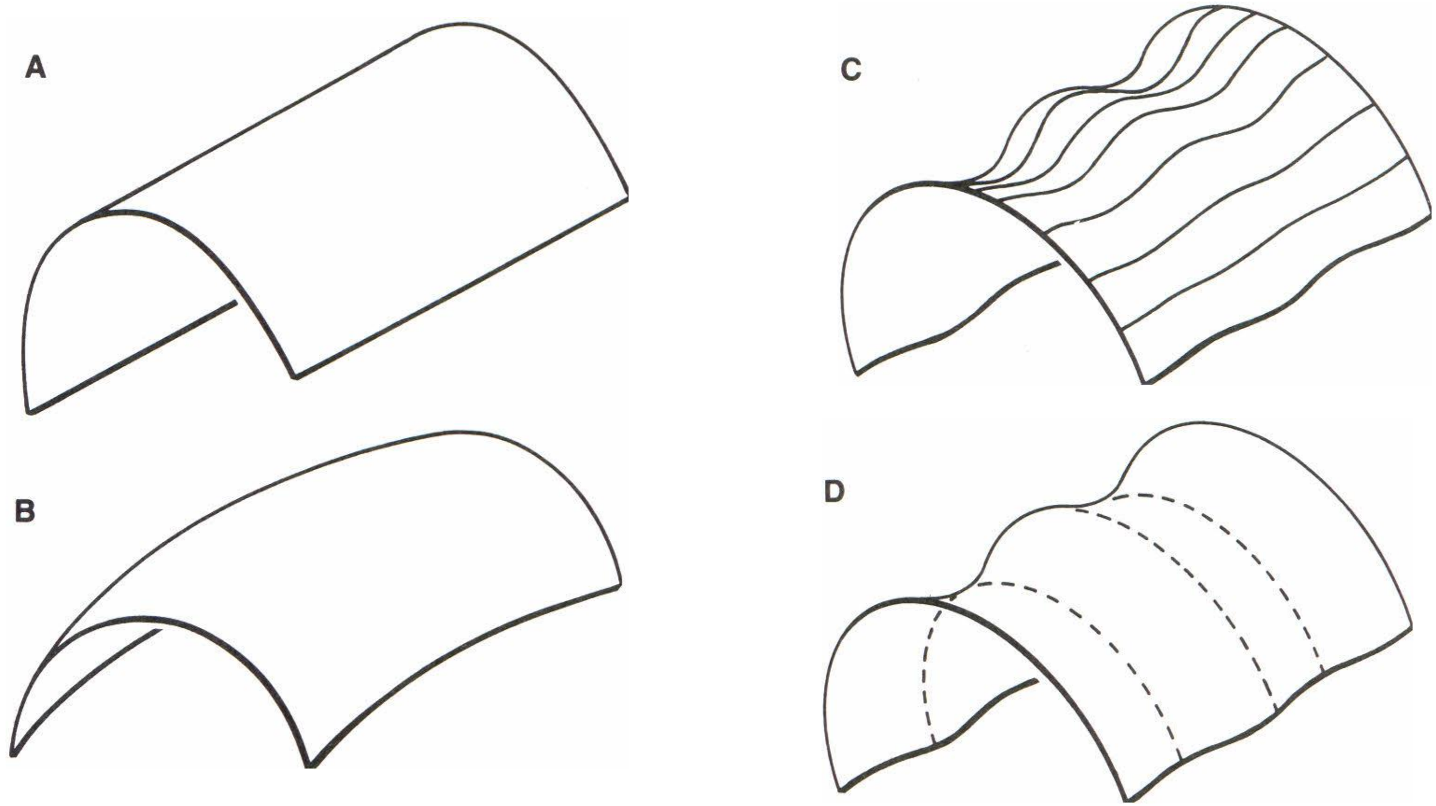


Figure 7.19 *(A)* Fold with straight hinge line. *(B)* Fold with systematically curved hinge line. (C) Fold with irregularly curved hinge line. *(D)* Subdivision of fold with irregularly curved hinge line into domains marked by nearly straight hinge lines.

Fold axis

A fold axis is a geometric (imaginary) straight line which when moved parallel to itself through space generates the shape of the fold.

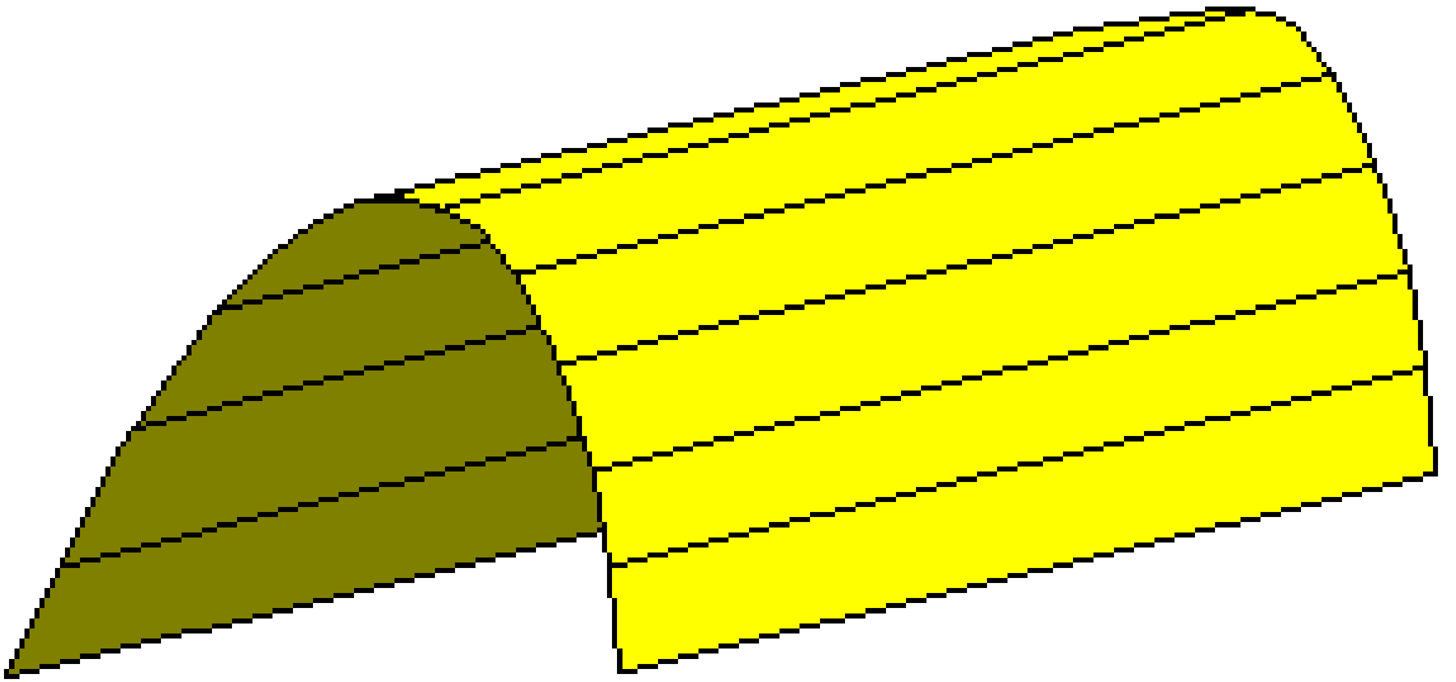
Non-cylindrical folds (with curved hinge lines) do not have fold axes.

and for the purpose of detailed structural analysis (for example, stereographic representation), it is necessary to subdivide them into several cylindrical folds, each with a relatively short, nearly straight hinge line.

Many folds are cylindrical; that is, the rocks have been deformed by simple bending without twisting.

The axis, or hinge, of the fold is the line of sharpest curvature of any given layer.

Wherever we measure the strike and dip of beds on the fold, we find that the attitudes are always parallel to a common direction, and that direction is also parallel to the axis of the fold.



Fold Axis

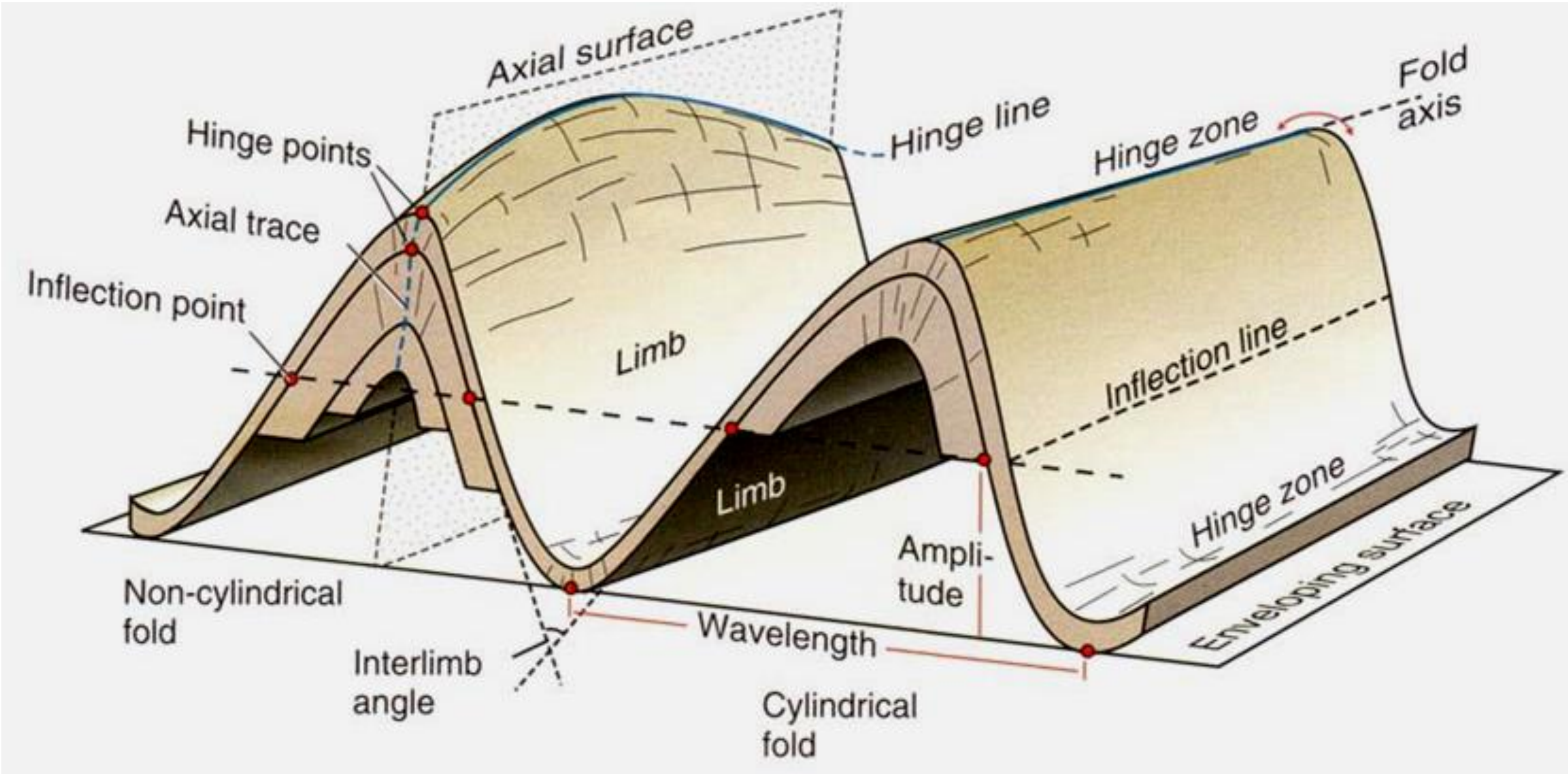


Figure 11.1 Geometric aspects of folds

The orientation of a folded surface can in part be specified by the orientation of its hinge line.

The orientation of a hinge line is described conventionally in terms of trend and plunge.

A single measurement of trend and plunge is adequate for hinge lines that are perfectly straight.

Knowing the orientation of the hinge line of a fold does not uniquely establish the orientation, or attitude, of the fold. Folds having the same hinge line orientation can have strikingly different configurations (Figure 7.20).

To describe unambiguously the attitude of a fold, it is necessary to measure yet another structural element, a geometric element known as an axial surface.

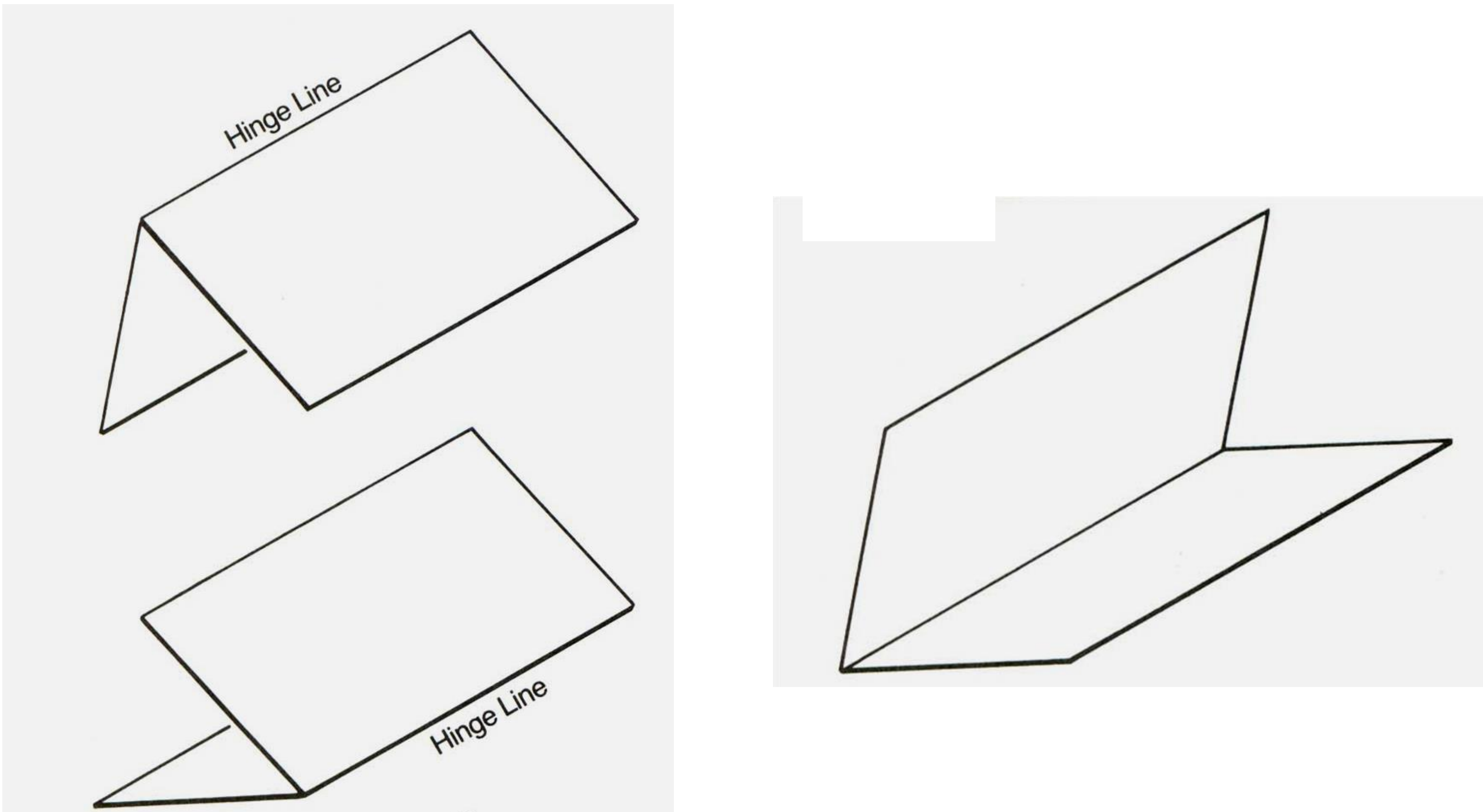


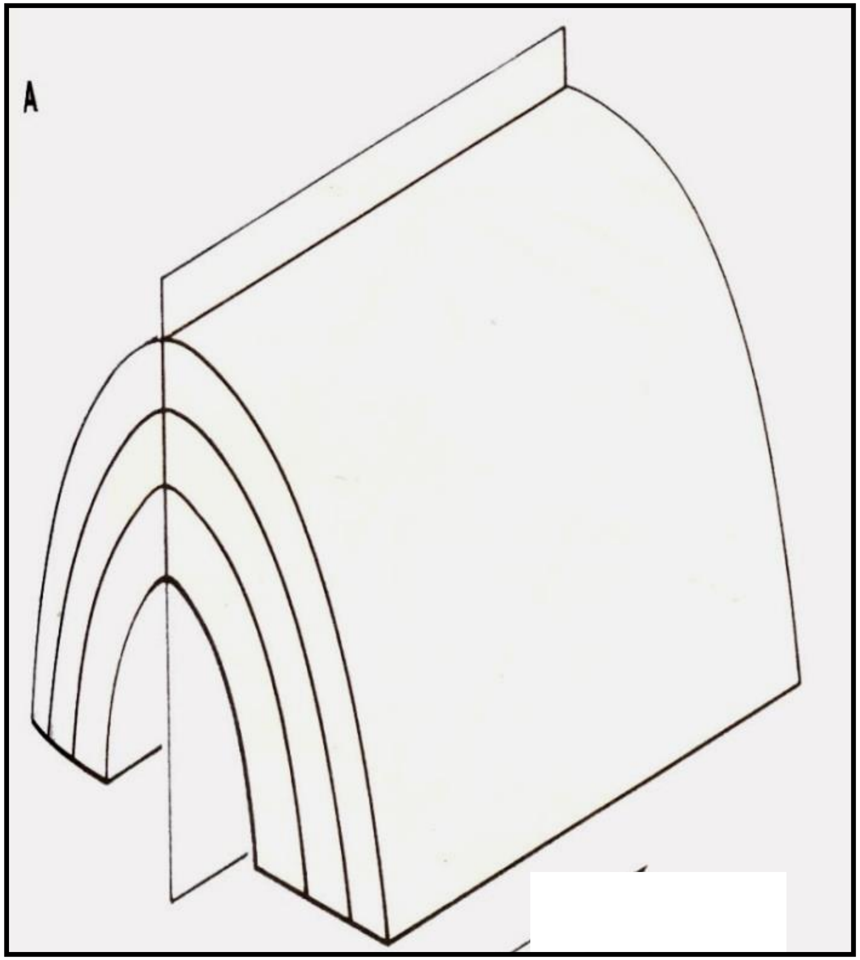
Figure 7.20 The trend and plunge of the hinge line of a fold does not uniquely define the overall orientation of the fold. See for yourself.

The axial surface of a fold passes through successive hinge lines in a stacking of folded surfaces (Figure 7.21).

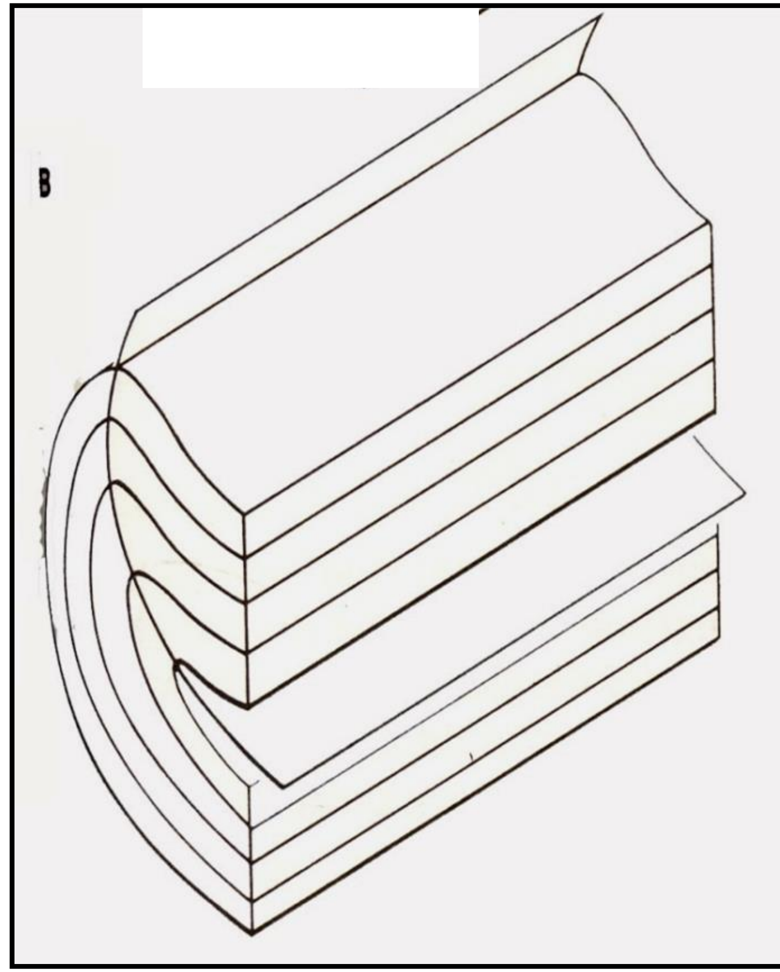
An imaginary plane that includes the fold axis and divides the fold as symmetrically as possible is called the axial plane of the fold

The axial surface of a fold may be planar (Figure *7.21A),* in which case it is called an axial plane.

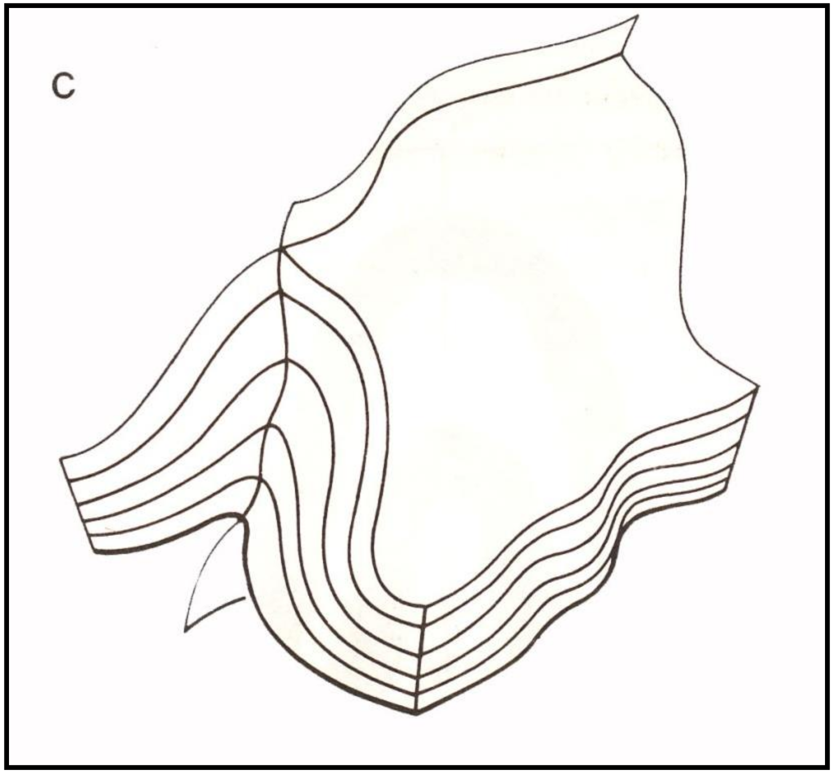
More commonly the axial surface of a fold is either systematically curved (Figure 7.21B) or nonsystematically irregular (Figure 7.21C), in which case axial surface is the appropriate term.



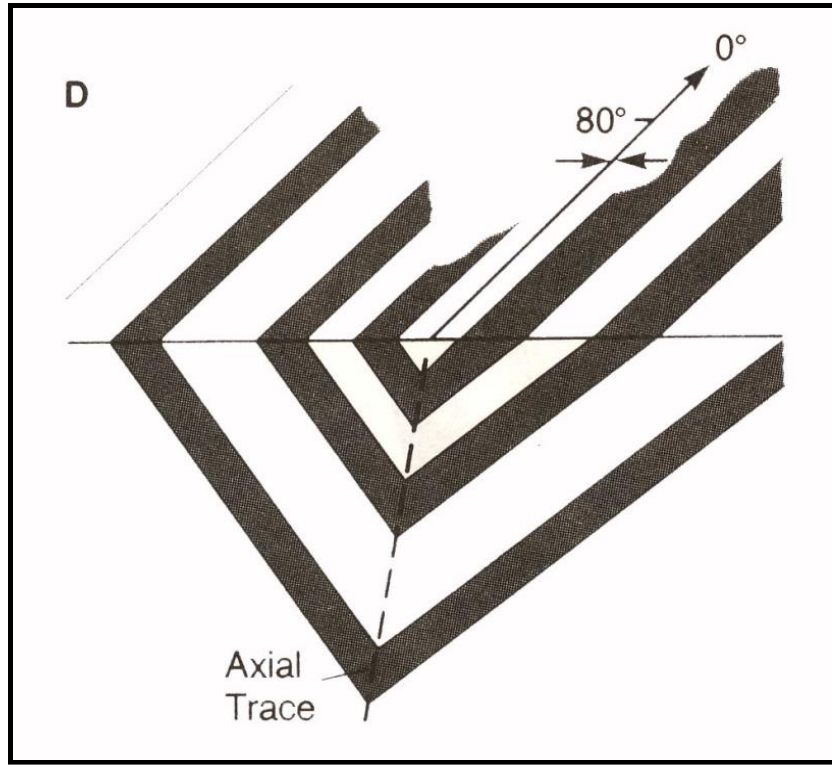
Fold with a planar Axial surface



curviplanar axial surfaFold with a systematically e



Fold with an irregularly curviplanar axial surface



Axial trace of a fold as seen in a cross-section and in map

In normal profile view, the trace of the axial surface of a fold can be seen to pass through successive hinge points in the stacking of folded surfaces (Figure *7.21D).* This line is called the axial trace of the fold in profile view.

In a more general sense, "axial trace" refers to the line of intersection of the axial surface with *any* other surface, whether it be the ground surface, the steep flank of a mountain, or the faces of a block diagram of folded layers (Figure 7.22).

The orientation of the axial surface of a fold is described in terms of strike and dip. A single strike-and-dip measurement is all that is necessary to describe the orientation of the axial plane of a fold.

For a nonplanar axial surface, however, a number of strike-and-dip measurements are required to document the full spectrum of orientations of the axial surface.

Knowing the orientation of the axial surface does not fix uniquely the attitude of the fold.

Folds having a common axial surface orientation can have radically different configurations (Figure 7.23).

Only when the orientations of both the hinge line and the axial surface of a fold are known can the configuration of the fold be firmly established.

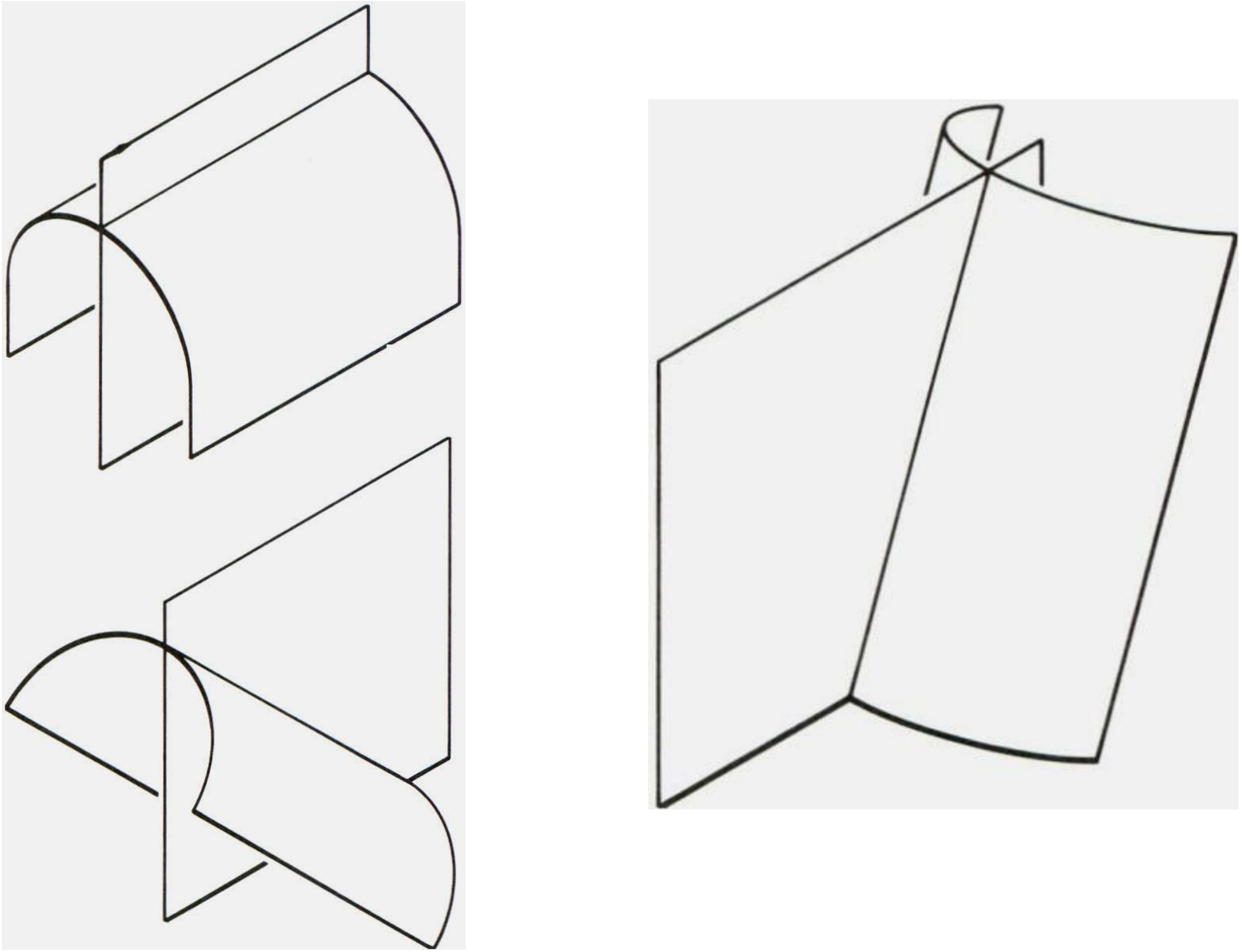
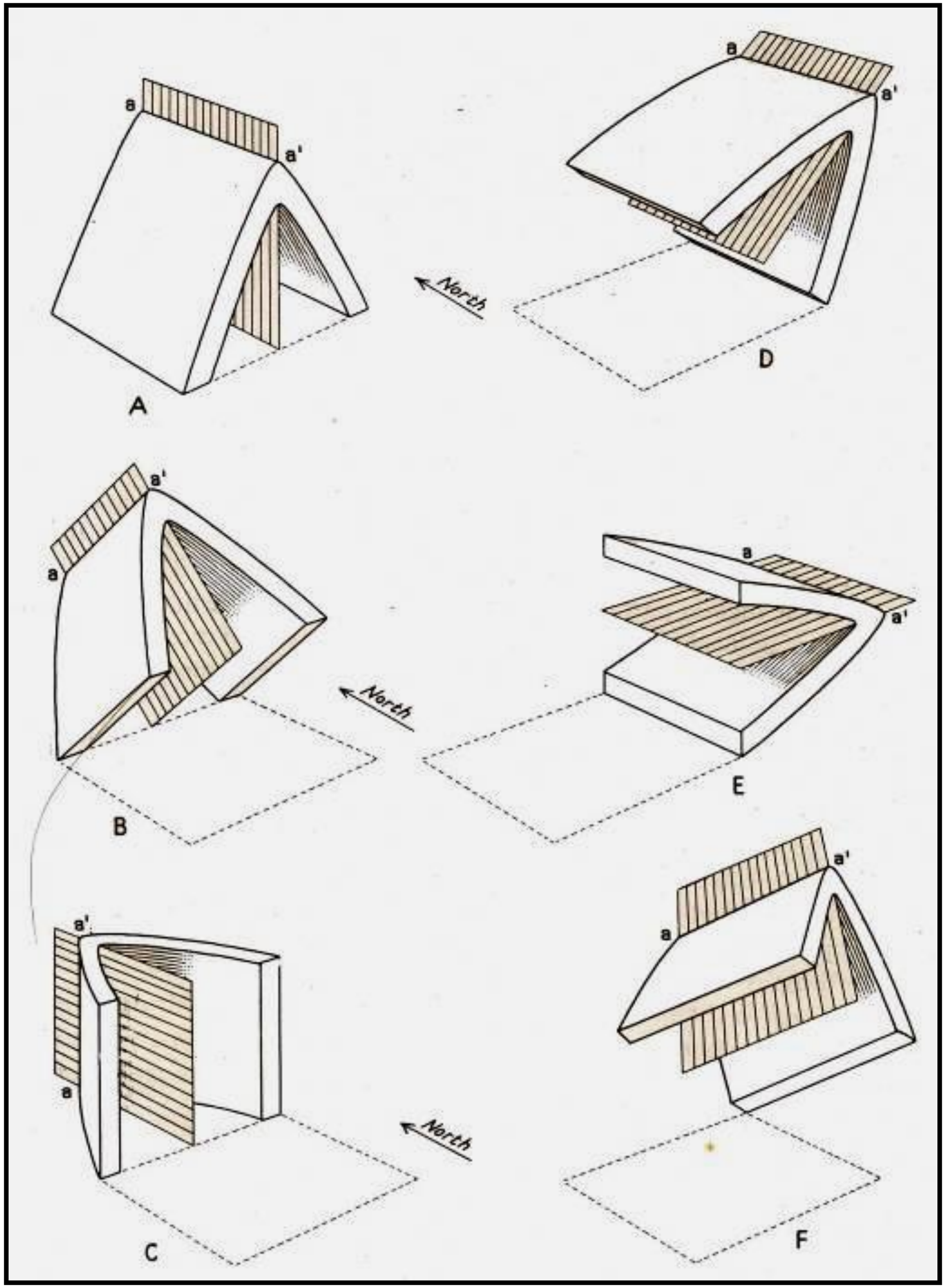


Figure 7.23: The strike and dip of the axial surface of a fold does not uniquely define the overall orientation of the fold



Different attitudes of axial planes and hinges of folds.

- *aa' is hinge of fold, axial planes are shaded*

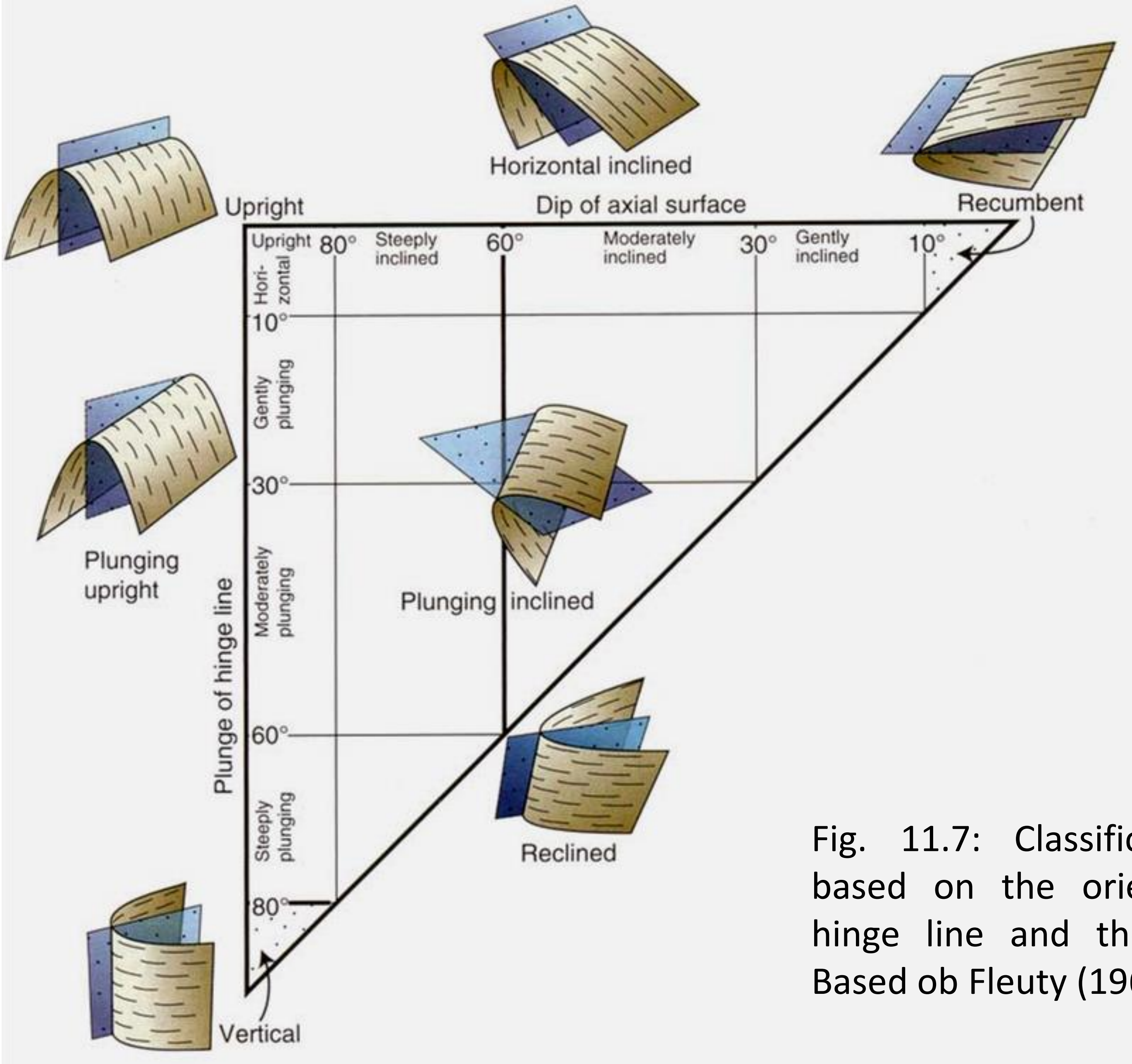


Fig. 11.7: Classification of folds based on the orientation of the hinge line and the axial surface. Based ob Fleuty (1964)

Nomenclature (Classification) of Folds

FOLD CLASSIFICATION

1. Classification based on convexity
2. Classification based on orientation of Axial Plane
3. Classification based on Interlimb Angle (Fleuty 1964)
4. Classification based Upon Fold Axis
5. Classification based on plunge of hinge line
6. Classification based upon shape of fold

1. Fold shape

chevron, as circular with a curved axis

2. Fold tightness

measured tangential to the folded surface at the inflection line of each limb), called the interlimb angle.

3. Fold symmetry

Not all folds are equal on both sides of the axis of the fold. Those with limbs of relatively equal length are termed symmetrical, and those with highly unequal limbs are asymmetrical.

4. Deformation style classes

Folds that maintain uniform layer thickness are classed as *concentric* folds. Those that do not are called *similar folds*. Similar folds tend to display thinning of the limbs and thickening of the hinge zone

1. Classification based on convexity

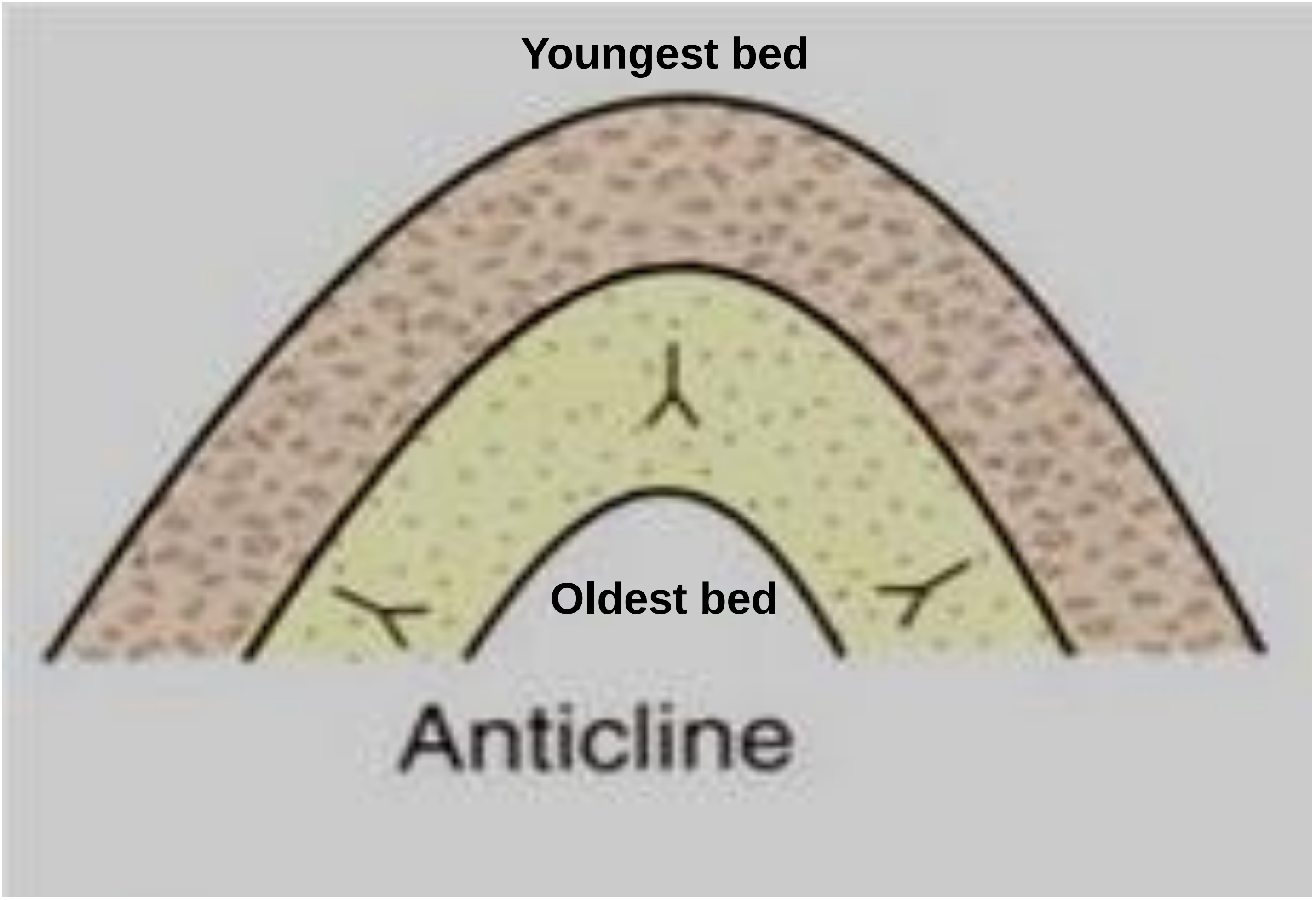
a) Antiform
b) Synform
c) Antiformal anticline (upward facing anticline; Anticline)
d) Synformal syncline (upward facing syncline; Syncline)
e) Antiformal syncline (Downward facing syncline)
f) Synformal anticline (Downward facing anticline)

Anticlines and Synclines
And monoclines

An anticline is a fold that is convex in the direction of the youngest beds in the folded sequence.

It is a fold that arches up as both sides of the rock are pushed inward. One can remember that the anticline creates this type of fold because the arch looks like an 'A' (for anticline).

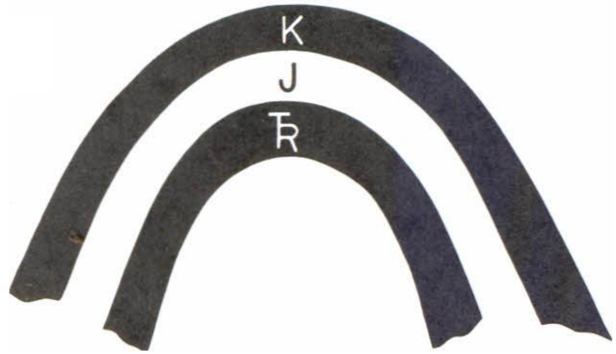
Anticlines are upward-arching folds.


Youngest bed
Oldest bed
Anticline

Ordinarily we think of anticlines as upright, convex-upward folds, like that shown in Figure *7.12A.* But even the "upside-down" anticline shown in Figure 7.12B is called an anticline, albeit a special kind known as a synformal anticline.

The adjective "synforrmal" means that the fold is concave upward.

A



B

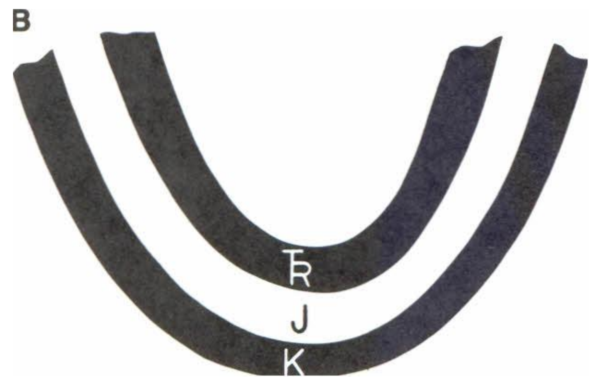


Figure 7.12 Anticlines and synclines. The cornerstones of fold terminology. Oldest layer is Triassic (R); youngest layer is Cretaceous (K); in-between is Jurassic (J). *(A)* Anticline. *(B)* Synformal anticline.

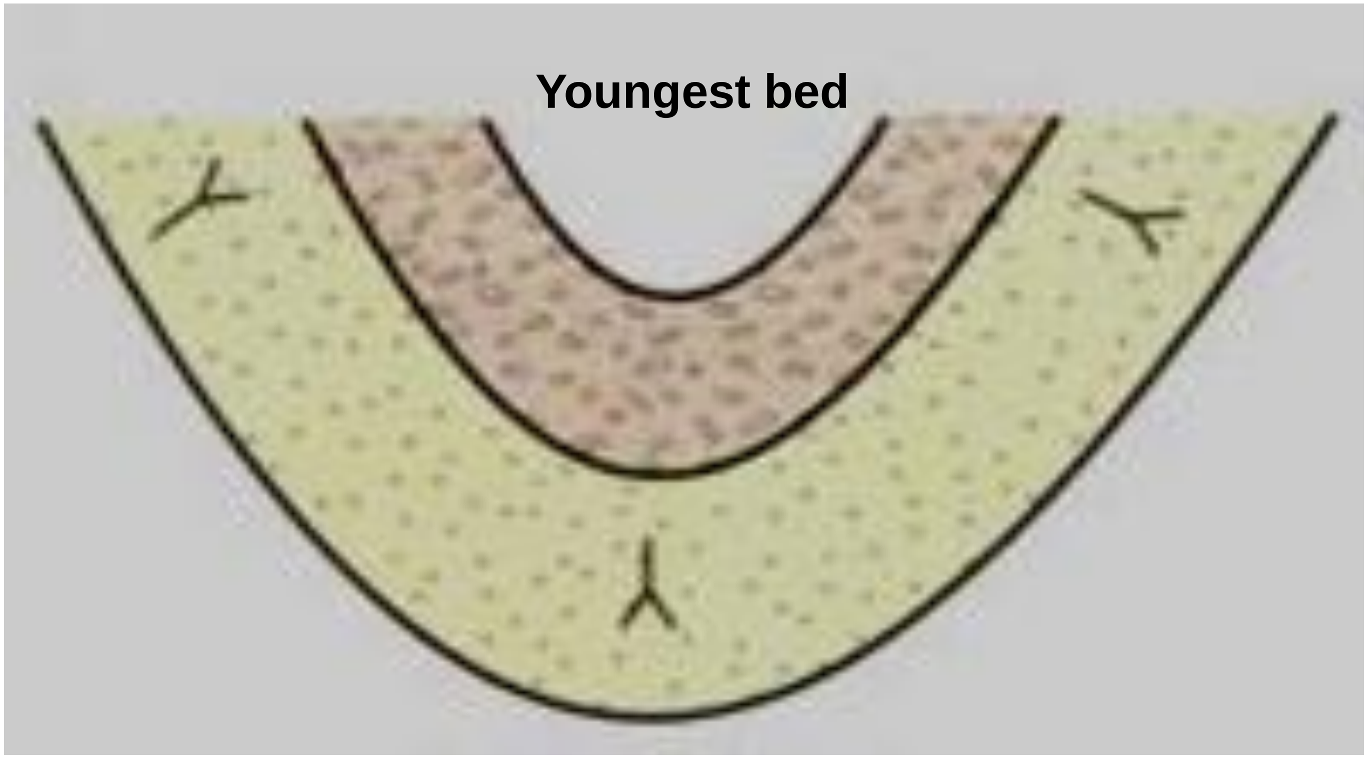
A syncline is a fold that is convex in the direction of the oldest beds in the folded sequence (Figure 7 *.12C).*

Synclines are downward-arching folds.

These too can be oriented in any way, from perfectly upright synclinal folds to convex upward antiformal synclines (Figure *7.12D).*

A syncline is a fold that sinks down as both sides of the rock are pushed inward.

One can remember that a syncline creates this type of fold because the fold 'sinks' downward, which sounds like 'syncline.'



Oldest bed

Syncline

C

D

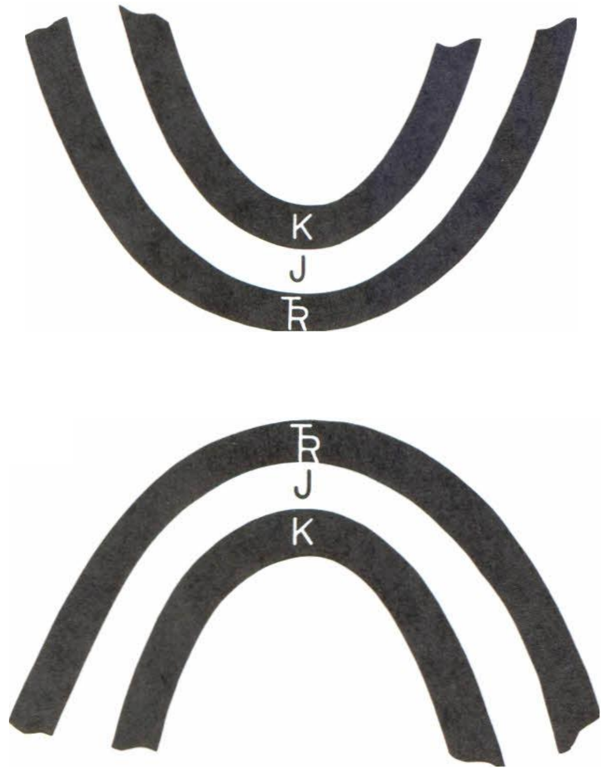
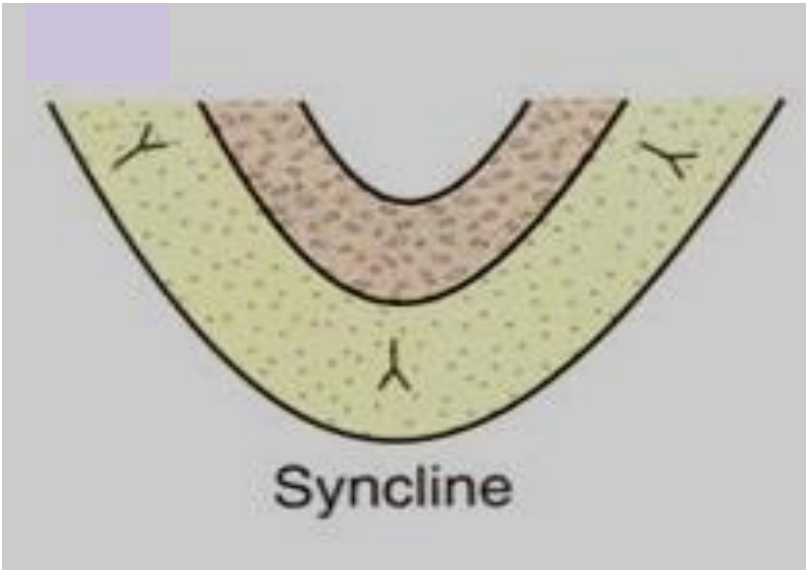
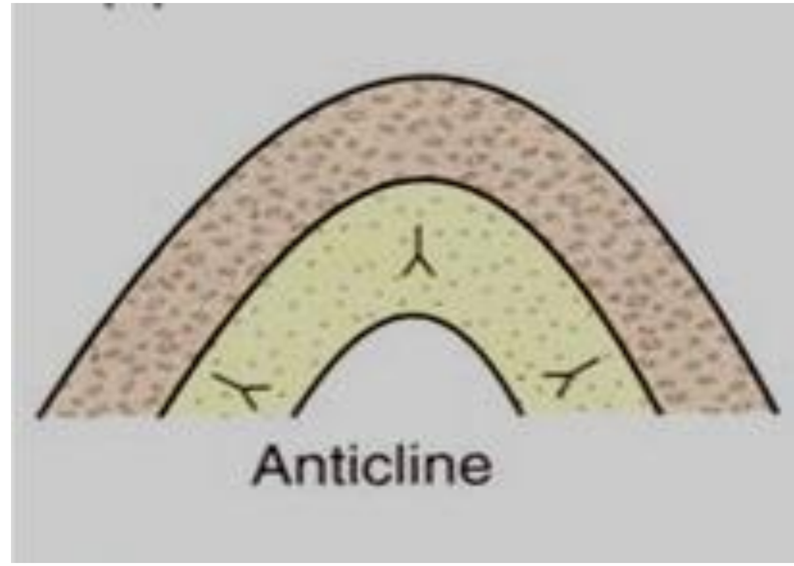


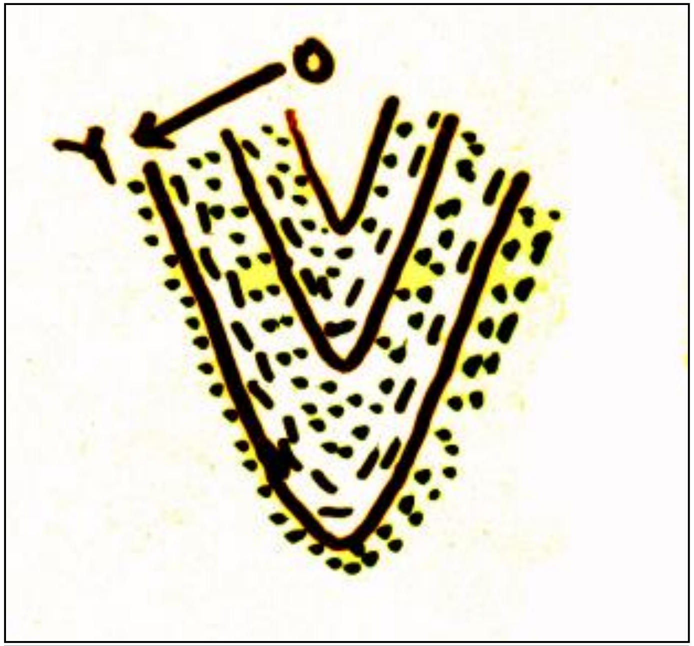
Figure 7.12 Anticlines and synclines. The cornerstones of fold terminology. Oldest layer is Triassic (R); youngest layer is Cretaceous (K); in-between is Jurassic (J). (C) Syncline. *(D)* Antiformal syncline.


Syncline


Anticline

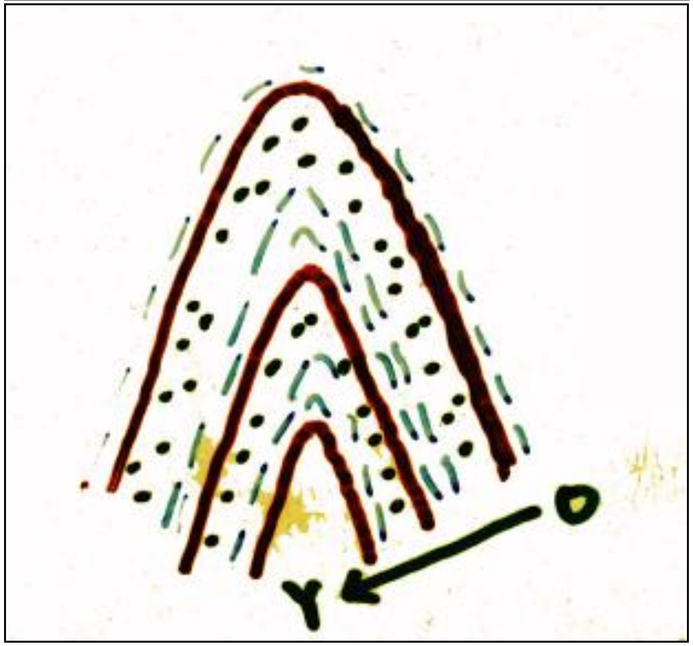
Synformal Anticline

Also called downward facing Anticline



Antiformal Syncline

Also called downward facing Syncline



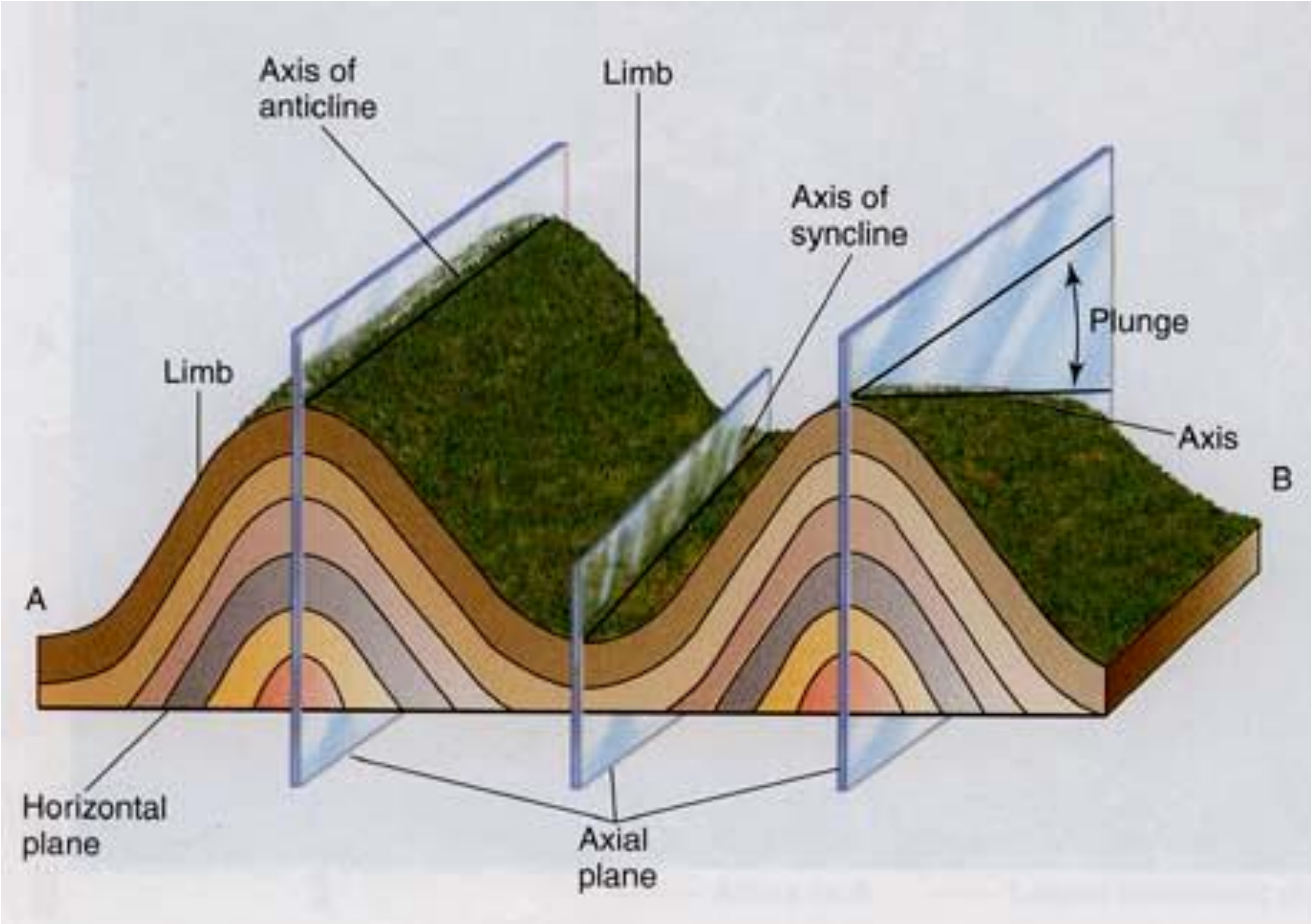
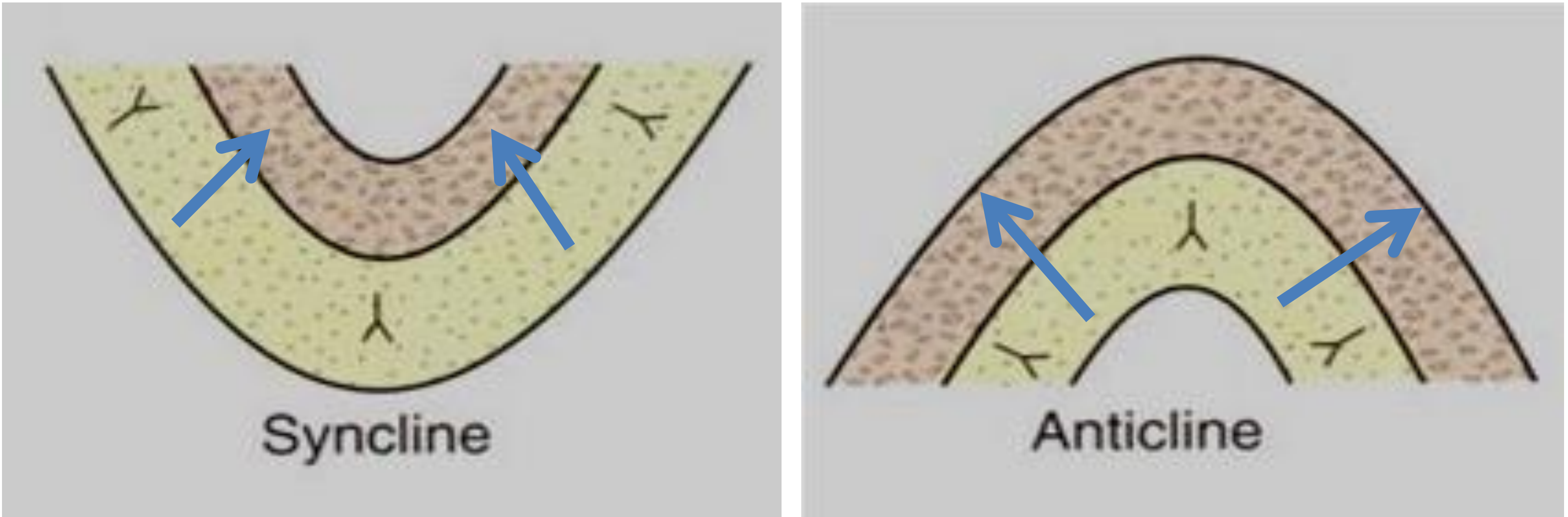
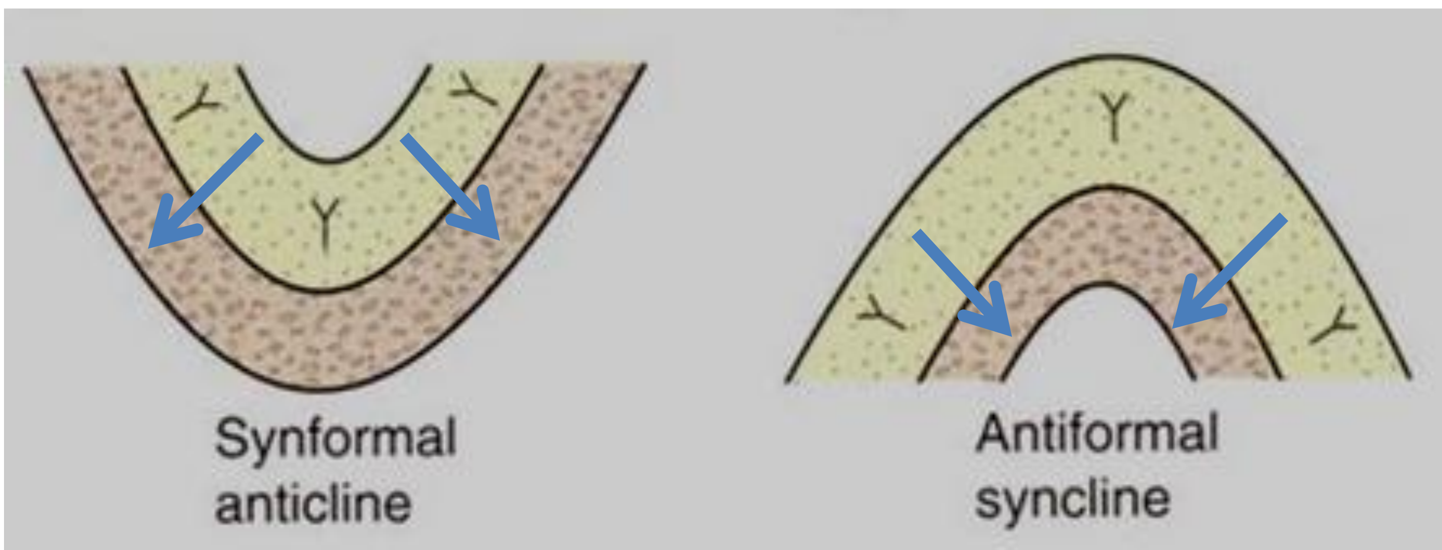


Fig. 9.21: Geometry of fold: Features of a simple fold. Note that the strata dip away from the axis of an anticline but towards the axis of a syncline. A. Fold axis horizontal. B. Fold axis plunging



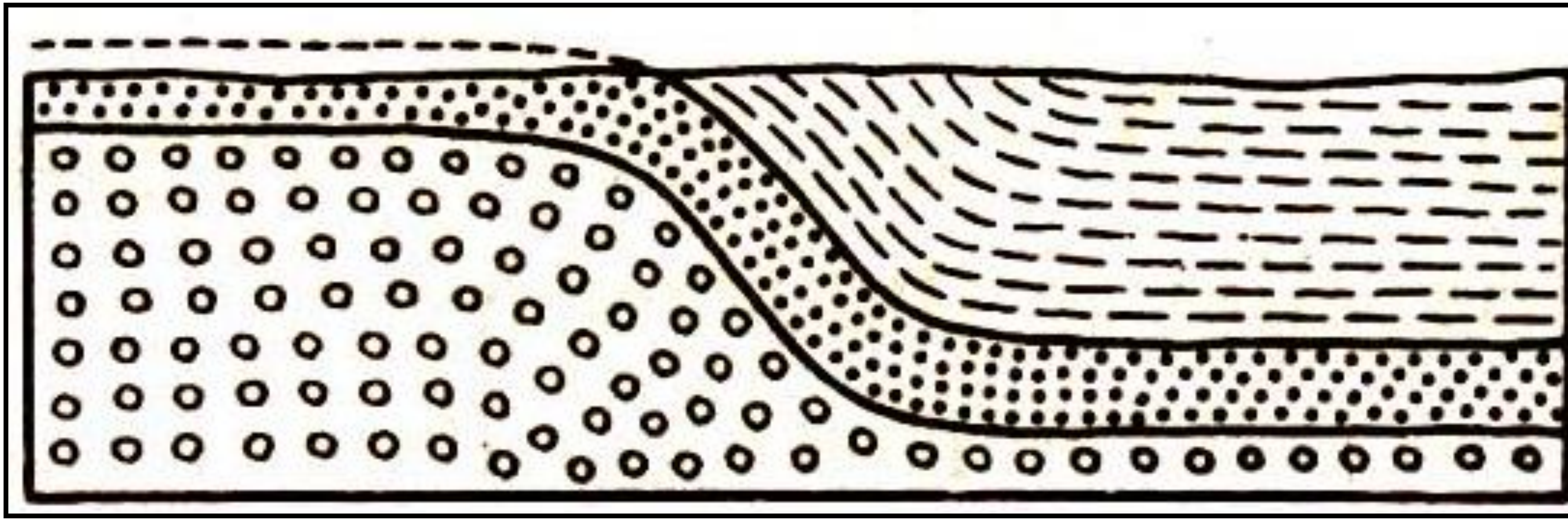
Stratigraphy known Y (younging direction)



Inverted anticline

Inverted syncline

Monoclines



Monocline

- In plateau area, where the bedding is relatively flat, the strata may locally assume a steeper dip.
- The beds in monocline may dip at angles ranging from a few degrees to 90 degree and the elevation of the same bed on opposite sides of monocline may differ by hundreds or even thousands of feet.

A monocline is a fold where the rock layers form an S-shape as the sides of the rock are compressed.

One can remember this type of fold because all the layers of rock are still horizontal, going in one direction instead of bending vertically upward or downward like anticlines and synclines.

And since 'mono' means 'one,' monoclines are layers in only 'one direction.’

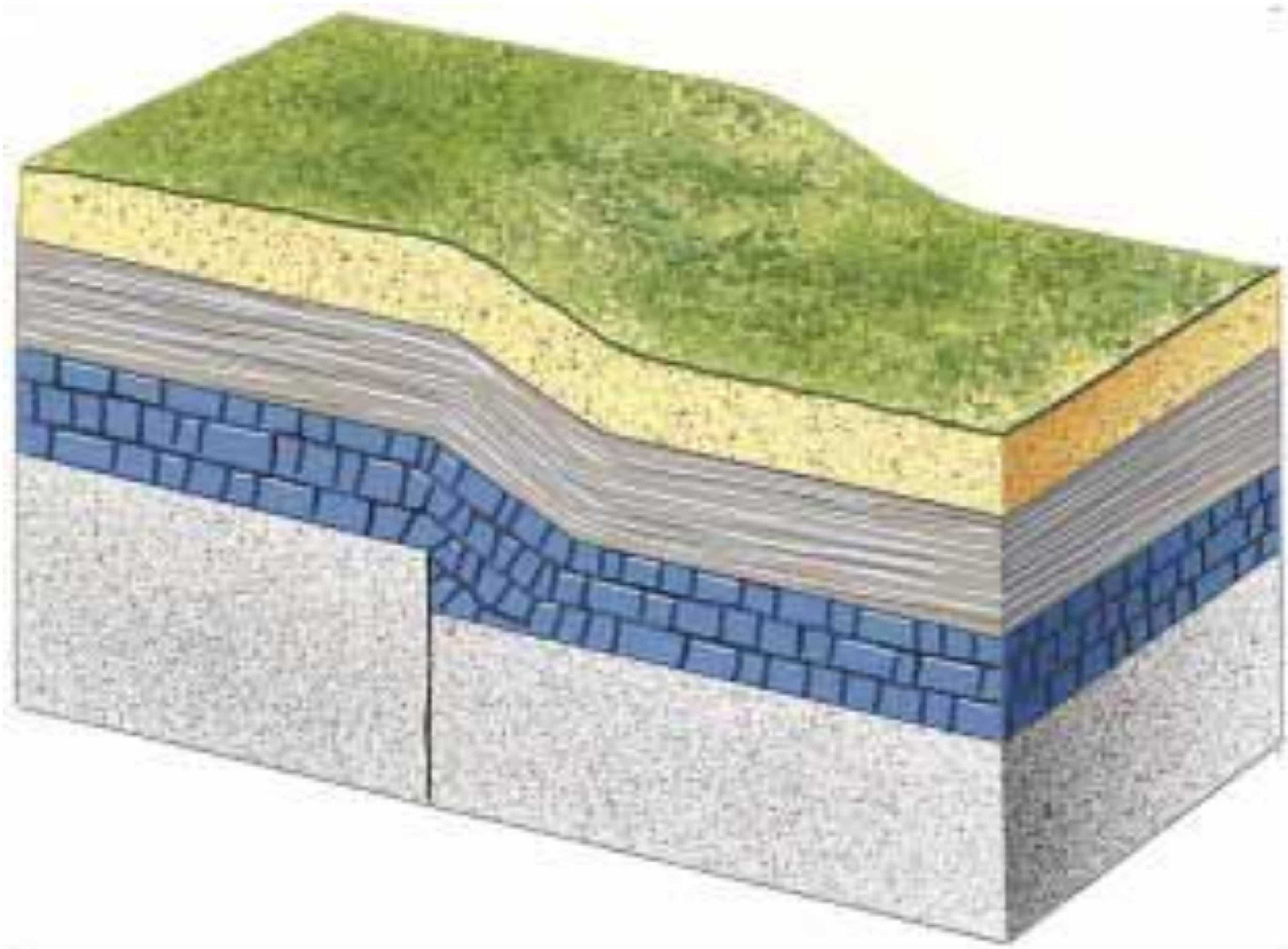
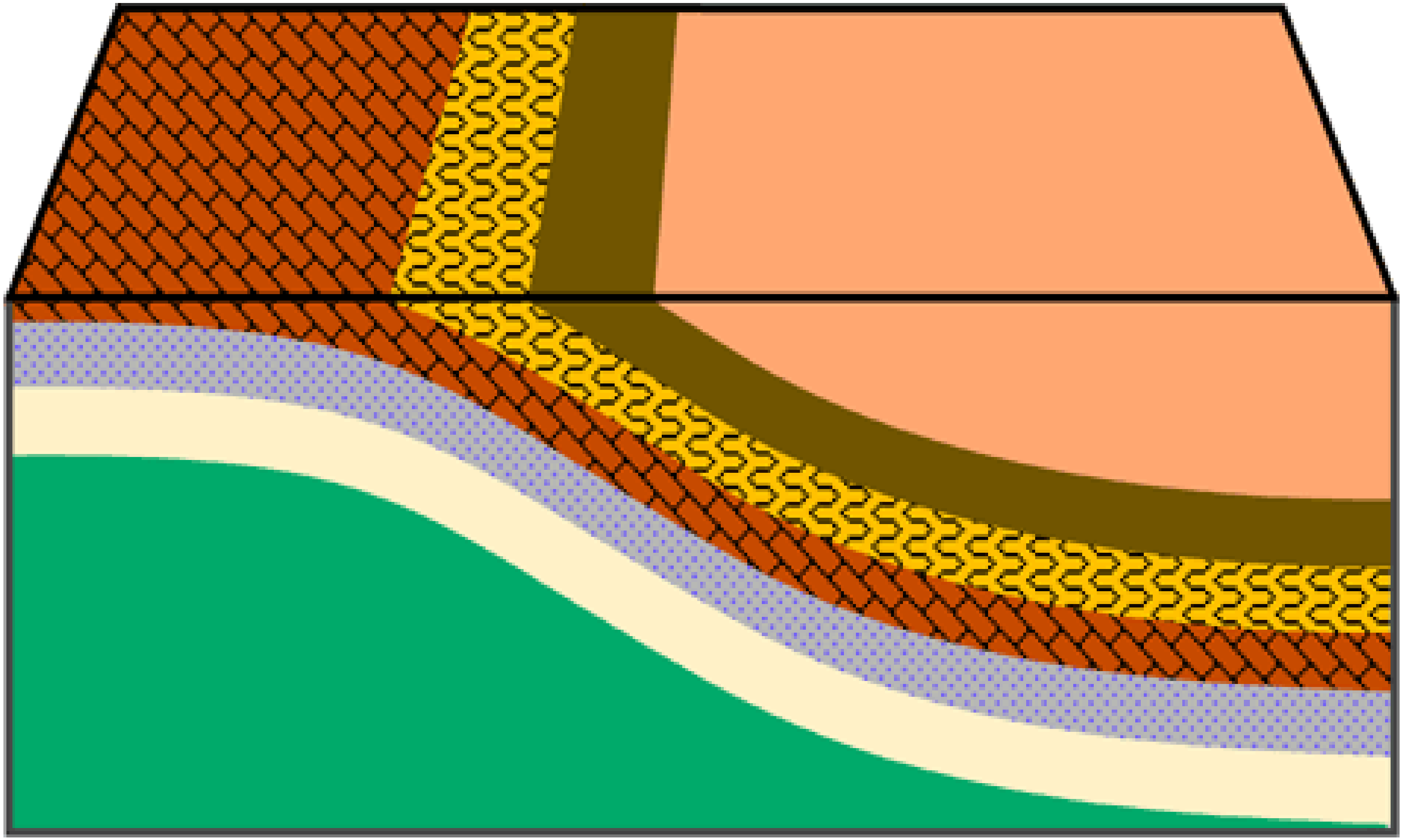


Figure 12–9 (a) A monocline formed where near-surface sedimentary rocks sag over a fault. (b) A monocline in southern Utah.

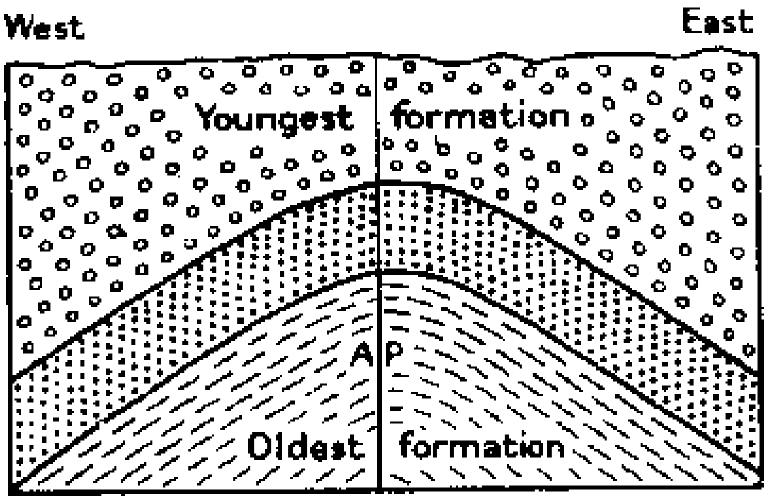


A number of different **folds** have been recognized and classified by geologists. The simplest type of fold is called a **monocline** (**Figure 10i-2**). This fold involves a slight bend in otherwise parallel layers of rock. **Figure 10l-2:** Monocline fold.

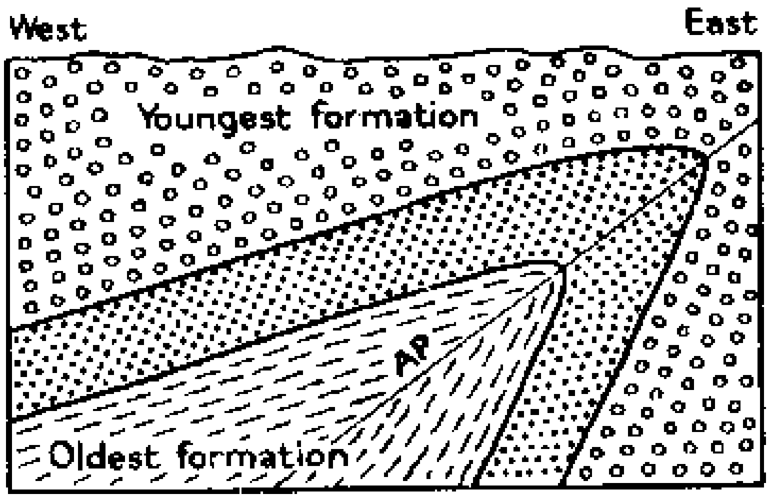
Monocline

2. Classification based upon orientation of Axial Plane

i. Upright fold
ii. Overturned fold (asymmetrical)



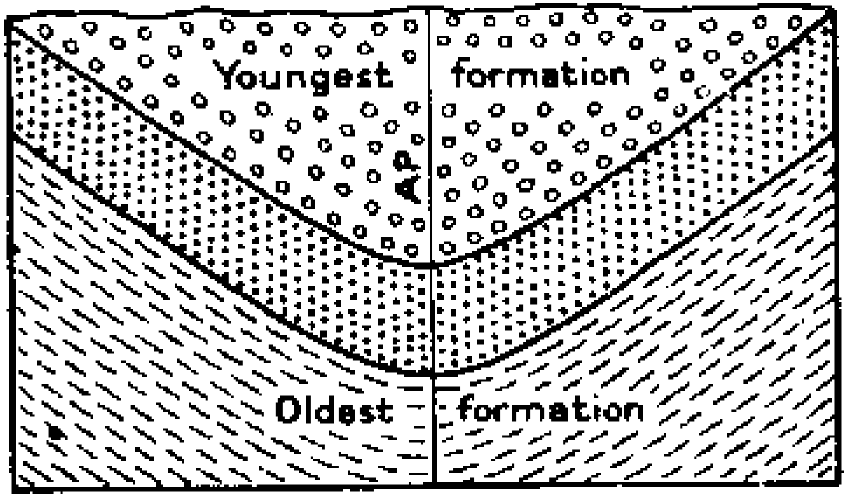
A



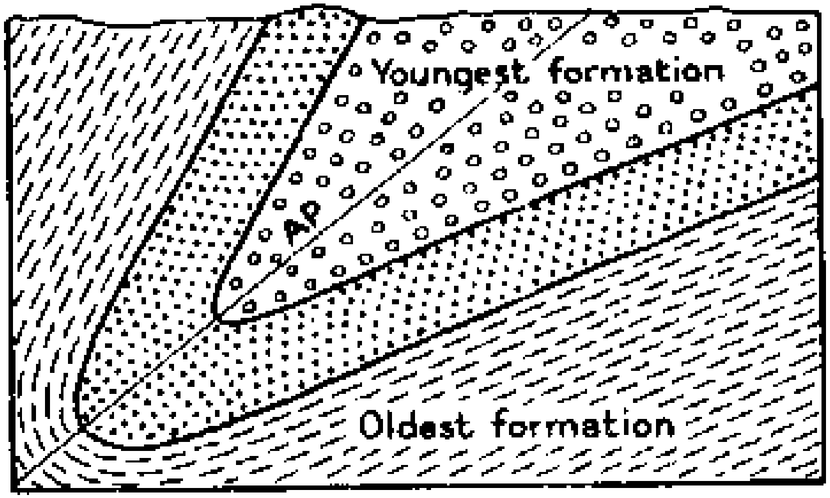
B

A. Symmetrical Anticline and
B. Asymmetrical Anticline

Classification based upon orientation of Axial Plane Contd…



A



B

A. Symmetrical Syncline and
B. Asymmetrical Syncline

Overturned Folds

It is very rare for anticlines and synclines to be completely upside down, but it is not at all uncommon for them to be overturned.

Overturned folds occur when the folding is so intense that the fold appears to have turned over on itself.

Similarly, we can have recumbent folds, which are even more extreme than overturned folds.

These are folds that are nearly horizontal. 'Recumbent' means 'lying down,' so you could think of this fold as lying down sideways.

The distinction between upside down and overturned is this:

upside-down folds are totally inverted, like the antiformal syncline shown in Figure 7.12B.

In contrast, a fold is considered to be overturned if at least one of its limbs (i.e., flanks) is overturned.

Saying that the limb of a fold is overturned does not mean that the fold is completely upside down.

It simply means that one limb has been rotated beyond vertical such that the facing direction of the limb points downward at some angle.

A schematic rendering of overturned anticlines and synclines is shown in Figure *7.13A.*

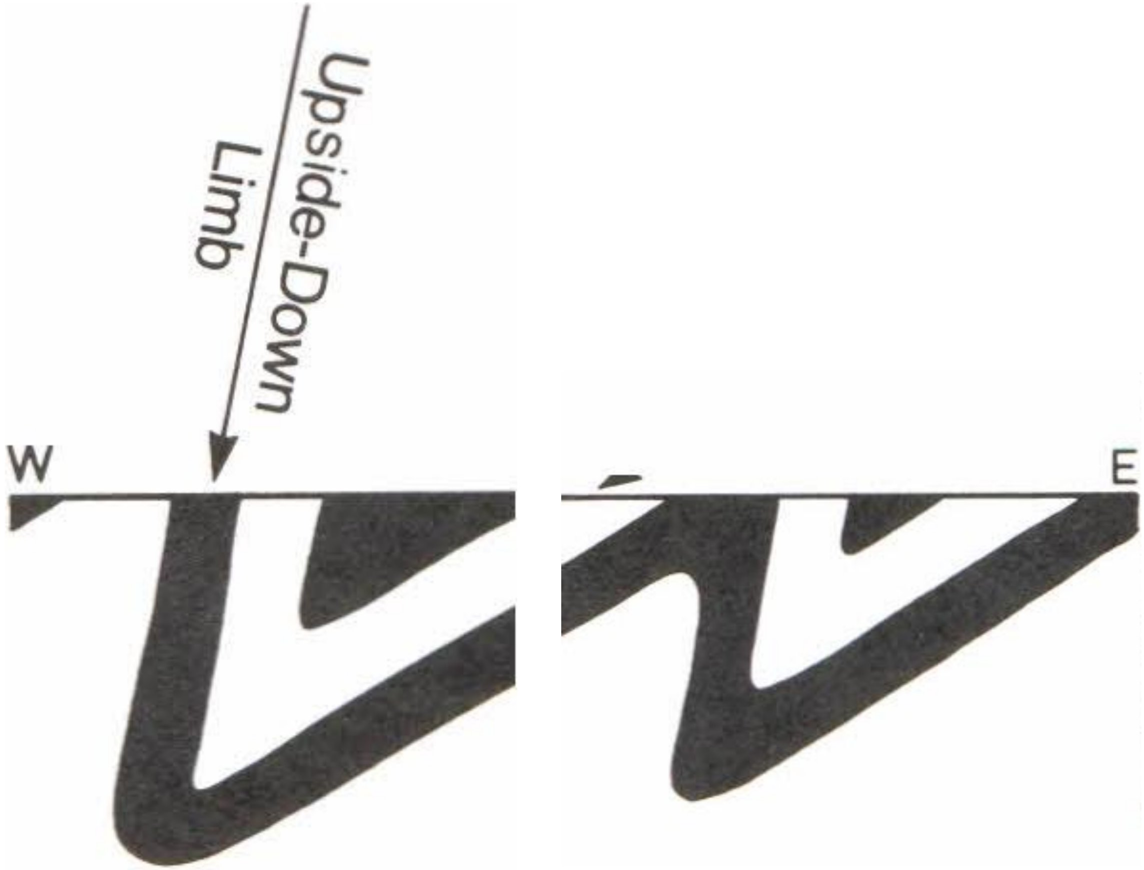
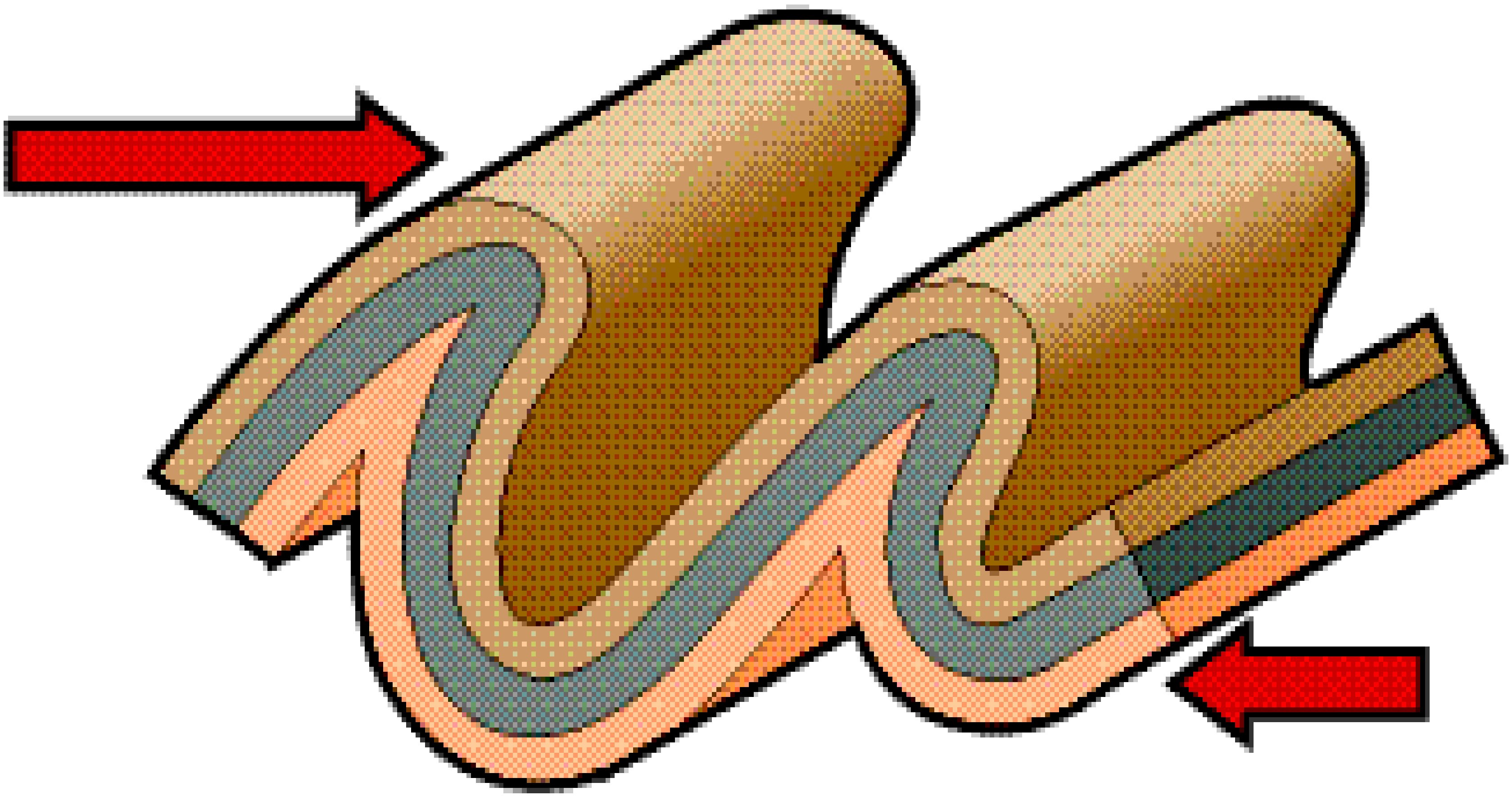


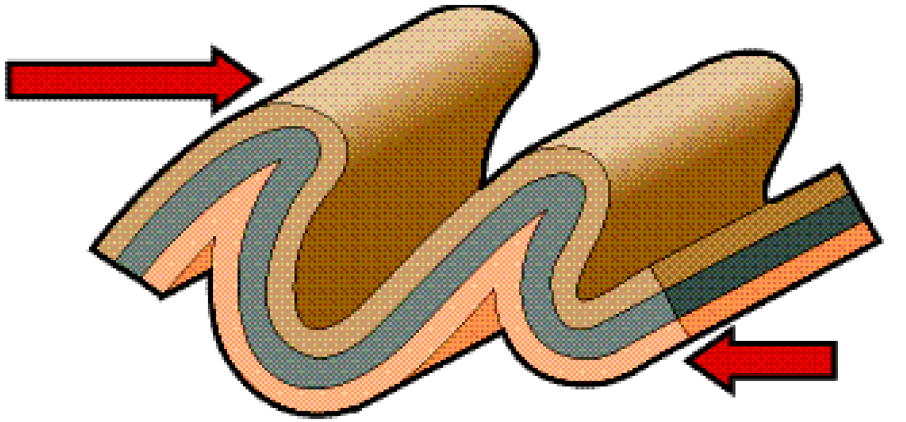
Figure 7.13 *(A)* Schematic rendition of overturned anticline and syncline. *(B)* The real thing! Overturned anticline and syncline in sedimentary rocks in the Funeral Mountains. Death Valley. California. Geologist barely visible in core of main anticline is Stan Ballard. (Photograph by S. J. Reynolds.)

Overturned folds (Overfolds)

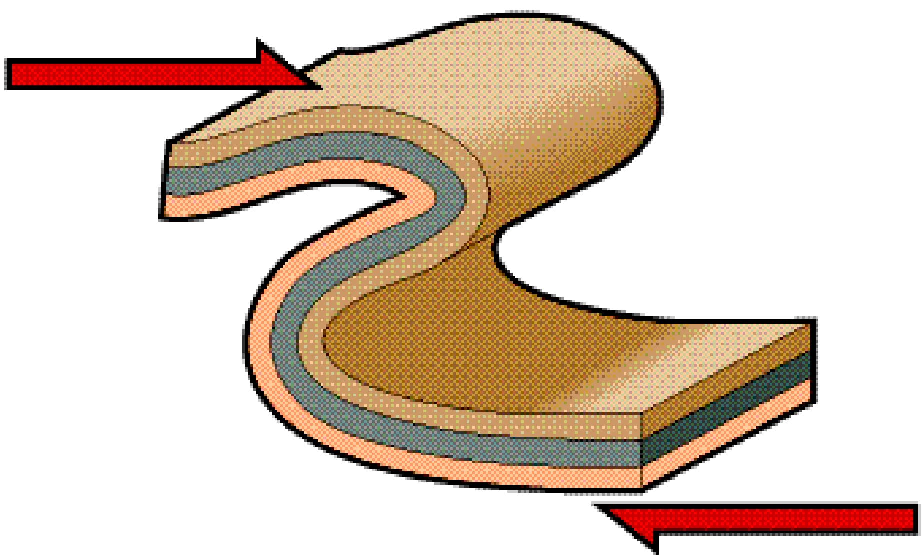
- **AP inclined, both limbs dip in same direction, usually at different angles.**
- **The overturned limb is one that has been rotated through more than 90 degree to attain its present attitude.**



An overturned fold



D Overturned folds



E Recumbent folds

Recumbent and Isoclinal folds

The terms "anticline" and "syncline" may have only limited application in describing superposed folds in a sedimentary and/or volcanic sequence.

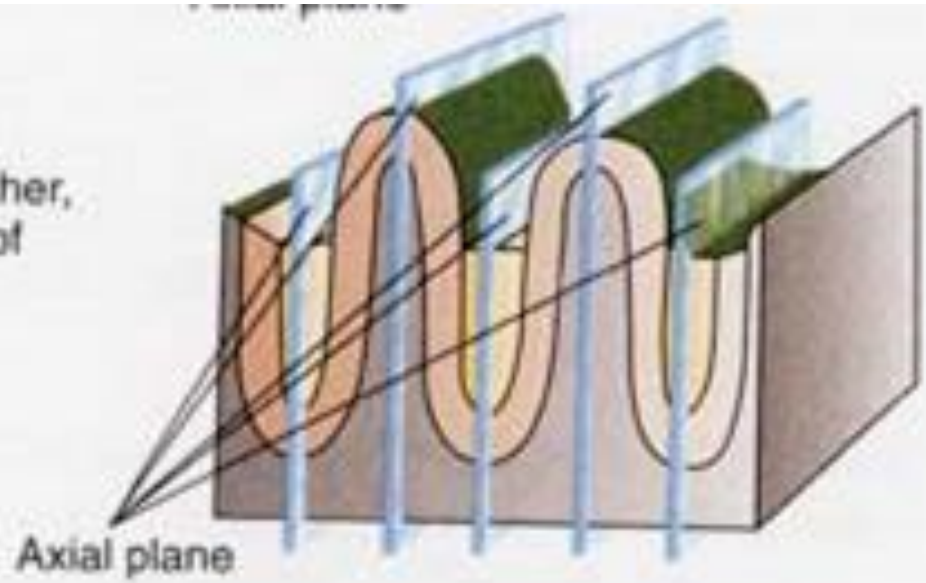
By way of example, the early-formed fold shown in structure profile view in Figure *7.15A* may be described as a recumbent, isoclinal anticline.

Recumbent" means that the fold lies on its side. "Isoclinal" means that the limbs of the fold are equally inclined.

We can have recumbent folds, which are even more extreme than overturned folds. These are folds that are nearly horizontal. 'Recumbent' means 'lying down,' so you could think of this fold as lying down sideways.

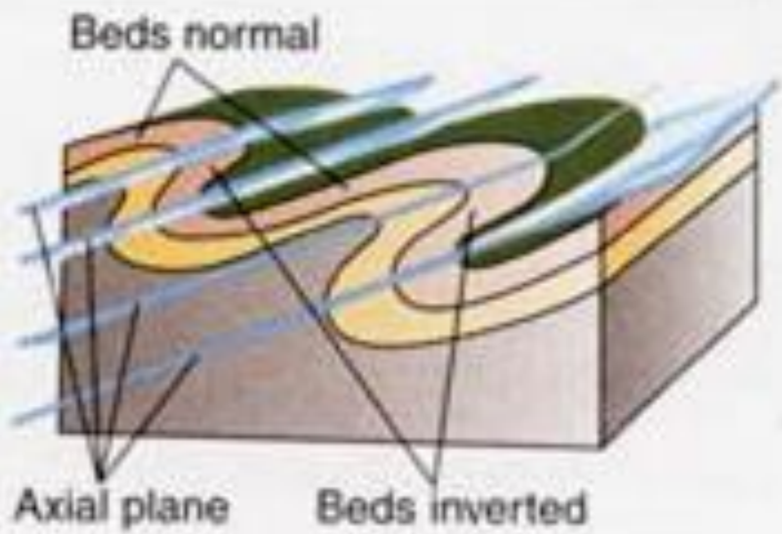
B. Isoclinal

Both limbs of any fold are parallel to each other, regardless of the dip of the axial plane.



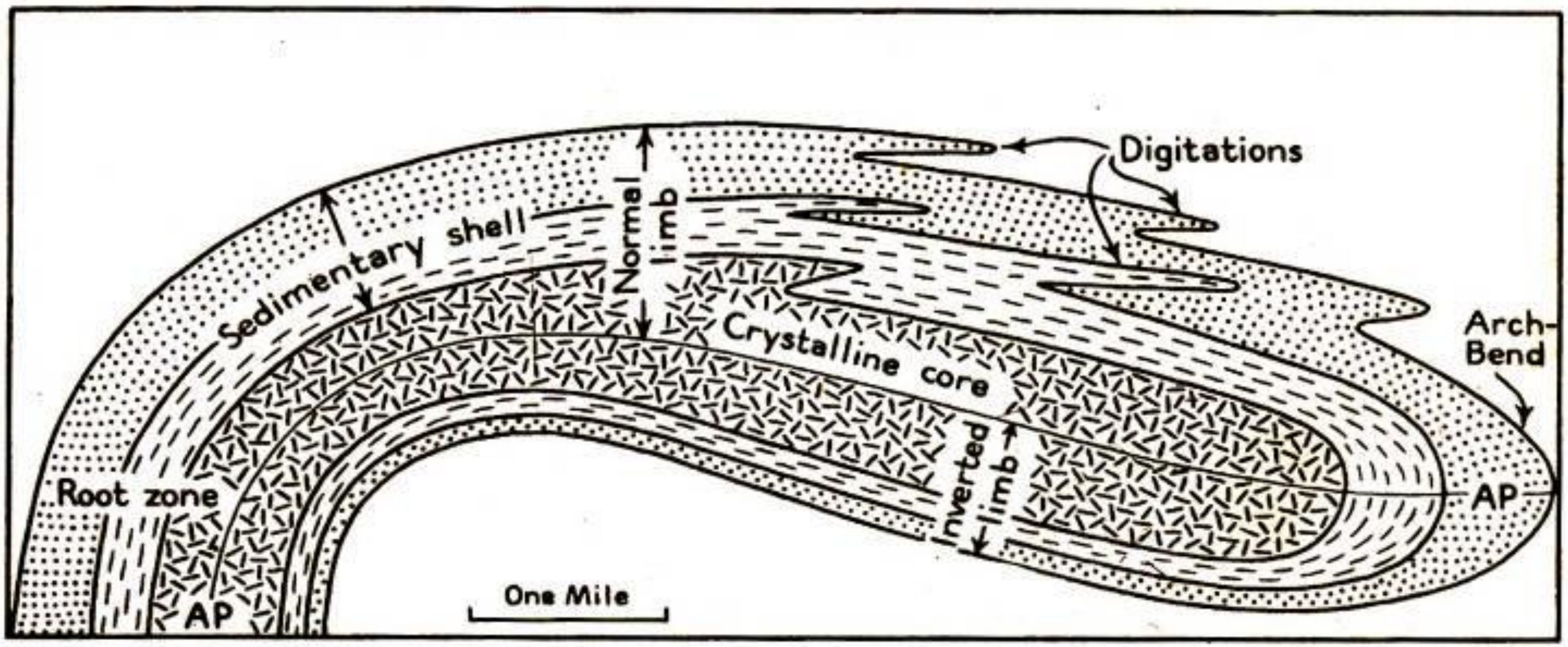
E. Recumbent

Axial planes are horizontal or nearly so. Strata on the lower limb of anticline and upper limb of syncline are upside down.



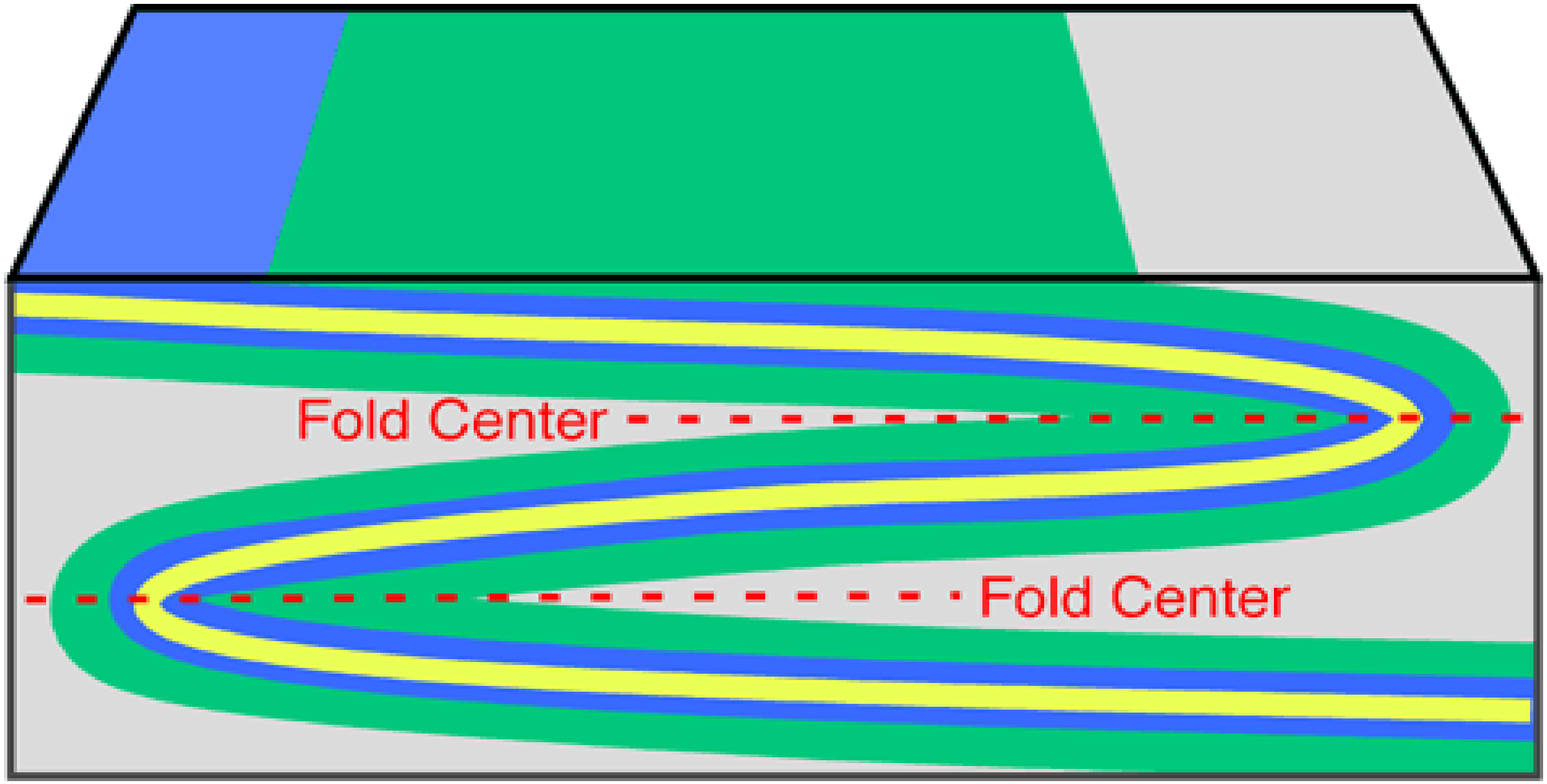
Recumbent Fold

- **AP horizontal**
- **In large scale recumbent fold, the strata in the normal limb are usually thicker than the corresponding beds in overturned limbs.**
- **Inner part of fold: core; Outer part of fold: Shell**
- **Subsidiary recumbent anticlines in the major fold are called digitations**
- **The place on the surface of the earth from which they arise are called root zones**

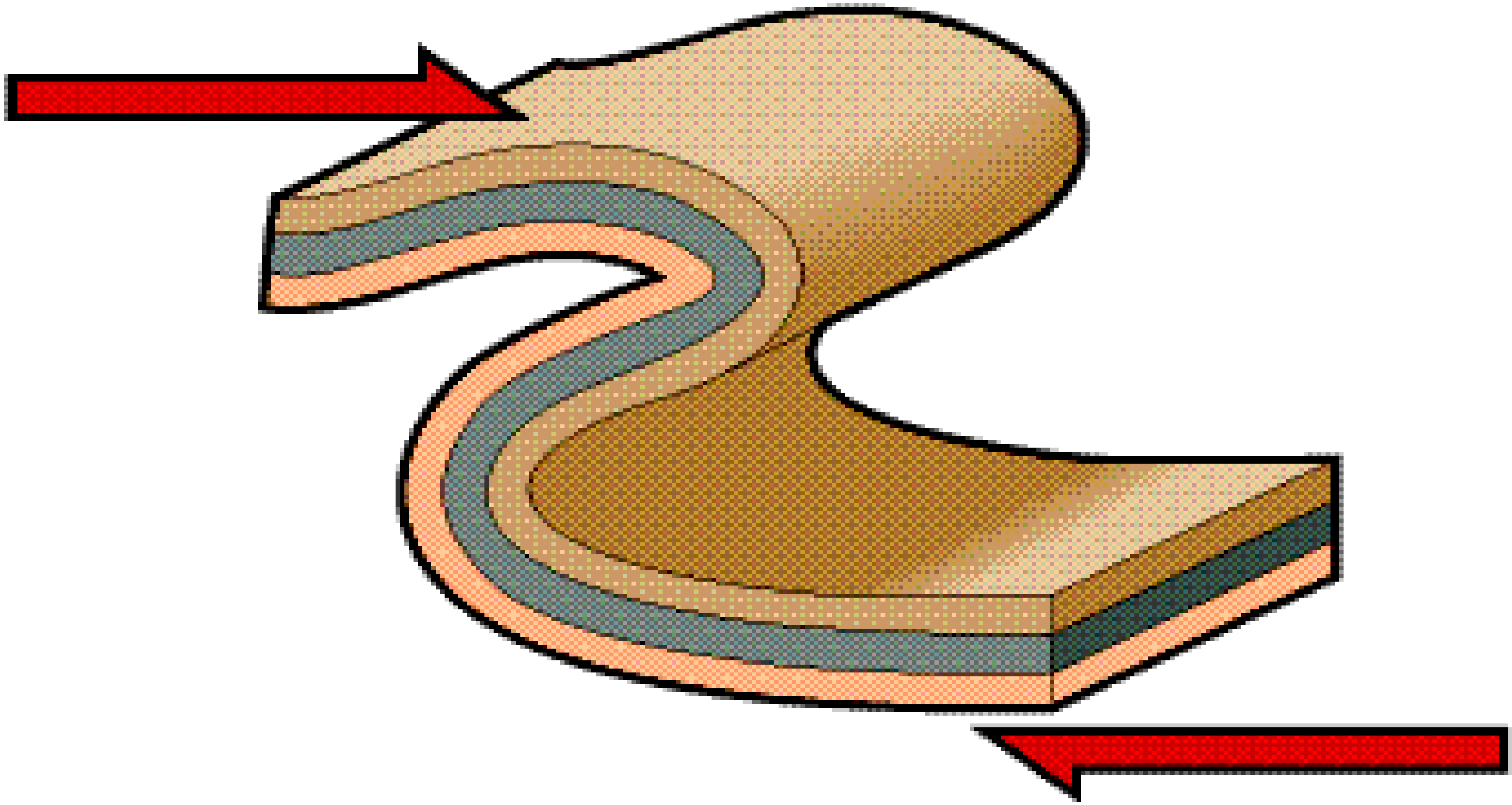


A recumbent fold

Figure 10l-7: Recumbent fold.



A **recumbent fold** develops if the center of the fold moves from being once vertical to a horizontal position (**Figure 10l-7**). Recumbent folds are commonly found in the core of mountain ranges and indicate that compression and/or shear forces were stronger in one direction. Extreme stress and pressure can sometimes cause the rocks to shear along a plane of weakness creating a **fault**. We call the combination of a **fault** and a **fold** in a rock an **overthrust fault**.

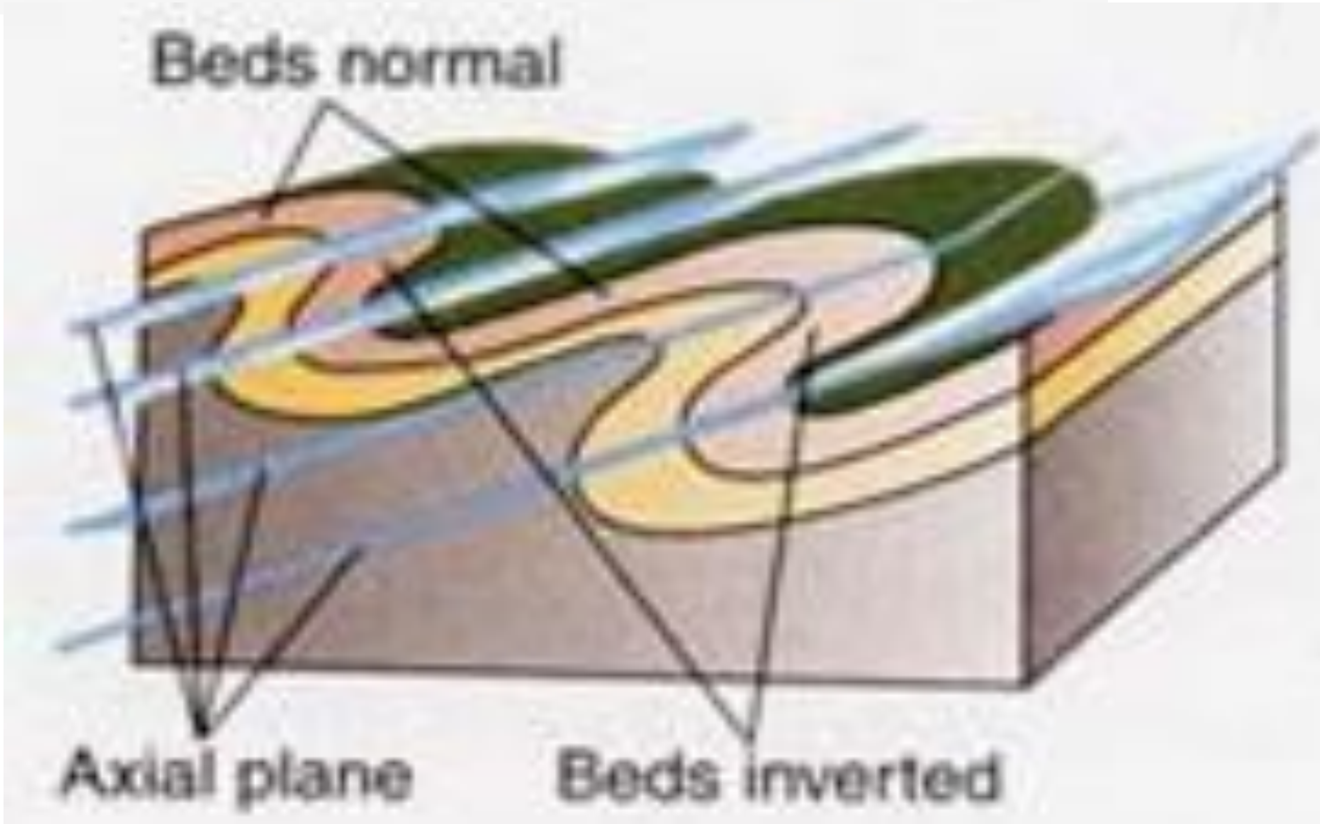


Recumbent Fold

Recumbent fold

Recumbent fold, King Oscar Fjord.

Folding from the Caledonian orogeny where Segelselskapets Fjord mouths into King Oscar Fjord, at 72°28'0.90"N, 24°41'55.44"W. The rock is of precambrian-cambrian age.



Recumbent fold: Axial planes are horizontal or nearly so. Strata on the lower limb of anticline and upper limb of syncline are upside down

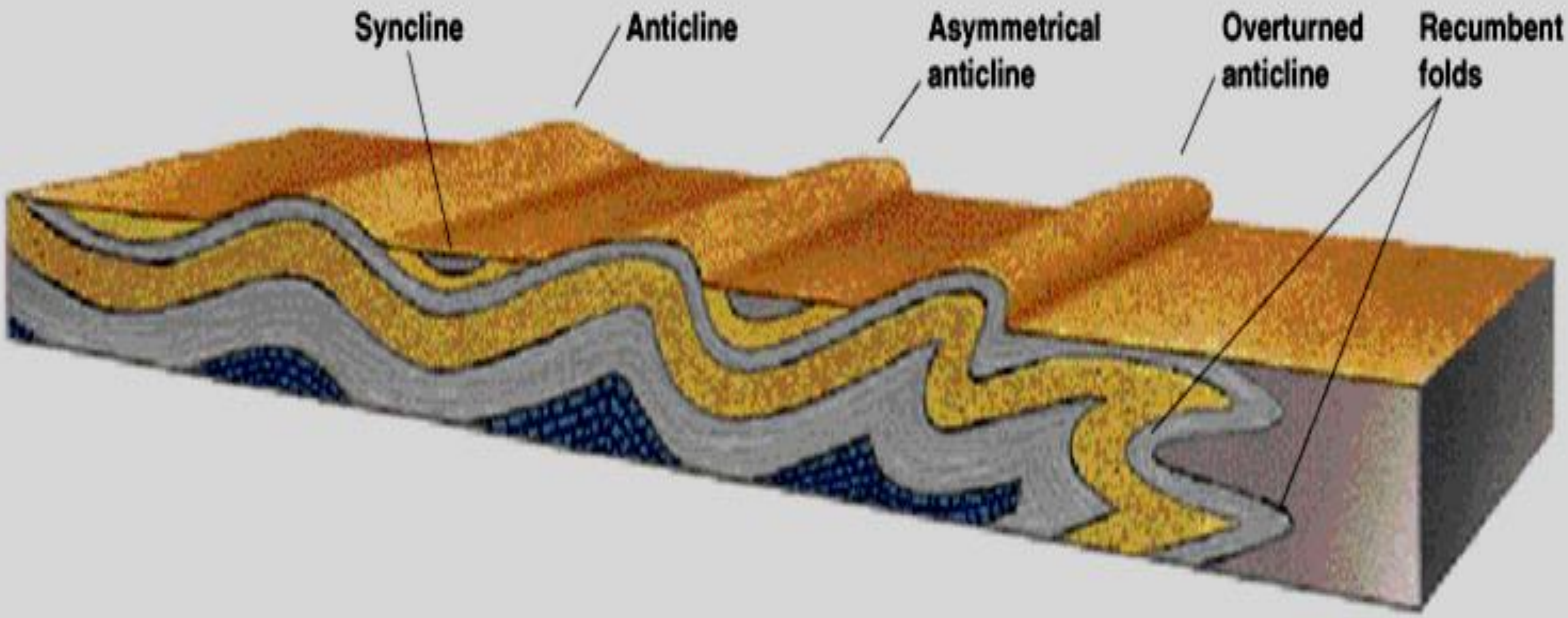


Fig. 8.5: Thompson and Turk: Earth Science and the Environment, 2/e

3. Classification based on Interlimb Angle (Fold tightness) (Fleuty 1964)

As part of the overall description of a folded surface, it is useful to convey a sense of the shape of the fold, including its tightness. Fold shape is described in normal profile view.

Normal profile views of folded surfaces are afforded by appropriately oriented outcrop exposures, photographs, geologic cross sections, and rock slabs or thin sections.

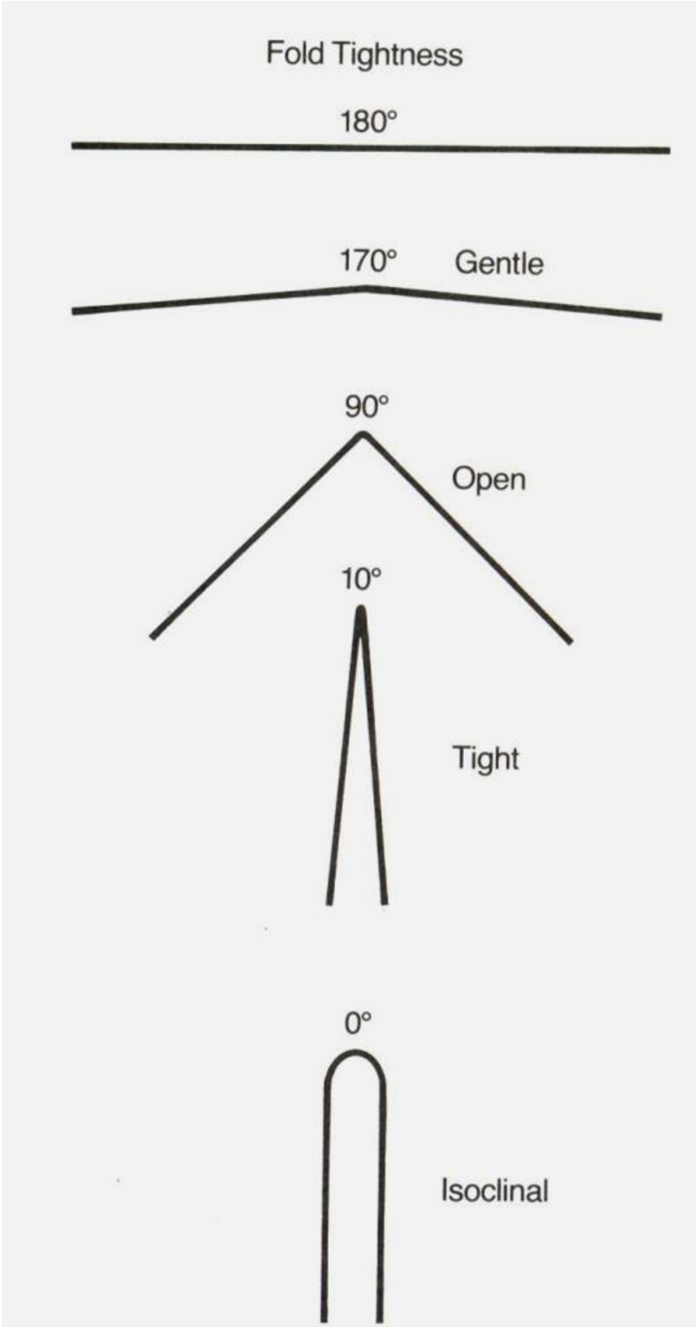
Fold tightness is described in terms of interlimb angle (Ramsay, 1967), the internal angle between the limbs of the folded surface.

1. **Gentle**
2. **Open**
3. **tight**

Gentle folds are marked by interlimb angles ranging from 170 to 180° (Figure 7.39).

Open folds have interlimb angles ranging from 90 to 170°. Folds are considered to be tight if they display interlimb angles in the range of 10 to 90°.

And isoclinal folds are marked by interlimb angles in the range of 0 to 10°. The cutoffs for isoclinal, tight, open, and gentle are easy to remember: 10, 90, and 170°.



Name (degree)	**Interlimb Angle**
Gentle	**120-180**
Open	**70-120**
Close	**30-70**
Tight	**0-30**
Isoclinal	**0**

Figure 7.38 Classification of folds according to tightness, based on the size of the interlimb angle. [Modified from Fleuty (1964). Published with permission of the Geologists Association.]

FOLD CLASSIFICATION

1. Classification based on convexity
2. Classification based on orientation of Axial Plane
3. Classification based on Interlimb Angle (Fleuty 1964)
4. Classification based Upon Fold Axis
5. Classification based on plunge of hinge line
6. Classification based upon shape of fold
7. Other classification

4. Classification based Upon Fold Axis

I. Cylindrical Folds

II. Non-cylindrical folds

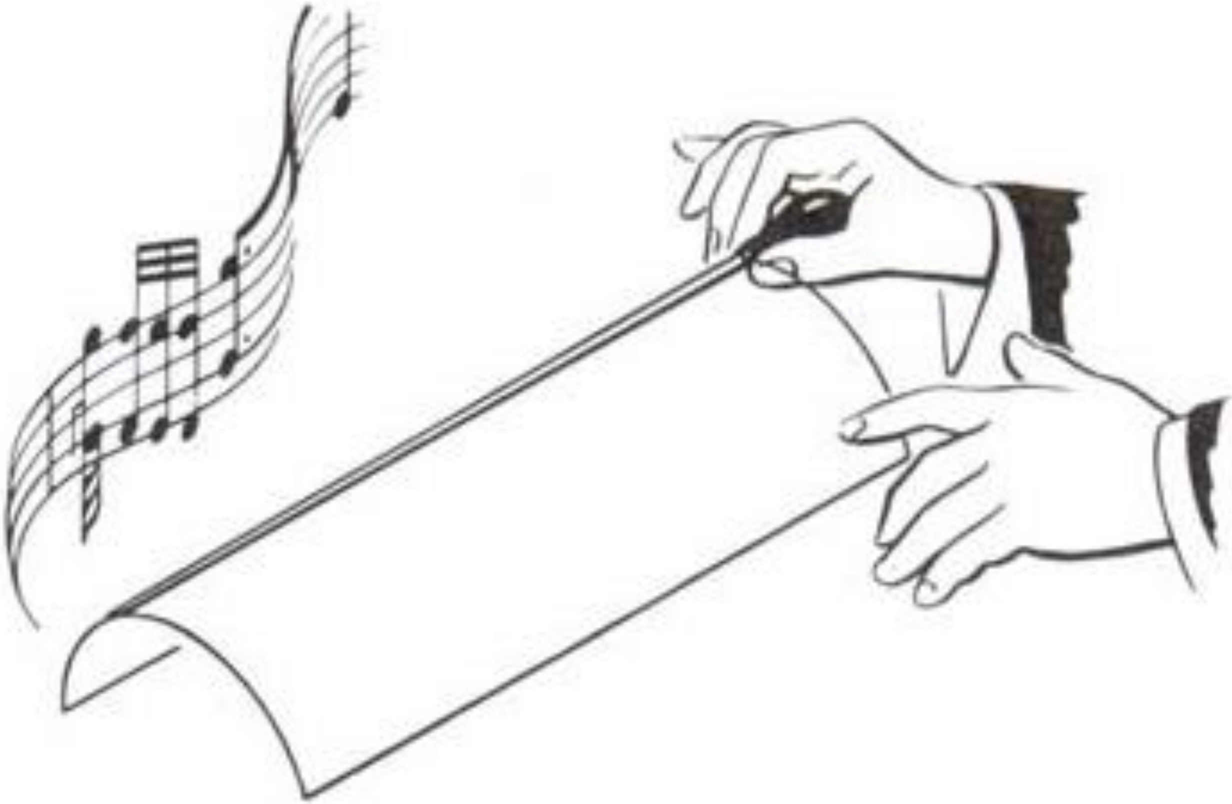
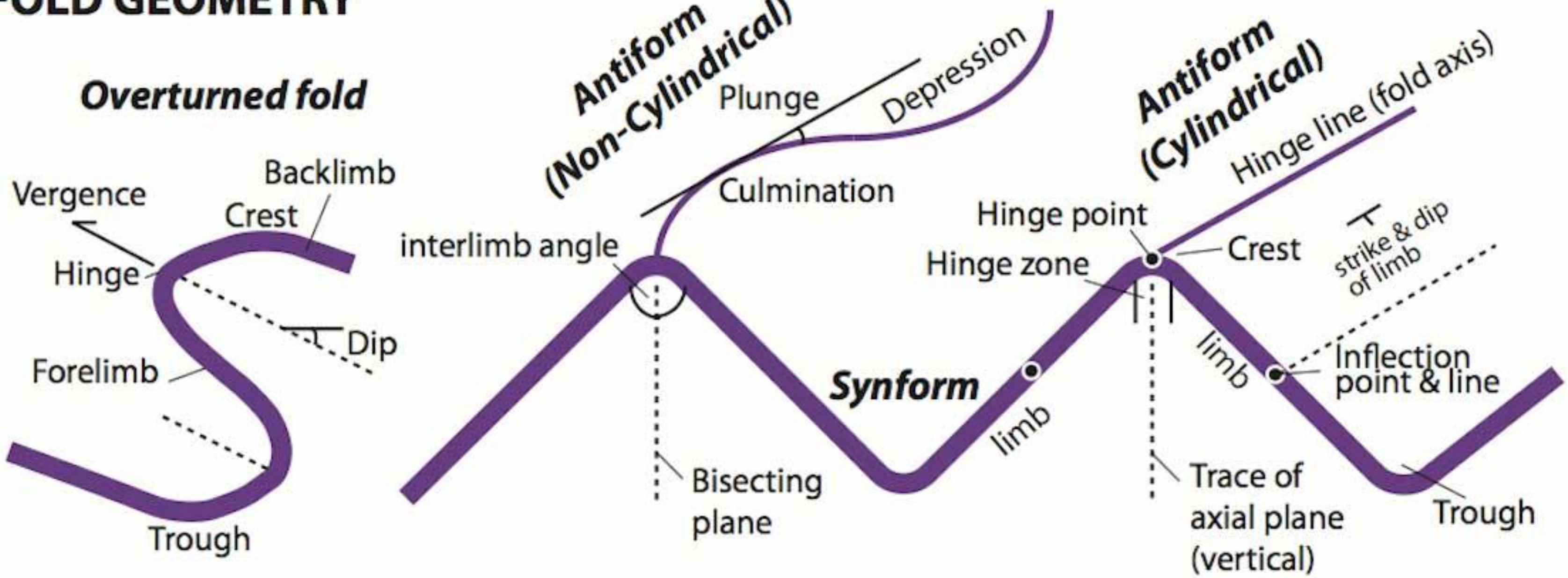
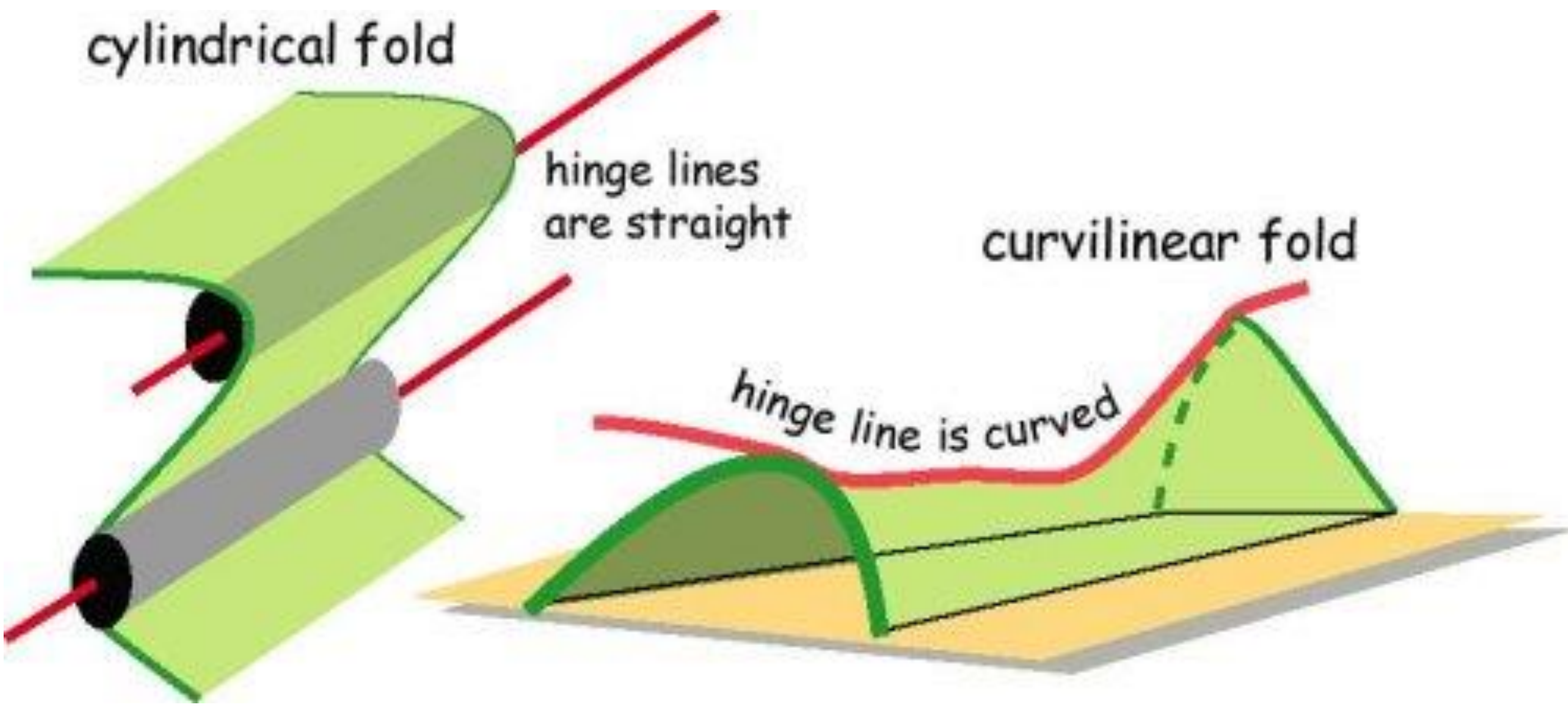


Figure 7.26 Fold axis, an imaginary straight line, which when moved parallel to itself, can define the form of the fold.

FOLD GEOMETRY



Rasoul Sorkhabi (2013)


cylindrical fold
hinge lines
are straight
curvilinear fold
hinge line is curved

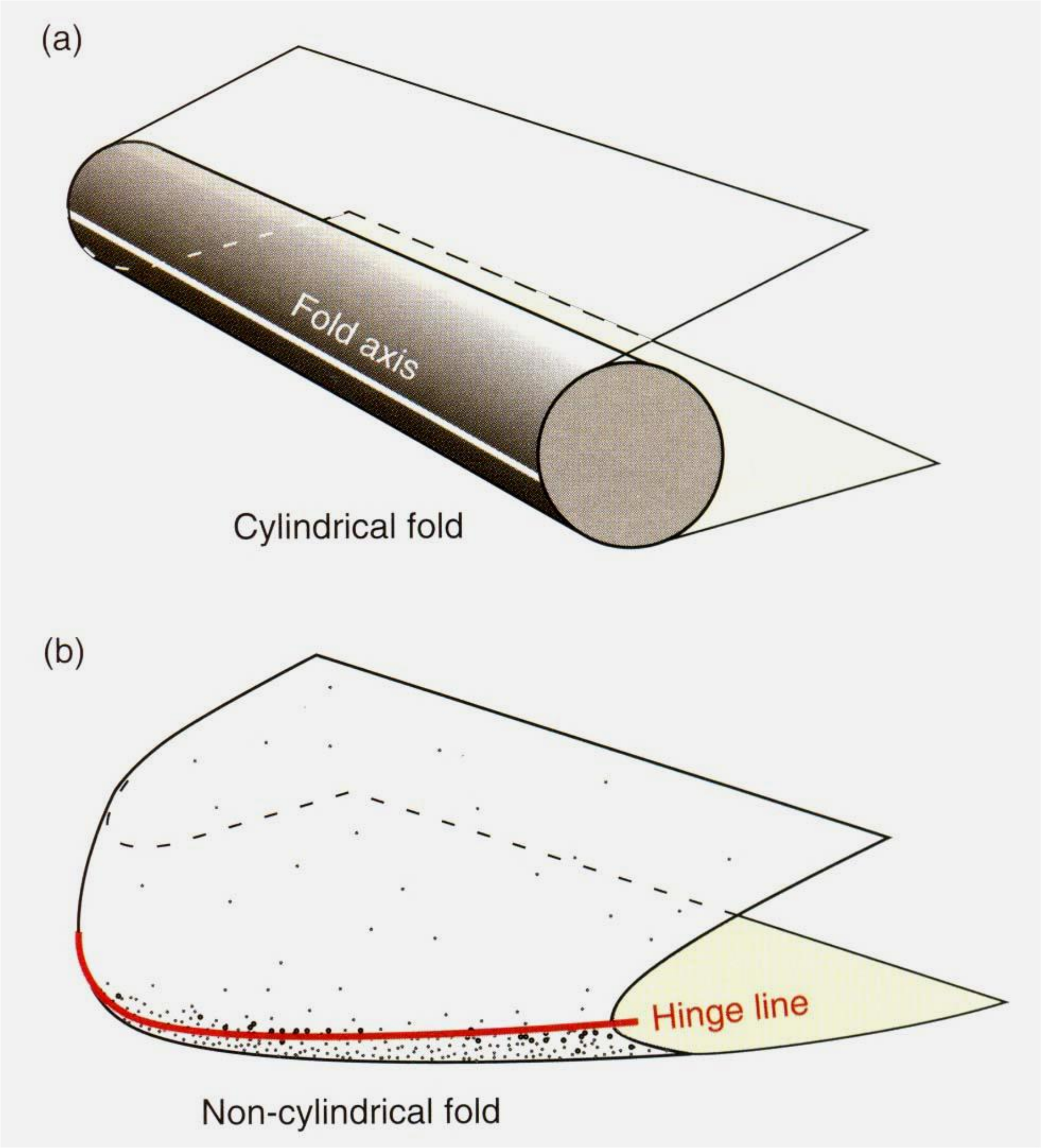
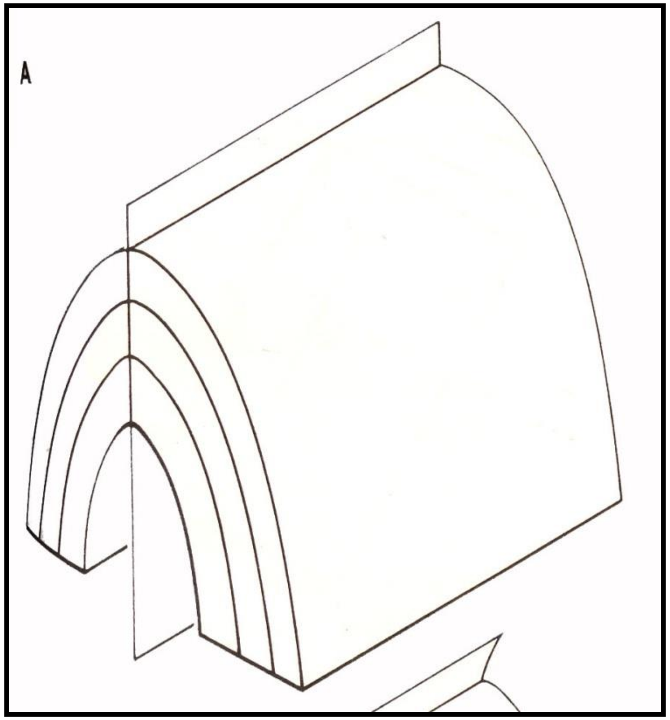
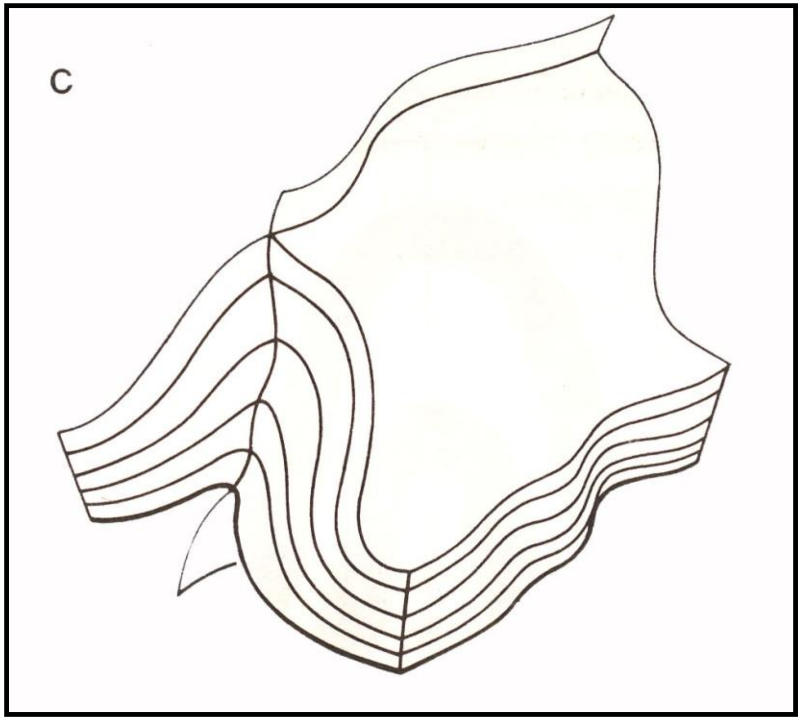


Fig. 11.4: Cylindrical and non-cylindrical fold geometries

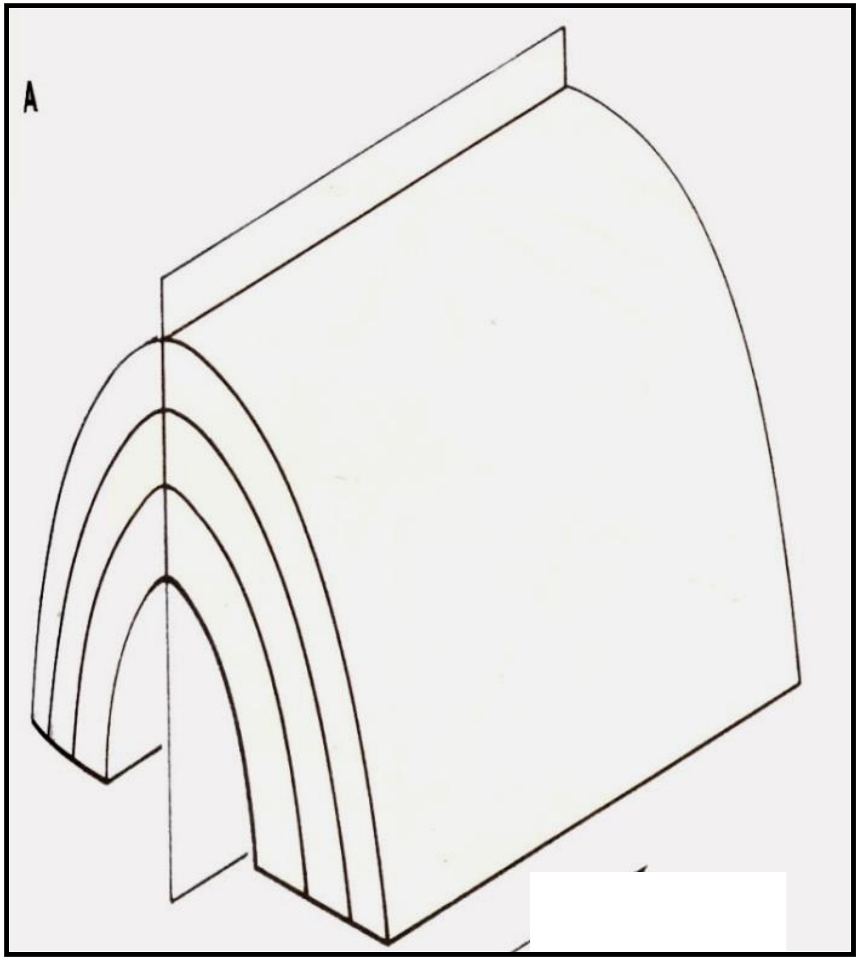
Classification based upon Fold Axis



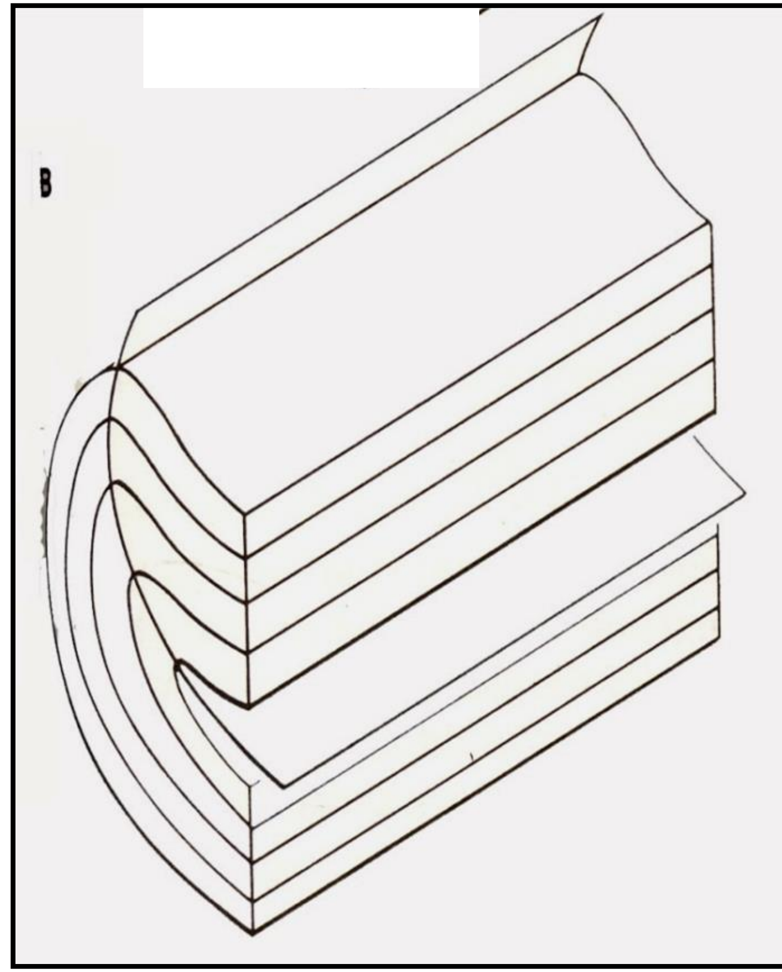
Cylindrical Fold



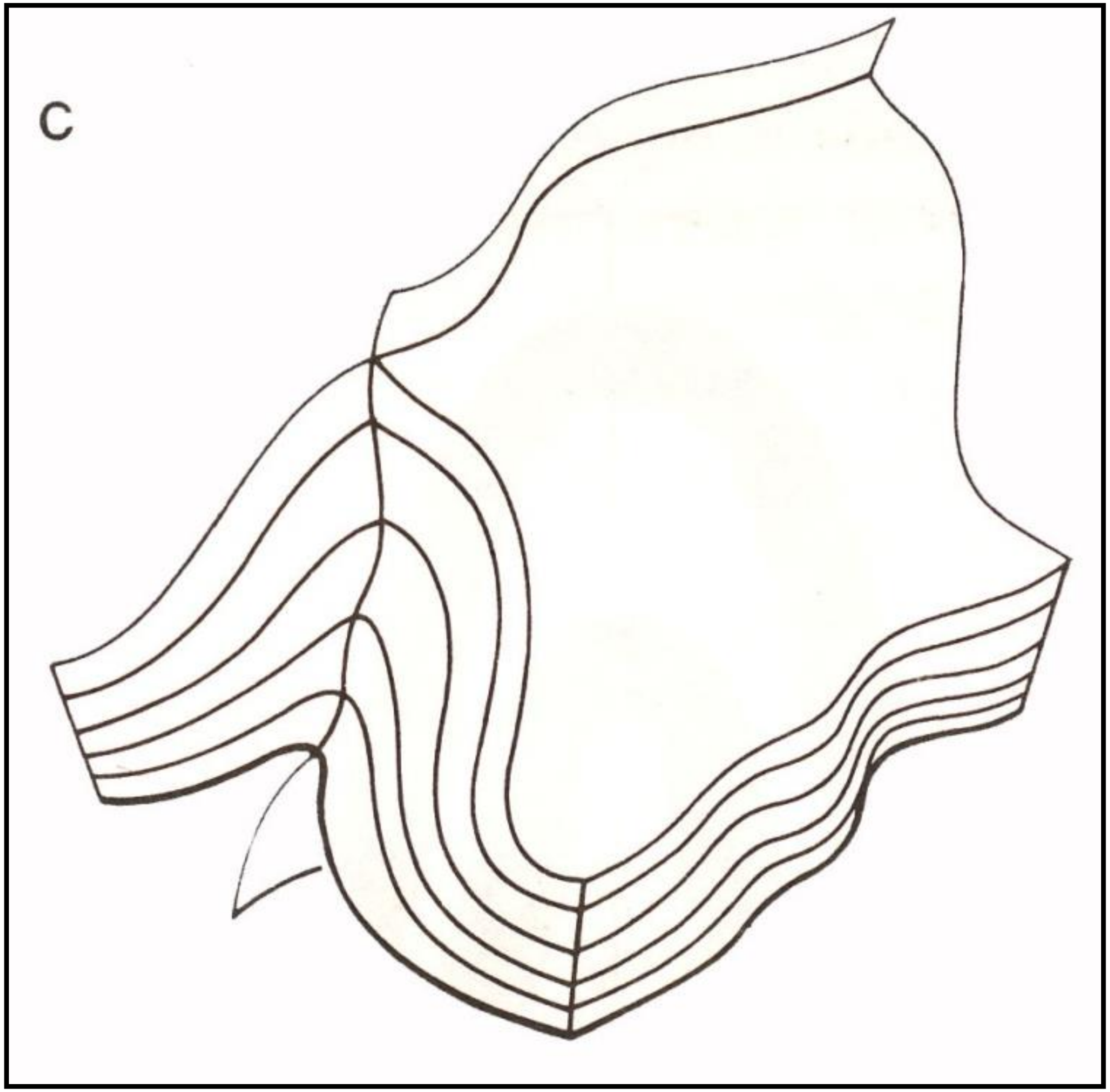
Non-cylindrical Fold



Cylindrical fold. Cylindrical fold. Fold with a planar Axial surface



Cylindrical fold. curviplanar axial surface.



Non Cylindrical fold. Fold with an irregularly curviplanar axial surface

In the most general sense, a *cylinder* is defined mathematically as a surface that is generated by a straight line that always moves parallel to itself.

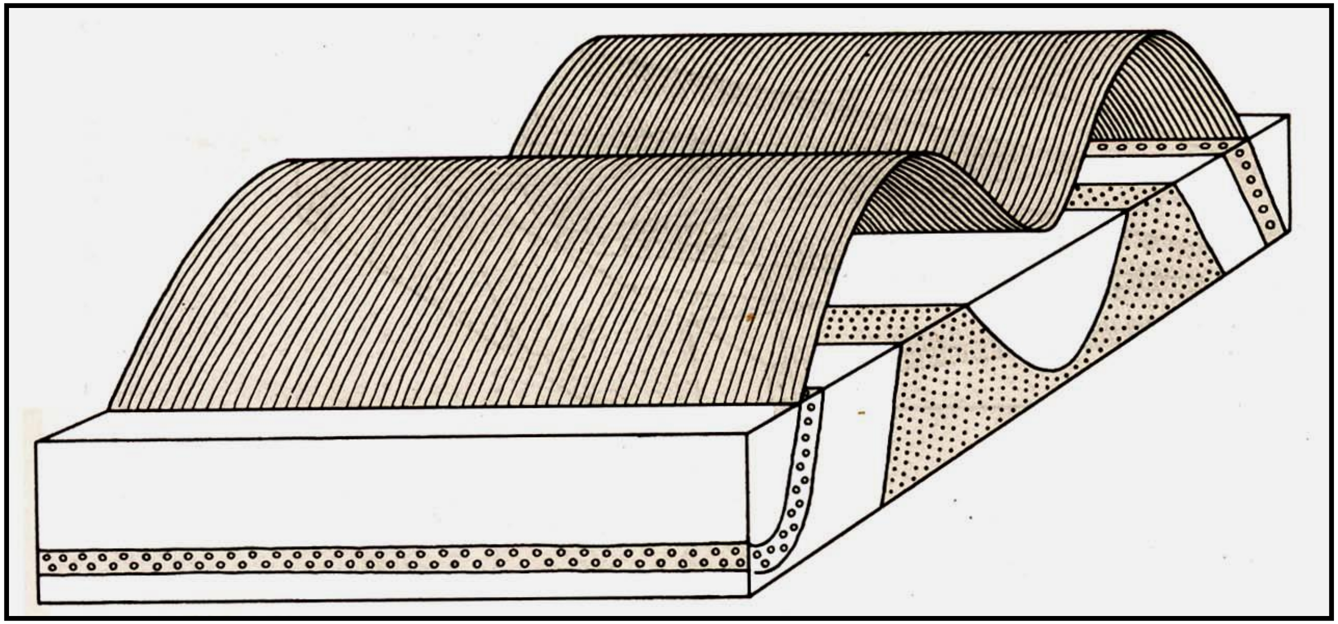
The cylinder need not be circular. While folds are usually not perfectly cylindrical, many are sufficiently close to make this a useful approximation.

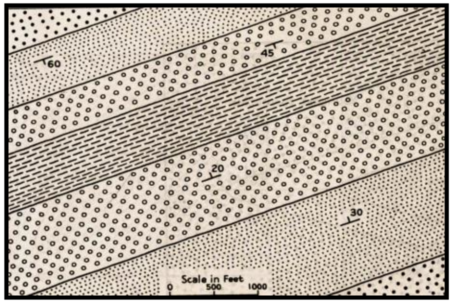
Some consequences of cylindrical geometry are:

1. **The line that generates the cylinder is parallel to the fold axis.**
2. **All planes tangent to the cylinder are tangent along a line parallel to the fold axis.**
3. **All planes tangent to the cylinder are parallel to the fold axis.**
4. **Therefore, any two planes tangent to the cylinder intersect in a line parallel to the fold axis.**
5. **All parallel cross-sections of the cylinder are identical.**
6. **Strike and dip measurements on a cylindrical fold define planes parallel to the fold axis. Any two of these planes intersect in a line parallel to the fold axis.**

5. Classification based on plunge (inclination) of hinge line

(i) Nonplunging Fold

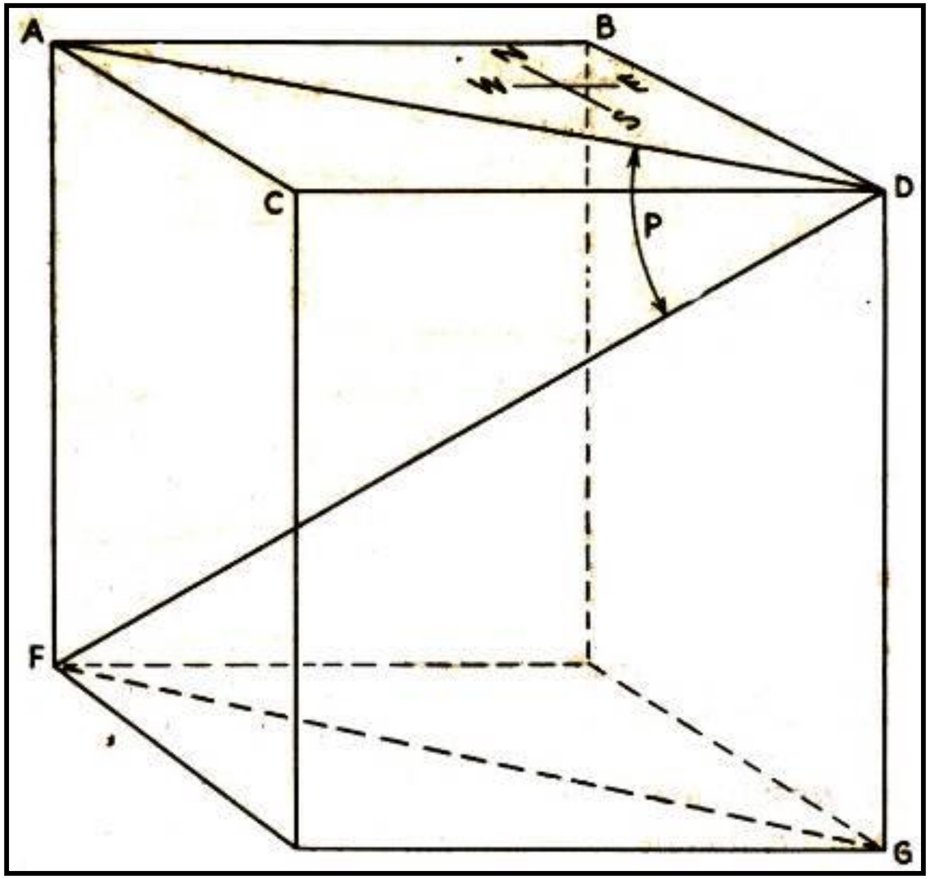




Geological map of Nonplunging syncline

The beds on the opposite limbs strike parallel to each other, they do not converge

Plunge of a Fold

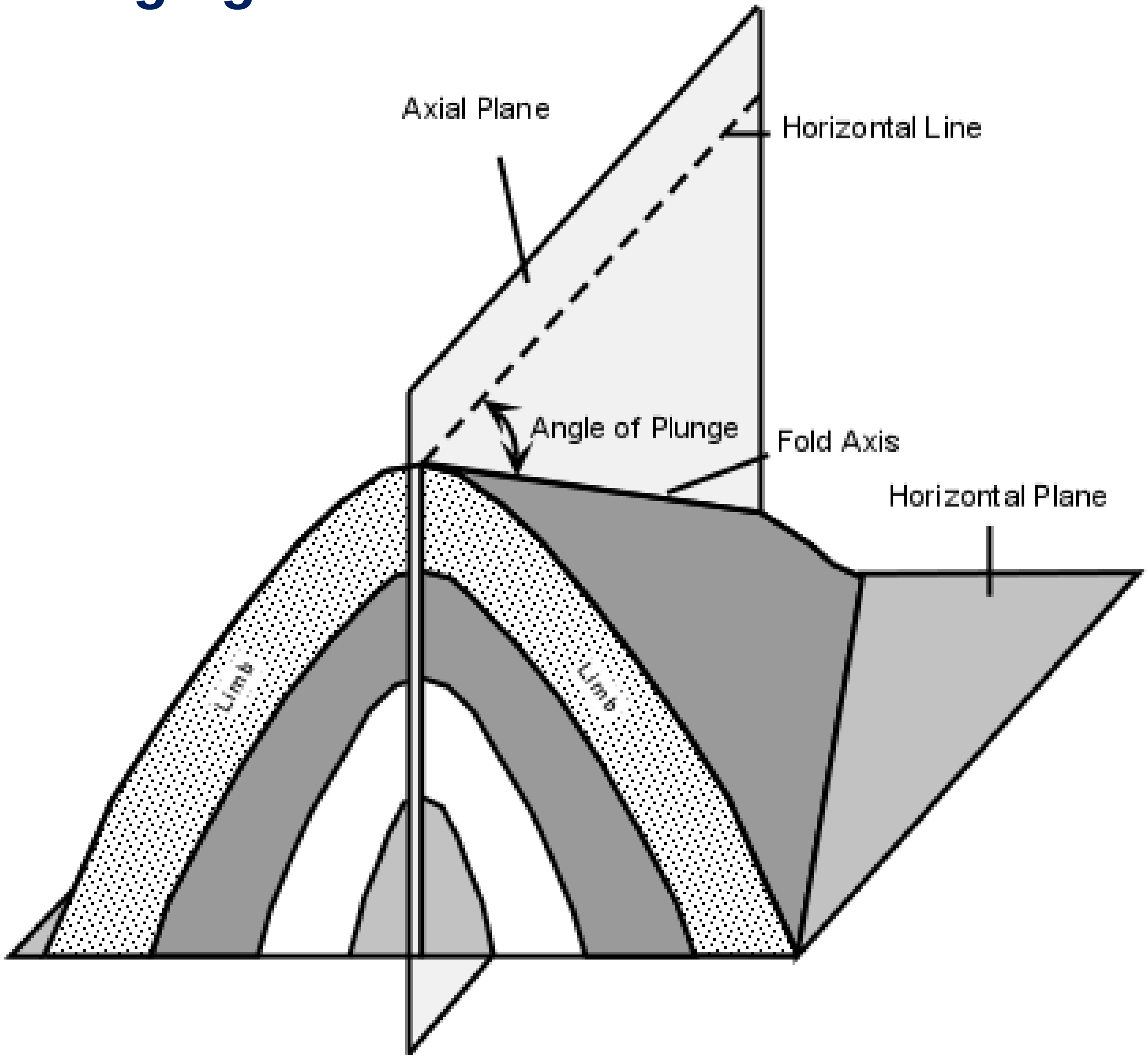


Attitude of Hinge of a Fold

FD : Hinge
AD : bearing of the horizontal projection of the hinge
P : Angle of plunge

The attitude of hinge line is defined by its bearing and plunge. Hinge line may be horizontal, inclined or vertical

(ii) Plunging Fold



Plunging Fold

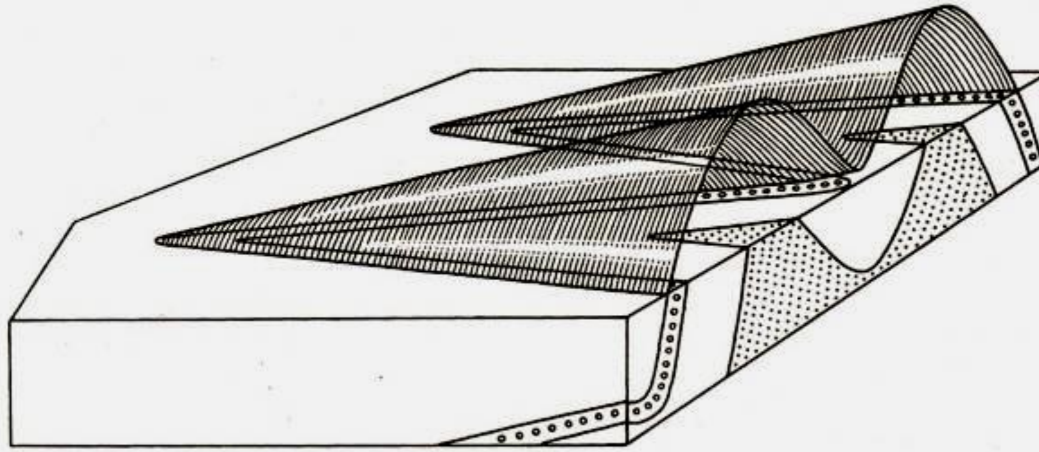


Fig. 3-22. Plunging folds. Plunge is about 10° to the left. One bed is shown by open circles; the part of this bed that has been removed by erosion is shown by lining.

Geological map of Plunging Anticline

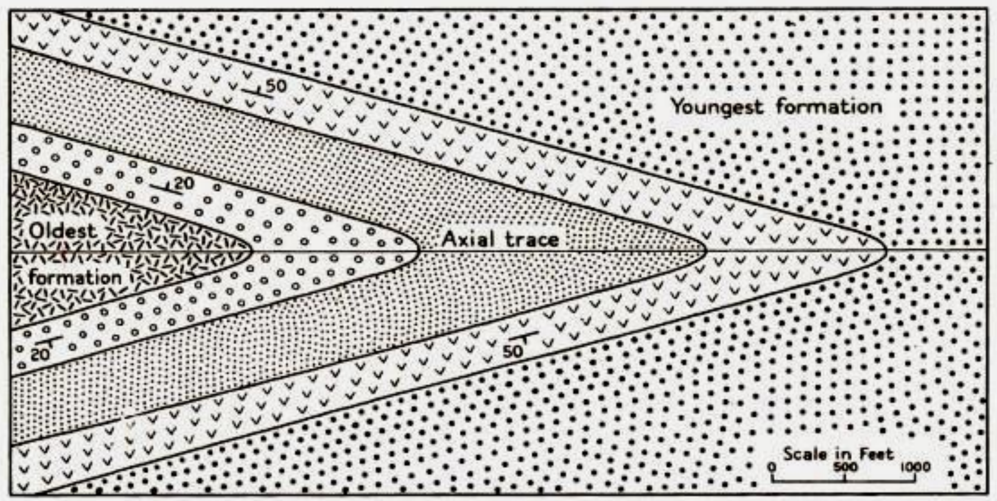


Fig. 3-23. Geological map of an anticline plunging east (to the right).

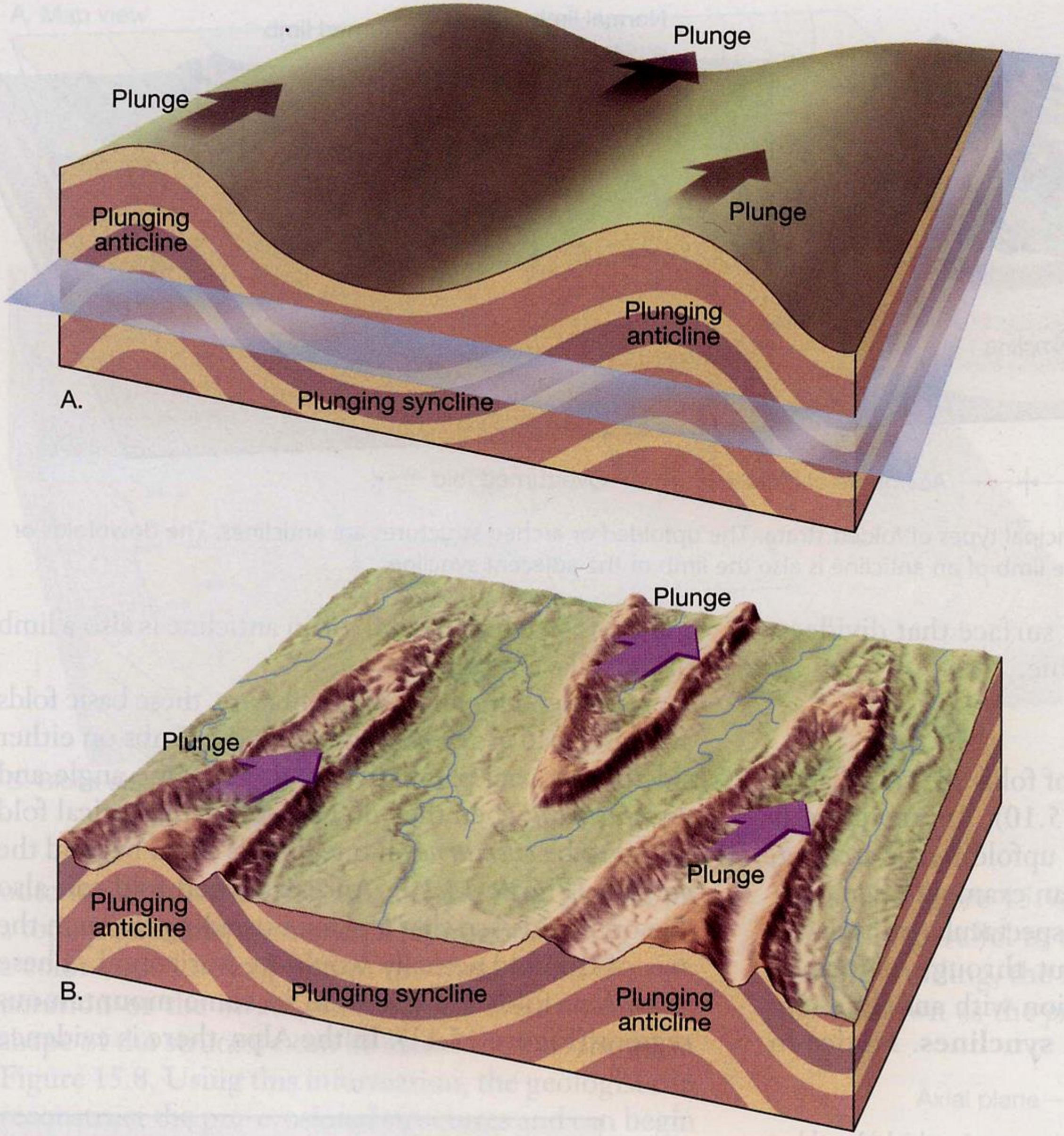


Figure 15.12 Plunging folds. **A.** Idealized view of plunging folds in which a horizontal surface has been added. **B.** View of plunging folds as they might appear after extensive erosion. Notice that in a plunging anticline the outcrop pattern "points" in the direction of the plunge, while the opposite is true of plunging synclines.

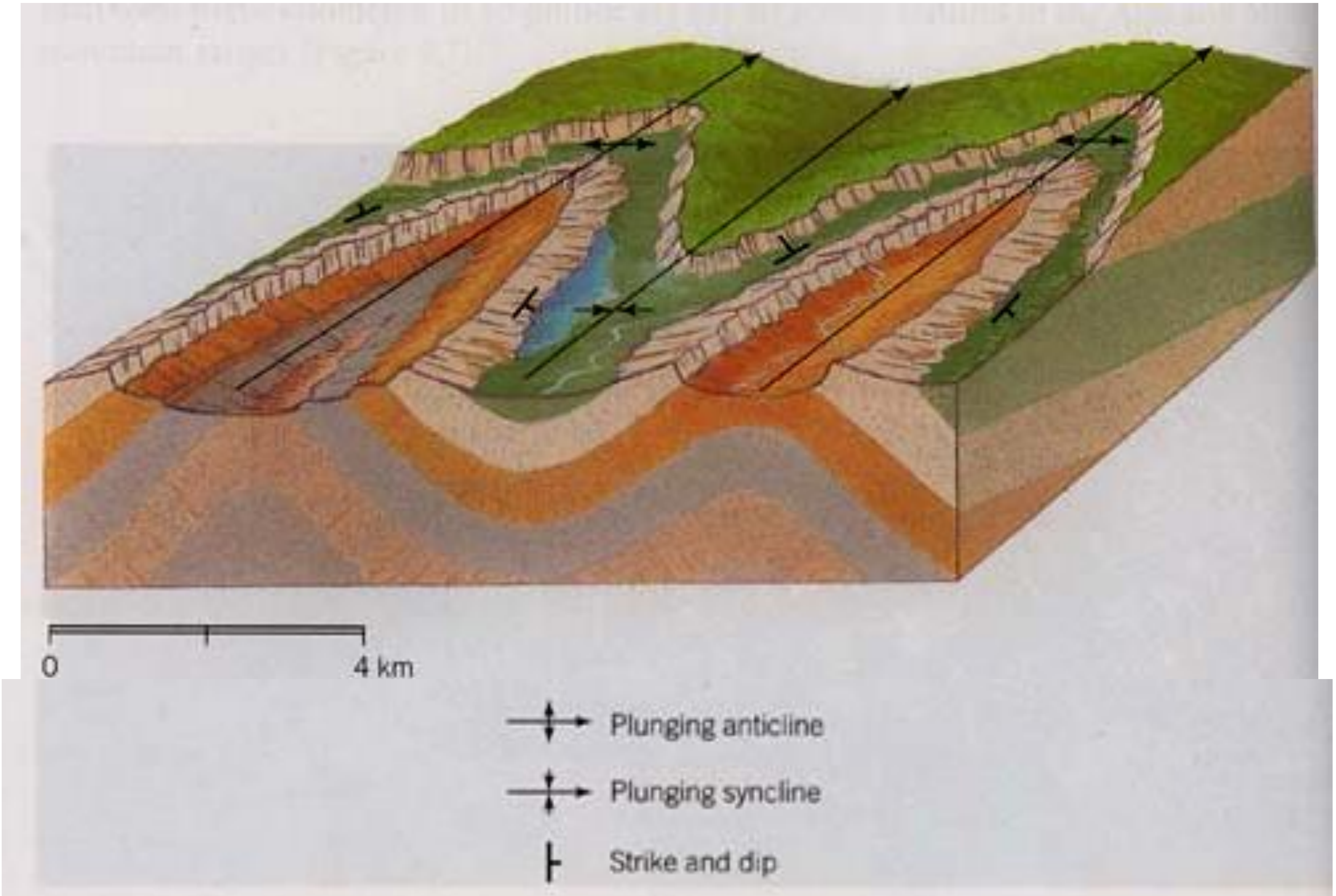
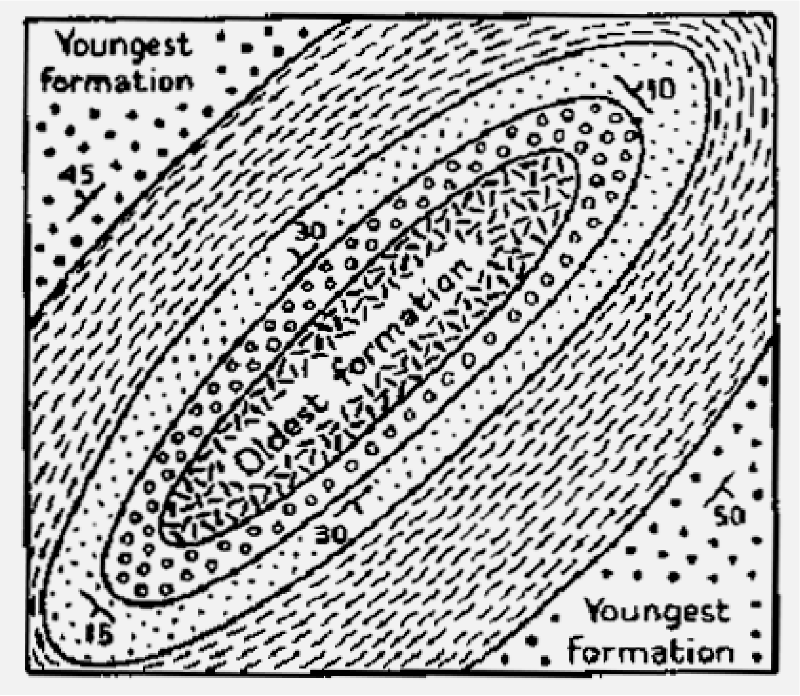


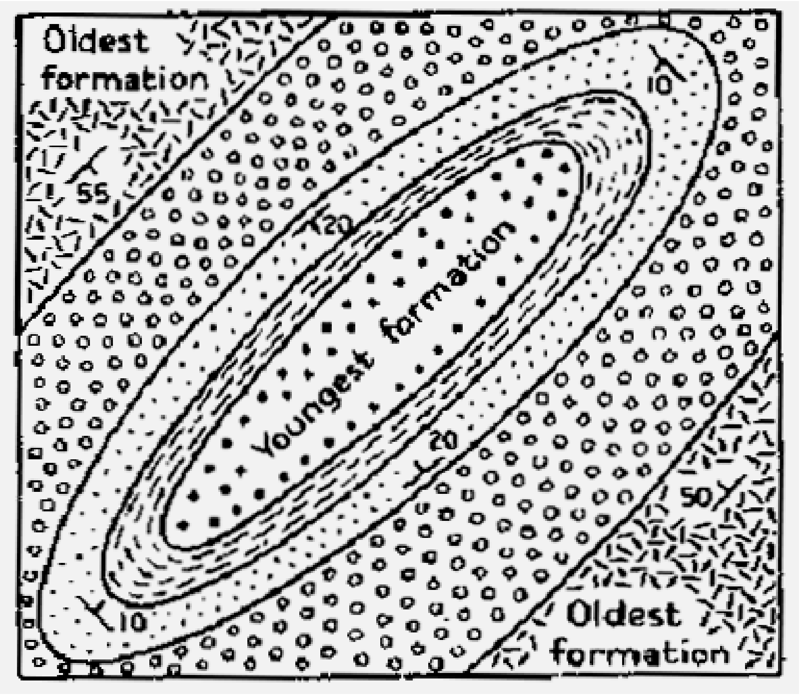
Fig. 9.9. The relationship between plunging anticlines and synclines. The “nose” of the anticline points in the direction of plunge, whereas the nose of the syncline points in the opposite direction. Also, it is common for deep valleys to erode in the cores of anticlines, leaving the synclines standing above them.

Fig. 15.13: Sheep Mountain, a doubly plunging anticline. Note that erosion has cut the flanking sedimentary beds into low ridges that make a “V” pointing in the direction of plunge. (Photo by John S. Shelton).

A doubly plunging fold is one that reverses its direction of plunge within the limits of the area under discussion



Doubly Plunging Anticline

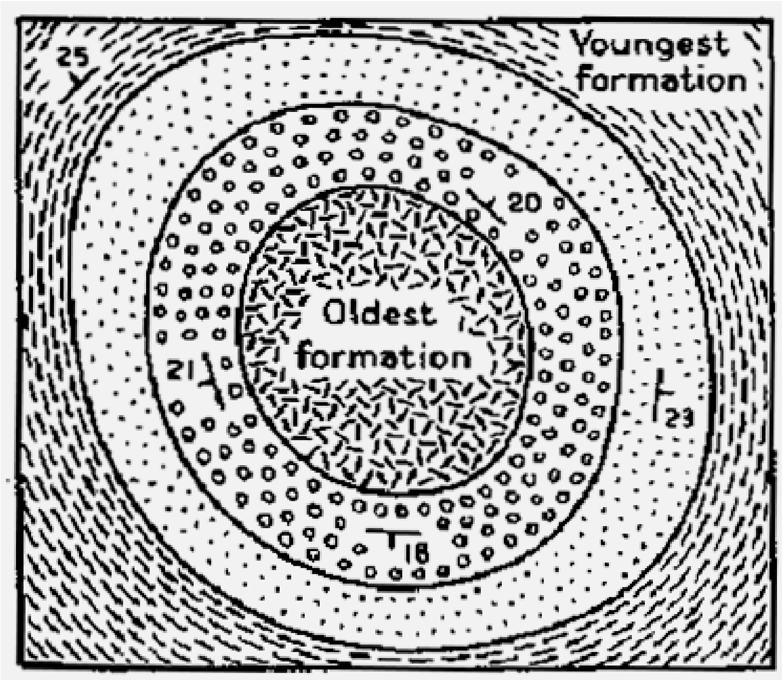


Doubly Plunging Syncline

Domes and Basins

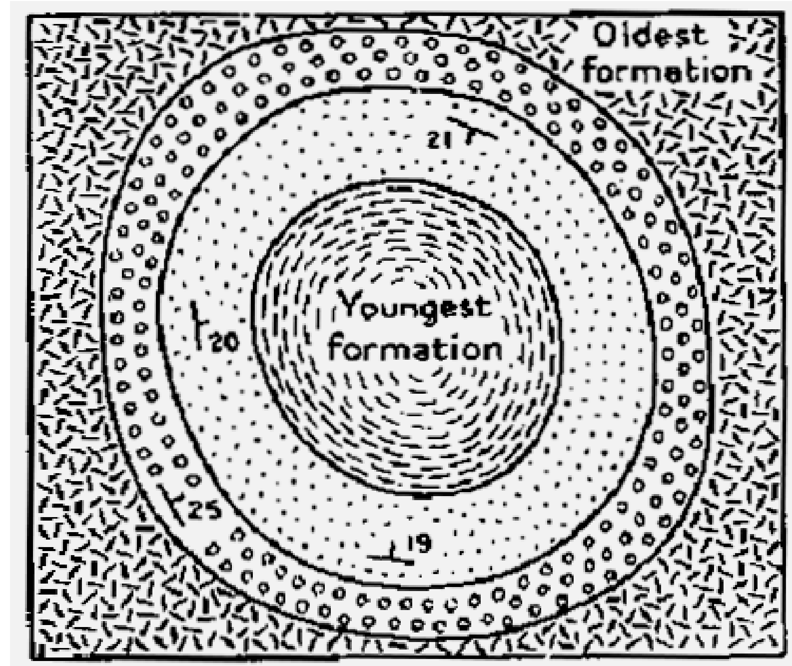
- ***Domes*** **are structures in which the beds dip away from a central point**

- ***Basins*** **are structures in which the beds dip toward a central point**



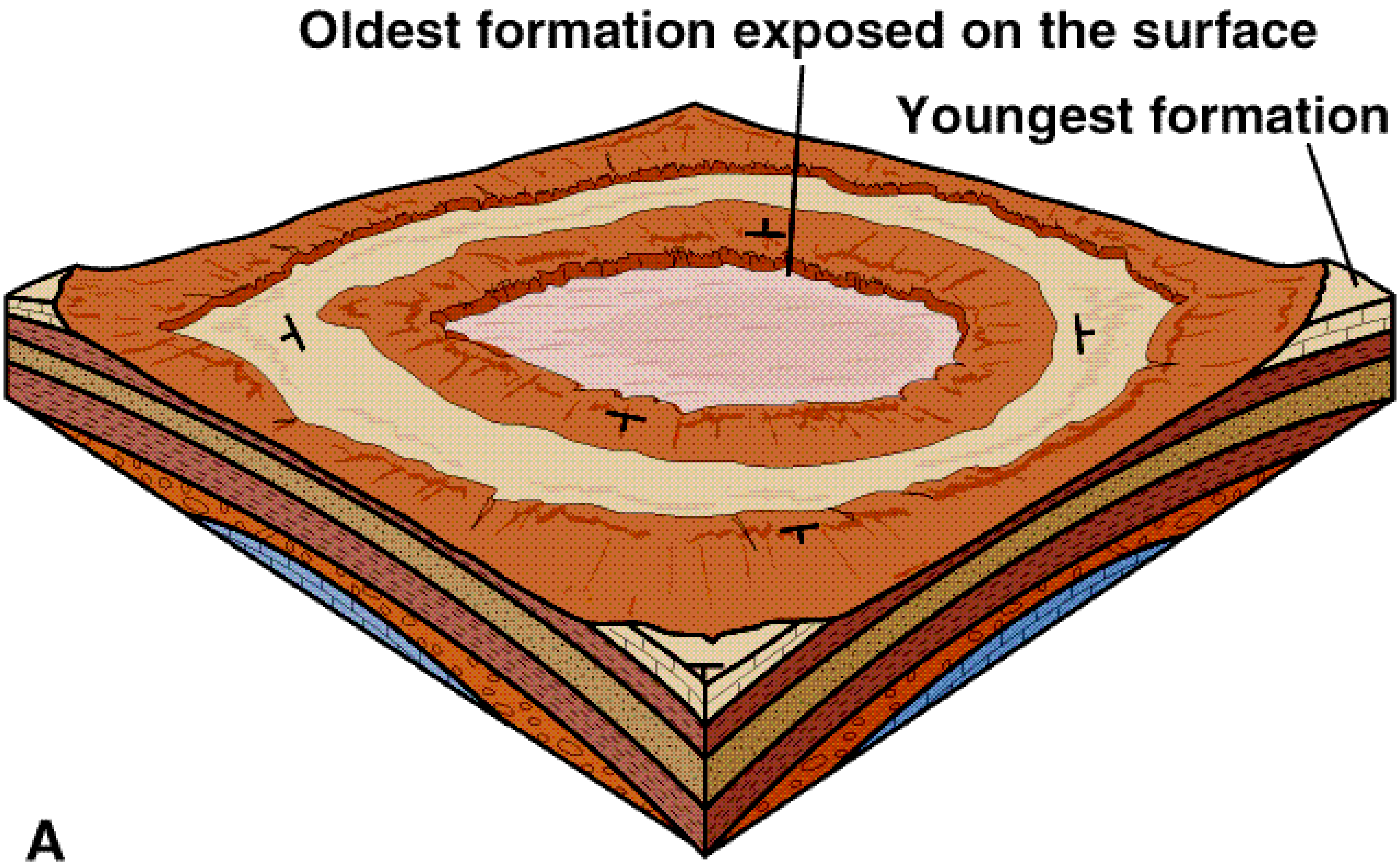
Dome

An anticlinal uplift without distinct trend

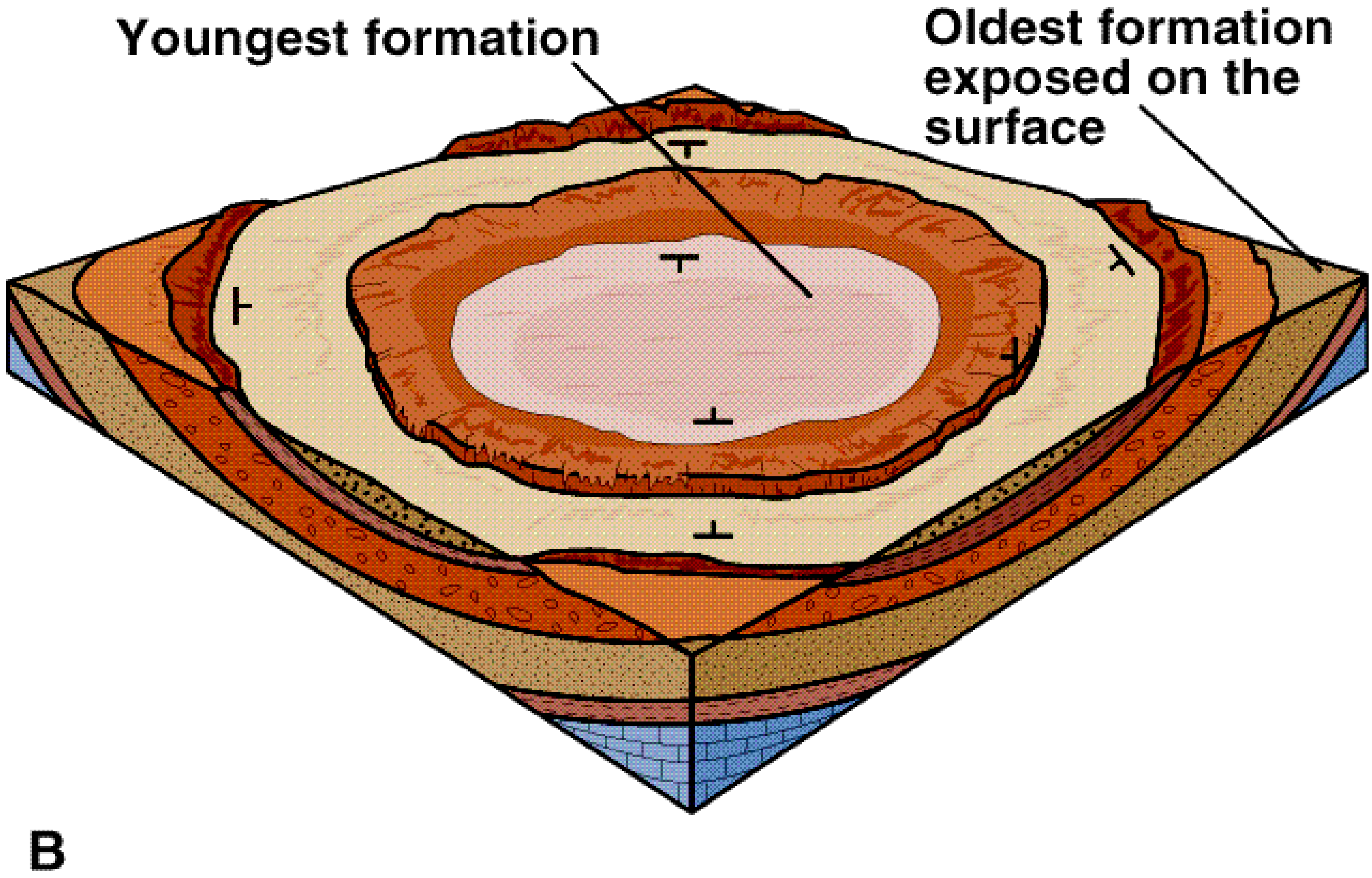


Basin

A Synclinal depression without distinct trend



Structural Dome



Structural Basin

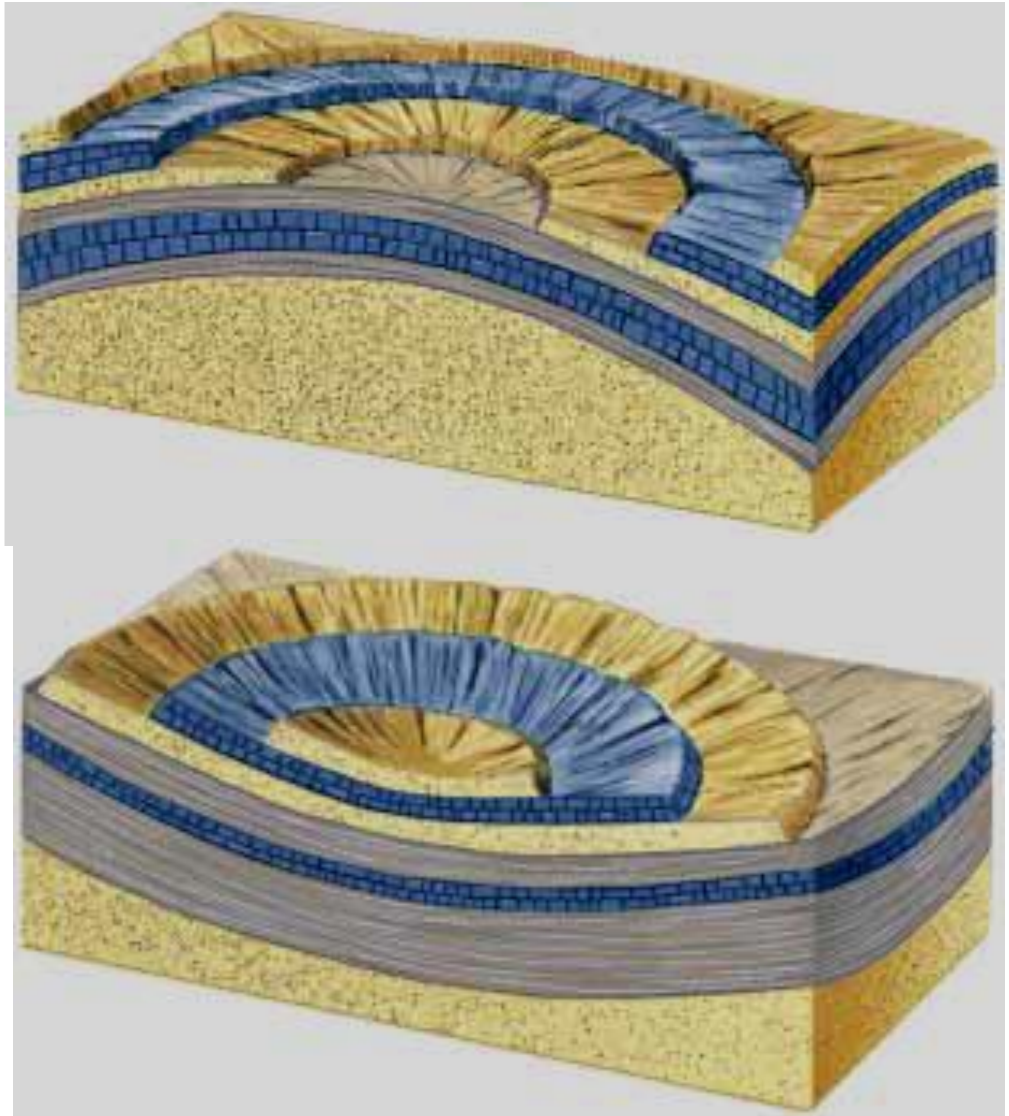


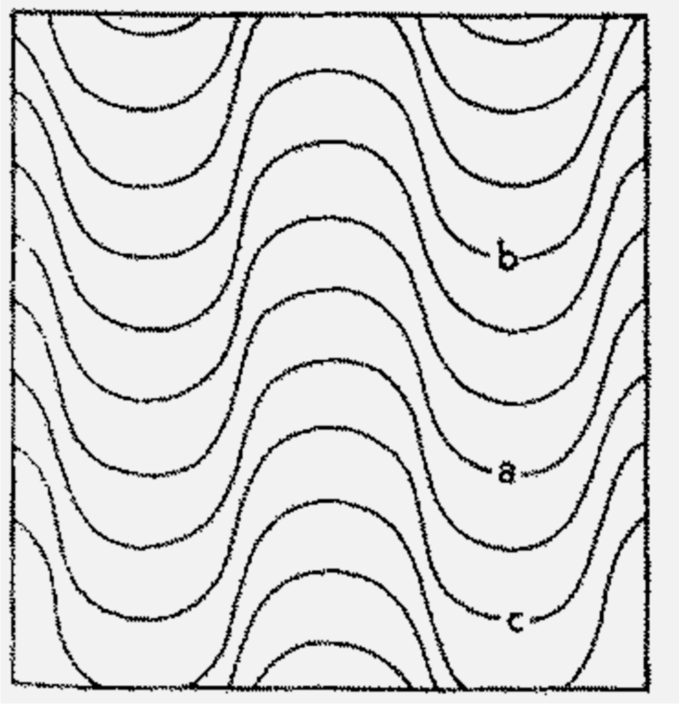
Figure 12–10 (a) Sedimentary layering dips away from a dome in all directions, and the outcrop pattern is circular or elliptical. (b) Layers dip toward the center of a basin.

Photo by D.. Rahm, courtesy of Rahm Memorial Collection, Western Washington University

A Dome

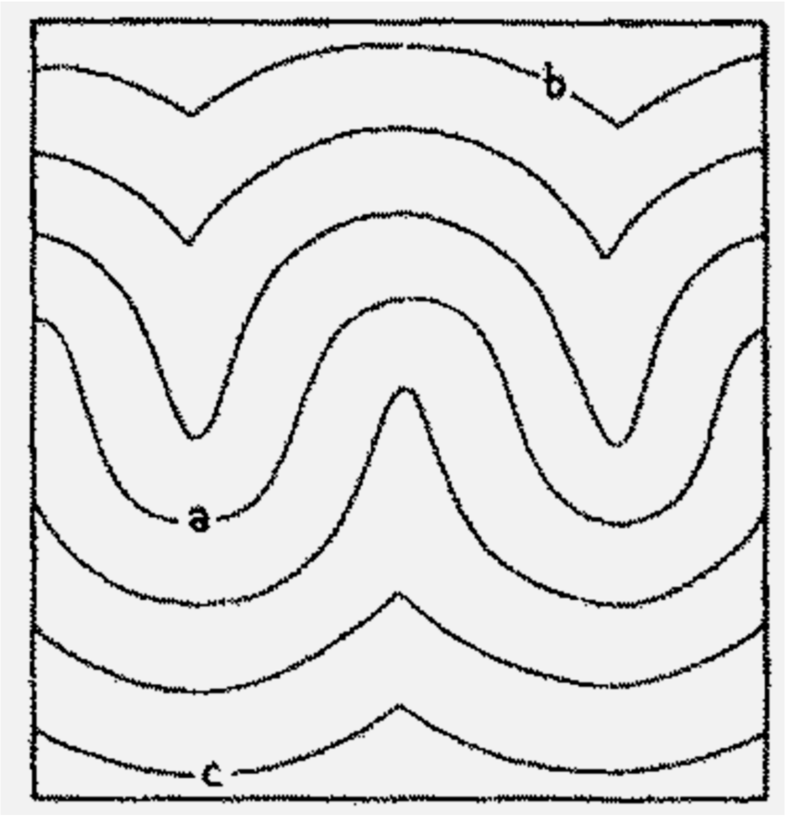
6. Classification based upon shape of fold

Similar folds



Similar folding: Thin on limb and thick near the hinge due to plastic movement away from limb i.e. towards hinge. These are found in less competent, weaker rocks, also called closed or tight fold

Parallel folding



Parallel folding (concentric folding): Thickness of the beds has not changed during the folding. The form of the fold changes upward and downward. i.e. The anticlines become sharper with depth, but broader and more open upward. Conversely, the synclines become broader with depth, but sharper upward. The fold die out downward and upwards.

Some folded surfaces have two hinges.

Box folds (or conjugate folds) are composed of three planar limbs connected by hinge points or narrow, restricted subangular hinge zones (Figure 7.35E).

7. Other Classifications (miscellaneous)

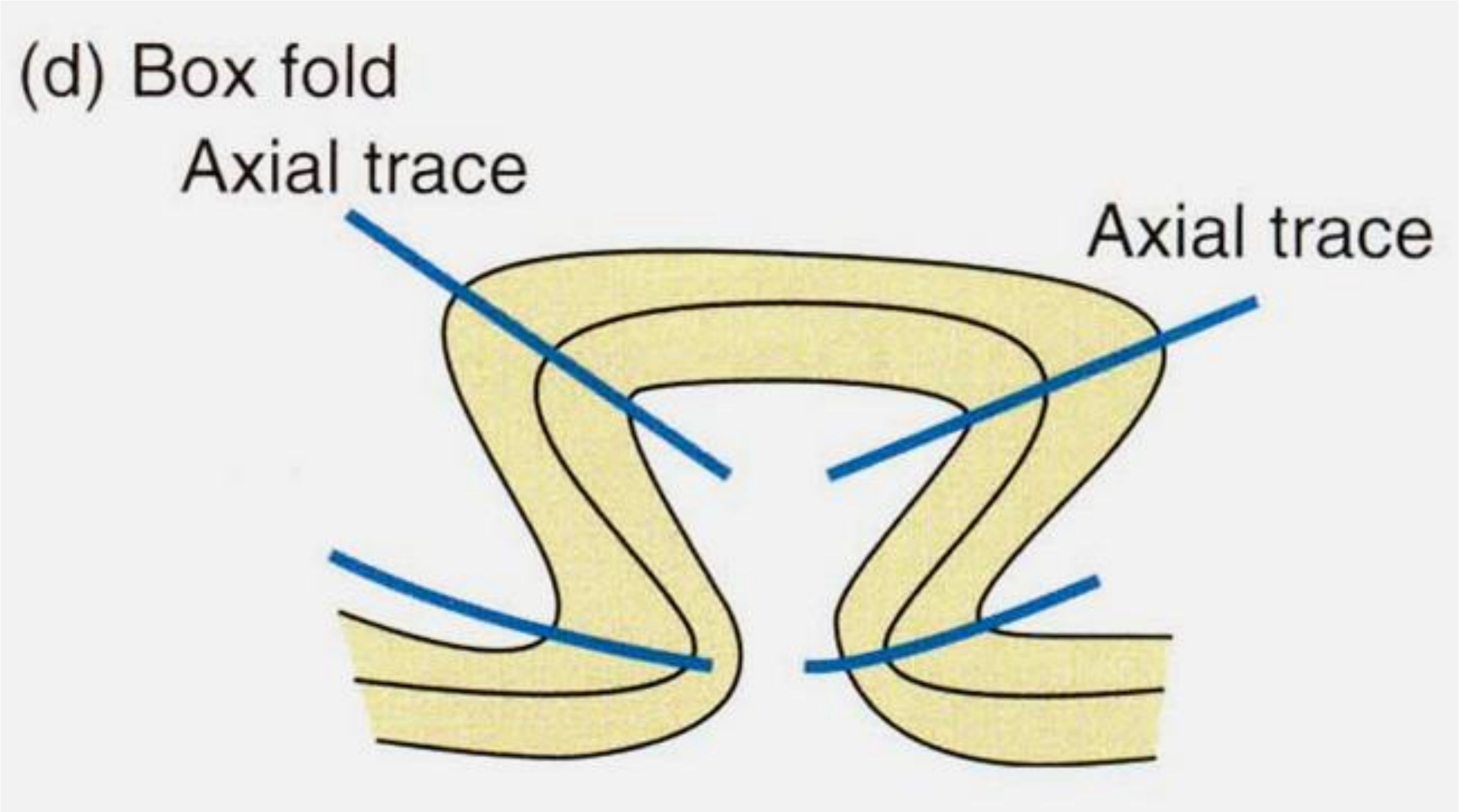
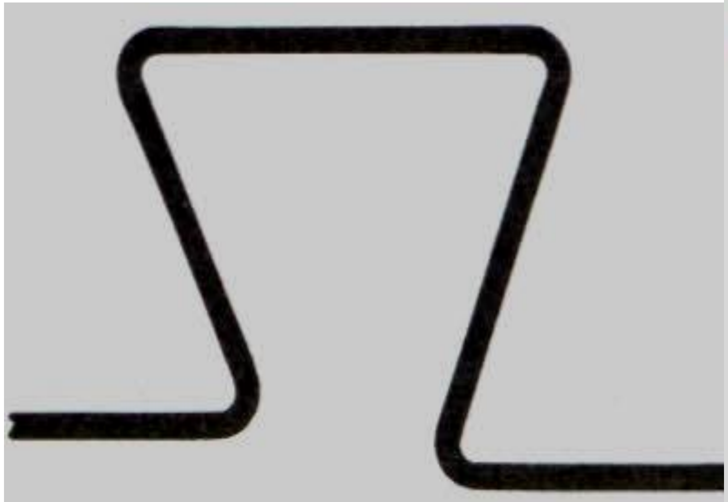
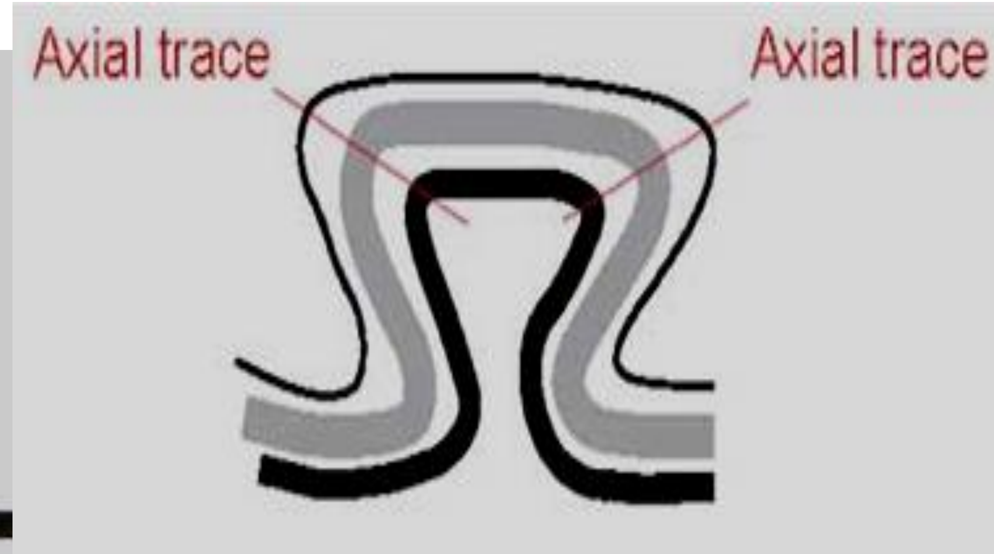


Figure 11.2 (a) Kink band, where the bisecting surface, i.e. the surface dividing the interlimb angle in two, is different from the axial surface. (b) Chevron folds (harmonic). (c) Concentric folds, where the arcs are circular. (d) Box folds, showing two sets of axial surfaces.





Box fold

Box fold in La Herradura Formation, Morro Solar, Peru.

A chevron fold, for example, is marked by planar limbs that meet at a discrete hinge point or at a very restricted sub angular hinge zone (Figure *7.35A).*

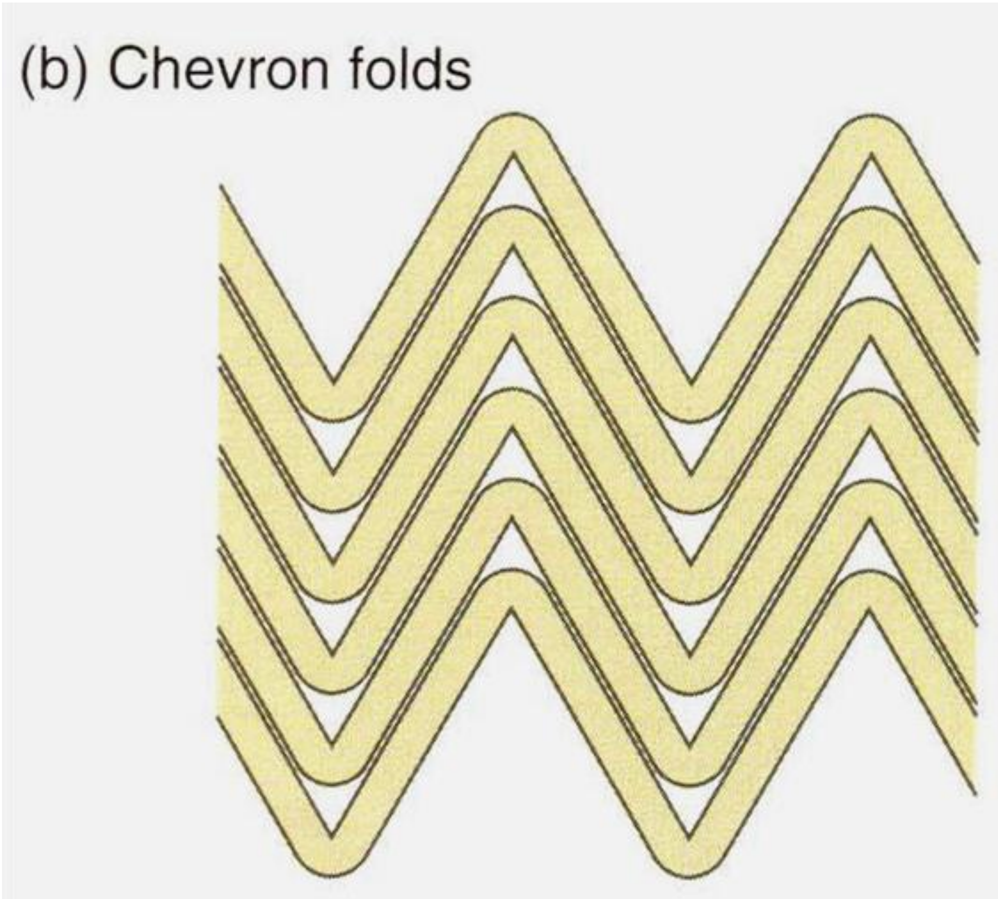
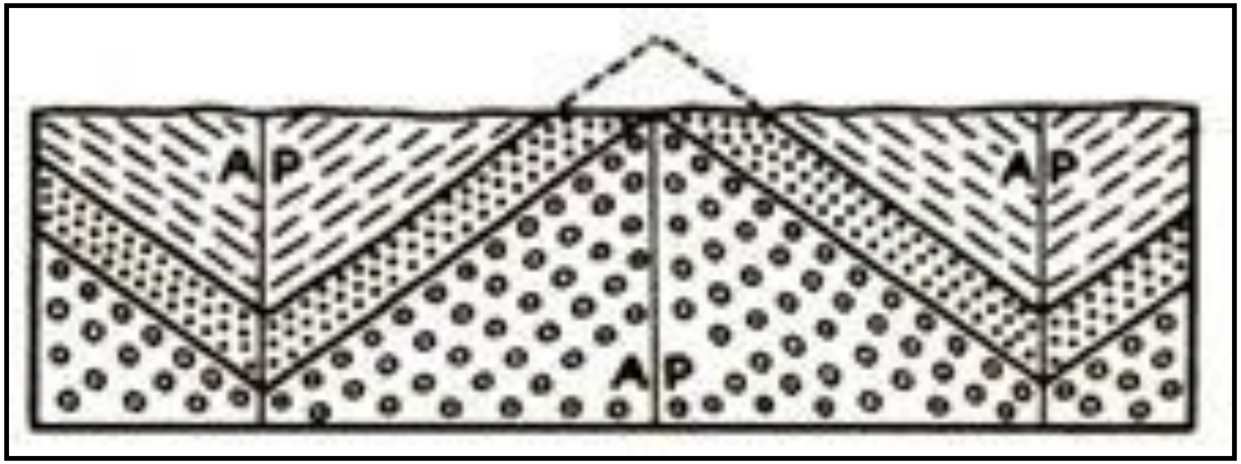
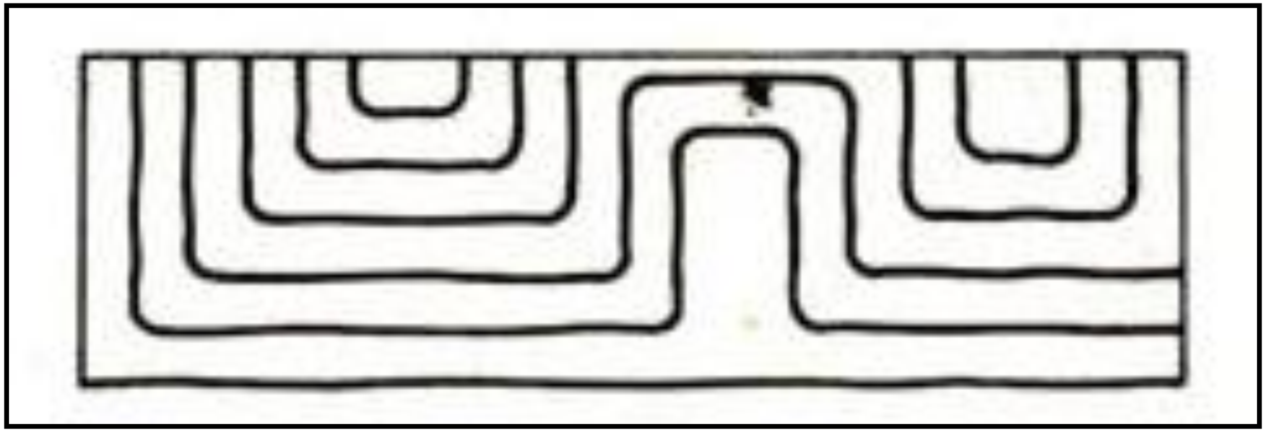


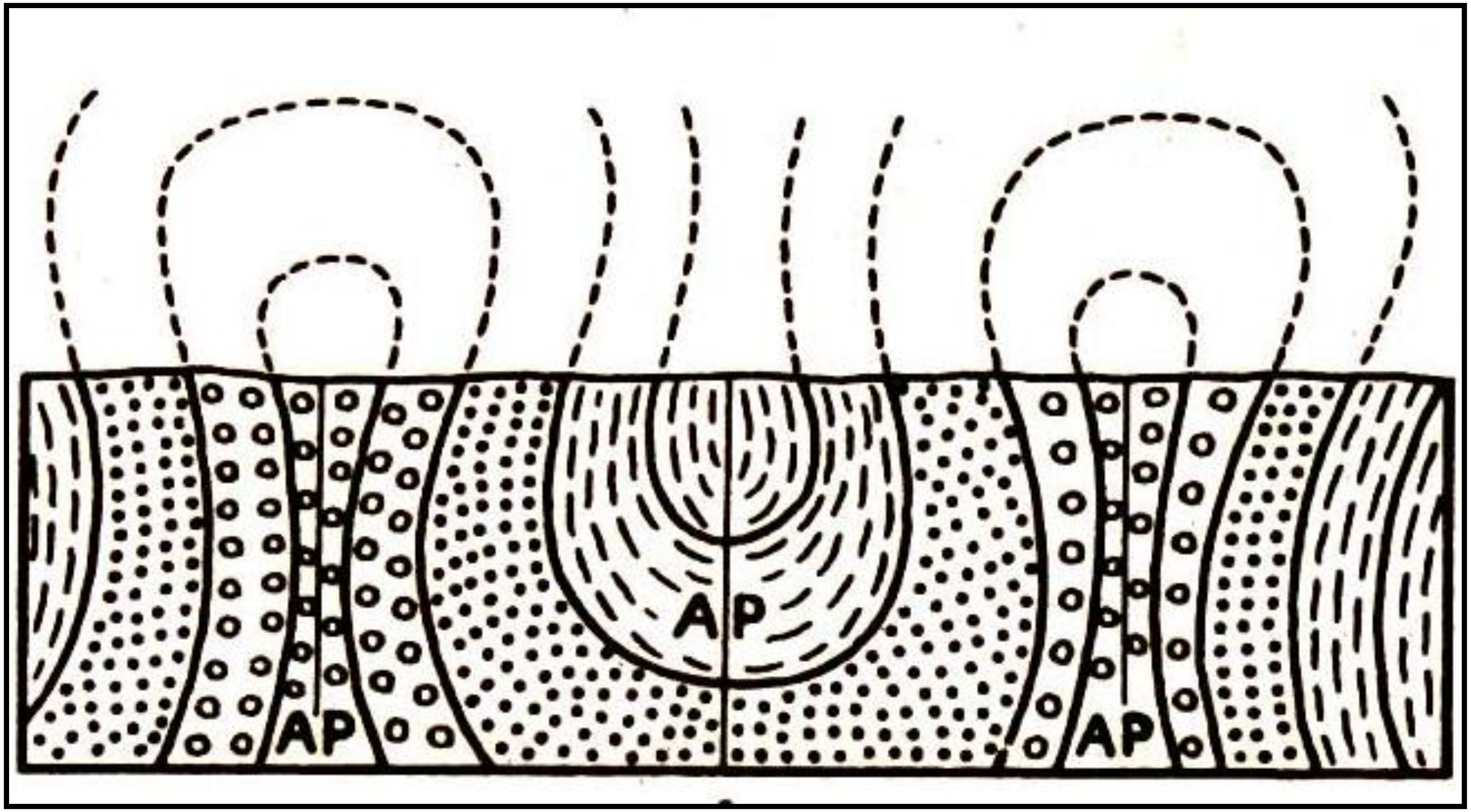
Figure 11.2 (a) Kink band, where the bisecting surface, i.e. the surface dividing the interlimb angle in two, is different from the axial surface. (b) Chevron folds (harmonic). (c) Concentric folds, where the arcs are circular. (d) Box folds, showing two sets of axial surfaces.

Chevron Fold
Hinges sharp and angular



Box Fold
Broad and flat crest,
two hinges present





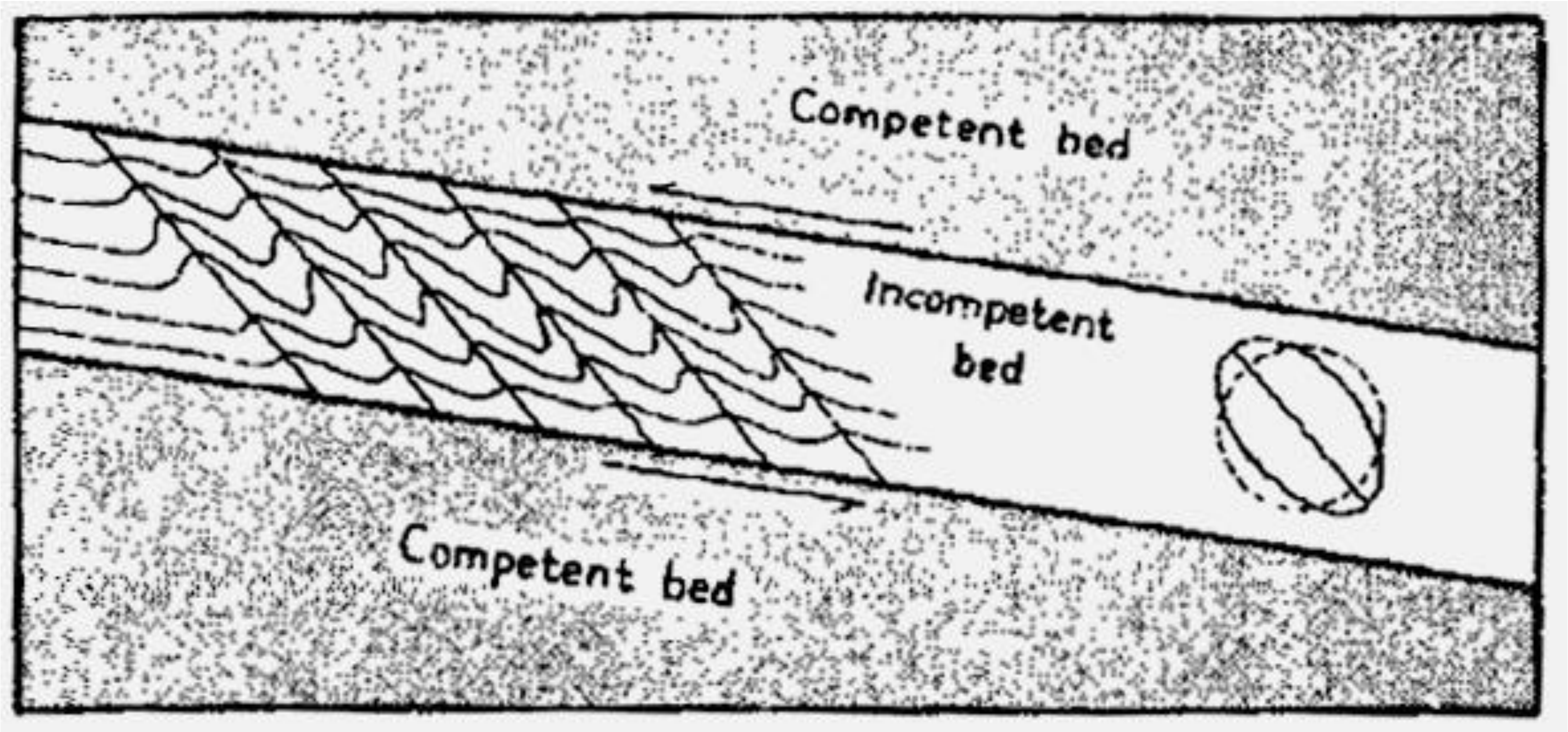
FAN FOLD

Both limbs are overturned

Anticlinal Fan Fold - Two limbs dip towards each other

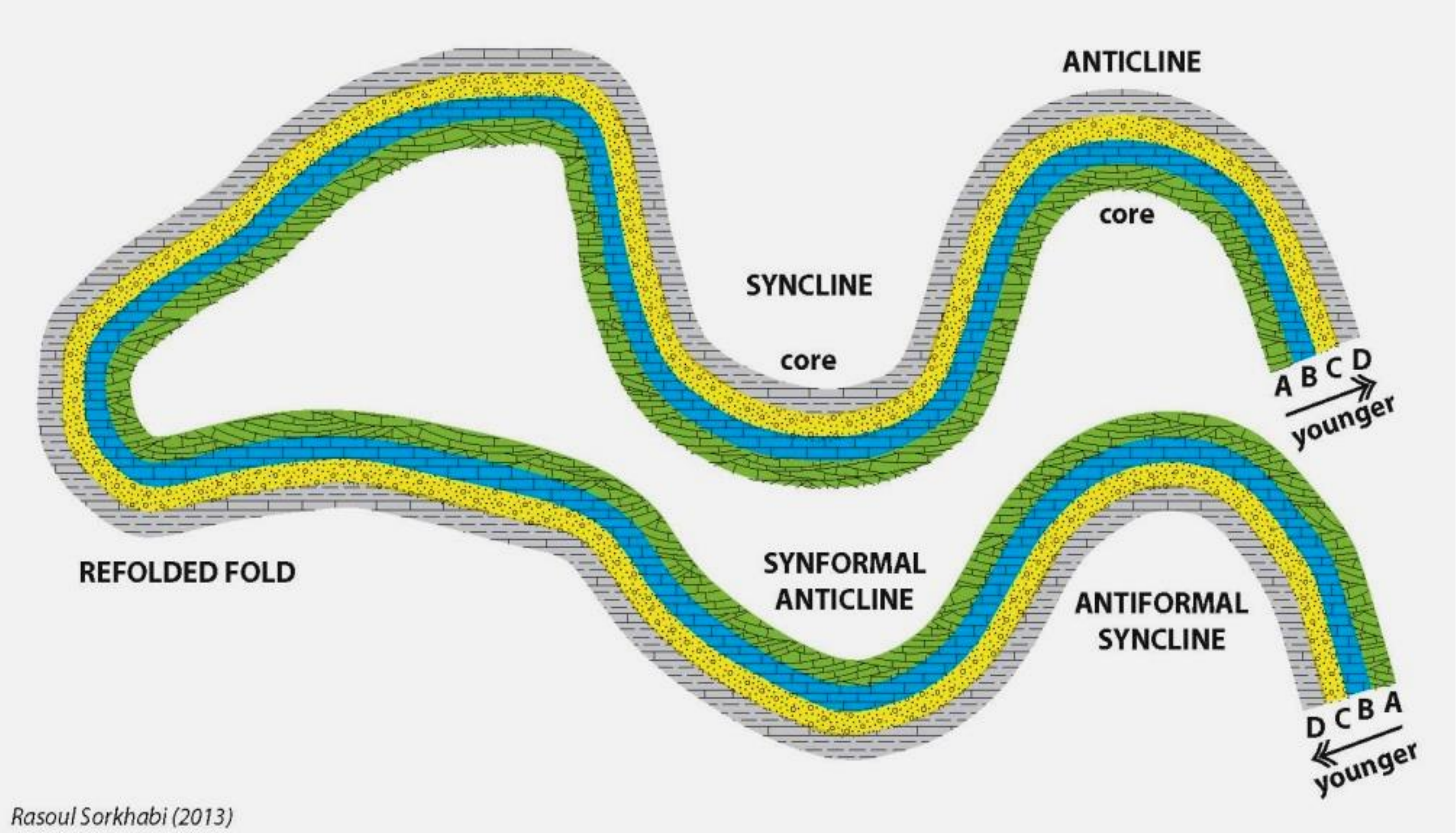
Synclinal Fan Fold - Two limbs dip away from each other

Drag Folds



Formed when a competent (strong) bed slides past an incompetent (weak) bed. i.e. results from shearing of beds past each other

Refolded fold

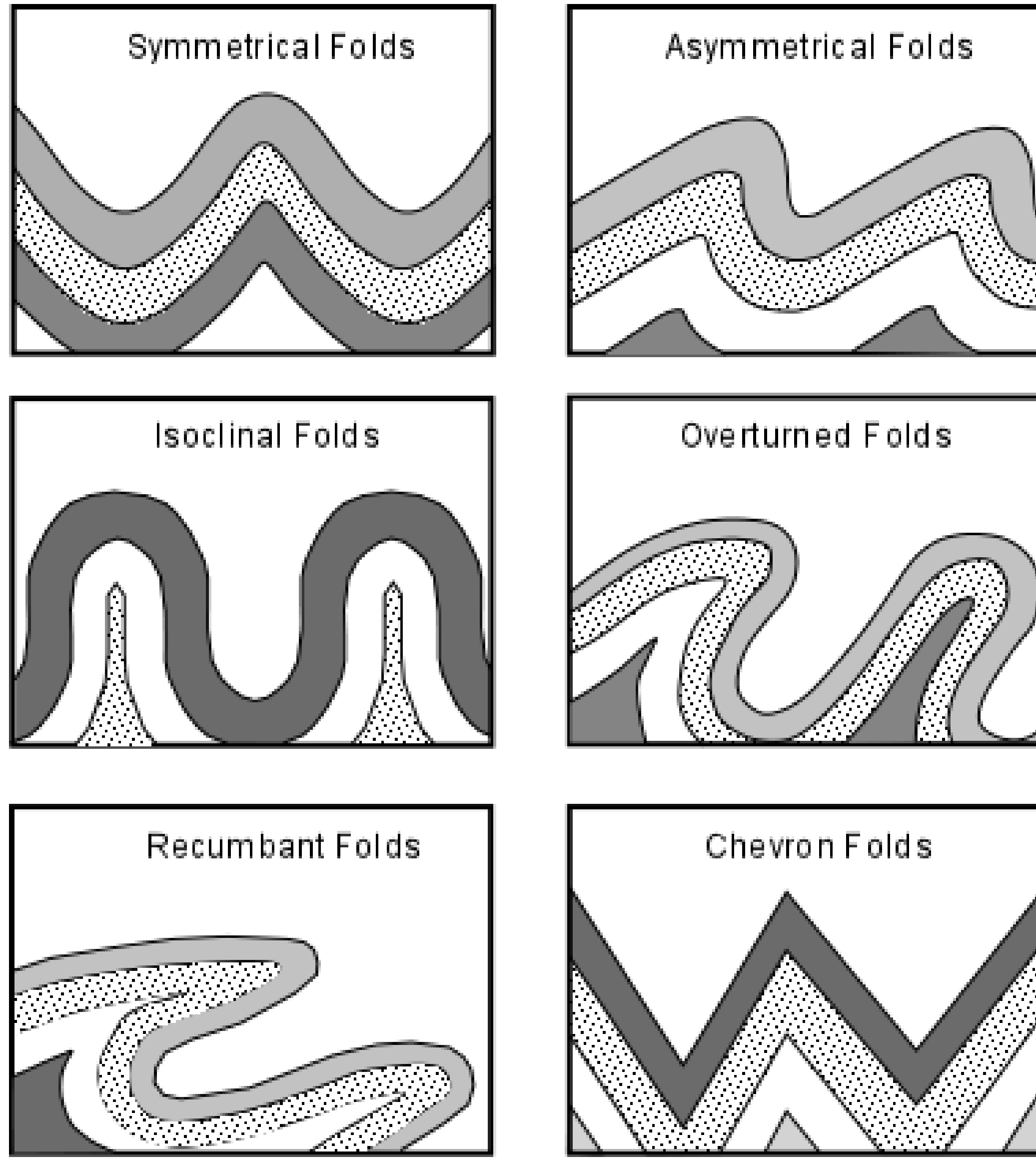


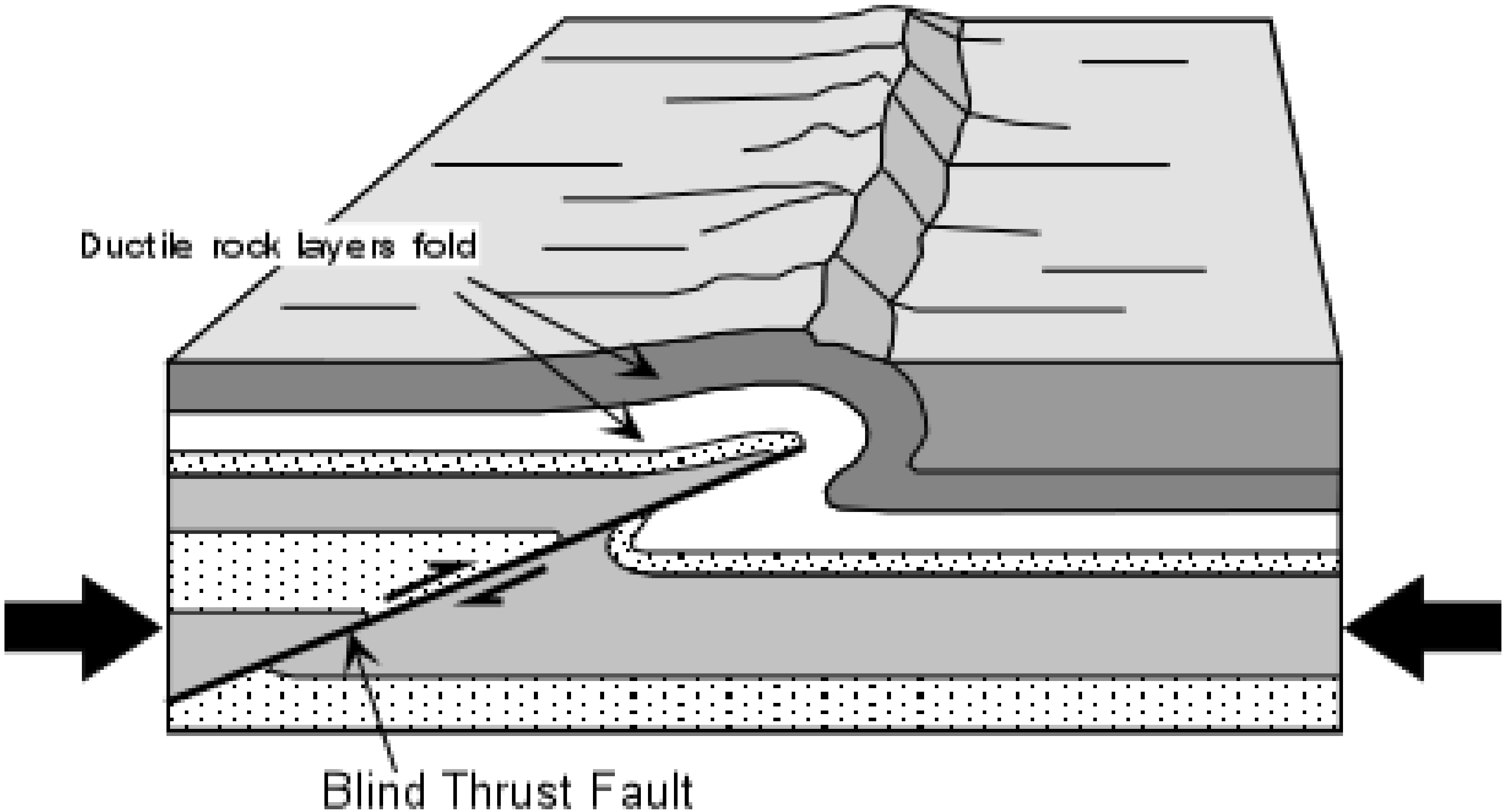
Thank you

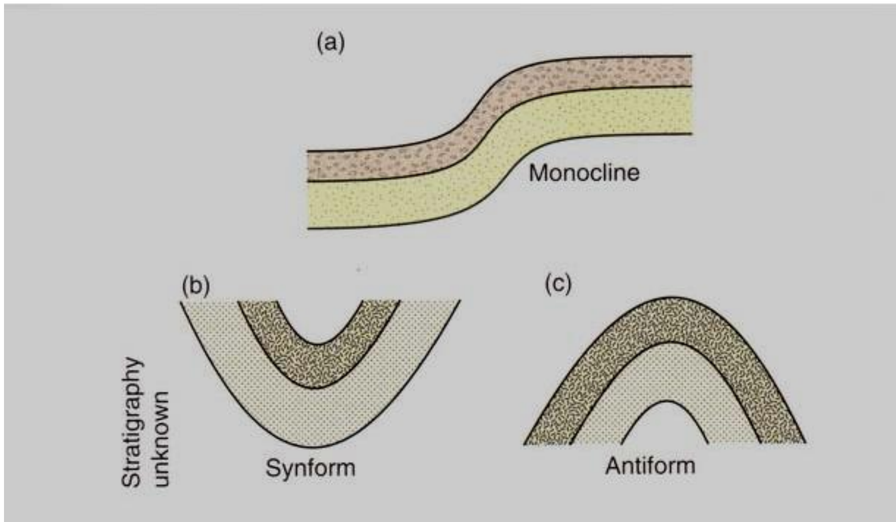
Summary

Folds can be classified based on their appearance

- ***Symmetrical fold:*** **two limbs of the fold dip away from the axis at the same angle.**
- ***Asymmetrical fold:*** **If the limbs dip at different angles.**
- ***Isoclinal fold:*** **If the fold is close up and have limbs that are parallel to each other (*iso* – equal; *cline*: inclined).**
- ***Overturned fold:*** **If the strata on one limb of the fold becomes nearly upside down.**
- ***Recumbent fold:*** **An overturned fold with an axial plane that is nearly horizontal**




Ductile rock layers fold
Blind Thrust Fault



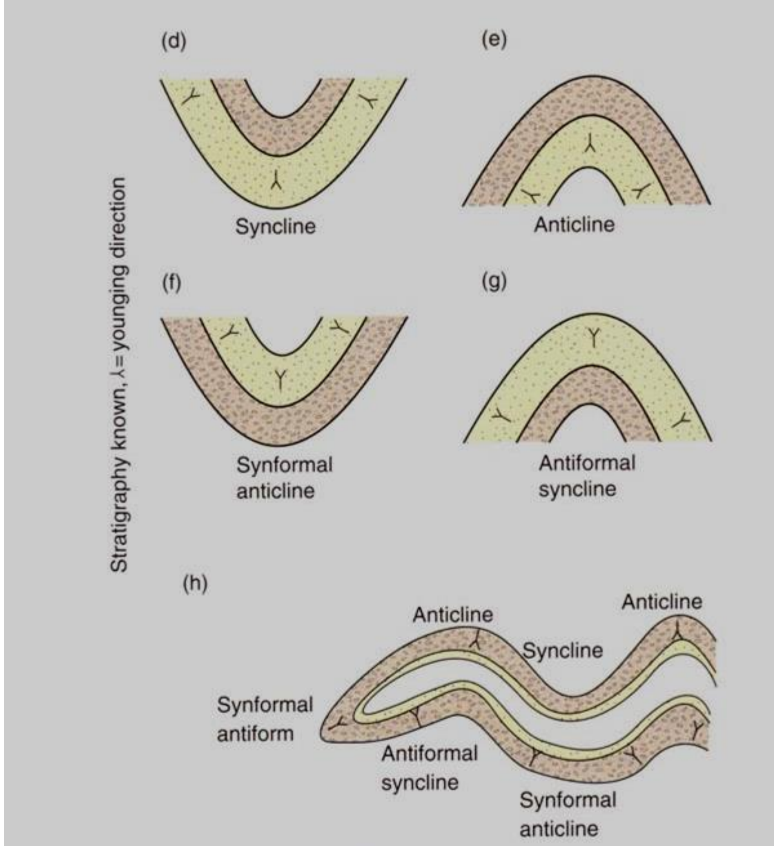


Figure 11.8 Basic fold shapes. The bottom figure illustrates how various types of syn- and antiforms may occur in a refolded fold.

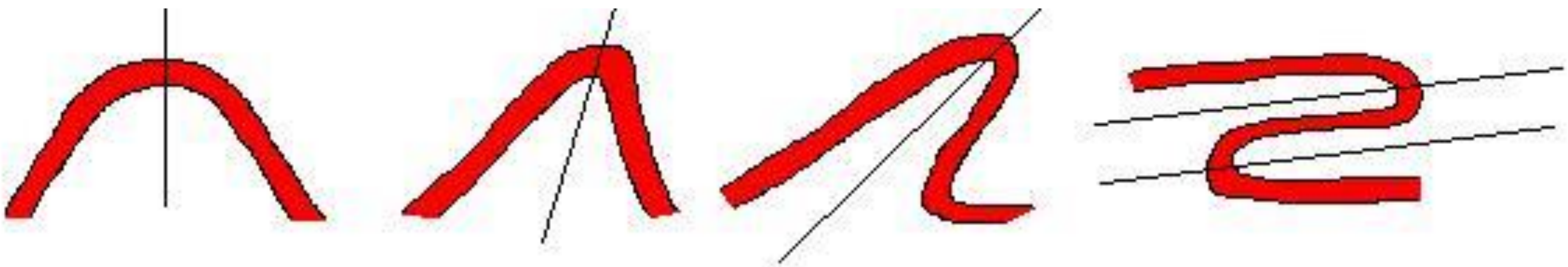
Fold shape
A fold can be shaped as a chevron, with planar limbs meeting at an angular axis, as **cuspate** with curved limbs, as circular with a curved axis, or as elliptical with unequal wavelength.
Fold tightness
Fold tightness is defined by the size of the angle between the fold's limbs (as measured tangential to the folded surface at the inflection line of each limb), called the interlimb angle. Gentle folds have an interlimb angle of between 180° and 120°, open folds range from 120° to 70°, close folds from 70° to 30°, and tight folds from 30° to 0°.[5] *Isoclines*, or *isoclinal folds*, have an interlimb angle of between 10° and zero, with essentially parallel limbs.

Fold symmetry

Not all folds are equal on both sides of the axis of the fold. Those with limbs of relatively equal length are termed symmetrical, and those with highly unequal limbs are asymmetrical. Asymmetrical folds generally have an axis at an angle to the original unfolded surface they formed on.

Deformation style classes

Folds that maintain uniform layer thickness are classed as *concentric* folds. Those that do not are called *similar folds*. Similar folds tend to display thinning of the limbs and thickening of the hinge zone. Concentric folds are caused by warping from active buckling of the layers, whereas similar folds usually form by some form of shear flow where the layers are not mechanically active. Ramsay has proposed a classification scheme for folds that often is used to describe folds in profile based upon curvature of the inner and outer lines of a fold, and the behavior of *dip isogons*. that is, lines connecting points of equal dip:[6]



Symmetrical fold

Asymmetrical fold

Overturned fold

Recumbent fold

Anticlines and synclines are the up and down folds that usually occur together and are caused by compressional stress.

Anticlines are folds in which each half of the fold dips away from the crest. Synclines are folds in which each half of the fold dips toward the trough of the fold. You can remember the difference by noting that anticlines form an “A” shape, and synclines form the bottom of an “S.”