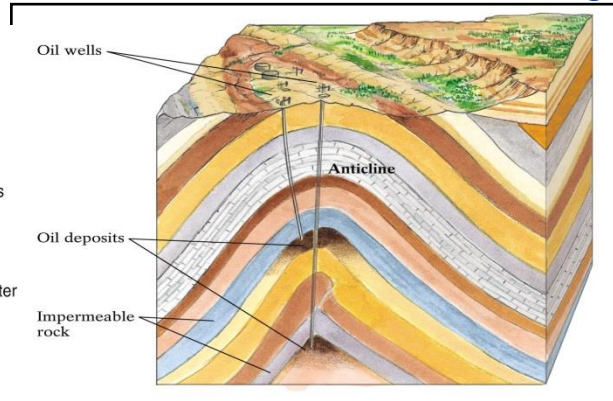
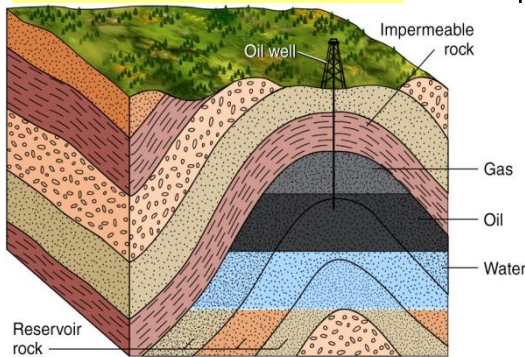


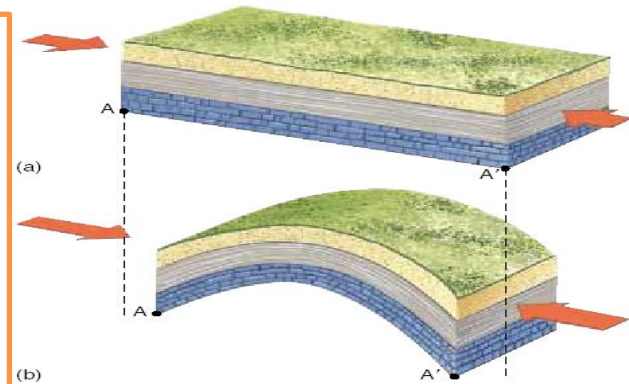
A geological fold occurs when one or a stack of originally flat and planar surfaces, such as , sedimentary strata are bent or curved as a result of plastic (permanent ) and ductile deformation. Folds in rocks vary in size from microscopic crinkles to mountain-size folds. A set of folds distributed on a regional scale constitutes a fold belt. Fold belts are typically associated with convergent plate boundaries and directed compressive stress.

## Why Study Folds ?

-Hydrocarbon traps.( Folds can trap oil and natural gas.)



Concentration of valuable mineral in the hinges of the fold



## *Scale types of Folds*

Folds can present in all scales

- microscopic (require magnification)
- mesoscopic (specimen and outcrop size)
- macroscopic (larger scale)



# Folds

**Antiform Fold:** fold that is convex upward, or **Anticline** fold that has older rocks in the center. **anticlines** are folds where the originally horizontal strata has been folded upward, and the two limbs of the fold dip away from the hinge of the fold.

**Synform Fold:** fold that is convex downward, in the simplest **syncline** the two limbs dip toward each other. The term has been extended to any fold where younger rocks are in the center Parts of Fold.

## Parts of folds

**Crest and Crestal plane:** The crest of the fold is the highest point of the fold surface or the hinge of fold. The plane connecting all the crests is called crestal plane.

**Trough and Trough plane:** The trough is the lowest points of the fold. The plane connecting such points may be called the trough plane.

**Hinge Point:** point of maximum curvature.(If the hinge is sharp, that point is called the hinge point otherwise it is called a hinge zone.)

**Hinge line:** The line connecting the points of maximum curvature of the bedding planes in a fold . Folds with a straight hinge line are called cylindrical folds.it may be horizontal, inclined, or vertical.it is defined by plunge/trend.

**Axial plane:** is the surface connecting the successive hinges of a folded strata. also it is the plane or surface that divides the fold as symmetrically as possible. The axial plane may be vertical, horizontal, or inclined.the attitude of A.p. is defibed by strike and dip.

**Axis:** fold axis is a line which lies parallel to the hinge line and marks the intersection of the axial plane with the hinge zone.

**Limbs or Flanks:** A limb extends from the axial plane in one fold to axial plane in the next. or it is that portion of curved surface between the hinge point and inflection point.

**Inflection Point:** point where curve changes from concave to convex. (if the transition from concave to convex involves a straight segment, there will be no inflection point ;then is arbitrarily taken to be the midpoint.)

**Inflection lines:** Lines connecting points of zero curvature.

**Median Surface:** Surface passing through the inflection points of a single folded layer

**Wavelength:** the line connecting three inflection points. Or is the distance from one anticlinal hinge to the next anticlinal hinge

**Amplitude:** Half the height of the structure measured from crest to trough. or the height between the crest and median surface, measured parallel to axial surface.

**Enveloping Surface:** imaginary plane that is tangential to the hinge zones of series of small folds.it contains all antiformal or synforma hinges.

**Interlimb Angle:** the minimum angle between the limbs as measured in the profile plane. We assume that the limbs are relatively planar or we use the tangent at the inflection points.

**Anticline** :fold that is convex upward,older rocks in the center.two limbs dip away from each other.

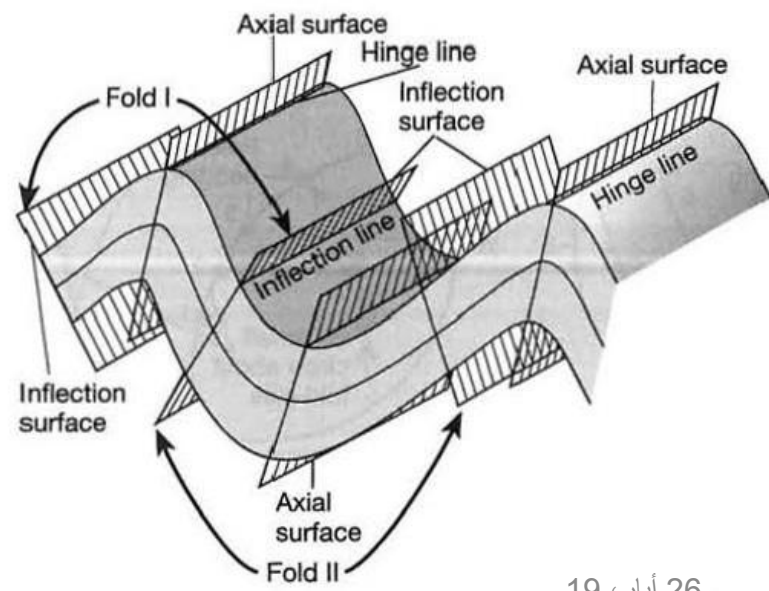
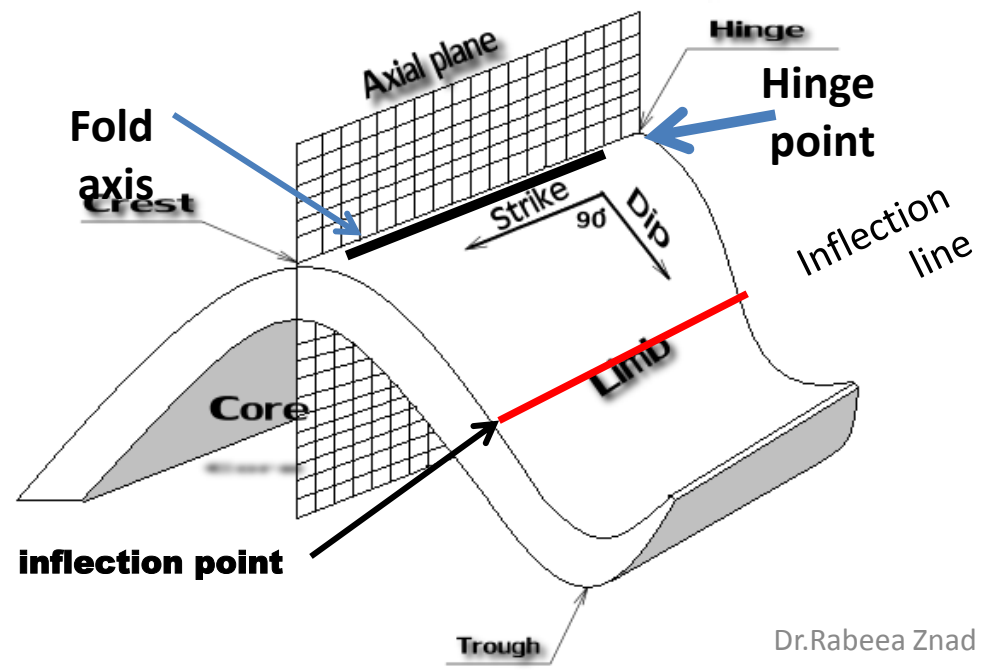
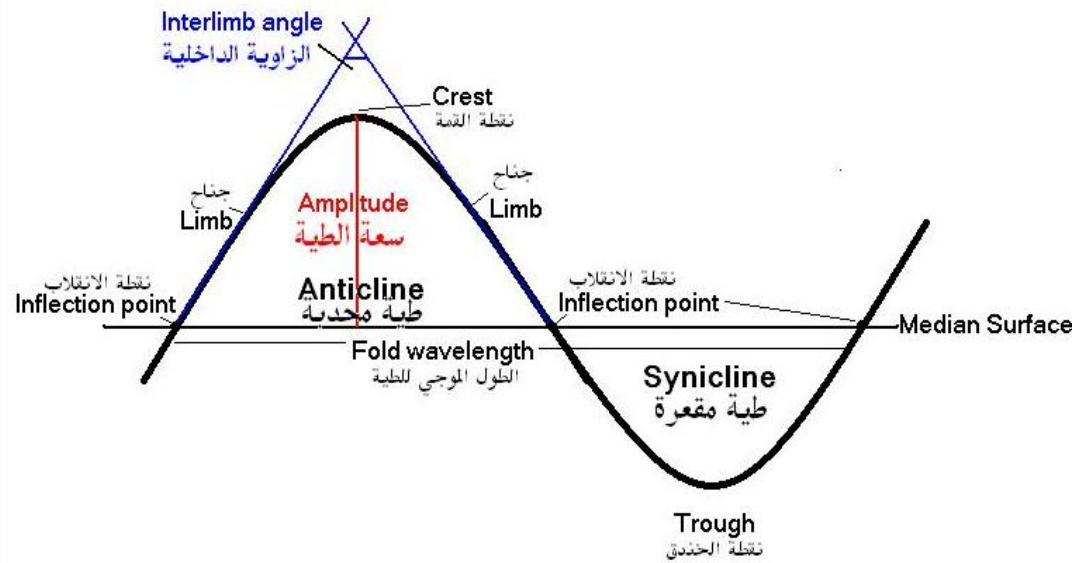
**Syncline**: fold that is convex downward. younger rocks in the center.two limbs dip toward each other.

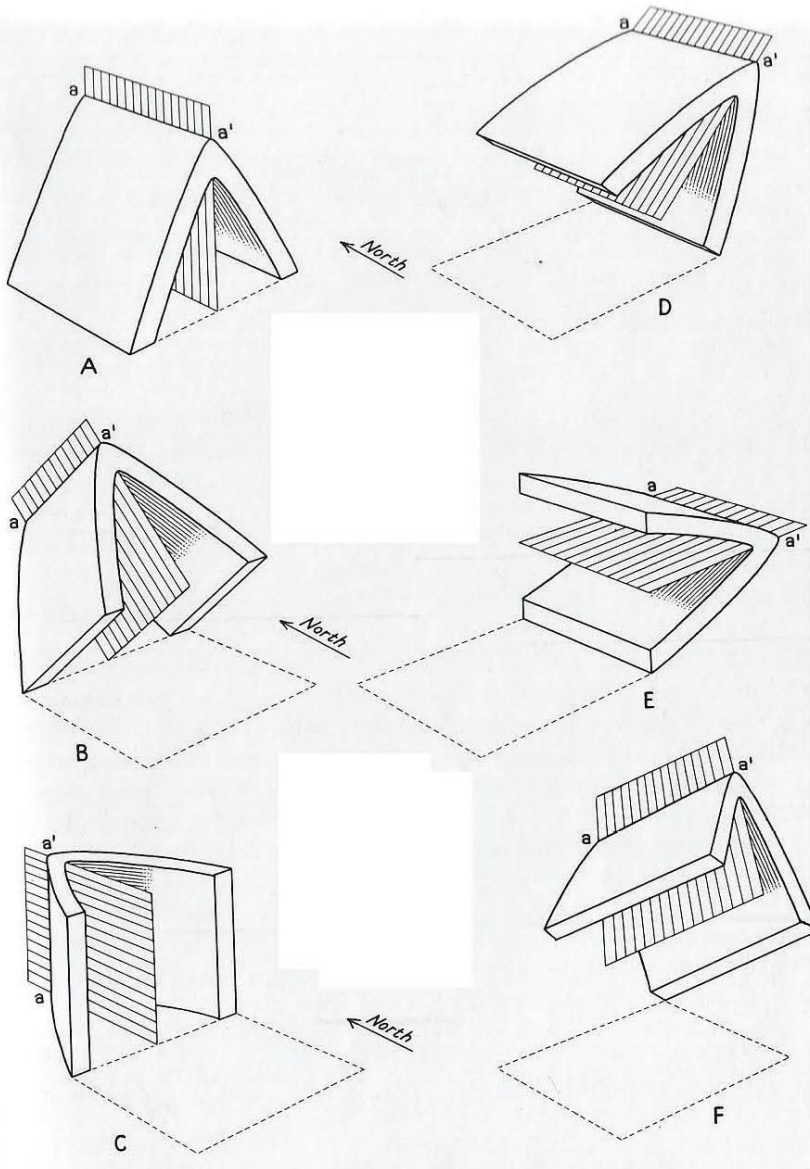
- **Fold axis (not a physical line) cannot be marked on the folded surface**

We tend to mix-n-match the terms hinge line and fold axis.

Strictly speaking however, the fold axis is a geometric (imaginary) element that does not have a fixed location.

A fold's hinge line, on the other hand is a fixed line upon a given stratigraphic layer.

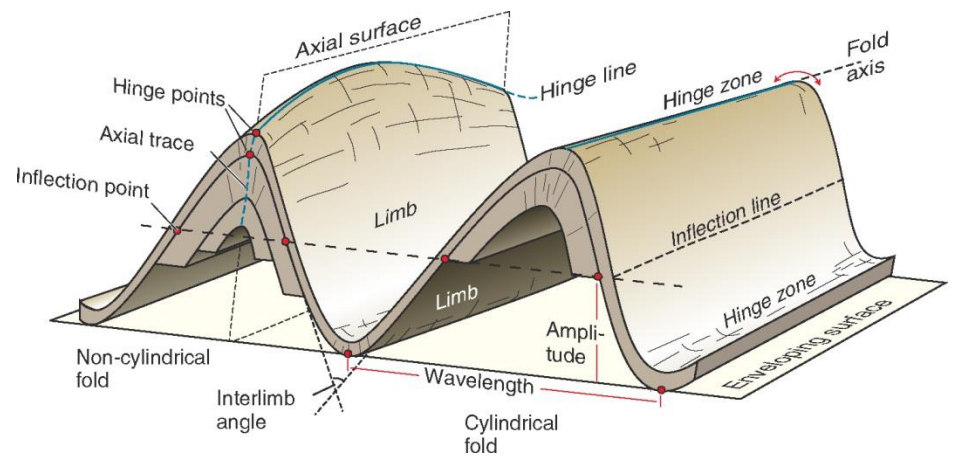




## Axial Plane

A few of the different attitudes assumed by axial planes and hinges of fold.  
 axial plane is shaded in each diagram.  
 aa' is hinge of fold.

The attitude of axial plane is defined by its strike and dip.



# Cylindrical Folds and Non-Cylindrical Folds

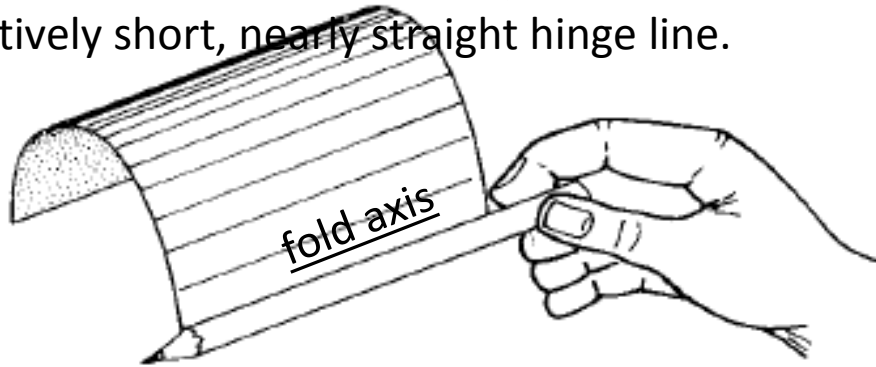
A **fold axis** is a geometric (imaginary) straight line which when moved parallel to itself through space generates the shape of the fold.

**Cylindrical fold:** fold with straight hinge line parallel to fold axis.

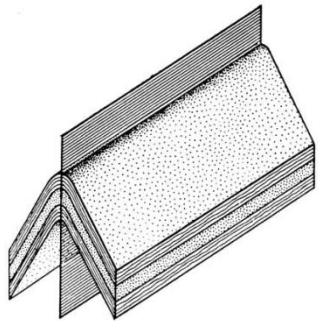
*hingeline & axis are the same for cylindrical fold.*

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

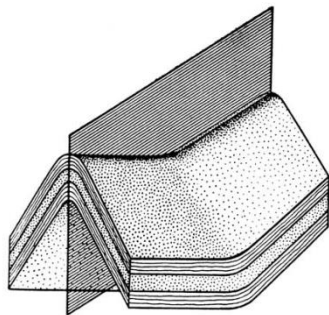
and for the purpose of detailed structural analysis (for example, stereographic representation), it is necessary to subdivide them into several cylindrical folds, each with a relatively short, nearly straight hinge line.



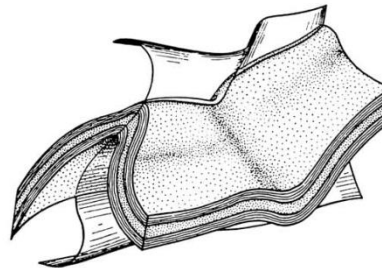
1 The concept of a cylindrically folded surface.



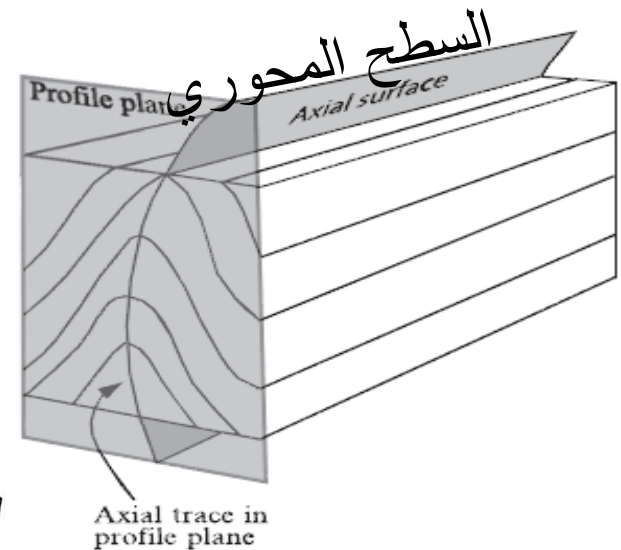
(a)



(b)

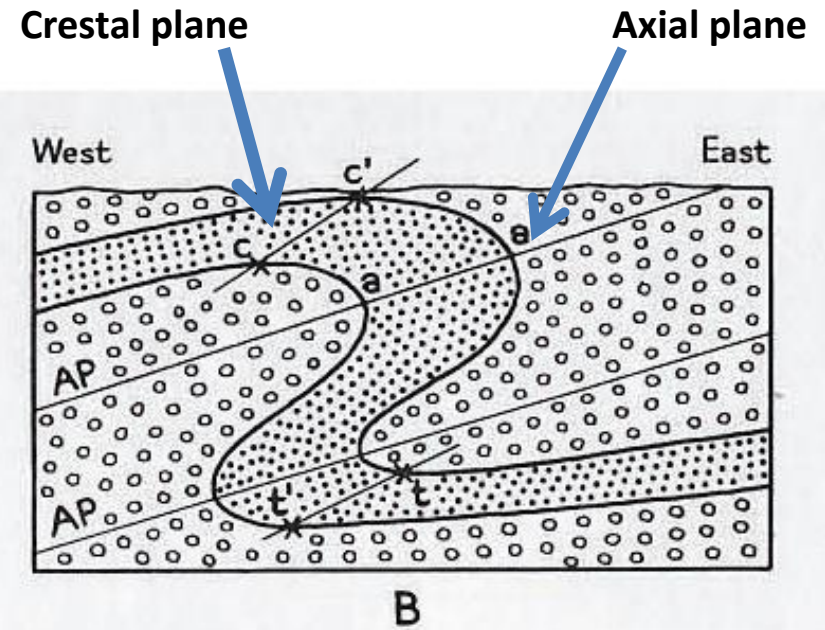
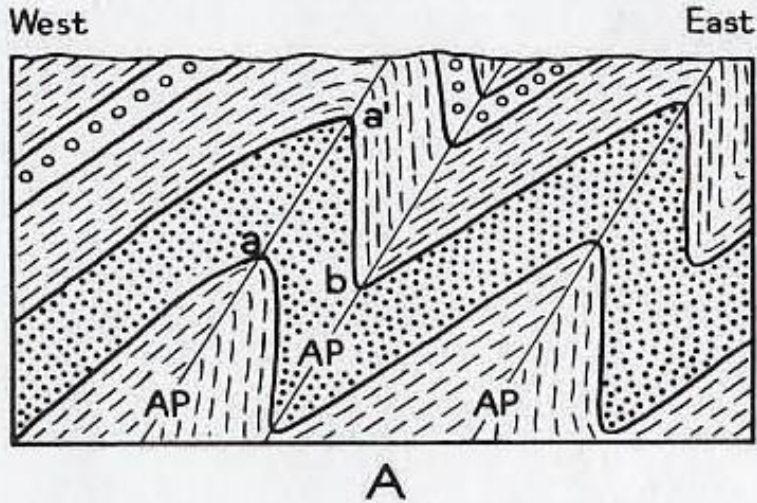


(c)

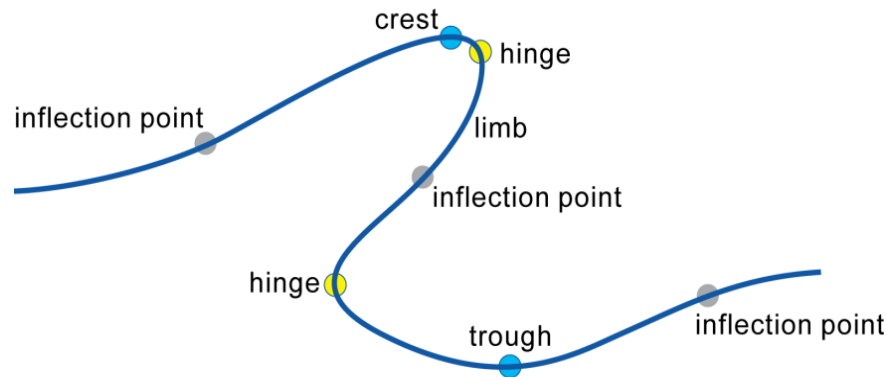


5 Profile plane and the axial surface of folds.

Although in many instances the hinge is at the highest part of the fold, as in fig A, this is not necessarily the case, as in fig B,C .



Parts of a fold .**AP**, axial plane; **a'b** ,limb of a fold; **c**, crest on one fold; **c'**,crest on another bed; **cc'** crestal plane; **t**, trough on one bed; **t'** trough on another bed; **tt'**, trough plane.

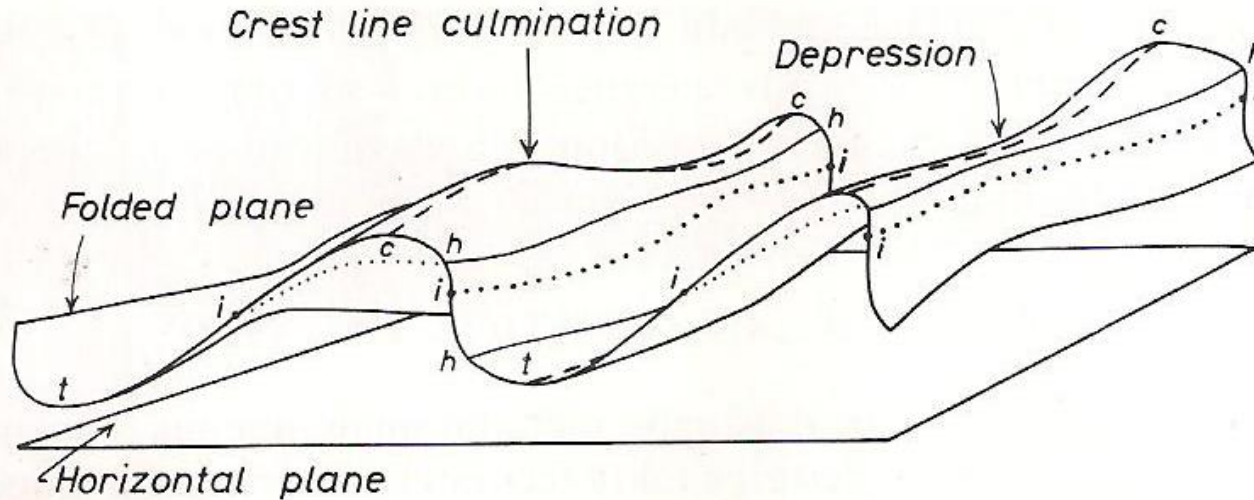


Basic terminology on a folded single surface

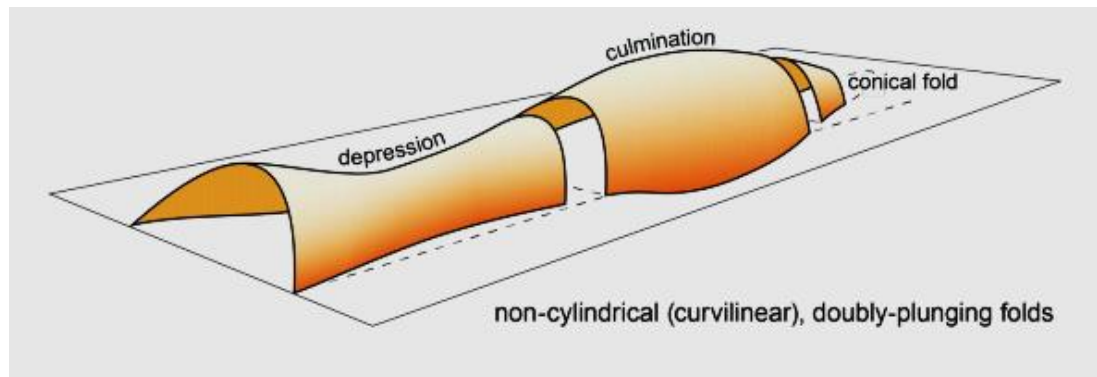


In general, fold hinge lines undulate, and these changes in orientation give rise to special structural forms.

The areas where crest and trough lines go through max. or min. elevations are called **Culmination** and **Depression** respectively.



*The location of crest lines (c), trough lines (t), hinge lines (h), and inflection lines (i) on a single folded surface.*

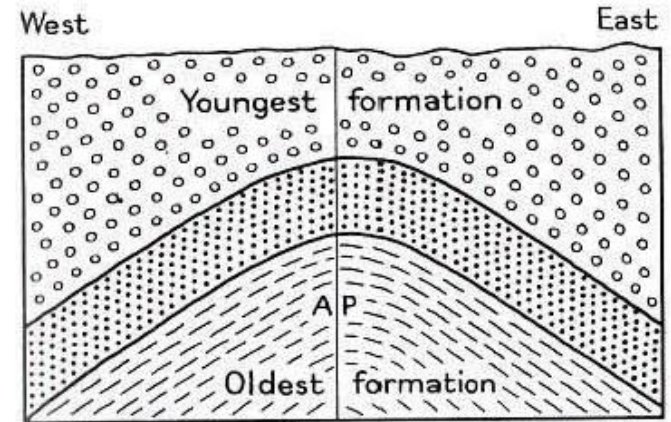
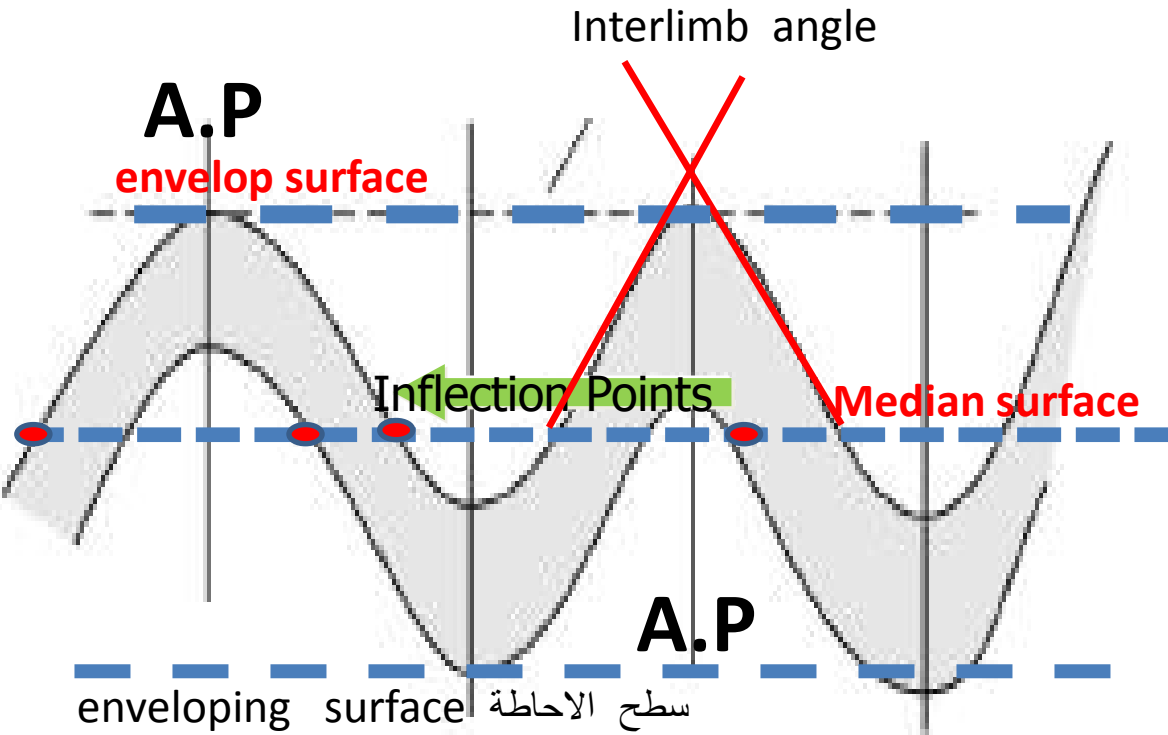


# Folds Symmetry

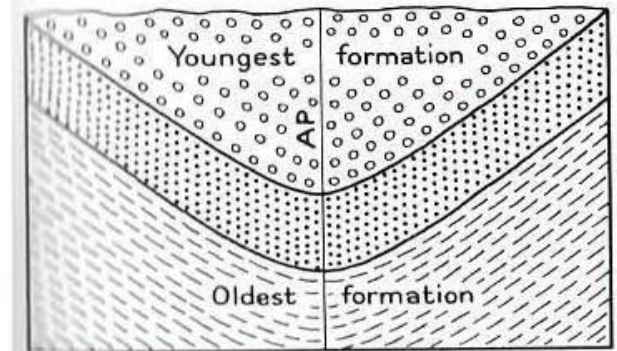
## Condition of Symmetrical Folds

- 1-vertical axial plane or upright.
- 2-Axial plane bisect the interlimb angle.

- 3-Equal length and dip angle of fold limbs.
- 4- A horizontal median surface and lie in the midpoints between parallel enveloping surfaces.



Symmetrical Anticline



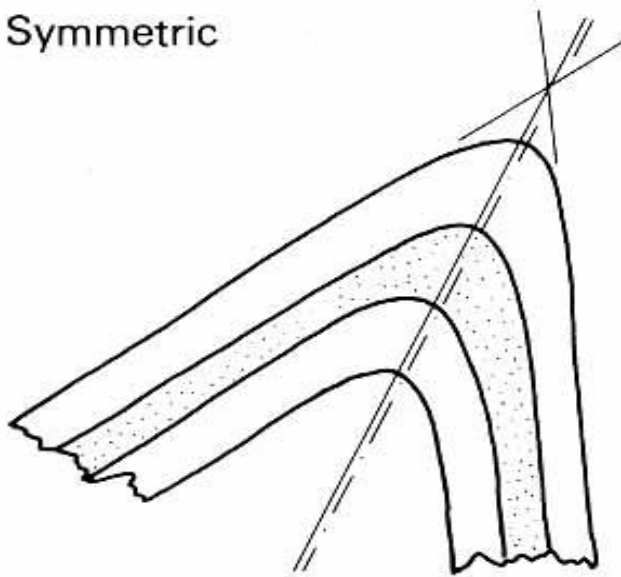
Symmetrical Syncline

## FOLD SYMMETRY

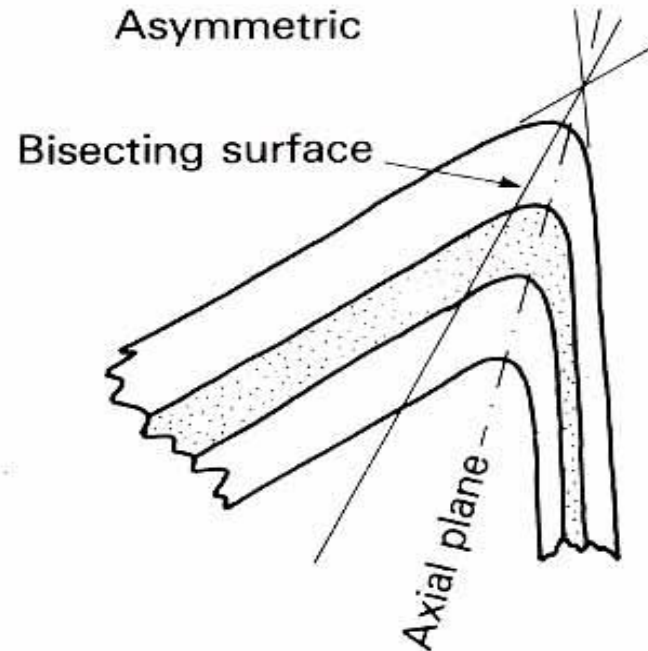
Symmetric fold: the axial surface bisects the angle made by the extension of the two limbs.

Asymmetric fold: the axial plane does not bisect the angle made by the extension of the two limbs.

Symmetric



Asymmetric



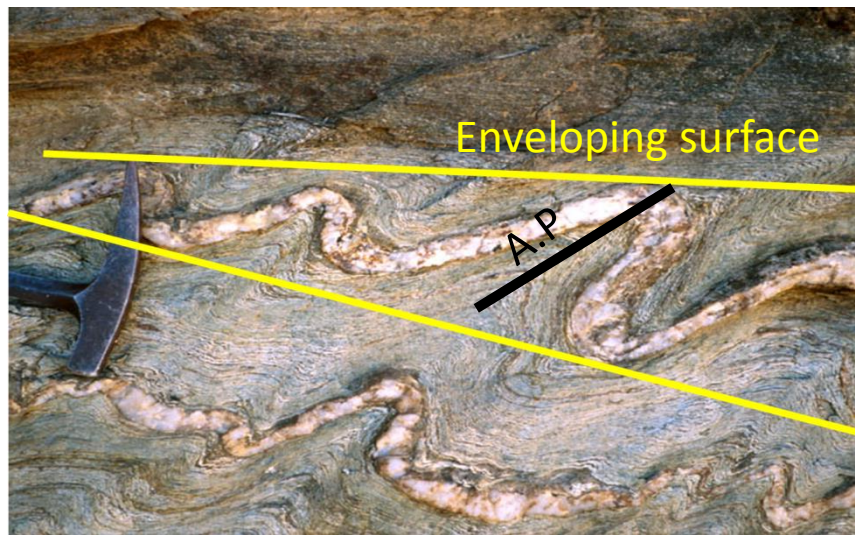
## Asymmetry and Vergence الاتكاء

If the axial plane is not a plane of symmetry, the limbs have unequal lengths and one limb dips more steeply than the other: the folds are **Asymmetric**. Their leaning direction suggests a relative sense of movement, termed the **apparent vergence**.

Vergency:- direction of acute angle made by intersection of hinge surface and enveloping surface.

Often used:to infer a sence of shear. A direction of tectonic transport or the clouser of large-scale folde.

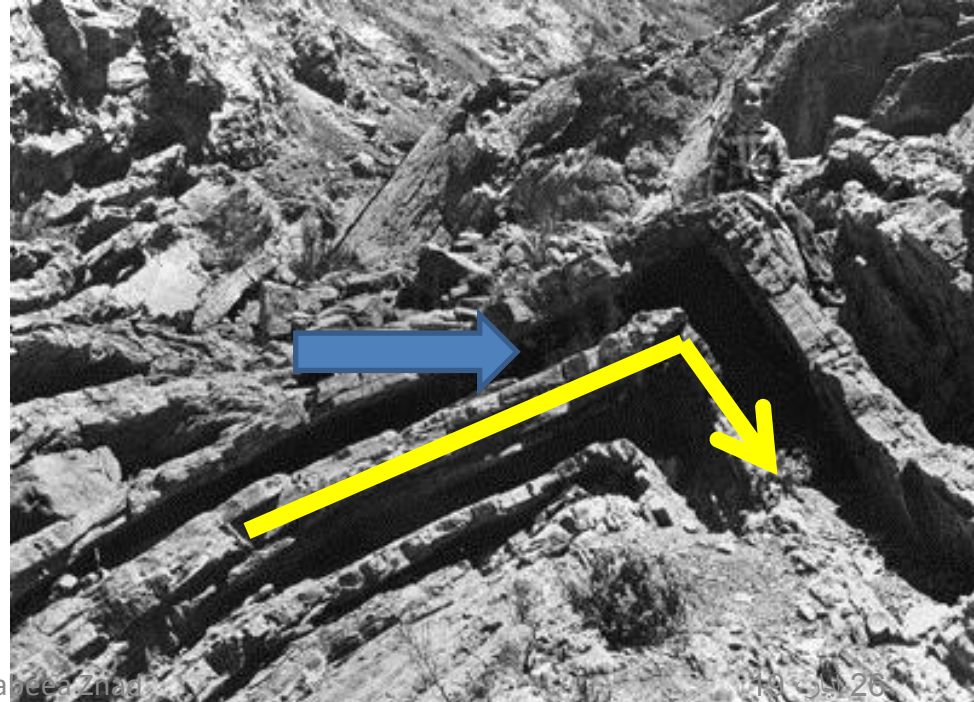
*The direction of apparent movement of the upper, long limb with respect to the shorter limb of an asymmetric fold is called the vergence. In other word, vergence is simply the sense of asymmetry.*



# Vergence

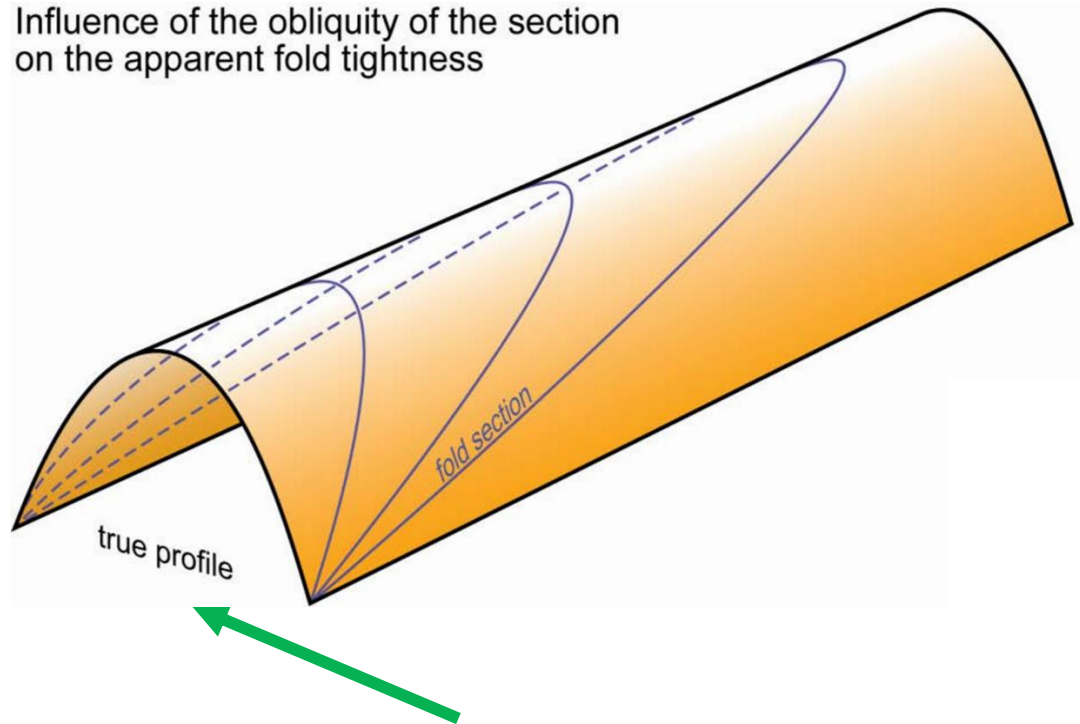
Vergence of a fold applies only to folds having one limb that dips more steeply and is shorter than the other—an asymmetric fold.

In symmetrical folds vergence is not a property. However, small folds on the limbs of symmetrical fold may exhibit vergence. Study of vergence may be useful in working out the overall direction of tectonic transport of all structures in an area and help to fix an observer's location on large fold.



# Profile of folds

The profile is a reference plane used to describe and measure all geometrical characteristics of the fold: symmetry, height or amplitude, wavelength, tightness, roundness. Indeed, these aspects vary with the angular relationship between any section plane and the folded surface.



المقطع العرضي الصحيح true profile يتم اعتماده في وصف انواع الطيات

# FOLDS TYPES

The following types of folds cover most of the folds that may be seen in the field, as well as cross sections drawn from geological maps .

(The cross sections are those vertical sections on the fold axis or the strike of folding beds or vertical at the axial Plane)

These types have been identified depending on:

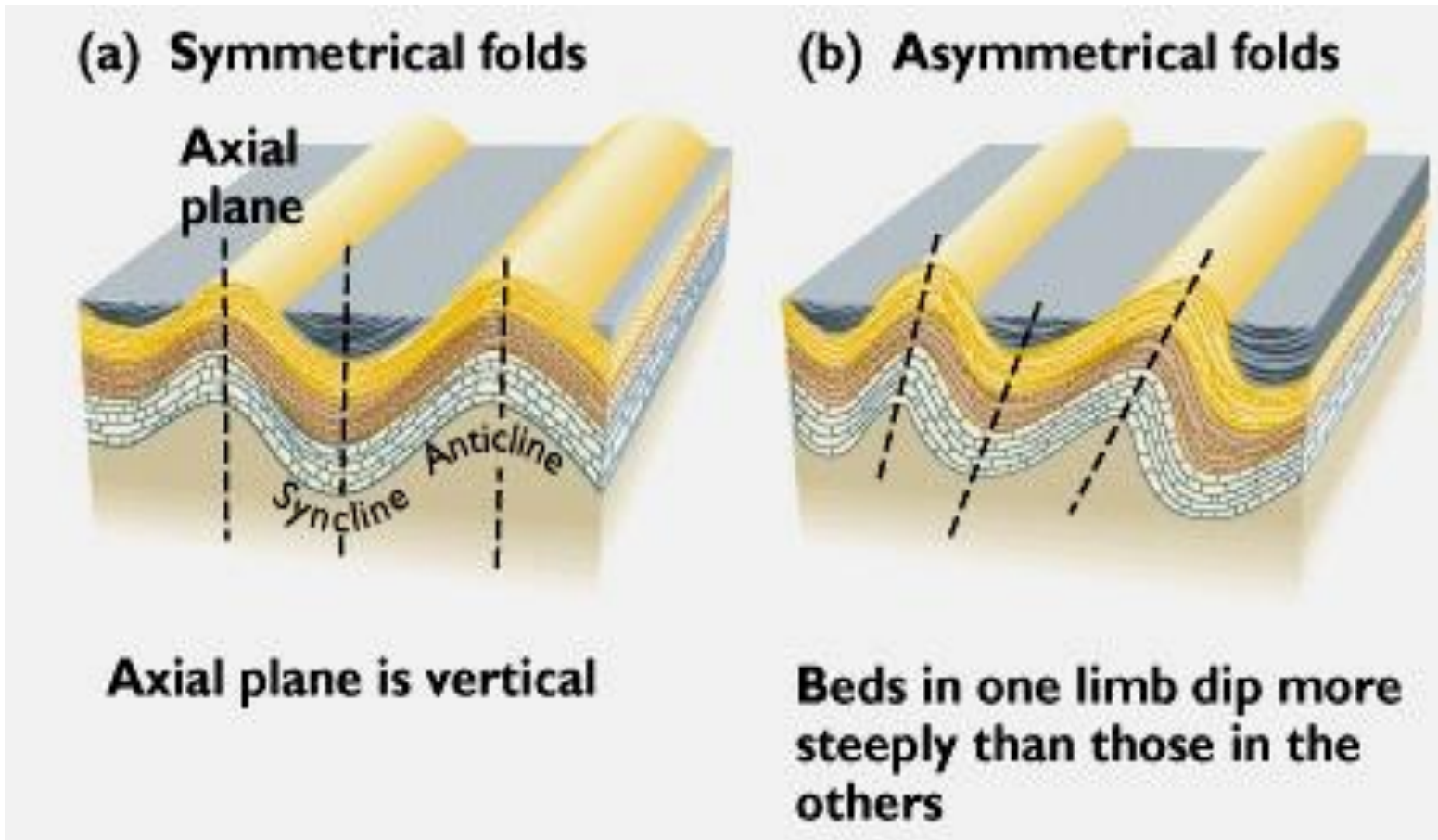
-Orientation of the Axial plane

-Dip of the Fold limbs

- 1- الطية المحدبة Anticline
- 2- الطية المقعرة Syncline
- 3- الطية المتكئة Overtured Fold
- 4- الطية المضطجة Recumbent Fold
- 5- الطية متساوية الميل Isoclinal Fold
- 6- الطية الصندوقية Box Fold
- 7- الطية المسننة(المنشارية او الشيفرونية) Chevron Fold
- 8- الطية المروحية Fan Fold
- 9- الطية المتوازية Parallel Fold
- 10- الطية المتشابهة Similar Fold
- 11- طية وحيدة الميل Monocline Fold
- 12- الطيات المطوية Refolded Folds
- 13- القبة والحوض Basin Dome

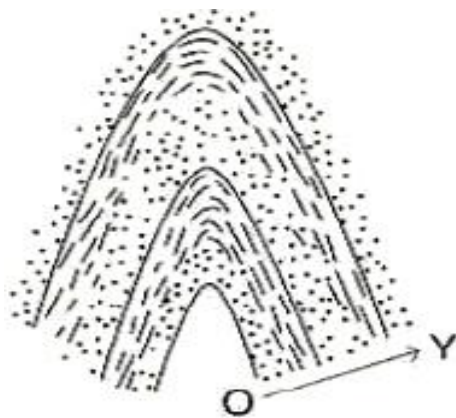
. Anticline :fold that is convex upward,older rocks in the center.  
two limbs dip away from each other

Syncline: fold that is convex downward. younger rocks in the center.  
two limbs dip toward each other

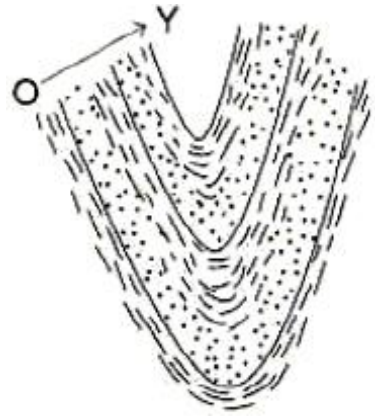




If the younging direction of rock is known, **antiform** is called (**anticline**) and **synform** is called (**syncline**).

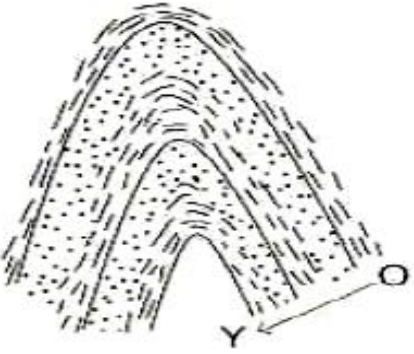


Antiformal Anticline

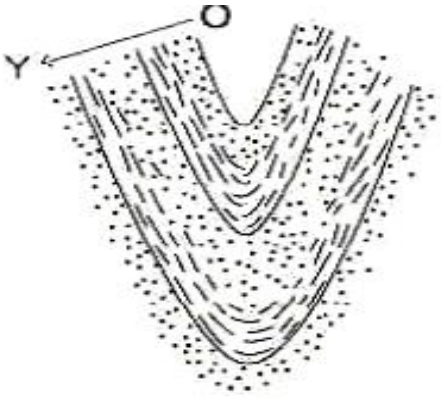
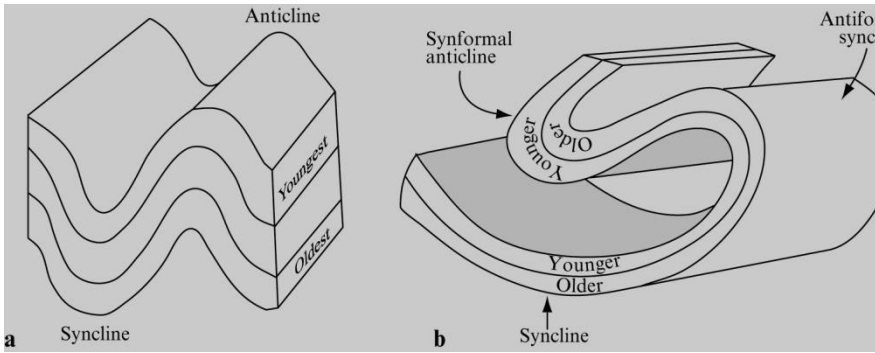


Synformal Syncline

Most anticline are convex up (antiformal), and syncline are concave up (synformal), although this geometry is not universal. In area of complex deformation where the entire Stratigraphy has been overturned. Anticlines actually may be synform and synclines may be antiformal.



Antiformal Syncline



Synformal Anticline

و Anticline or Syncline للتابع الطبقي

Antiformal or Synformal للشكل الخارجي

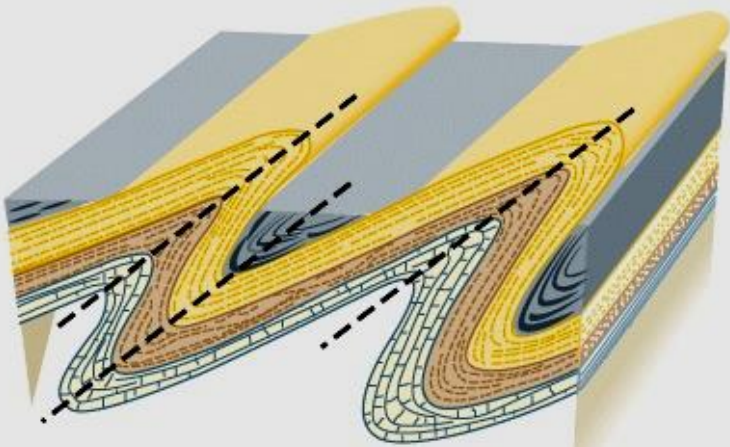
## Overtured Fold

الطية المتكئة او المقلوبة

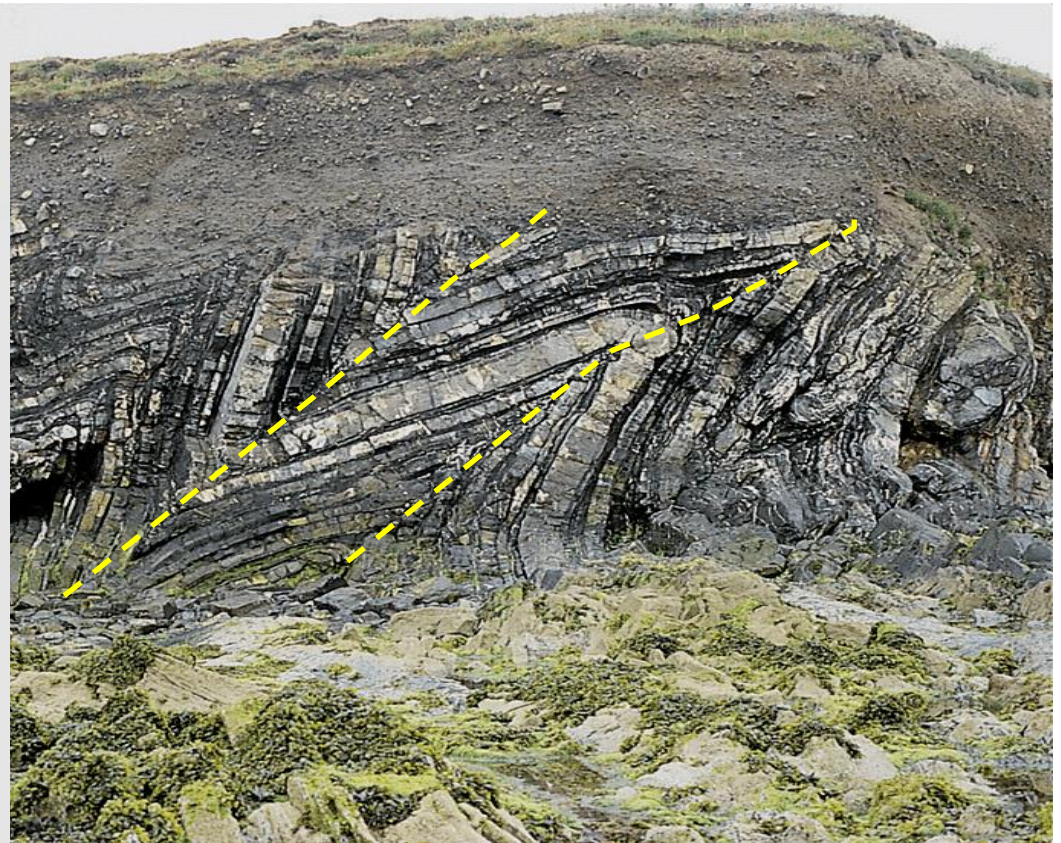
*In overtured fold or overdold the axial plane is inclined, and both limbs dip in the same direction, usually at different angles.*

The overtured, inverted, or reversed limb is one that has been rotated through more than  $90^\circ$  to attain present attitude.

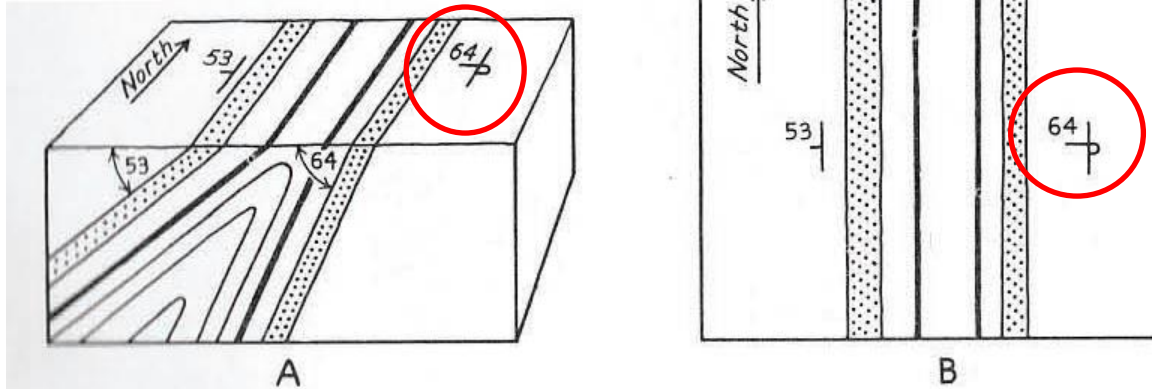
(c) Overtured folds



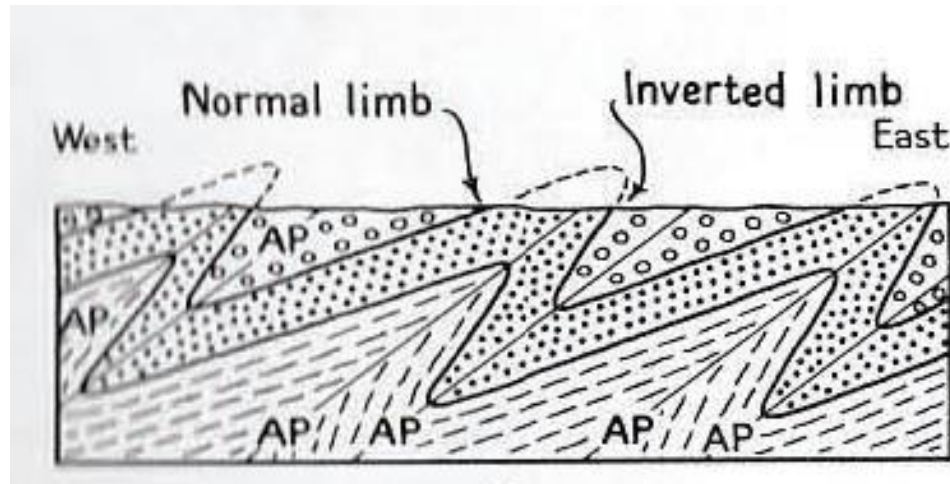
Both limbs dip in same direction but one limb has been tilted beyond vertical



The following figure represents a section of a overturned fold with its representation on a geological map. Note the symbols used for the inverted limb

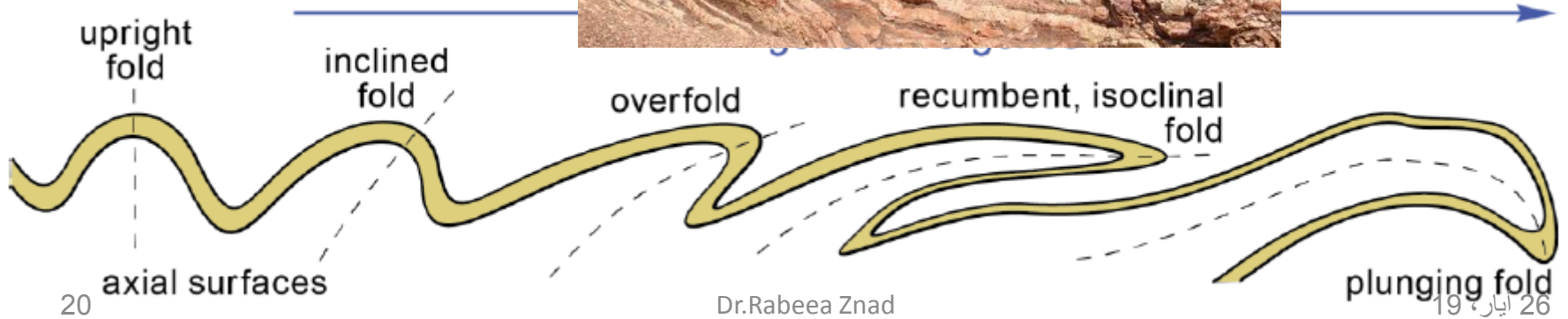
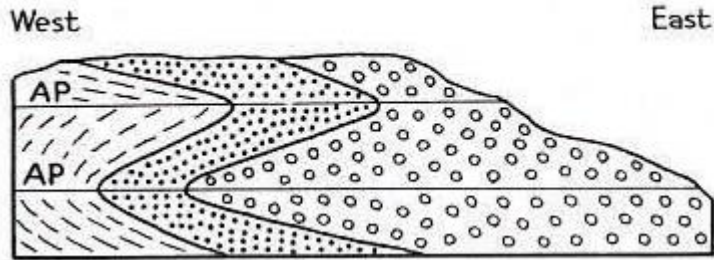
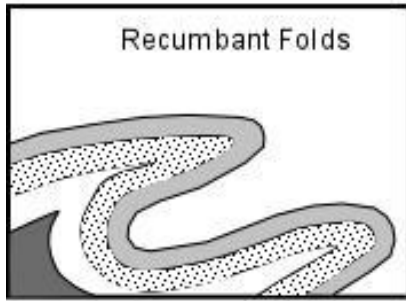


Dip-strike symbol for overturned strata. (A) Block diagram. (B) Map. The dip-strike symbol with 53 beside it indicates beds that dip 53° to the west (left) and are not overturned. The dip-strike symbol with 64 beside it indicates beds that dip 64° to the west (left), but are overturned.



# Recumbent Fold - الطية المضطجة

A recumbent fold is one in which the axial plane is essentially horizontal or nearly horizontal.



*Isoclinal fold* الطية متساوية الميل

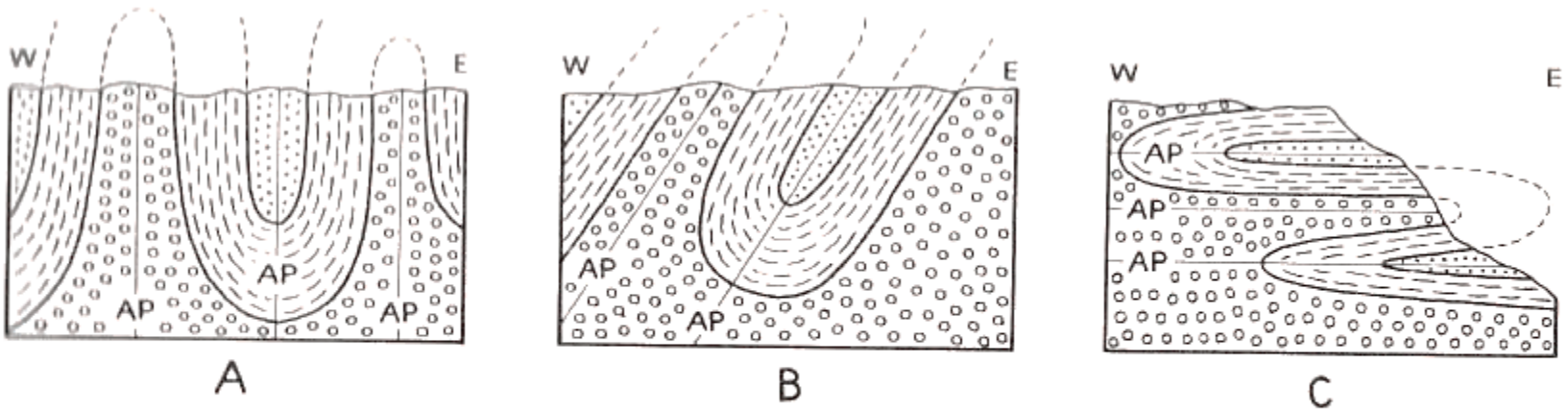
Folds in which the two limbs dip at equal angles in the same direction.

*A vertical isoclinal fold* : is one in which the axial plane is vertical.

*An inclined or overturned isoclinal fold* : is one in which the axial plane is inclined.

*A recumbent isoclinal fold* : is one in which the axial plane is horizontal.

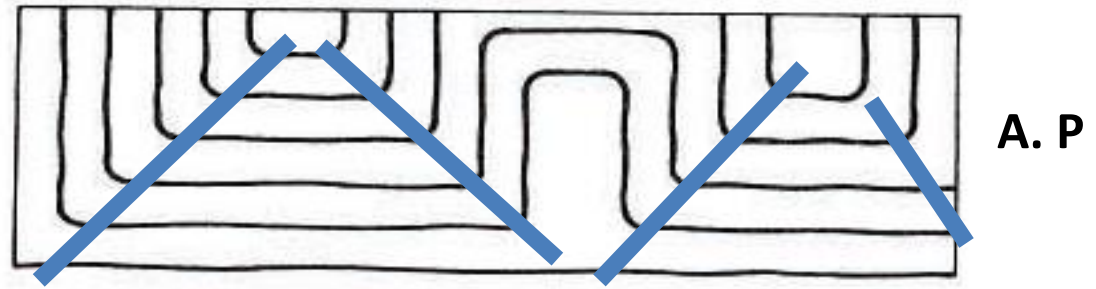
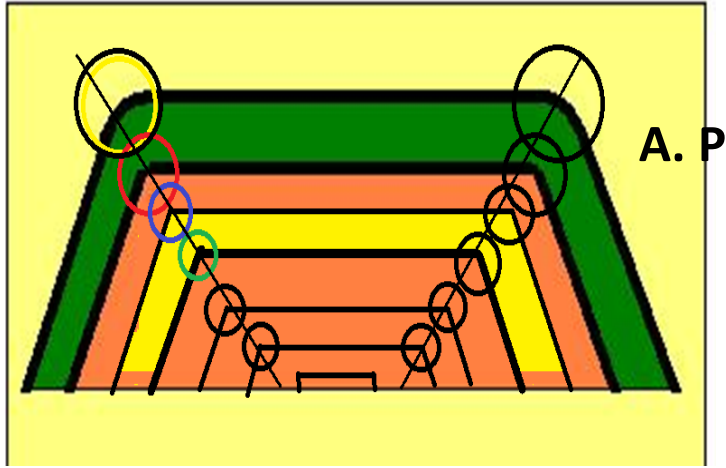
Many recumbent folds are isoclinal



Isoclinal folds. *AP*, Axial planes. (A) Vertical isoclinal folds. (B) Inclined isoclinal folds. (C) Recumbent isoclinal folds.

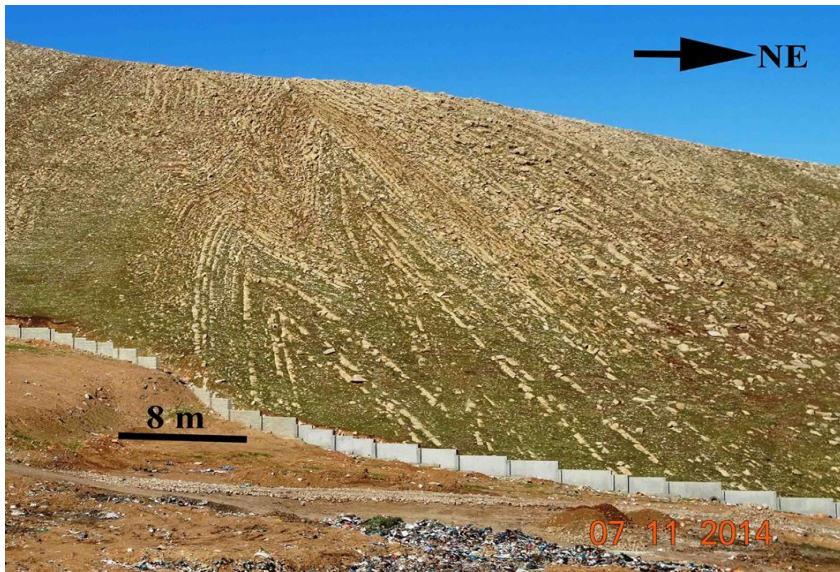
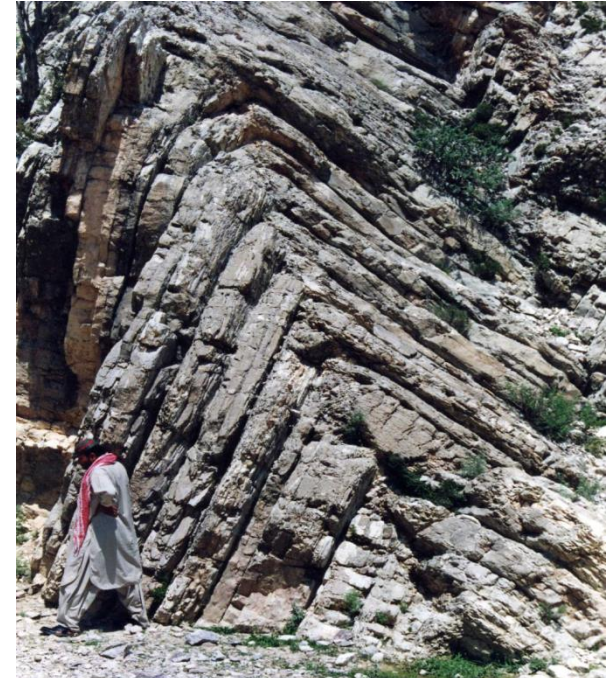
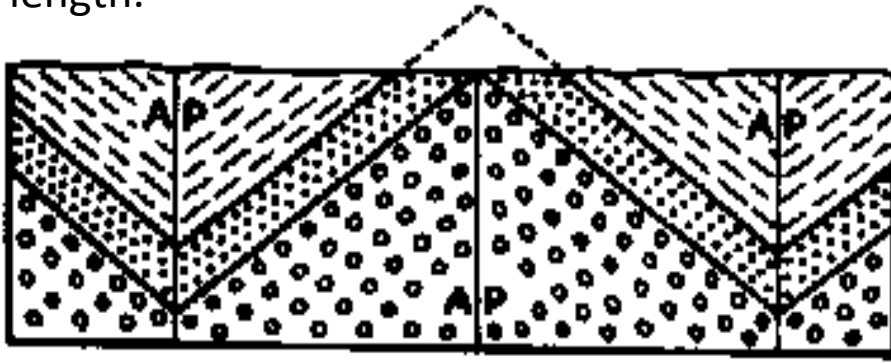
## الطية الصندوقية *Box Fold*

A box fold is one in which the crest is broad and flat; two hinges are present, one on either side of the flat crest.



## - الطية المسننة (المنشارية او الشيفرونية) *Chevron Fold*

A chevron fold is one in which the hinges are sharp to angular and the limbs are straight and equal length.



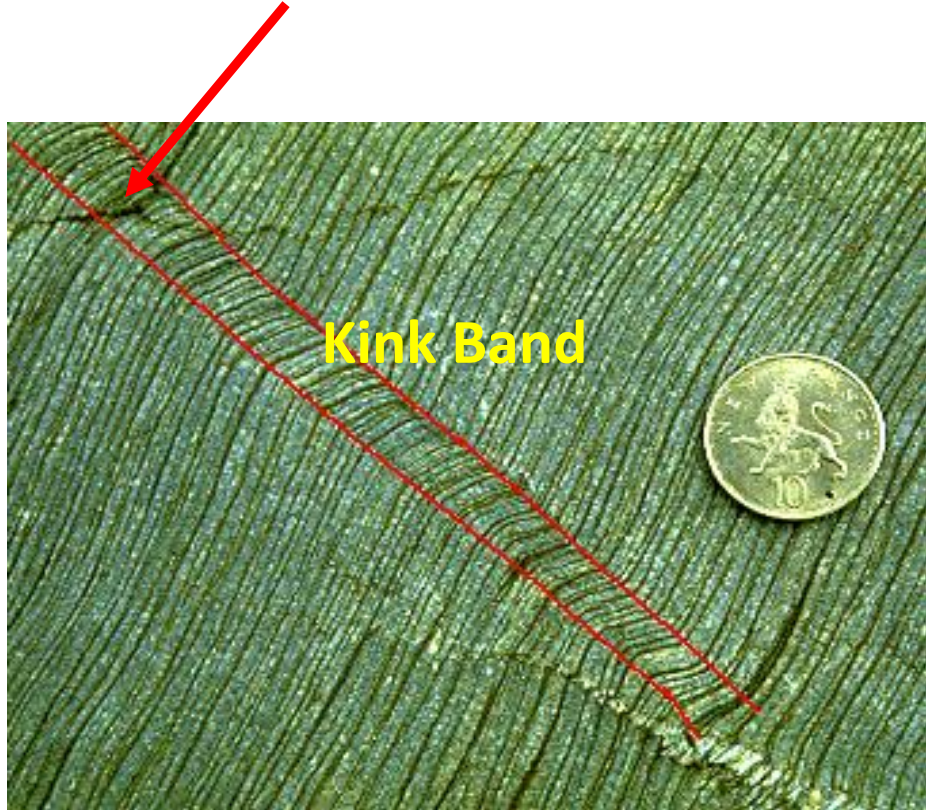
Overturned Chevron Folds in Balambo Formation  
(Said Sadiq town –Sulamania City)



في بعض الاحيان قسم من الطيات ذات الغلق الحاد تكون غير متماثلة وصغيرة محصورة في مناطق ضيقة تمتد لعدة امتار مشابهة لشريط حيث ان ميل الطبقات في **المنطقة الضيقة** اما اقل او اكثر من ميل امتدادها خارج هذه المنطقة ويطلق على هذا النوع من الطيات بطيات الفتل Kink Band وعند تقاطع هذه الشرائط مع بعضها نحصل على ما يسمى بالفتل المزدوج conjugate kink

### A kink Bands:

An Asymmetric chevron with a very long limb and a very short limb metric



Kink bands; are narrow bands, usually only a few inches or few feet wide, in which the beds assume a dip that is steeper or gentler than that in the adjacent beds.

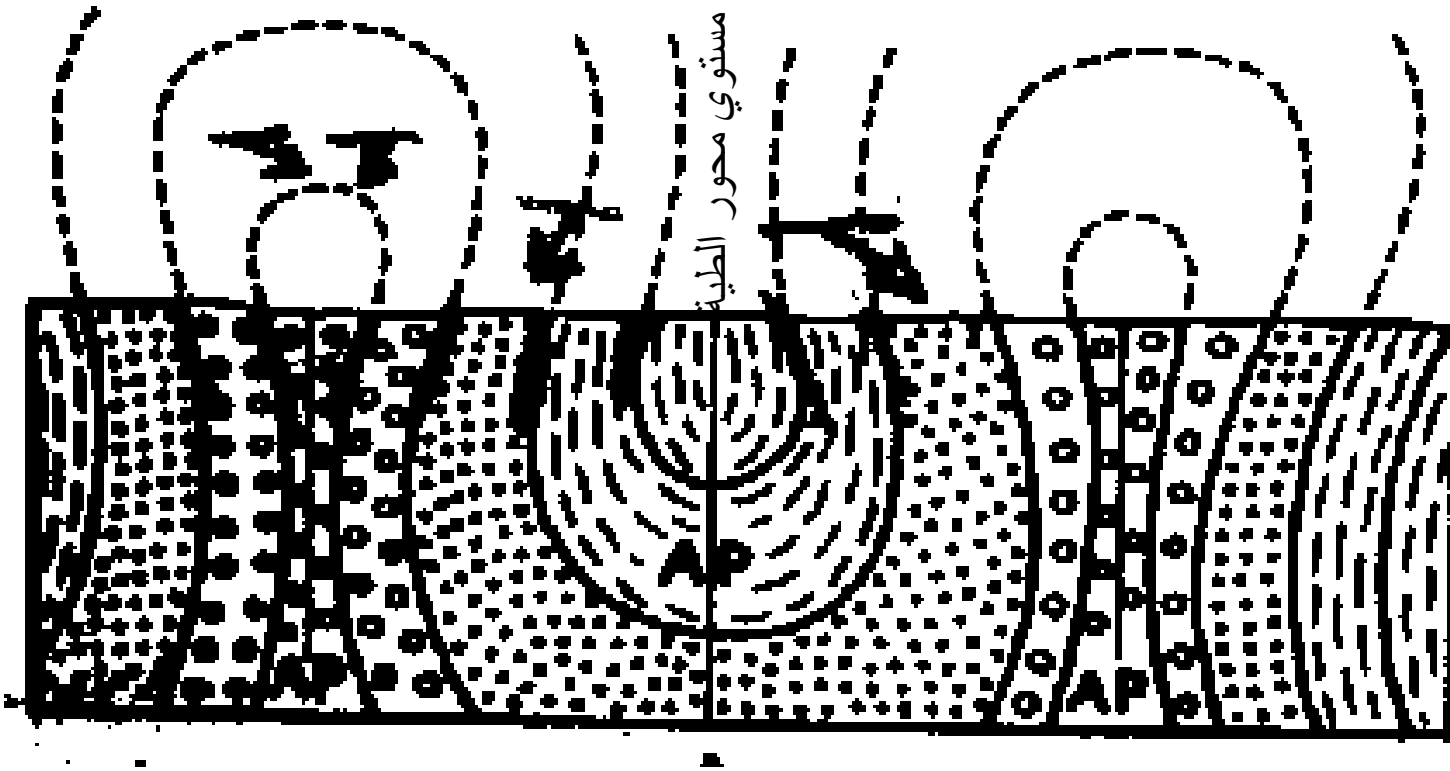
(Almost are found in finely laminated, strongly anisotropic rocks like shale and slate)



## Fan Fold الطية المروحية

A fan fold is both limbs are overturned.

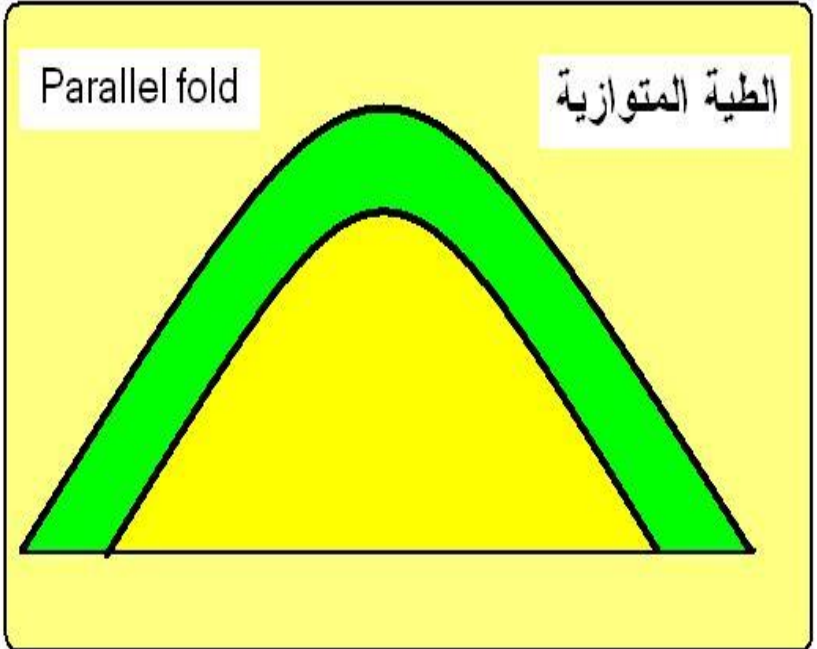
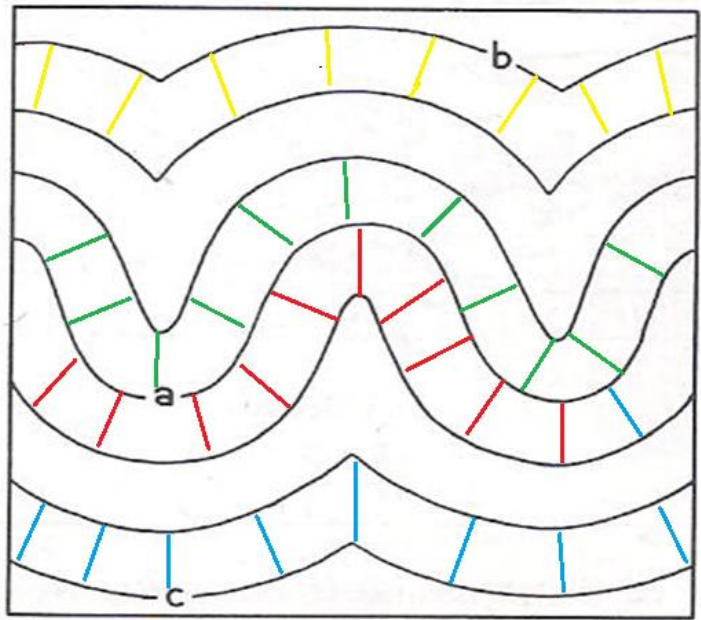
In the *anticlinal fan fold*, the two limbs dip toward each other; in the *synclinal fan fold*, the two limbs dip away from each other.



## Parallel Fold الطية المتوازية

A fold is **parallel** if the thickness of folded layers, measured normal to the bed, is constant all around the fold. In other words, the strata are bent in parallel curves .

It is apparent, under such conditions, the **form** of the fold must change upward and downward. The Anticline become sharper with depth, but broader and more open upward. Conversely, the Syncline become broader with depth, but sharper upward.



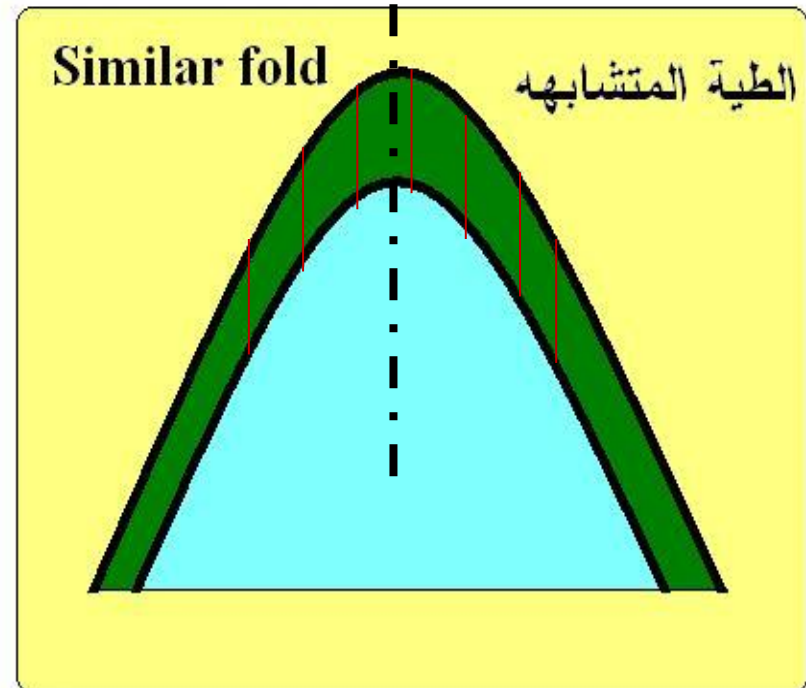
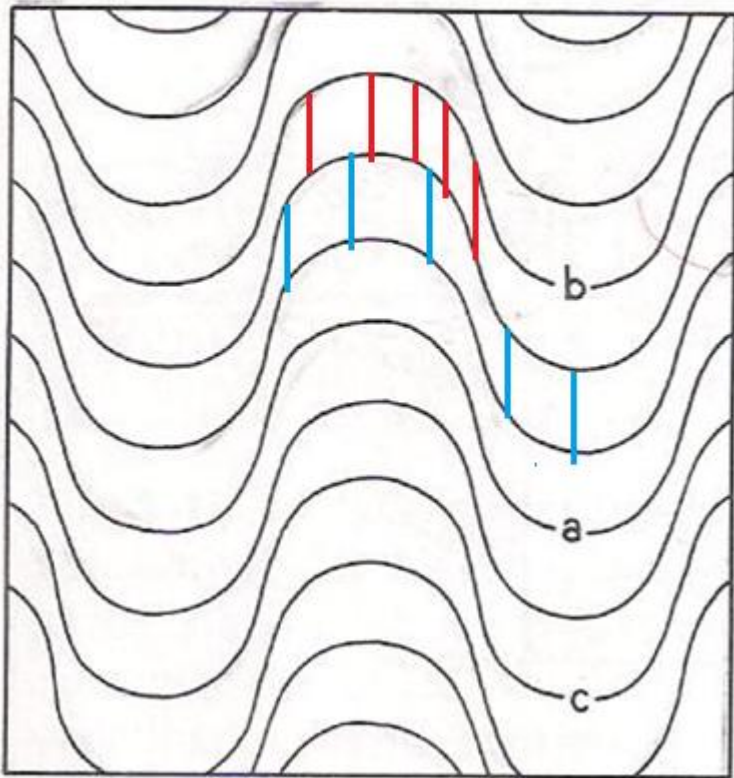
Parallel folds are typical of competent layers

## Similar folds الطيات المتشابهة

Folds of constant bed thickness parallel to axial plane.

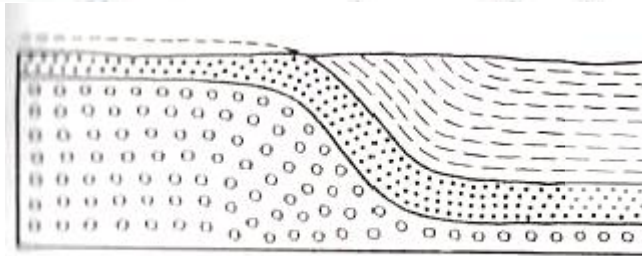
In the case of shape of the folds may vary along the axial plane and right angles to fold axis. Here every bed is thinner in limbs and thicker near the hinges. For this, there must be considerable plastic movement of material away from the limbs and towards the hinges.

### Similar Fold



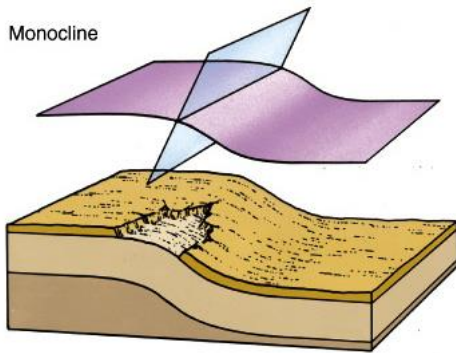
## طية وحيدة الميل *Monoclinal or Homocline Fold*

The term homocline, from the Greek meaning “one inclination,” may be applied to strata that dip in one direction at a relatively uniform angle. Although many homoclines are, if large areas are considered, limbs of folds, the term is useful to refer to the structure within the limits of a small area. But many geologists use the term monocline to refer to rocks that dip uniformly in one direction.



A

Monocline



### Monocline

Folds with only one limb



**Monoclines are often the result of movement along buried faults**



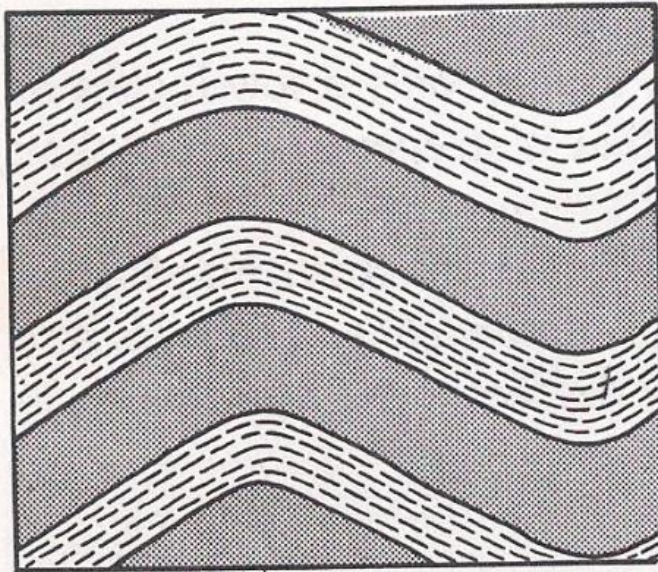
*Close or Tight Fold* الطية المغلقة او المحكمة

A closed or tight fold; is one in which the deformation has been sufficiently intense to cause flowage of the more mobile beds so that these beds thicken and thin.

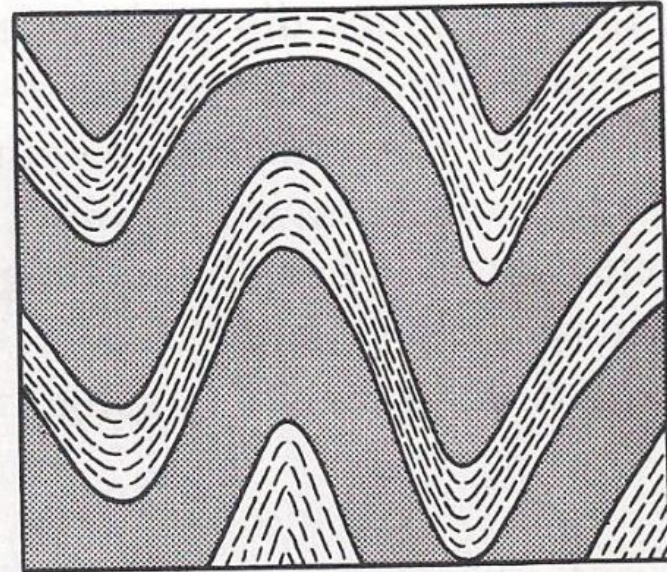
Conversely,

*Open fold* الطية المفتوحة

an open fold is one which this flowage has not taken place.



A



B

. Open and closed folds. (A) Open folds. (B) Closed fold

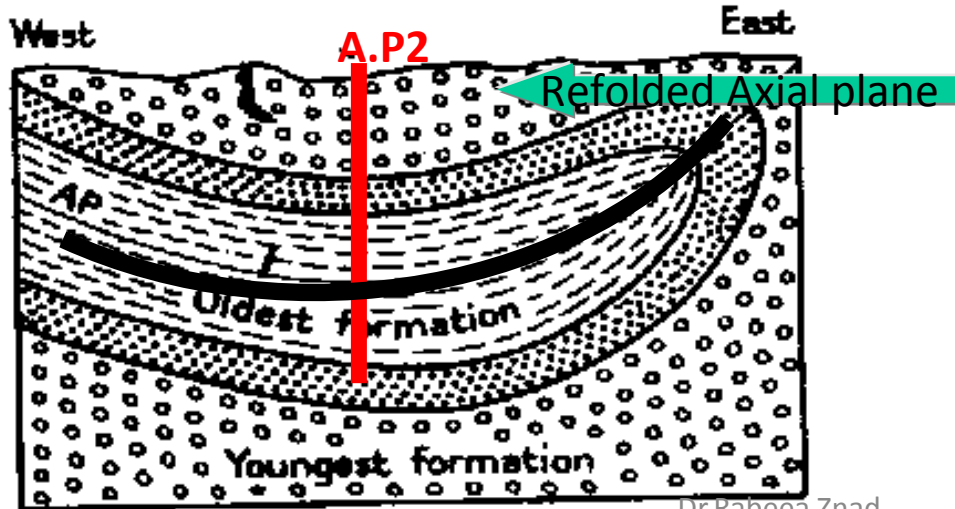
# الطيّات المطوية Refolded Folds

In areas affected by two or more deformation phases, a secondary set of folds may be superimposed on earlier folds.

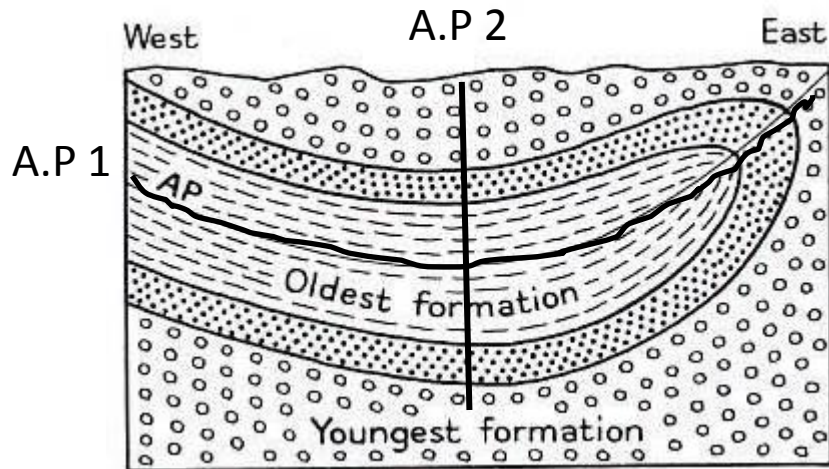
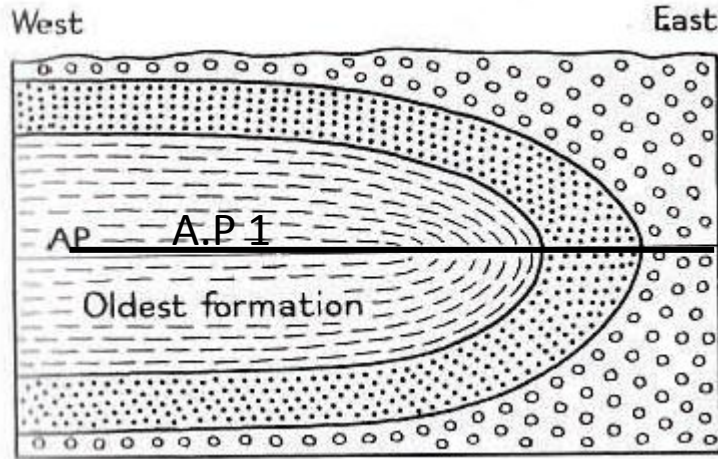
Folds modified by a later fold phase are known as Refolded folds.

Imagine a tight to isoclinal recumbent fold being refolded during a later tectonic phase. We now have a set of secondary synforms and antiforms. The younging direction across their respective axial surfaces will depend on whether we are on the inverted or upright limb of the recumbent fold,

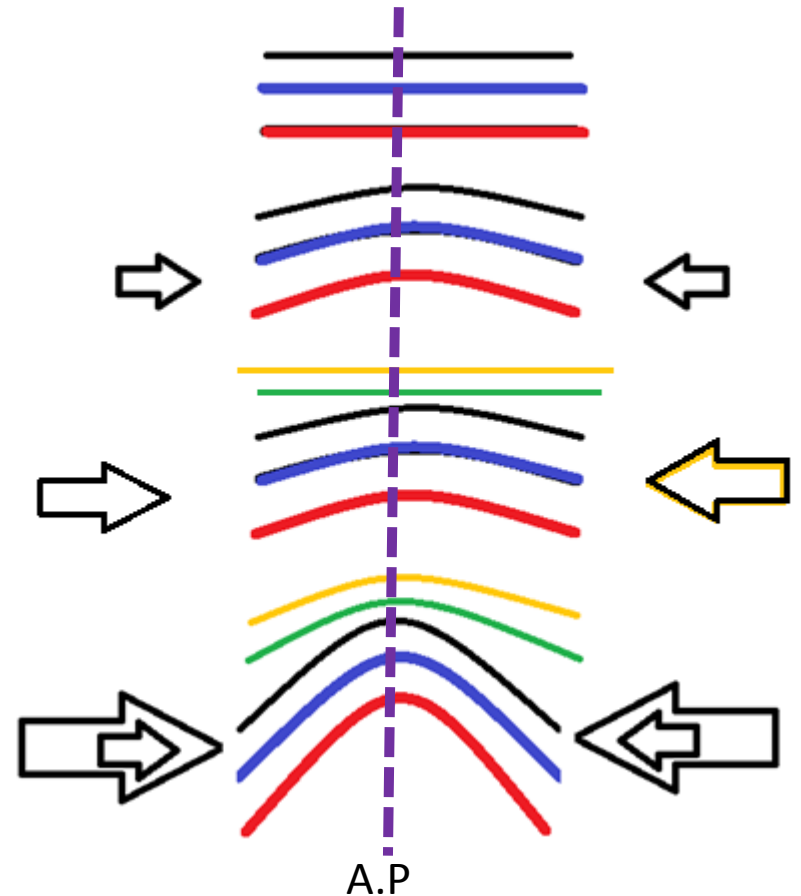
الطيّات في الطبيعة تنشأ بسبب تأثير قوة تكتونية واجهاد على طبقات القشرة الارضية , ولكن قد يتغير اتجاه القوة مما يسبب نشوء او اعادة طي للطبقات المطوية سابقاً , اما على 1 نفس مستوى محورها او يتكون سطح محوري ثاني عمودي او مائلا على مستوى محور الطية الاولى وقد يتولد اكثر طور للطي مما يعقد الصورة النهائية للتركيب الجيولوجي. ونلاحظ هذا التعقيد في مناطق ذات جيولوجية معقدة والتي تأثرت بقوة تكتونية امتدت الى فترات زمنية طويلة او تأثرها بقوى تكتونية في ازمان واتجاهات مختلفة .



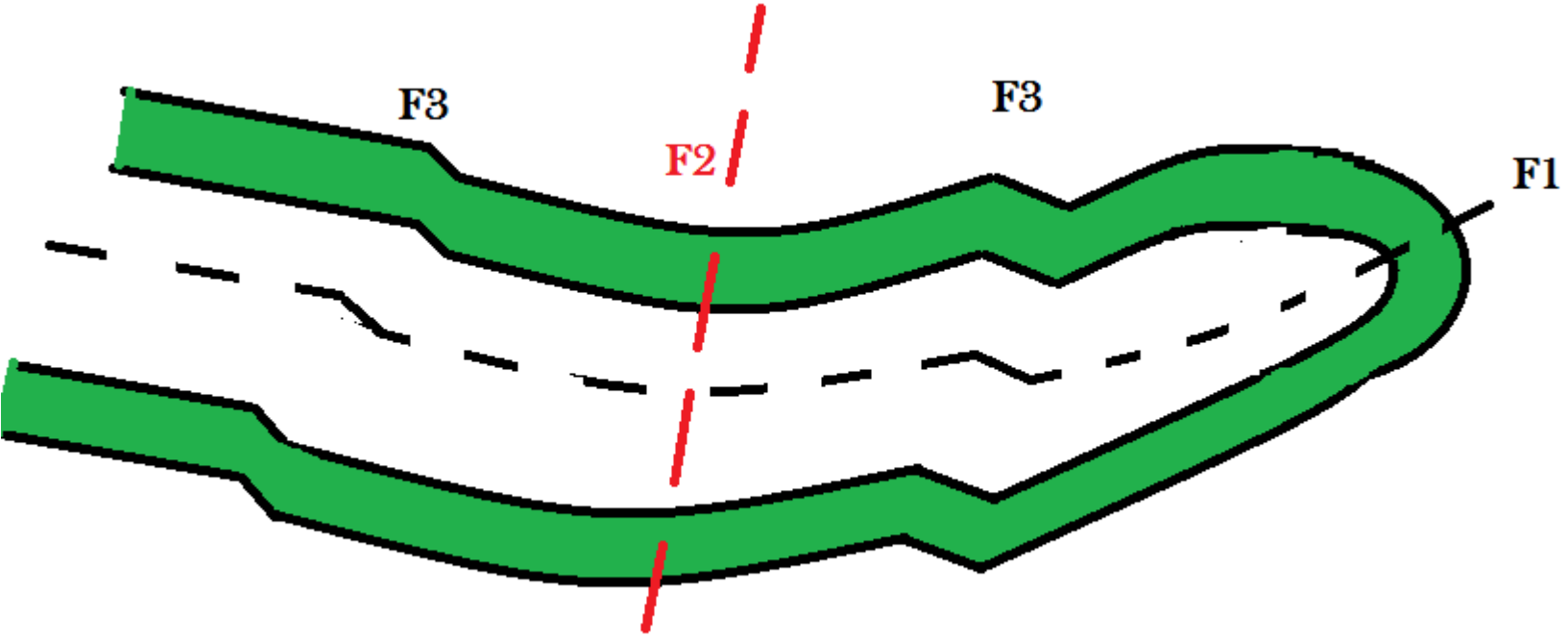
A second axial surface is formed vertically or inclined at the plane of the first fold axis



Re-folding at the same Axial plane .Note that the older layers were exposed to two tectonic phases ,which increased the folding tightness. while the younger layers were exposed to one phase .



In some areas the refolding may be deduced from the map patterns  
 Figure below , shows three stages of folding ,F 1 Is the axial surface of  
 a recumbent fold . this was then refolded into an open synform F2 with gentle limbs  
 Finally, the kink bands F3 developed.



F1 Oldest      F2 Intermediate      F3 Youngest



# Refolded Folds

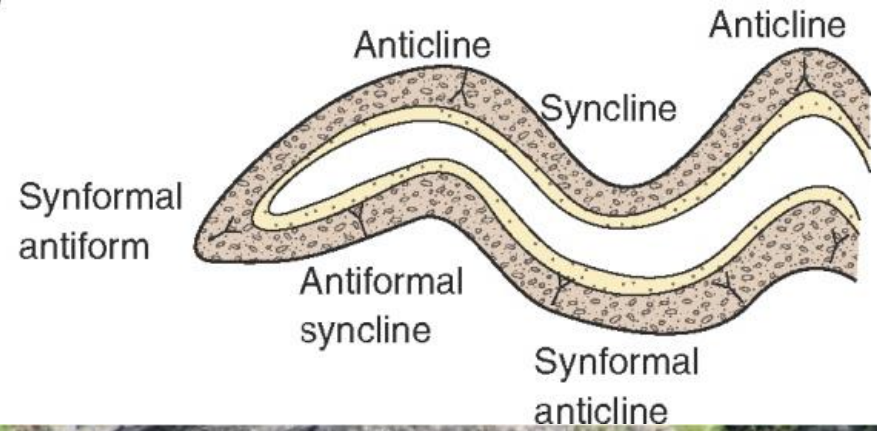


Plate 12. *Refolded fold*. An older fold, the axial surface of which is horizontal on right side of photograph, has been refolded by a fold of which the axial surface dips steeply to the left. Loch Hourn, Scotland. Photo: J. Haller.

الطية المحدبة العملاقة Anticlinoria

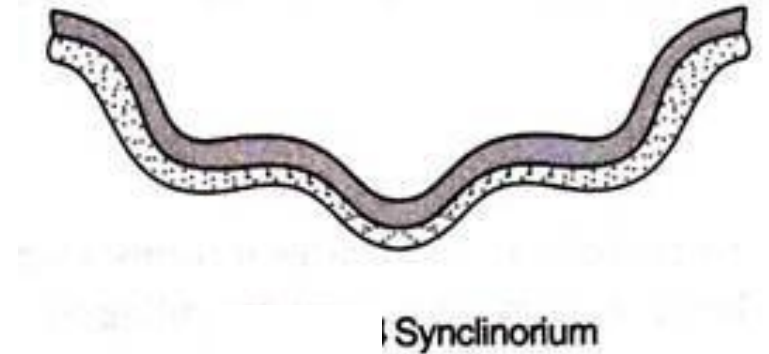
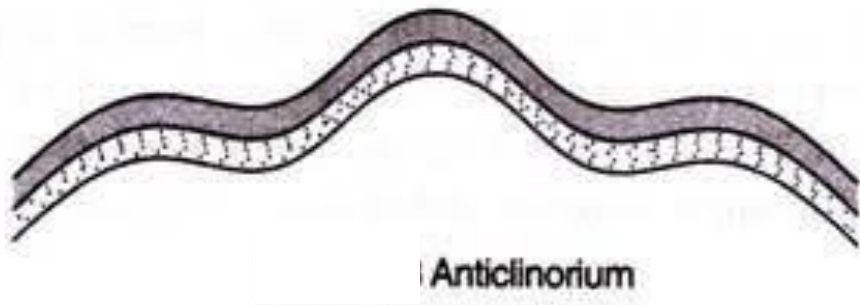
الطية المقعرة العملاقة Synclinoria

وهي الطيات الرئيسية المركبة من عدة طيات اصغر.

- Anticlinoria and Synclinoria (plural), are large-scale (10's of km), first-order anticlines and synclines, respectively, that typically contain second- and third-order fold sets within them.

**Anticlinorium** --- This is a system of anticlines and synclines which are all arched up into a major up fold

**Synclinorium**:---This is a system of anticlines and synclines which are all arched down into a major down fold

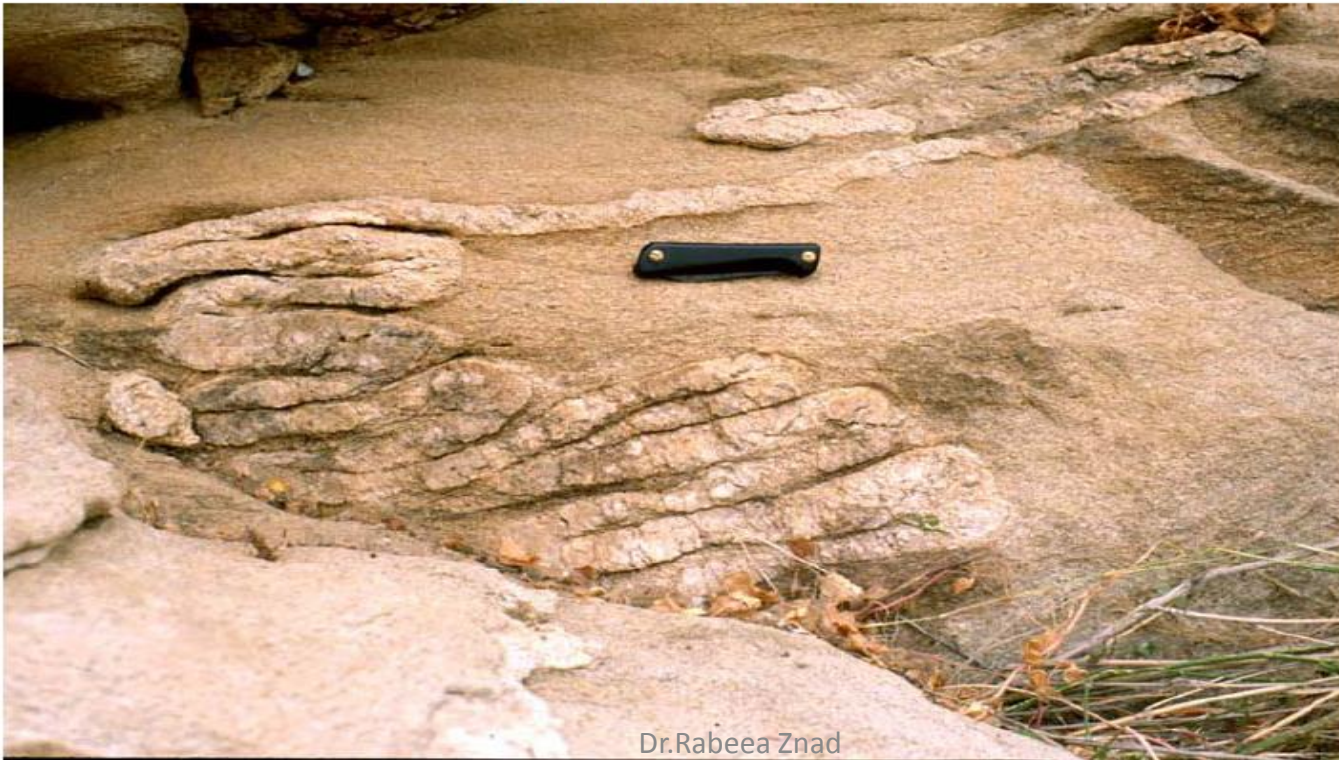


## طيات البيكماتايت Ptygmatic folds

طيات متعاقبة غير منتظمة مؤلفة من طبقة مفردة ذات سمك ثابت تتواجد بشكل مثالي في العروق المطوية بشدة ضمن صخور متحولة.

**Ptygmatic folds:** Irregular and isolated single layer folds that typically occur as tightly folded veins in metamorphic rocks

### Ptygmatic Folds



# Multilayer Folds

# الطي في عدة طبقات

The wide spectra of fold style and size arises because the mechanical instabilities in a multilayered sequence depend upon a great number of factors, and nature brings these factors together in many different folds outline.

The main control factors on fold geometry in multilayered folding are:

- 1-Numbers of a Competent Beds.
- 2-Thickness of a Competent Beds.
- 3-Competency Contrast Between Competent and Incompetent Beds.
- 4-Distance Between Competent Beds.

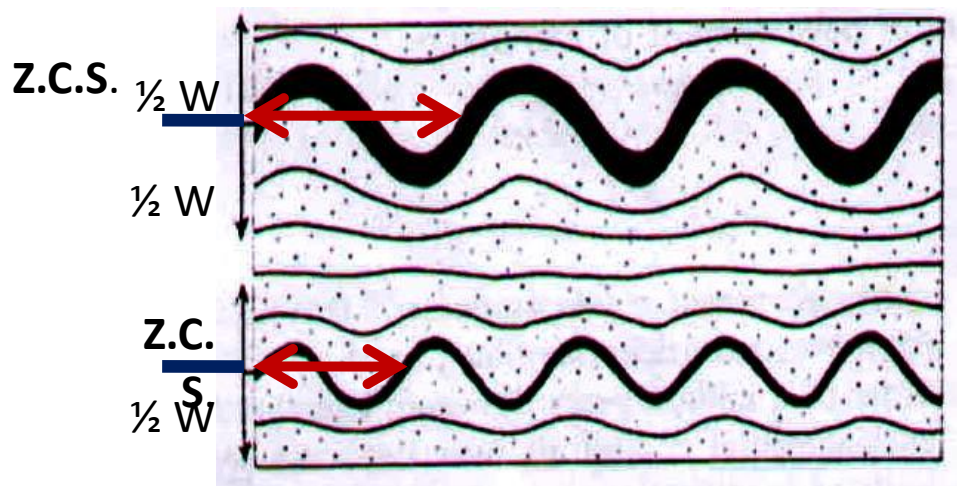
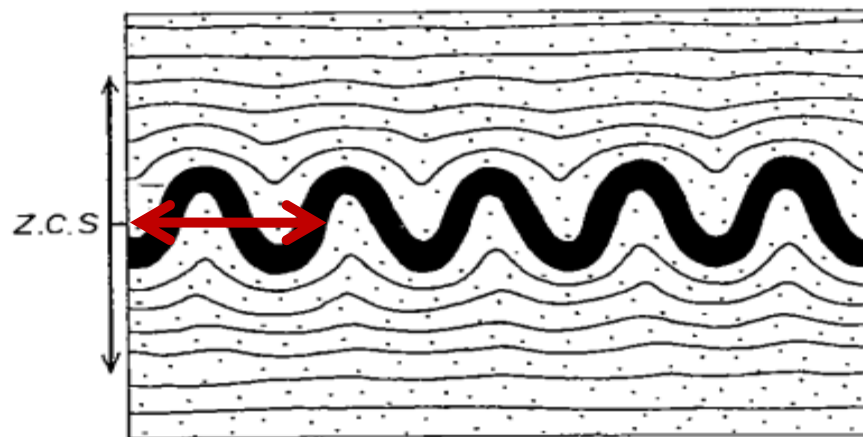
the complex interaction of these factors may leads to overlapping zones of contact strain Z.C.S around each competent layer, consequently, different styles of geometrical harmony would exist.

Zone of Contact Strain (Z.C.S): Is the field in which sideways buckling of thick competent layer displaced the surrounding less competent layers in the field zone of contact strain of width from the median surface of the folded competent layer to (half wave length  $W/2$ ) the top and bottom.as shown in the figure.

حقل الانفعال المؤثر Zone of Contact Strain هو الحقل الذي يؤثر فيه طي طبقة صلدة سميكة على طبقات اقل سمكا حولها وهذا الحقل يمتد بمقدار نصف الطول الموجي (للطبقة الصلدة) الى الاعلى ونصف الى الاسفل كما موضح بالشكل.

# Zone of Contact Strain

A. Single competent layer



**Black** is competent layers. **Stippled** is incompetent layers.

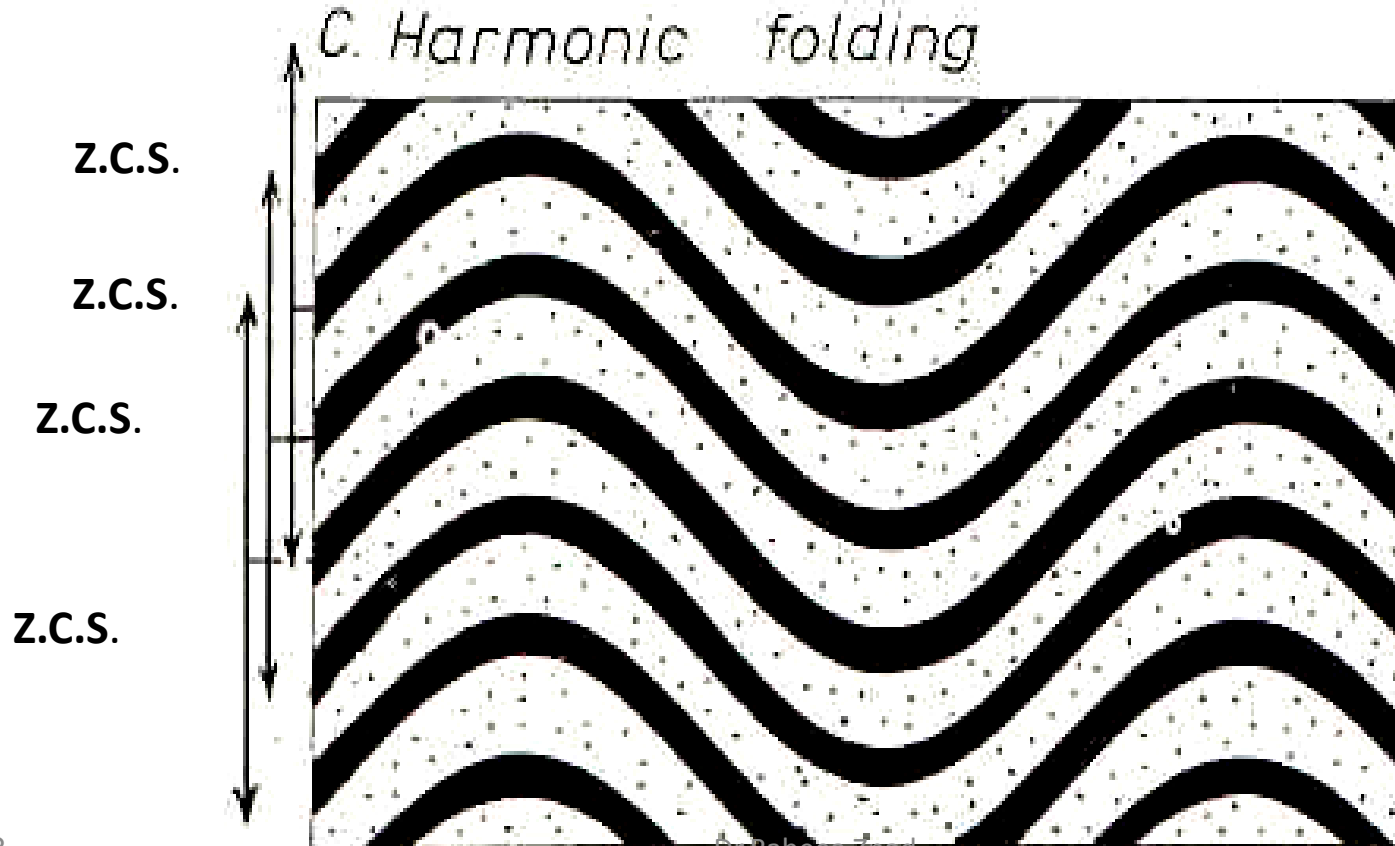
Note : The growth of a fold in competent layers, *displaces* the adjacent material , an effect termed contact strain

# الطيّات المتناغمة Harmonic Folds

Harmonic folds form When successive layers in a folded stack have:-

- 1- approximately the same wavelength and amplitudes ,
- 2-the same thickness of competent layers.
- 3-if the competent-incompetent ductility contrast are similar.
- 4-if the spacing between the layers is not too variable so that the Z.C.S. overlaps.

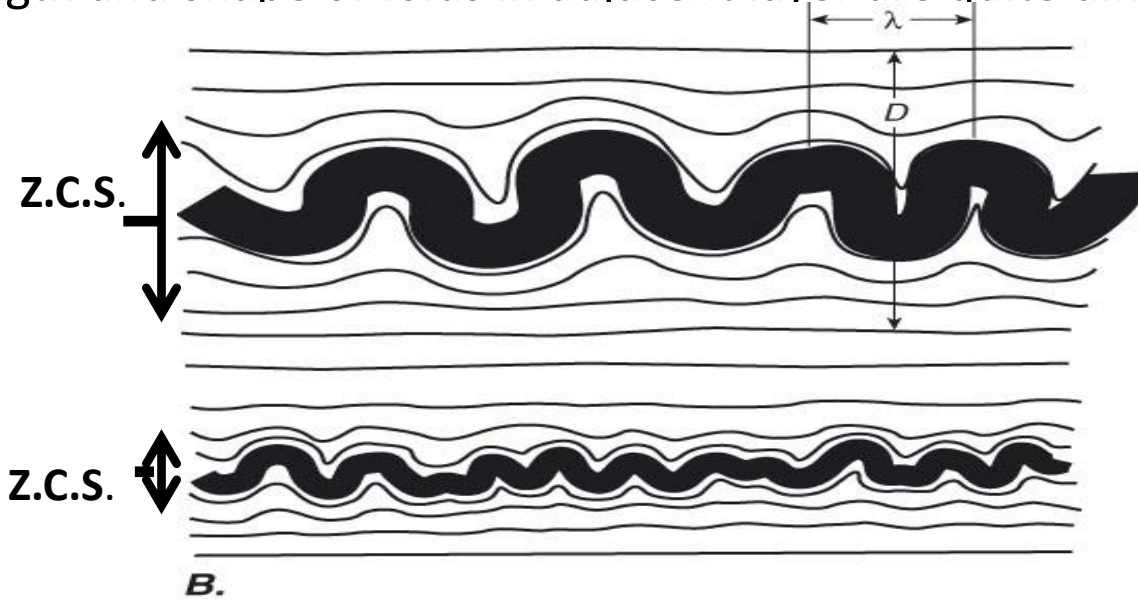
إذا كانت الطبقات الصلدة وغير الصلدة متساوية السمك والمسافة الفاصلة صغيرة ومتساوية تقريبا و فرق الصلادة بينهما متشابه , لذلك سوف تتساوى وتتداخل (من حيث التأثير) حقول الانفعال للطبقات الصلدة , وعندها يطلق على الطيات الناشئة (بالطيّات المتناغمة)



## الطيات الغير متناغمة Disharmonic Folds

Disharmonic folds form when successive layers in fold stack have :

- 1- two or more competent layers are present.
- 2- Different in thickness and widely separated.
- 3- Spacing between them is greater than this zone of contact strain , then the geometry of the folds in each will develop independently of each other.
- 4- Wavelength and shape of folds in adjacent layer are quite different.

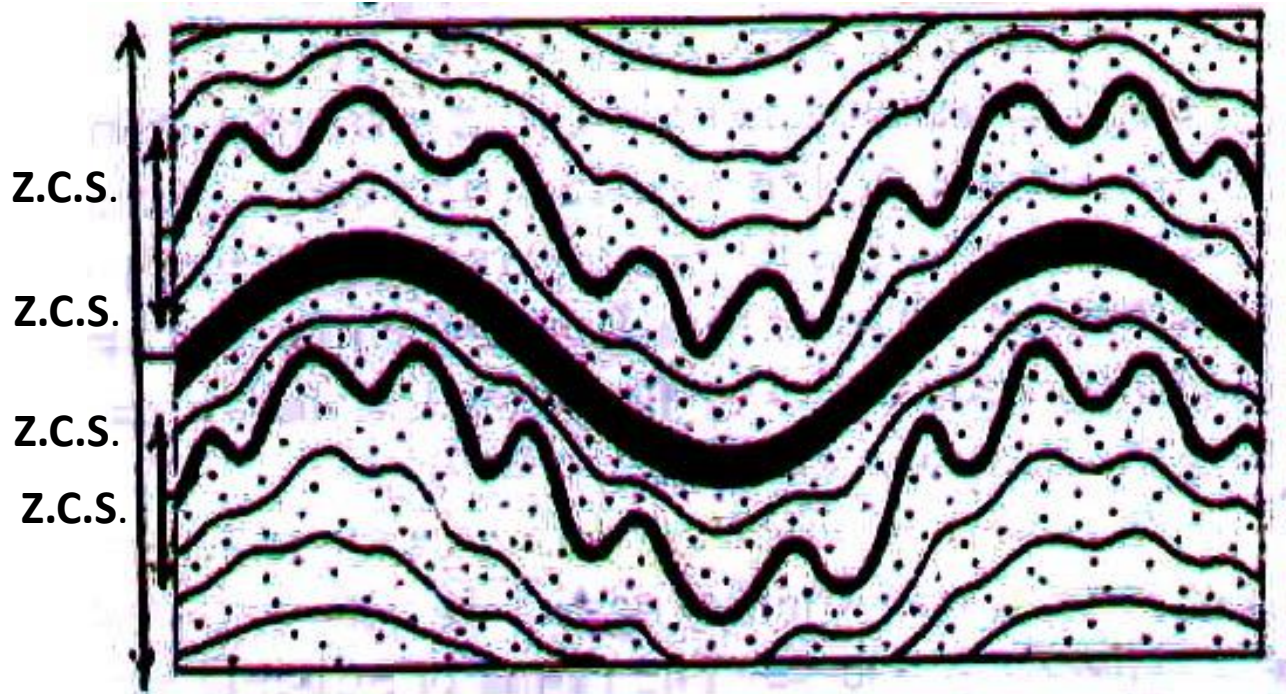


هي نمط الطيات التي تكون فيها طبقاتها الصلدة وغير الصلدة غير متساوية السمك والمسافة الفاصلة بينها كبيرة، لذلك سوف ينشأ لها حقلين غير متماثلين من الانفعال المؤثر Zones of contact strain وليس هناك تفاعل بينهما بسبب كبر المسافة. لذلك سوف تحتفظ طبقة بخواصها من حيث السعة والطول الموجي وتأثيرها على الطبقات الغير صلدة.

## الطية متعددة التناغم polyharmonic fold

polyharmonic folds form when successive layers in fold stack have :-

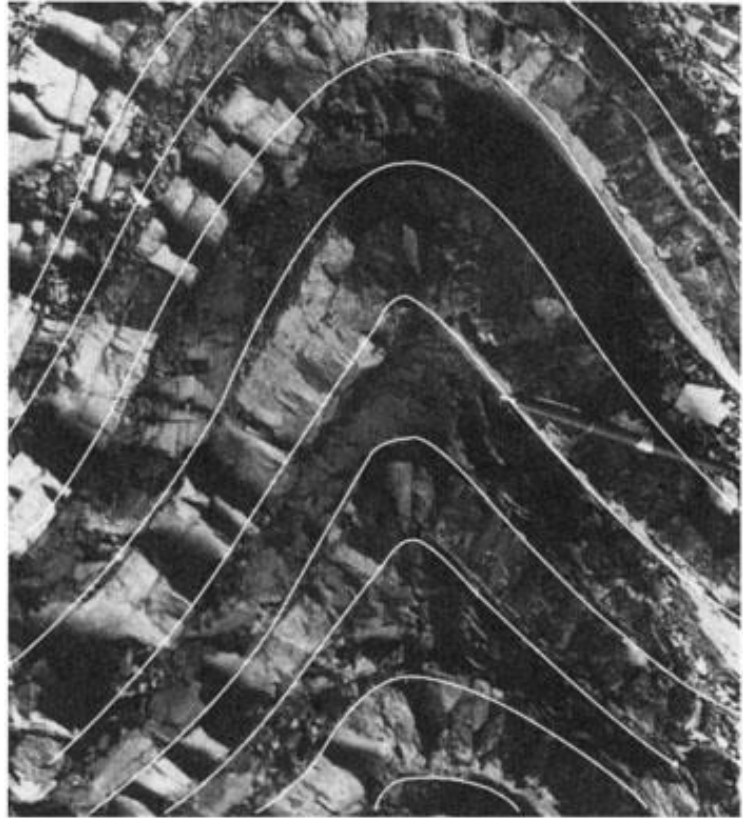
- 1- two or more competent layers are markedly differing thickness.
- 2- or markedly different competent –incompetent layers contrast.
- 3-the spacing between competent layers are too variable, so more than one wave length will be partial connected and overlapped with other.



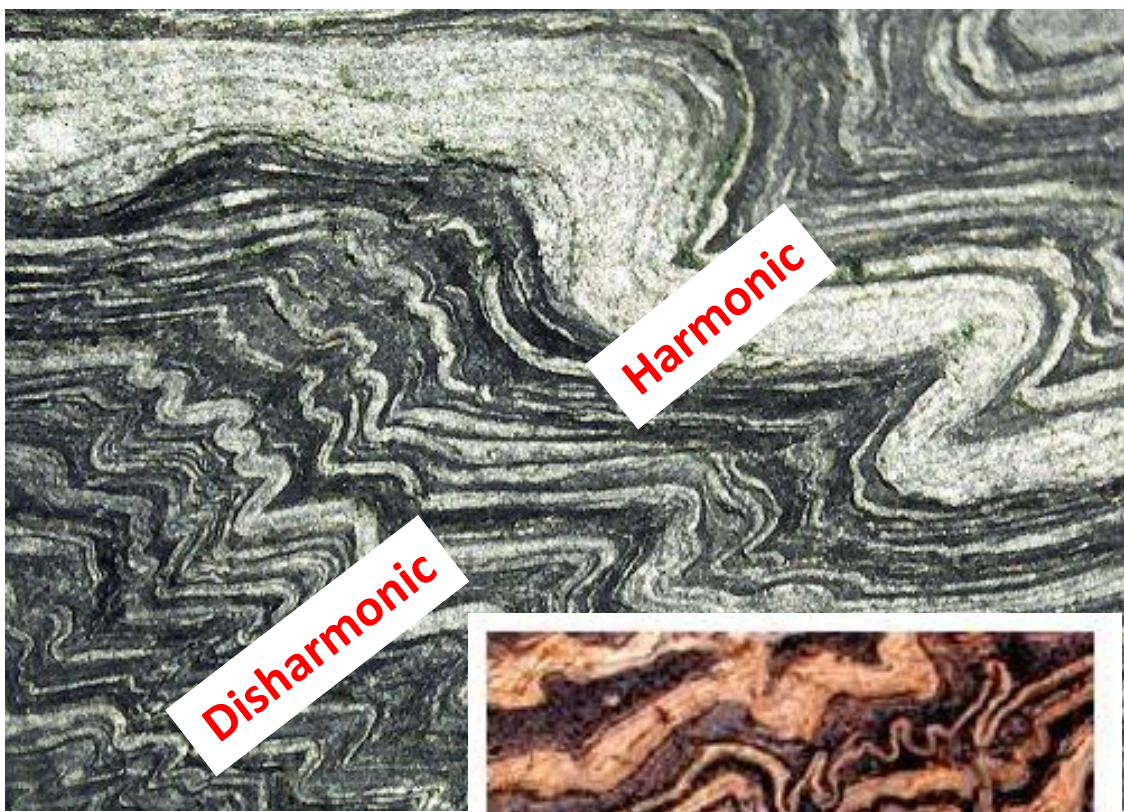
**Polyharmonic folding**

وهو نمط الطية التي طبقاتها الصلدة غير متساوية السمك والمسافة بينهما متغيرة فضلا عن تغير فرق الصلادة مع الطبقات الغير صلدة , عليه سوف ينشأ اكثر من حقل انفعال مؤثر Zones of contact strain (غير متمائل) مما يعطي نمط طي غير متناغم

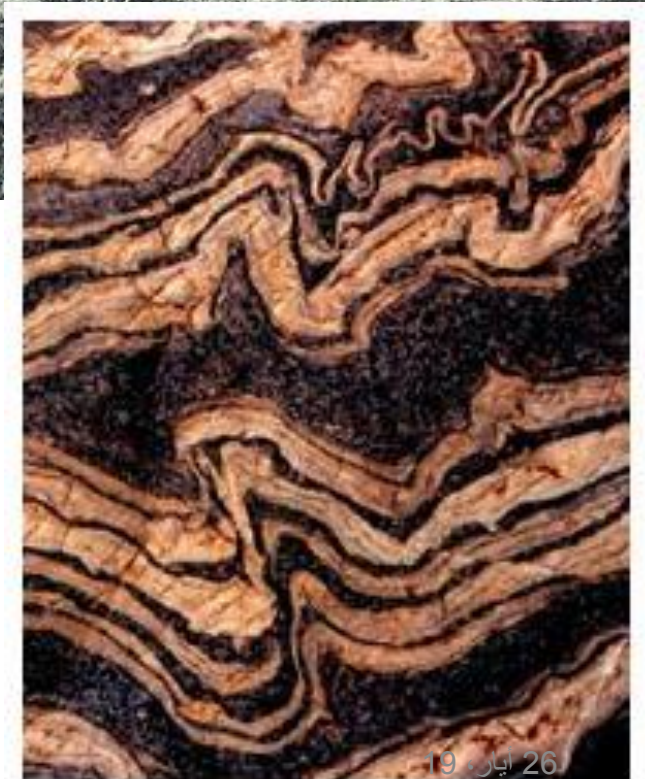




C. Harmonic

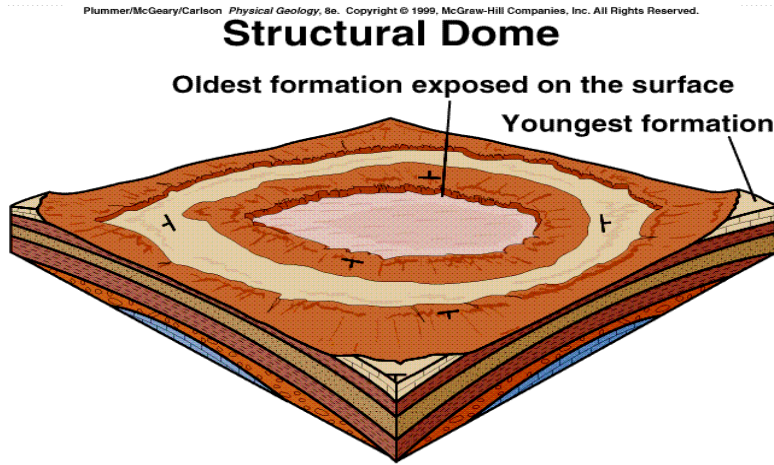


Polyharmonic

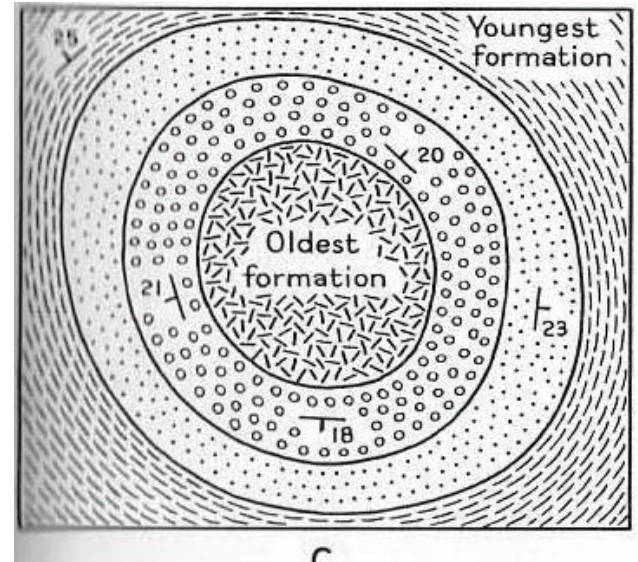


# Dome

A dome is an anticlinal uplift that has no distinct trend

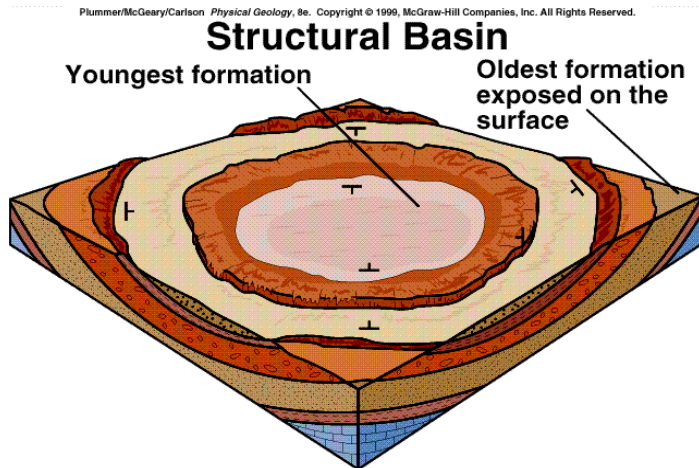


# القبة Dome

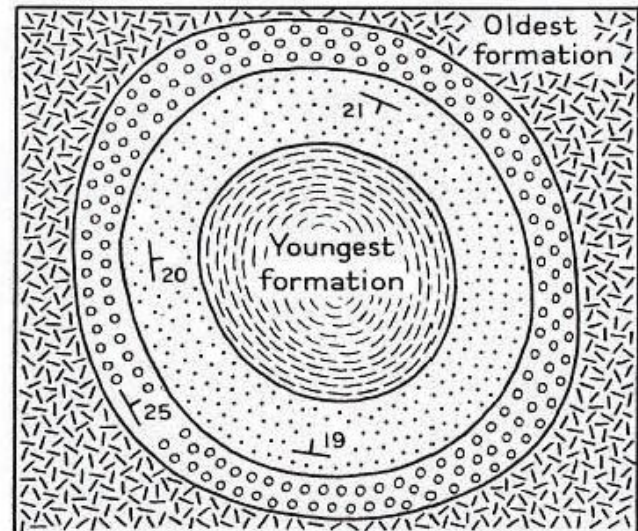


# Basin

A basin is a synclinal depression that has no distinct trend.



# الحوض Basin



# Aerial photo of a structural dome. Rocks dip away from the center



