

# Fold (geology)

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For other uses, see [Fold \(disambiguation\)](#).



Very tight folds. Formation near [Moruya](#), [New South Wales](#), [Australia](#)



A fold in Slichowice nature reserve in [Kielce](#) (Variscan [orogeny](#))



Rainbow Basin [Syncline](#) in the [Barstow Formation](#) near [Barstow, California](#)

The term **fold** is used in [geology](#) when one or a stack of originally flat and planar surfaces, such as [sedimentary strata](#), are bent or curved as a result of permanent [deformation](#). Synsedimentary folds are those due to slumping of sedimentary material before it is [lithified](#). Folds in rocks vary in size from microscopic crinkles to mountain-sized folds. They occur singly as isolated folds and in extensive fold trains of different sizes, on a variety of scales. Folds form under varied conditions of [stress](#), [hydrostatic pressure](#), [pore pressure](#), and [temperature](#) - hydrothermal gradient, as evidenced by their presence in soft [sediments](#), the full spectrum of [metamorphic rocks](#), and even as primary flow structures in some [igneous rocks](#). A set of folds distributed on a regional scale constitutes a [fold belt](#), a common feature of [orogenic zones](#). Folds are commonly formed by shortening of existing layers, but may also be formed as a result of displacement on a non-planar [fault](#) (*fault bend fold*), at the tip of a propagating fault (*fault propagation fold*), by differential [compaction](#) or due to the effects of a high-level [igneous intrusion](#) e.g. above a [laccolith](#).

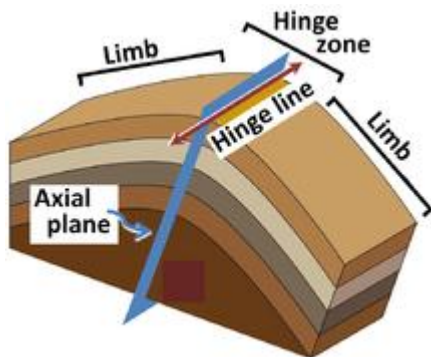
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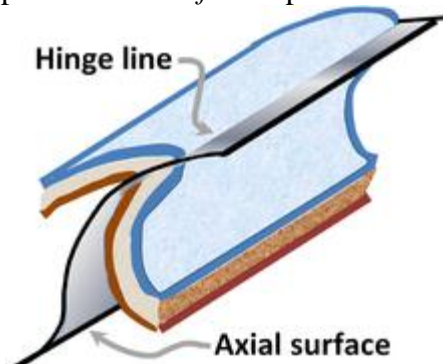
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## [\[edit\]](#) Describing folds



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



 Cylindrical fold with axial surface not a plane. <sup>[1]</sup>

Folds are classified by their size, fold shape, tightness, dip of the axial plane.<sup>[2]</sup>

### [\[edit\]](#) **Fold terminology in two dimensions**

Looking at a fold surface in profile the fold can be divided into *hinge* and *limb* portions. The limbs are the flanks of the fold and the hinge is where the flanks join together. The hinge point is the point of maximum radius of [curvature](#) for a fold. The [crest](#) of the fold is the highest point of the fold surface, and the [trough](#) is the lowest point. The [inflection point](#) of a fold is the point on a limb at which the [concavity](#) reverses; on regular folds, this is the midpoint of the limb.

### [\[edit\]](#) **Fold terminology in three dimensions**

The hinge points along an entire folded surface form a hinge line, which can be either a *crest line* or a *trough line*. The [trend and plunge](#) of a linear hinge line gives you information about the orientation of the fold. To more completely describe the orientation of a fold, one must describe the *axial surface*. The axial surface is the surface defined by connecting all the hinge lines of stacked folding surfaces. If the axial surface is a planar surface then it is called the [axial plane](#) and can be described by the [strike and dip](#) of the plane. An *axial trace* is the line of intersection of the axial surface with any other surface (ground, side of mountain, geological cross-section).

Finally, folds can have, but don't necessarily have a *fold axis*. A fold axis, "is the closest approximation to a straight line that when moved parallel to itself, generates the form of the fold." (Davis and Reynolds, 1996 after Donath and Parker, 1964; Ramsay 1967). A fold that can be generated by a fold axis is called a *cylindrical fold*. This term has been broadened to include near-cylindrical folds. Often, the fold axis is the same as the hinge line.<sup>[3][4]</sup>

### [\[edit\]](#) **Fold shape**

It is necessary to convey a sense of the shape of the fold. A fold can be shaped as a [chevron](#), with planar limbs meeting at an angular axis, as **cusped** with curved limbs, as [circular](#) with a curved axis, or as elliptical with unequal [wavelength](#).

### [\[edit\]](#) **Fold tightness**

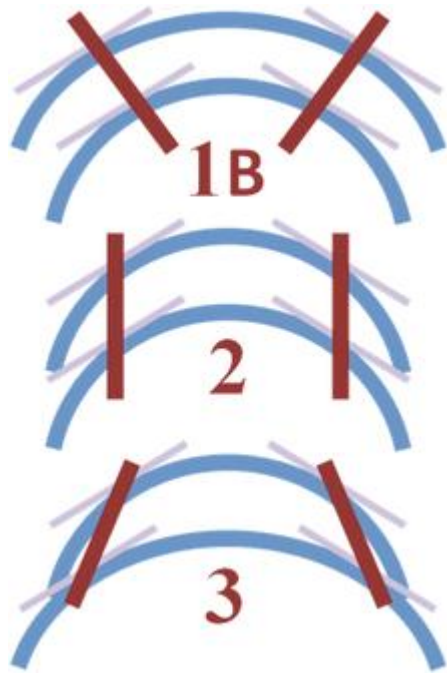
Fold tightness is defined by the angle between the fold's limbs, called the [interlimb angle](#). Gentle folds have an interlimb angle of between 180° and 120°, open folds range from 120° to 70°, close folds from 70° to 30°, and tight folds from 30° to 0°. <sup>[5]</sup> *Isoclines*, or *isoclinal folds*, have an interlimb angle of between 10° and zero, with essentially parallel limbs.


### [\[edit\]](#) **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.

[\[edit\]](#) 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:<sup>[6]</sup>



 Ramsay classification of folds by convergence of dip isogons (red lines).<sup>[7]</sup>  
 Ramsay classification scheme for folds

Class	Curvature $C$	Comment
1	$C_{inner} > C_{outer}$	Dip isogons converge
1A		Orthogonal thickness at hinge narrower than at limbs
1B		Parallel folds
1C		Orthogonal thickness at limbs narrower than at hinge
2	$C_{inner} = C_{outer}$	Dip isogons are parallel: <b>similar</b> folds
3	$C_{inner} < C_{outer}$	Dip isogons diverge

[\[edit\]](#) Fold types



Anticline



Monocline at Colorado National Monument



Recumbent fold, [King Oscar Fjord](#)

- [Anticline](#): linear, strata normally dip away from axial center, *oldest* strata in center.
- [Syncline](#): linear, strata normally dip toward axial center, *youngest* strata in center.
- [Antiform](#): linear, strata dip away from axial center, age unknown, or inverted.
- [Synform](#): linear, strata dip toward axial centre, age unknown, or inverted.
- [Dome](#): nonlinear, strata dip away from center in all directions, *oldest* strata in center.
- [Basin](#): nonlinear, strata dip toward center in all directions, *youngest* strata in center.
- [Monocline](#): linear, strata dip in one direction between horizontal layers on each side.
- [Chevron](#): angular fold with straight limbs and small hinges
- Recumbent: linear, fold axial plane oriented at low angle resulting in overturned strata in one limb of the fold.
- Slump: typically monoclinial, result of differential compaction or dissolution during sedimentation and lithification.
- Ptygmatic: Folds are chaotic, random and disconnected. Typical of sedimentary slump folding, [migmatites](#) and decollement detachment zones.
- Parasitic: short wavelength folds formed within a larger wavelength fold structure - normally associated with differences in bed thickness<sup>[8]</sup>
- Disharmonic: Folds in adjacent layers with different wavelengths and shapes<sup>[8]</sup>

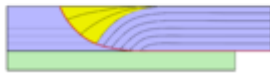
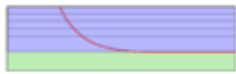
(A [homocline](#) involves strata dipping in the same direction, though not necessarily any folding.)

## [\[edit\]](#) Causes of folding

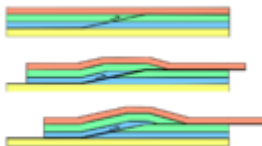
Folds appear on all scales, in all rock types, at all levels in the crust and arise from a variety of causes.

### [\[edit\]](#) Layer-parallel shortening

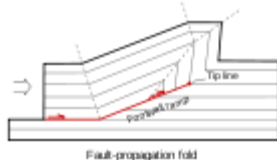
When a sequence of layered rocks is shortened parallel to its layering, this deformation may be accommodated in a number of ways, homogeneous shortening, reverse faulting or folding. The response depends on the thickness of the mechanical layering and the contrast in properties between the layers. If the layering does begin to fold, the fold style is also dependent on these properties. Isolated thick [competent](#) layers in a less competent matrix control the folding and typically generate classic rounded buckle folds accommodated by deformation in the matrix. In the case of regular alternations of layers of contrasting properties, such as sandstone-shale sequences, kink-bands, box-folds and chevron folds are normally produced.<sup>[9]</sup>



Rollover anticline



Ramp anticline



Fault-propagation fold

### [\[edit\]](#) Fault-related folding

Many folds are directly related to faults, associate with their propagation, displacement and the accommodation of strains between neighbouring faults.

#### [\[edit\]](#) Fault bend folding

Fault bend folds are caused by displacement along a non-planar fault. In non-vertical faults, the hanging-wall deforms to accommodate the mismatch across the fault as displacement progresses. Fault bend folds occur in both extensional and thrust faulting. In extension, listric faults form rollover anticlines in their hanging walls.<sup>[10]</sup> In thrusting, *ramp anticlines* are formed whenever a thrust fault cuts up section from one detachment level to another. Displacement over this higher-angle ramp generates the folding.<sup>[11]</sup>

### [\[edit\]](#) **Fault propagation folding**

Fault propagation folds or *tip-line folds* are caused when displacement occurs on an existing fault without further propagation. In both reverse and normal faults this leads to folding of the overlying sequence, often in the form of a [monocline](#).<sup>[12]</sup>

### [\[edit\]](#) **Detachment folding**

When a thrust fault continues to displace above a planar detachment without further fault propagation, [detachment folds](#) may form, typically of box-fold style. These generally occur above a good detachment such as in the [Jura Mountains](#), where the detachment occurs on middle [Triassic evaporites](#).<sup>[13]</sup>

### [\[edit\]](#) **Compaction**

Folds can be generated in a younger sequence by differential compaction over older structures such as fault blocks and [reefs](#).<sup>[14]</sup>

### [\[edit\]](#) **Folding in shear zones**

Shear zones that approximate to [simple shear](#) typically contain minor asymmetric folds, with the direction of overturning consistent with the overall shear sense. Some of these folds have highly curved hinge lines and are referred to as *sheath folds*. Folds in shear zones can be inherited, formed due to the orientation of pre-shearing layering or formed due to instability within the shear flow.<sup>[15]</sup>

### [\[edit\]](#) **Sedimentary folding**

Recently deposited sediments are normally mechanically weak and prone to remobilisation.

### [\[edit\]](#) **Slump folding**

When slumps form in poorly consolidated sediments they commonly undergo folding, particularly at their leading edges, during their emplacement. The asymmetry of the slump folds can be used to determine paleoslope directions in sequences of sedimentary rocks.<sup>[16]</sup>

### [\[edit\]](#) **Dewatering**

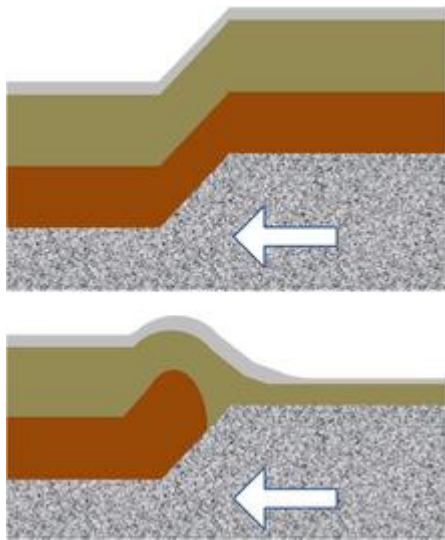



Rapid dewatering of sandy sediments, possibly triggered by seismic activity can cause convolute bedding.<sup>[17]</sup>

## [\[edit\]](#) Igneous intrusion

The emplacement of igneous intrusions tends to deform the surrounding [country rock](#). In the case of high-level intrusions, near the Earth's surface, this deformation is concentrated above the intrusion and often takes the form of folding, as with the upper surface of a [laccolith](#).<sup>[18]</sup>

## [\[edit\]](#) Flow folding



 Flow folding: this picture uses [artistic license](#) to show the effect of an advancing ramp of rigid rock into compliant layers. Top: low drag by ramp: layers are not altered in thickness; Bottom: high drag: lowest layers tend to crumple.<sup>[19]</sup>

The compliance of rock layers is referred to as *competence*: a competent layer or bed of rock can withstand an applied load without collapsing and is relatively strong, while an incompetent layer is relatively weak. When rock behaves as a fluid, as in the case of very weak rock such as rock salt, or any rock that is buried deeply enough, they typically show *flow folding* (also called *passive folding*, because little resistance is offered): the strata appear shifted undistorted, assuming any shape impressed upon them by surrounding more rigid rocks. The strata simply serve as markers of the folding.<sup>[20]</sup> Such folding is also a feature of many igneous intrusions and [glacier](#) ice.<sup>[21]</sup>

## [\[edit\]](#) Folding mechanisms

Folding of rocks must balance the deformation of layers with the conservation of volume in a rock mass. This occurs by several mechanisms.



Example of a large-scale crenulation, Glengarry Basin, W.A., an example of chevron-type flexural-slip folds.

### [\[edit\]](#) **Flexural slip**

Flexural slip allows folding by creating layer-parallel slip between the layers of the folded strata, which, altogether, result in deformation. The best analogy is bending a phone book, where volume preservation is accommodated by slip between the pages of the book.

### [\[edit\]](#) **Buckling**


Typically, folding is thought to occur by simple buckling of a planar surface and its confining volume. The volume change is accommodated by *layer parallel shortening* the volume, which grows in *thickness*. Folding under this mechanism is typically of the similar fold style, as thinned limbs are shortened horizontally and thickened hinges do so vertically.

### [\[edit\]](#) **Mass displacement**

If the folding deformation cannot be accommodated by flexural slip or volume-change shortening (buckling), the rocks are generally removed from the path of the stress. This is achieved by [pressure dissolution](#), a form of metamorphic process, in which rocks shorten by dissolving constituents in areas of high strain and redepositing them in areas of lower strain. Folds created in this way include examples in [migmatites](#), and areas with a strong axial planar [cleavage](#).

## [\[edit\]](#) **Mechanics of folding**



 Weathered marble anticline at [General Carrera Lake, Chile](#)

Folds in rock are formed in relation to the [stress field](#) in which the rocks are located and the [rheology](#), or method of response to stress, of the rock at the time at which the stress is applied.

The rheology of the layers being folded determines characteristic features of the folds that are measured in the field. Rocks that deform more easily form many short-wavelength, high-amplitude folds. Rocks that do not deform as easily form long-wavelength, low-amplitude folds.