Indian Institute of Technology, Kanpur
Department of Earth Sciences

ESO213A: Fundamentals of Earth Sciences

Lecture 22. Folds-and-Foldings

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Aims of this lecture

- Definition of a fold in single and multilayer system
- Basic terminologies associated with folds' description

The Concept and Definition

- A fold is represented by a curved surface or a stack of curved surfaces whose initial curvature has increased by deformation.
  - Since stratification in undeformed sedimentary beds is planar within a short distance, a distinctly curved or wavy stratification surface is commonly described as a fold.
  - Folds occur in all scales; from mountain or orogenic belts to sub-microscopic features.

The Concept and Definition

- We mostly observe folds defined by the deformation induced curvatures of sedimentary bedding planes, however, folding is possible and also commonly observed in any layer having competence contrast with associated layers. These include dikes, veins, metamorphic/igneous compositional layers, foliations etc. In general, fold generating layers are commonly termed as "***form surfaces***"


http://maps.unomaha.edu


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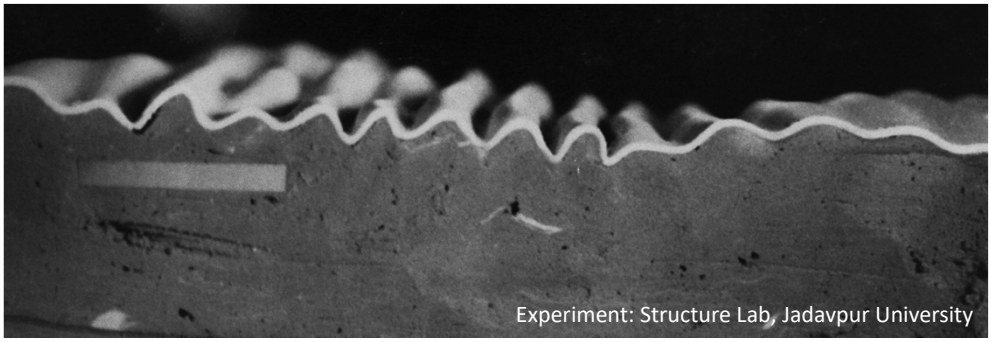
monash.edu.au

Why studding fold in important?

- Fold are one of the most spectacular natural structures.. they are beautiful.
- Fold are studied to reveal their 2D and 3D geometries.
- The shape, orientation and extent of folds are of critical importance in finding economically valuable deposits and predicting their continuity.
- Studying folds and associated structures (foliations, in particular) are also important in revealing the tectonic processes in Earth. The variety of folded structures and shapes record significant information of the many physical, chemical and mechanical aspects of the deformation.

Buckling

- Active folding or buckling is a fold process that can initiate when a layer is shortened parallel to the layering
- A contrast in viscosity is required for buckling to occur, with the folding layer being more competent than the host rock (matrix). The result of buckling is rounded folds, typically parallel and with more or less sinusoidal shape.



Experiment: Structure Lab, Jadavpur University

Buckling: Characteristics

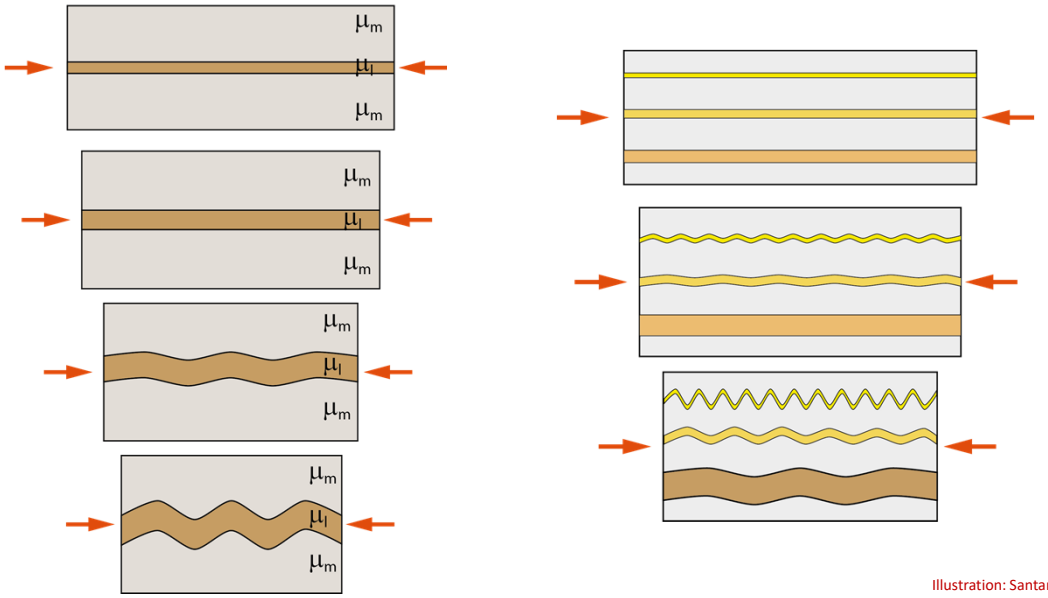


Illustration: Santanu Misra

Bending

Bending occurs when forces act across layers at a high angle, unlike buckle folds where the main force acts parallel to a layer.

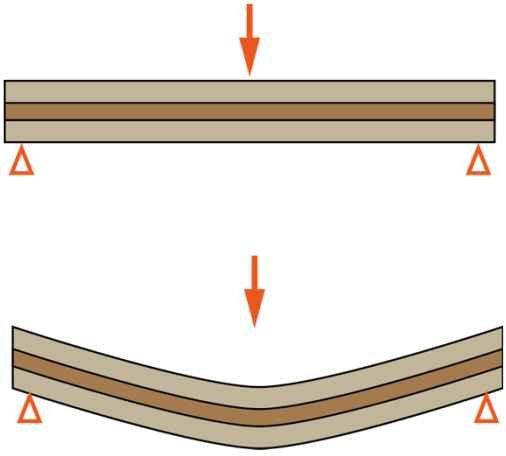


Illustration: Santanu Misra

Passive Folding

Passive folds are produced by accentuation of pre-existing curvatures of layers by more or less homogeneous strain.

The homogeneity of strain is not an essential condition. What is required is that the strain in neighbouring points of the successive layers is approximately the same. This implies that passive folding can take place only if there is no significant competence contrasts among the layers.

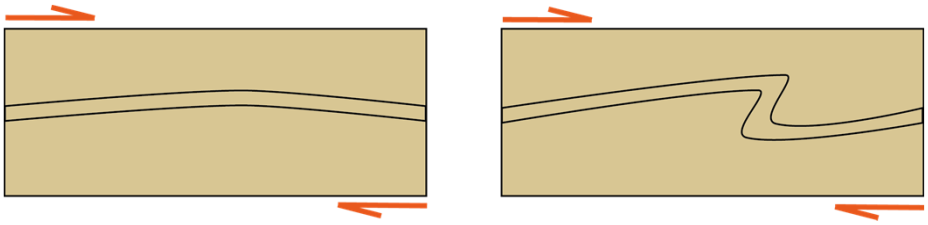


Illustration: Santanu Misra

How to study a folded structure

- The descriptions and associated terminologies of folded structures have evolved through time and they are not always very consistent.
- The defining and constituent elements of the folds can be described best with the characteristic geometries of a single folded surface (an interface between two layers of rocks). A stack of layers can also be folded and termed as multilayer folds.

Photo: Santanu Misra

Photo: Santanu Misra

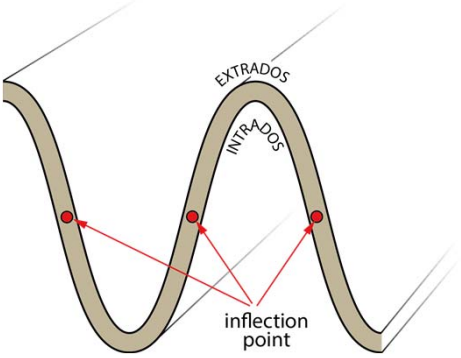
The way we shall learn

- We will first define some special features as points of a single layer fold at its cross section, i.e., where the “waviness” is best visible in 2D.
- We shall extend the points then in the third dimension to understand the linear features of the folds in 3D.
- We finally will connect the lines, wherever possible and applicable to construct some imaginary surfaces, which farther constrain the folded sequence.

Elements of single-layer fold

Inflection point & Fold train

- The trace of a folded surface appears as a wavy line on the plane of the transverse profile.
- A point which separates a convex and a concave segment of the wavy line is called an *inflection point*. In other words, the points of inflection separate, on the transverse profile, fold-segments of opposite senses of curvature.
- The outer- and and inner-arc in fold are *Extrados* are *Intrados*, respectively.
- A *fold train* is a series of folds with alternating senses of curvatures.



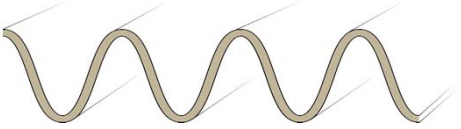


Illustration: Santanu Misra

Elements of single-layer fold

Antiform & Synform

- Fold segments, which are **convex upward**, are *antiforms* and folds that are **concave upward** are *synforms*.
- A fold train is generally characterised by alternate antiforms and synforms.

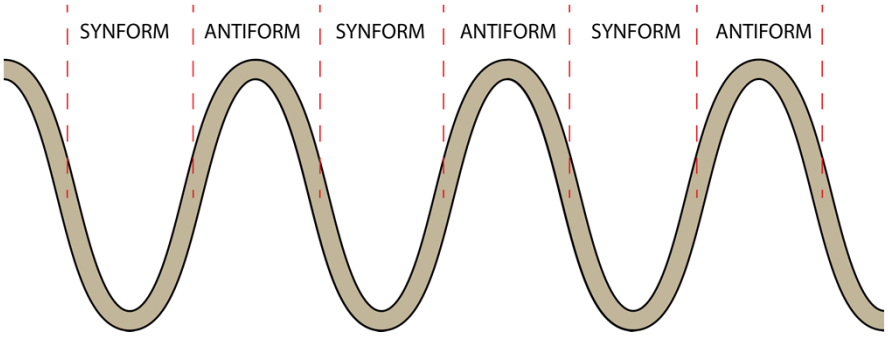


Illustration: Santanu Misra

Sense of Curvature

- **Antiform**: A fold that closes upward
- **Synform**: A fold that closes downward
- **Neutral**: A fold that closes sidewise

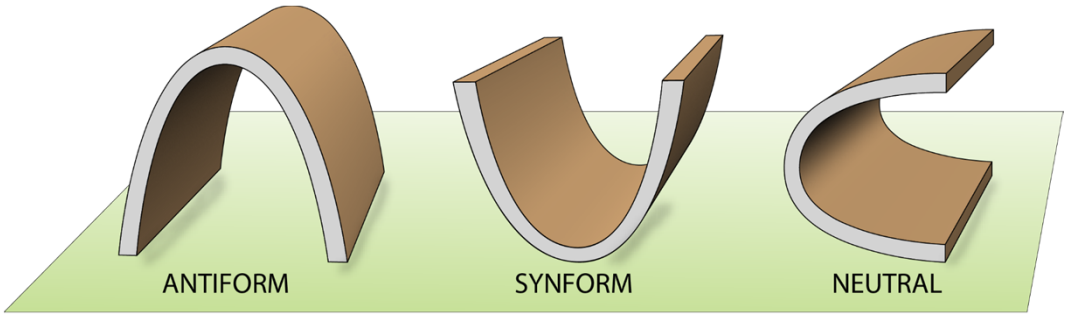


Illustration: Santanu Misra

Stratigraphic Younging Direction to fold closure - I

- **Anticline**: A fold in which the direction of younging is away from the fold core (intrados)
- **Syncline**: A fold in which the direction of younging is towards the the fold core (intrados)

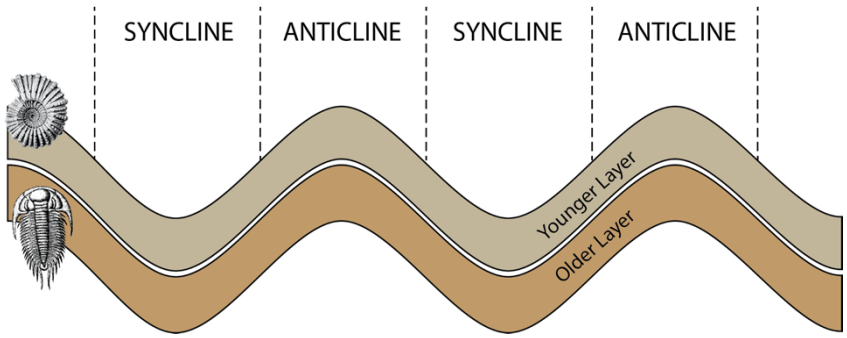


Illustration: Santanu Misra

Stratigraphic Younging Direction to fold closure - III

- **Synformal Anticline**: A fold that closes downward but with direction of younging away from the fold core (intrados)
- **Antiformal Syncline**: A fold that closes upward but in which the younging is towards the fold core (intrados)

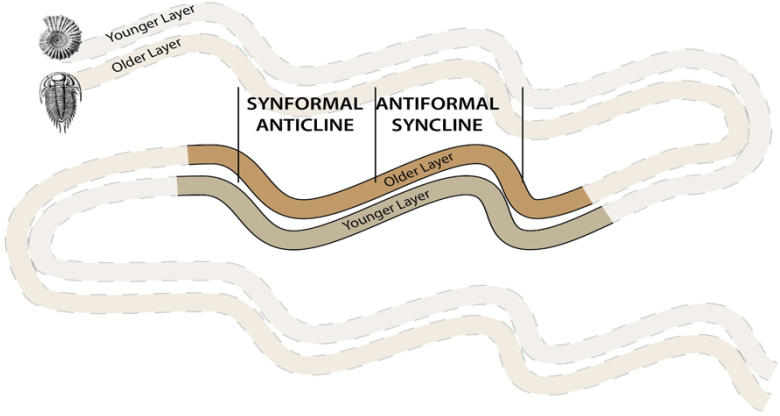


Illustration: Santanu Misra

Symmetry of fold

- **Symmetric Fold**: A fold is symmetric, if in profile, the shape of one side of the hinge is a mirror image on other side and the limbs are identical in length. The plane of symmetry is the axial plane and also the bisector of the median surface.
- **Asymmetric Fold**: A fold that does not have any mirror plane of symmetry, and the limbs are of unequal length.

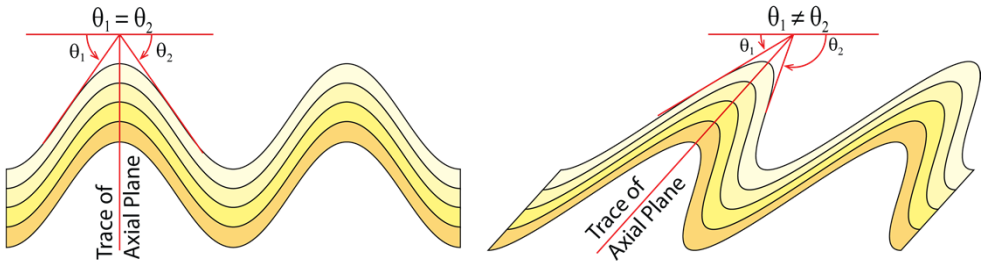


Illustration: Santanu Misra

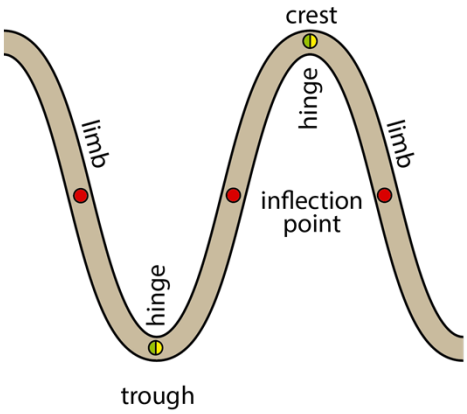
Elements of single-layer fold

Curvature, Hinge, Limb, Crest and Trough

- Curvature is the measure of the change of orientation per unit distance along the line/surface; a circular arc has constant curvature and straight line has no curvature.
- In a fold train, the curvature is measured from one inflection point to the next.
- In this curved segment, the *hinge* is point where the curvature is largest. A fold segment may have more than one hinge points.
- The *hinge* zone is the segment of highly curved line around the hinge point.
- The *limbs* (*flanks*) are regions of lowest curvatures and includes the inflection points.
- The *crest* and *trough points* are the points of highest and lowest elevations, in a fold train, respectively. Crest and trough, may or may not coincide the hinge points of the fold rain.

Elements of single-layer fold

Curvature, Hinge, Limb, Crest and Trough



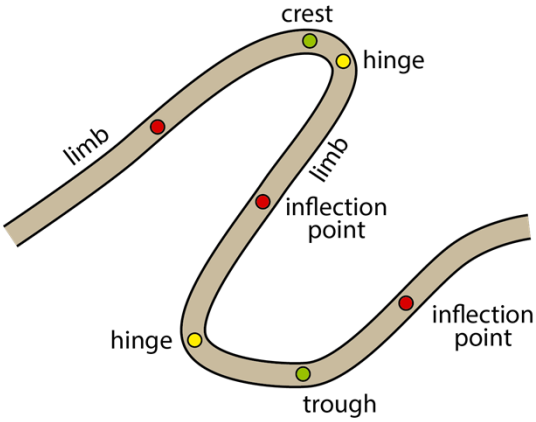


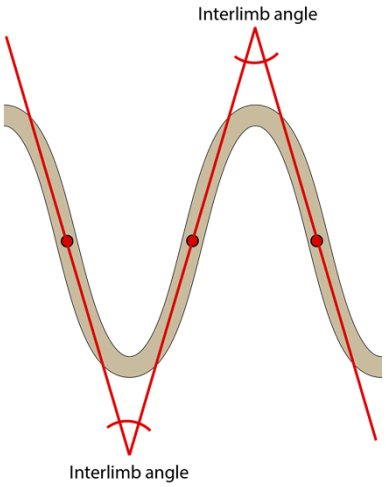
Illustration: Santanu Misra

Elements of single-layer fold

Interlimb angle

Interlimb angle of a folded layer is the angle enclosed by its two limbs.

Interlimb angle measures the tightness of the folded structure.



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Elements of single-layer fold

Fold Axis

- A fold axis is a line which, moving parallel to itself, generates the folded surface.

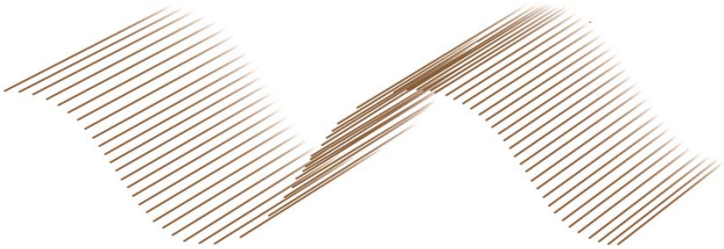
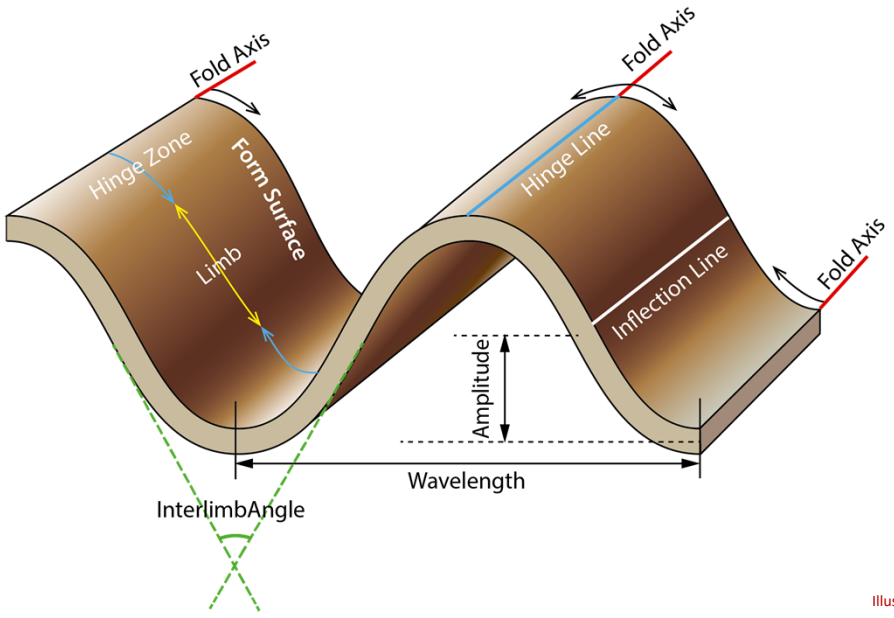


Illustration: Santanu Misra

- The fold axis does not have a fixed position in space; it has only a constant orientation throughout a volume of rock within which the fold is cylindrical.
- The geometry of a cylindrical fold is best described by the orientation of the fold axis along with a description of the section perpendicular to the fold axis. Such a section is called a *transverse profile* or simply a *profile*.

Elements of single-layer fold



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Elements of single-layer fold

Enveloping Surface, Median Surface, Amplitude and Wavelength

- The *Enveloping Surfaces* are the two surfaces (nor necessarily parallel to each other) that bound the fold train developed in a single folded surface
- The *Median Surface* includes and connects all the inflection lines of a fold train in a single surface.
- The *Amplitude* of any fold is the distance from the median surface to either of the enveloping surfaces measured parallel to the axial surface.
- The *Wavelength* is the distance measured parallel to the median surface, between one point of a fold and the geometrically similar point on a neighbouring fold in the same fold train. For example, the distance from one antiformal hinge to the next antiformal hinge.

Elements of single-layer fold

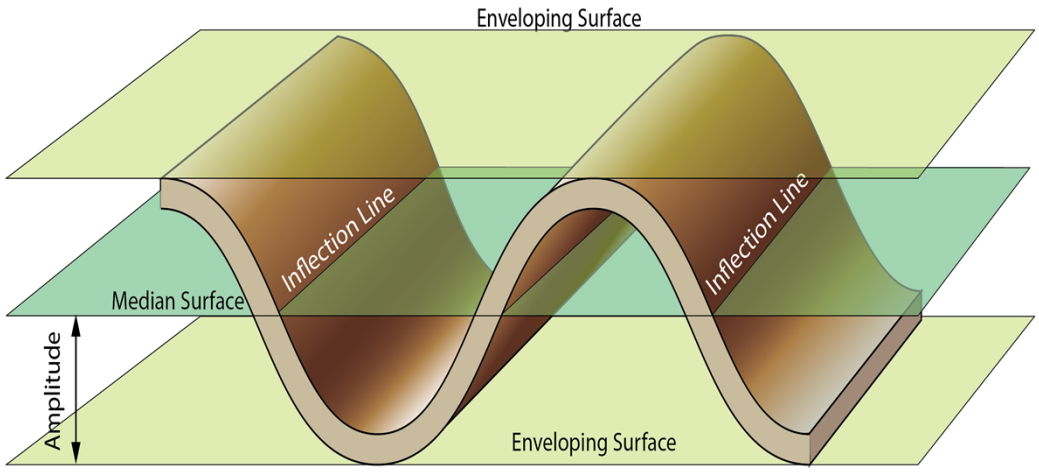


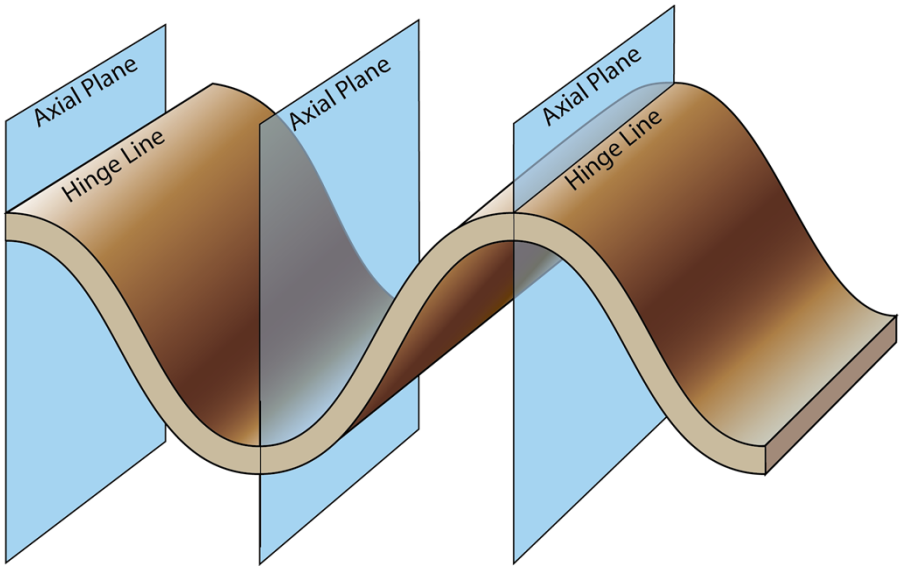
Illustration: Santanu Misra

Elements of single-layer fold

Axial Surface and Trace of Axial Surface

- The surface joining all hinge lines in a particular nested set of folds is generally known as *Axial Surface (Hinge Surface* or *Axial Planes)*.
- The intersection of the axial surface with the form surface (intersection lineation) is known as *Axial Surface Trace* and generally indicate the fold axis of the associated fold.
- The *Axial Surface Trace* can be seen on any other surface (exposure, outcrop, topography) other than the form surface and they are not at all defining the fold axis

Elements of single-layer fold



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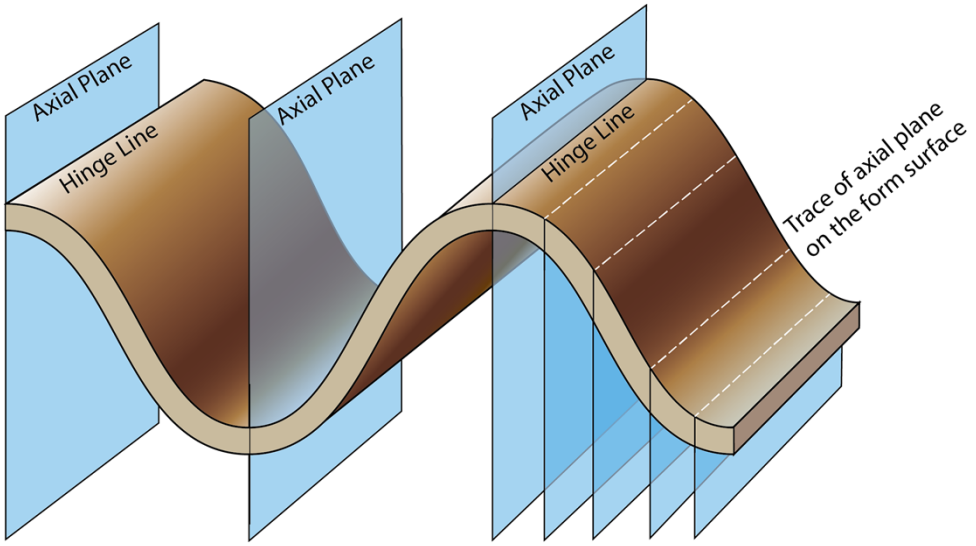
Elements of single-layer fold



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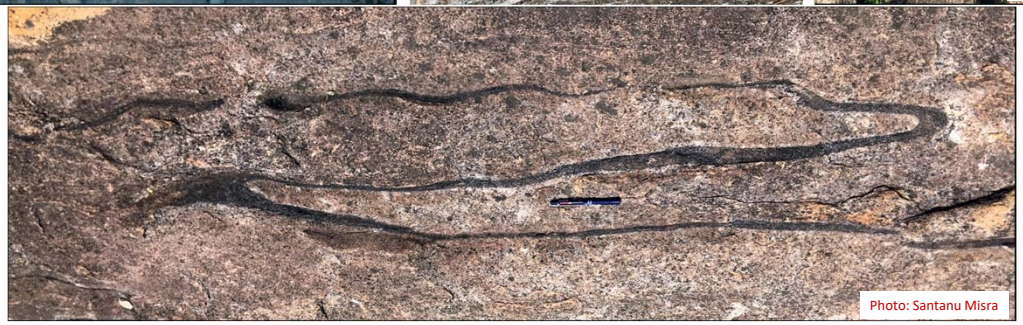
Fold Interference


Photo: JG Ramsay


Photo: internet


Photo: Santanu Misra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Next Lecture

Basic Structures and related terminologies
(Fault, Fold and Shear Zones)