

Folds

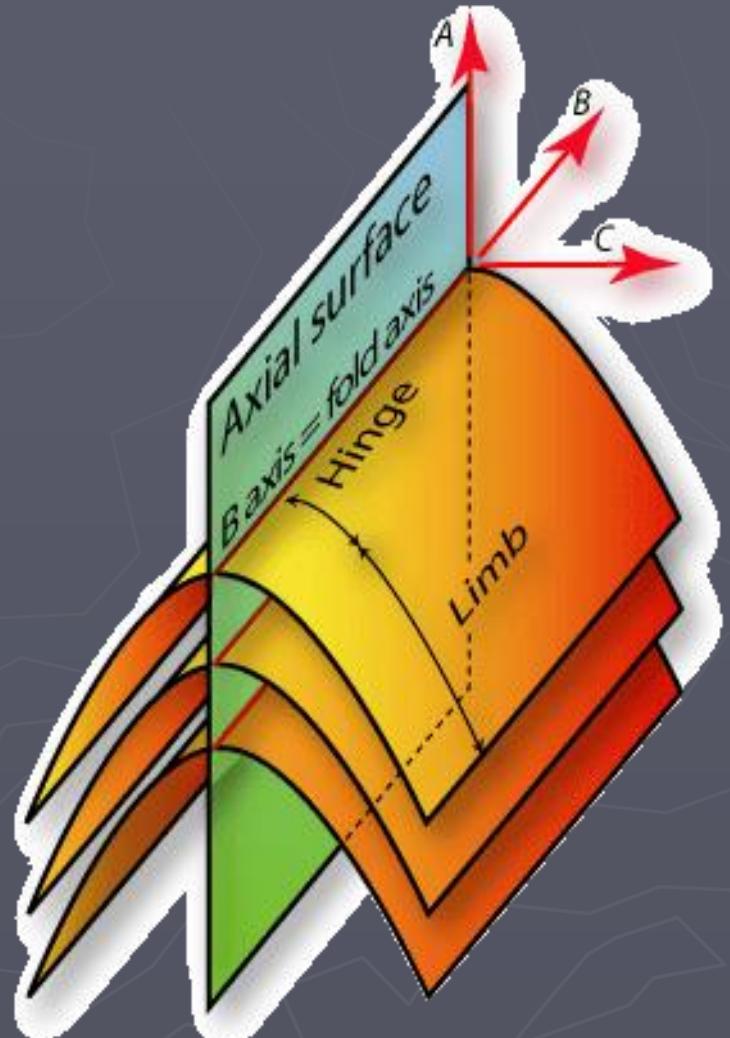


BASIC DEFINITIONS

- ▶ **DUCTILE DEFORMATION:** permanent solid-state deformation in which there is no loss of cohesion at the scale of crystals and larger
 - Due to flow at the atomic scale
 - Favored by higher temperature and lower strain rate
- ▶ **FOLD:** a wavelike undulation that develops due to ductile deformation of layered rock

BASIC FEATURES OF A FOLD

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

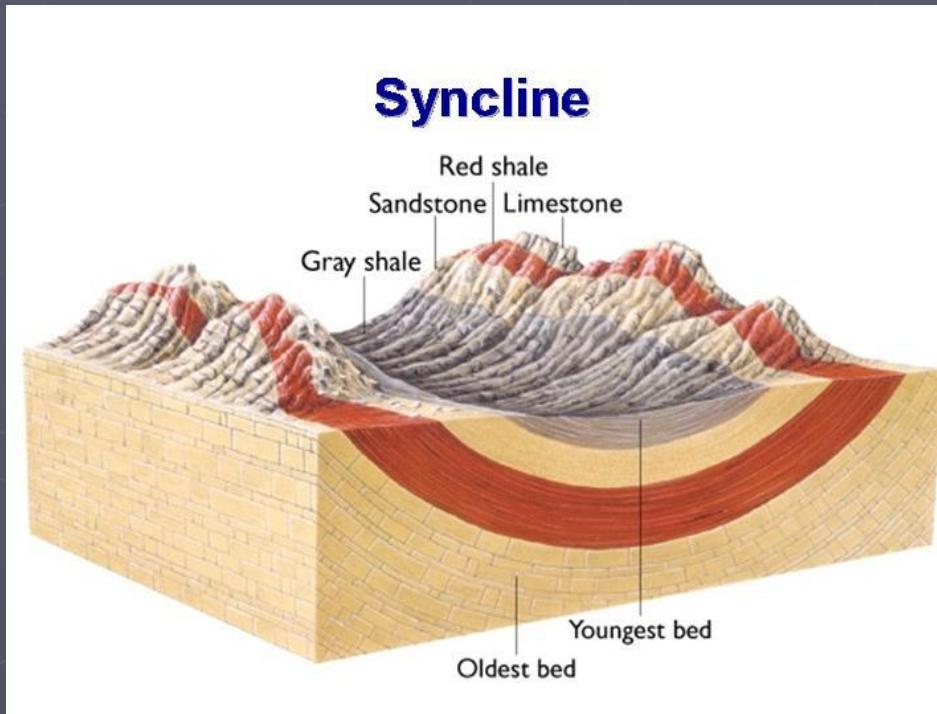


FOLD CLASSIFICATION

- ▶ Folds are 3-dimensional structures
- ▶ Far more complex classification than faults
- ▶ Classification is based on many criteria
 - Curvature
 - Orientation of Axial Plane
 - Orientation of Fold Axis
 - Shape of Layers
 - Shape of Hinge

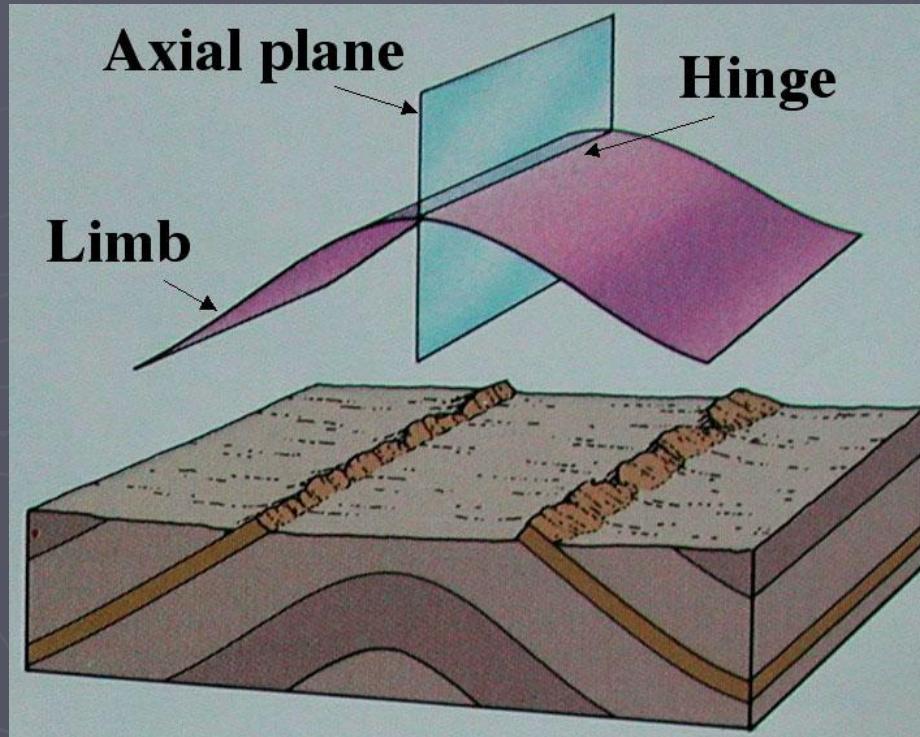
SYNFORM and SYNCLINE

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



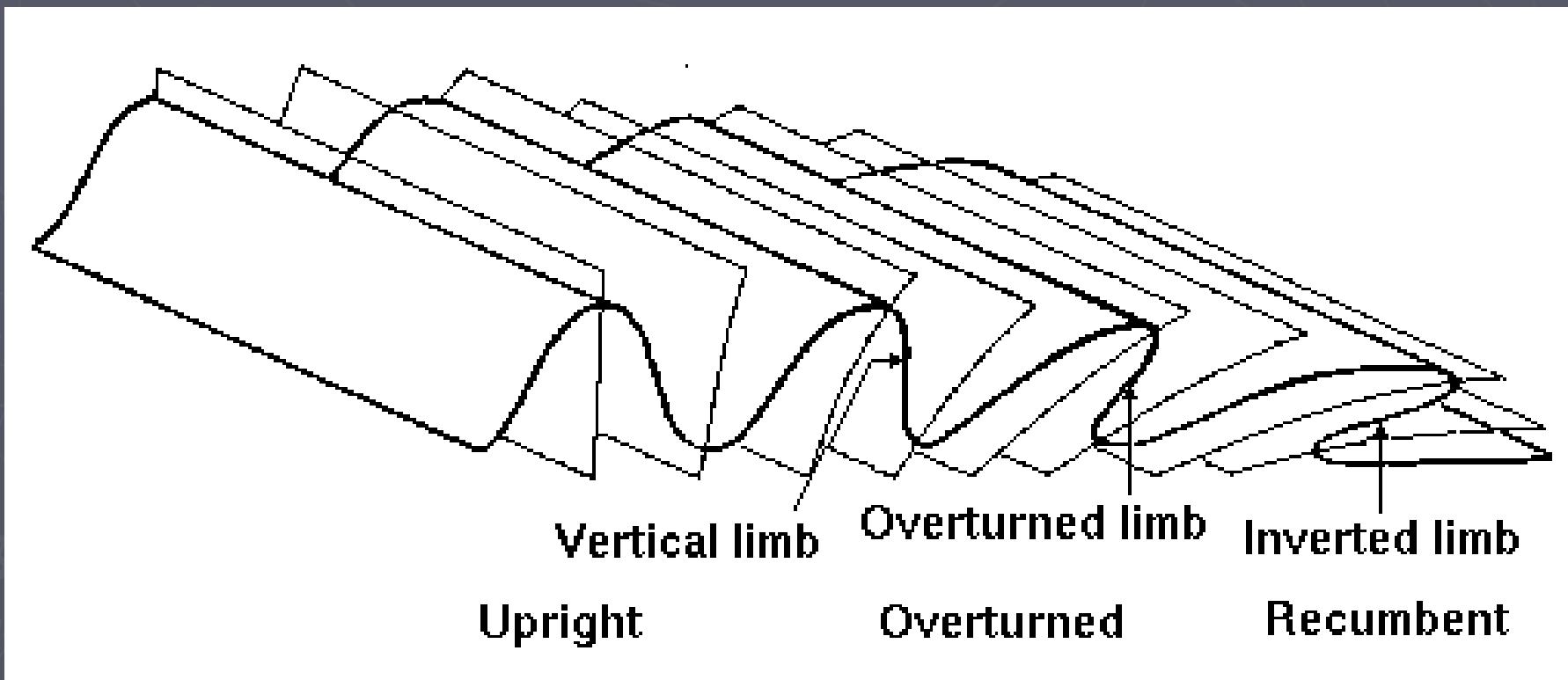
ANTIFORM and ANTICLINE

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



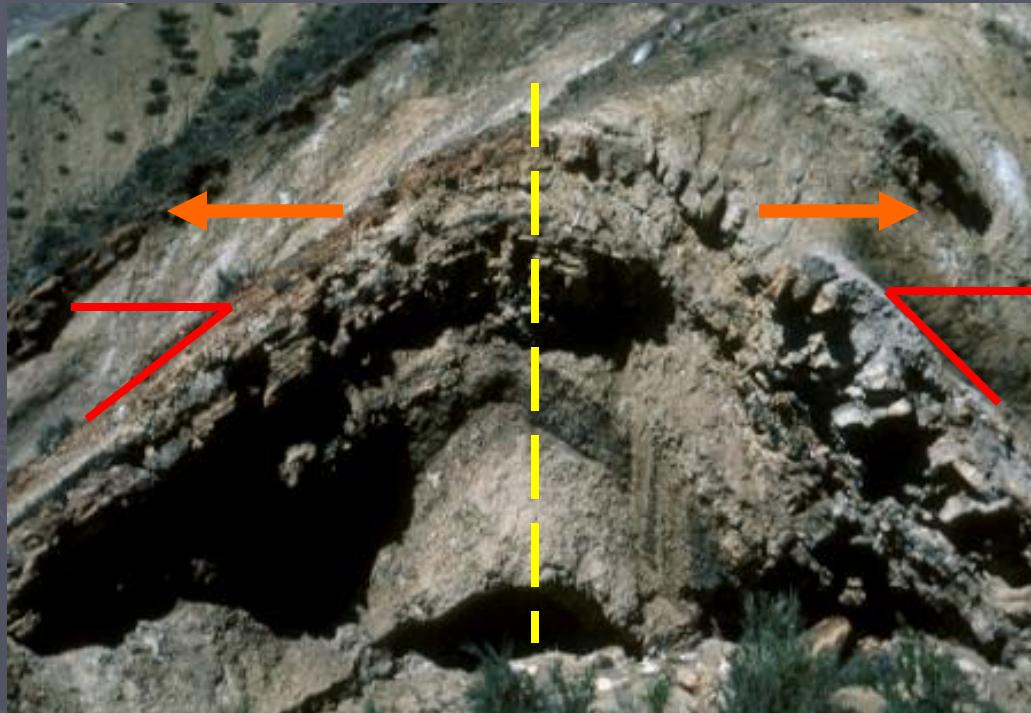
FOLD CLASSIFICATION BY ORIENTATION

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



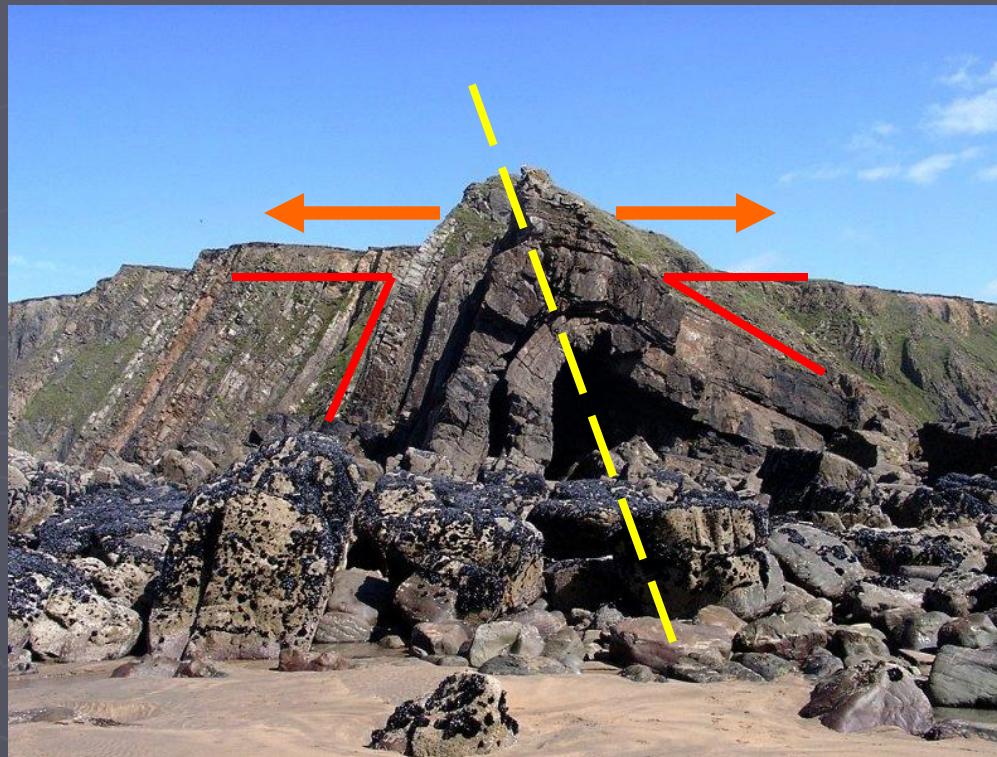
FOLD CLASSIFICATION BY ORIENTATION

- ▶ Folds can be classified based on the dips of limbs and the axial plane
 - **UPRIGHT FOLD:** Vertical AP, Dip Direction of limbs are opposite but Dip Angle is equal



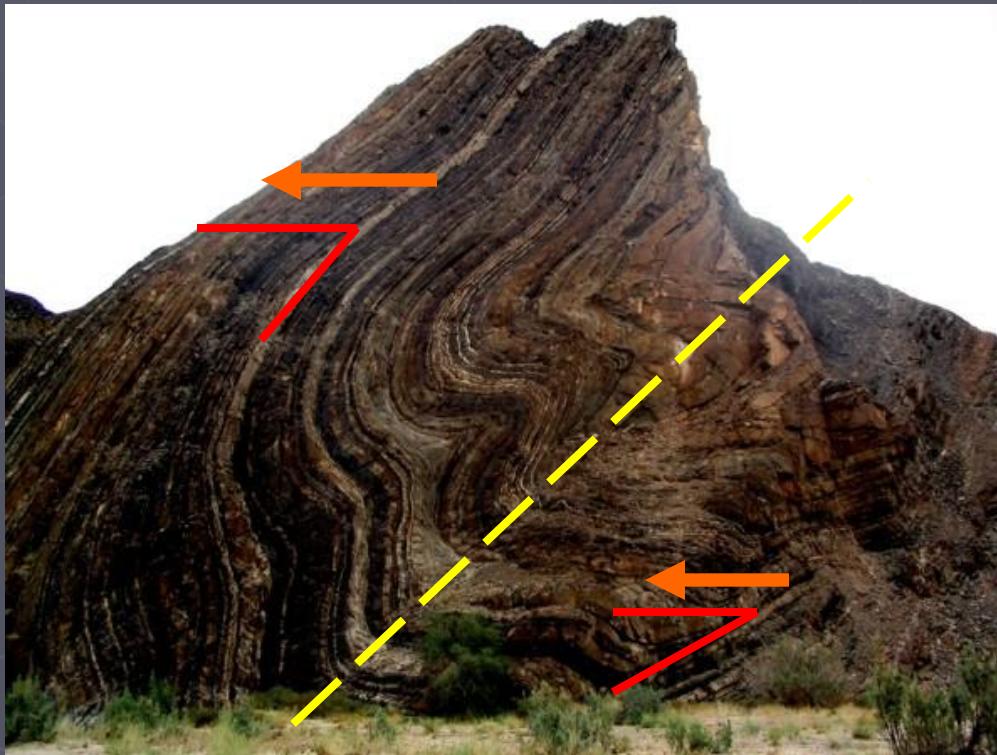
FOLD CLASSIFICATION BY ORIENTATION

- ▶ Folds can be classified based on the dips of limbs and the axial plane
 - **INCLINED FOLD:** Non-vertical AP, Dip Direction of limbs are opposite, Dip Angles are different, both limbs are upright



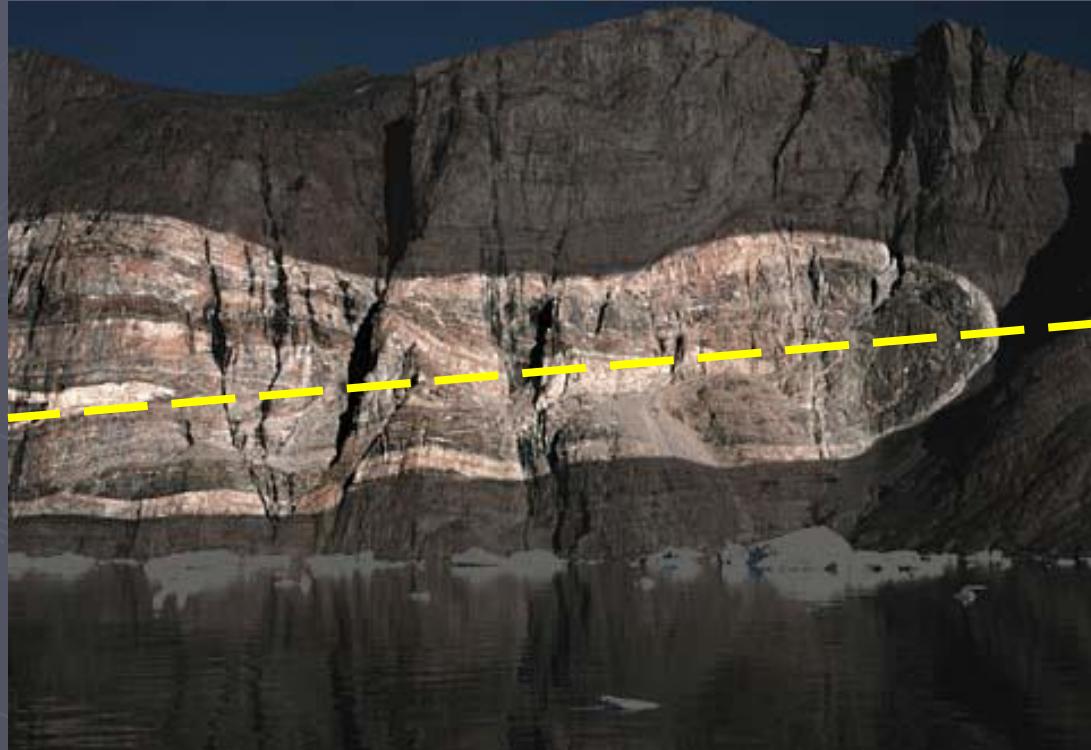
FOLD CLASSIFICATION BY ORIENTATION

- ▶ Folds can be classified based on the dips of limbs and the axial plane
 - **OVERTURNED FOLD:** Non-vertical AP, Dip Direction of limbs are the same, Dip Angles are different, one limb is upside-down

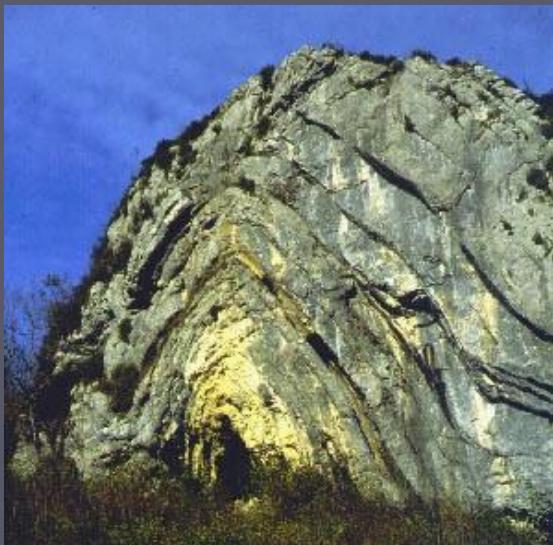


FOLD CLASSIFICATION BY ORIENTATION

- ▶ Folds can be classified based on the dips of limbs and the axial plane
 - **RECUMBENT FOLD:** Horizontal AP, one limb is upside-down



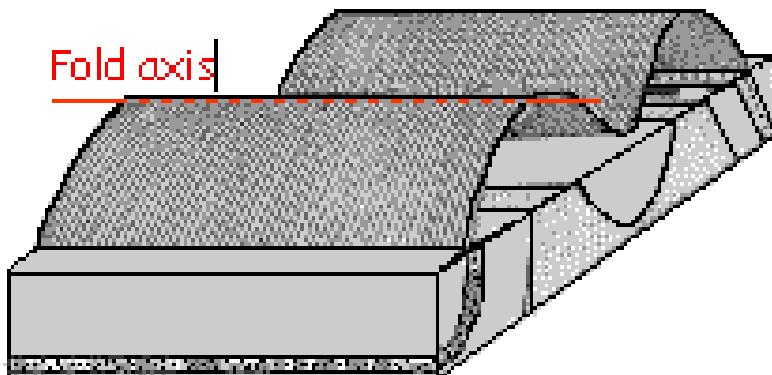
Classify the Fold



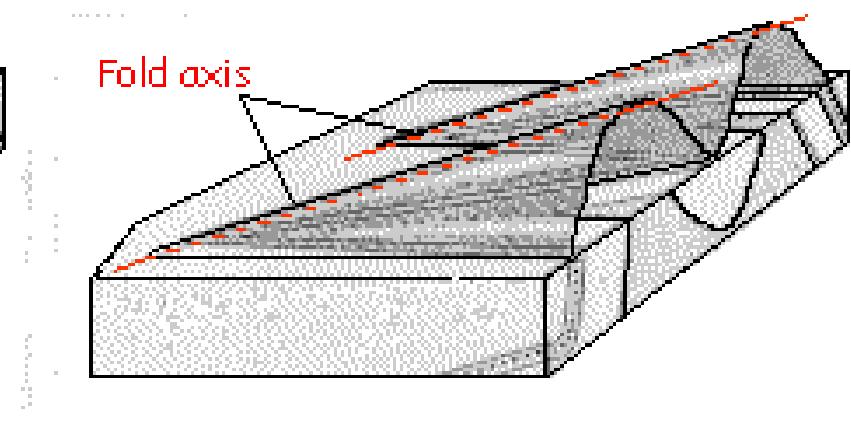
FOLD CLASSIFICATION BY FOLD AXIS

- ▶ Folds can be classified based on the orientation of the fold axis
 - Horizontal or Non-Plunging
 - Plunging
 - (Shallow, Moderate, Steep, Vertical, North, South, East, West, etc)

Non-Plunging Fold



Plunging Fold

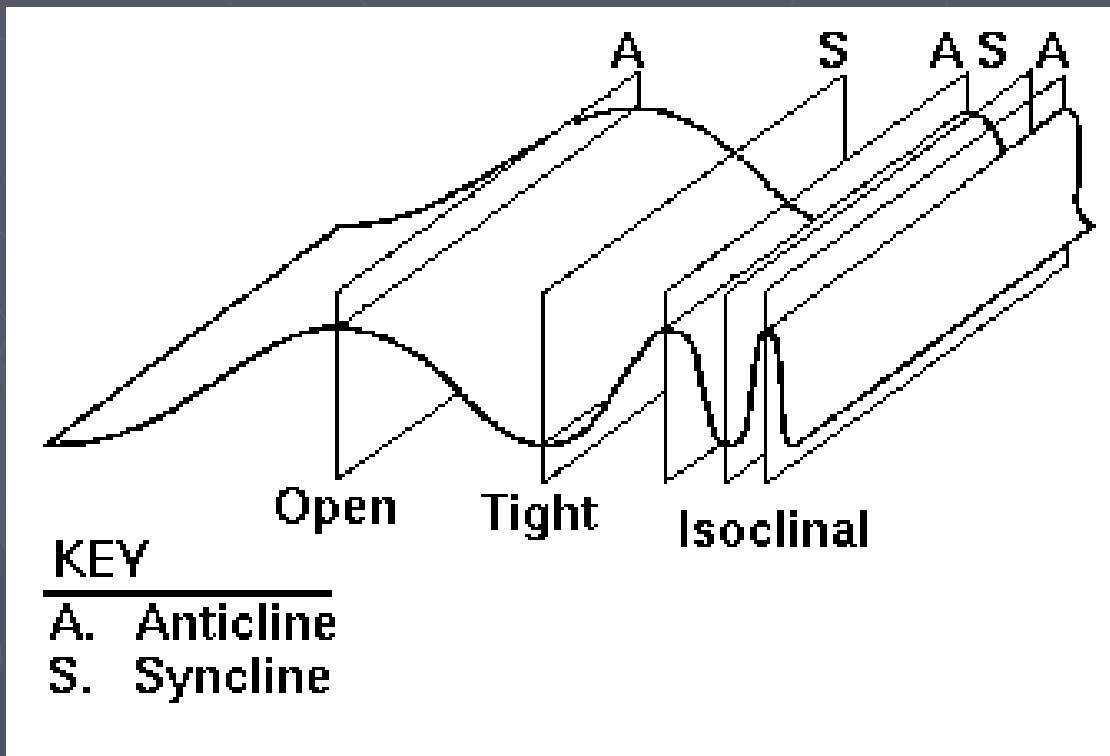


TREND and PLUNGE

- ▶ Strike and dip define the orientation of planar features (e.g., fault, axial plane)
- ▶ Trend and plunge define the orientation of linear features (e.g., fold axis)
 - Trend is measured as azimuth (0-360) pointing in the plunge direction
 - Plunge is the angle measured from the horizontal to the line (0-90)

FOLD CLASSIFICATION BY INTERLIMB ANGLE

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



Gentle: 180-120

Open: 120-70

Close: 70-30

Tight: 30-1

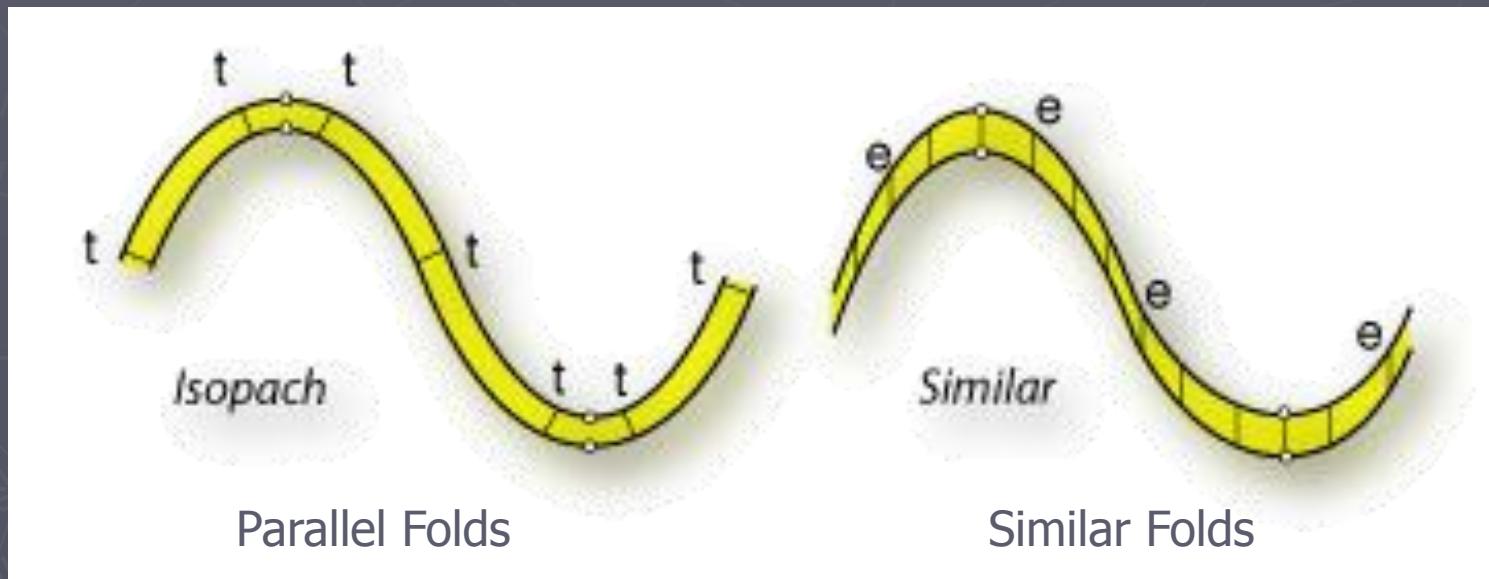
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Classify the Fold



FOLD CLASSIFICATION BY LAYER THICKNESS

- ▶ Folds can be classified based on the thickness of a given layer around the fold
- ▶ Variations in layer thickness around a fold are a function of the deformation mechanisms associated with the fold



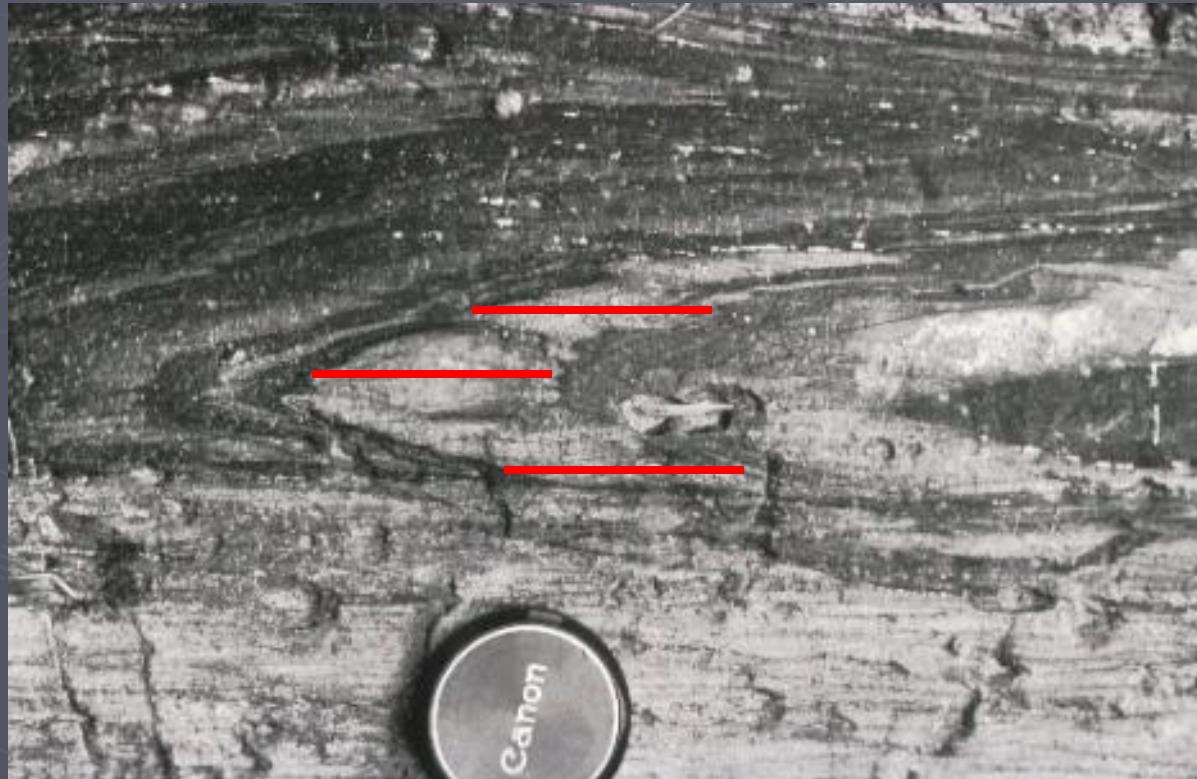
FOLD CLASSIFICATION BY LAYER THICKNESS

- ▶ **PARALLEL FOLDS:** maintain layer thickness perpendicular to the layer surface
- ▶ No flow of the rock during folding
- ▶ Typical of low-temperature (shallow) deformation



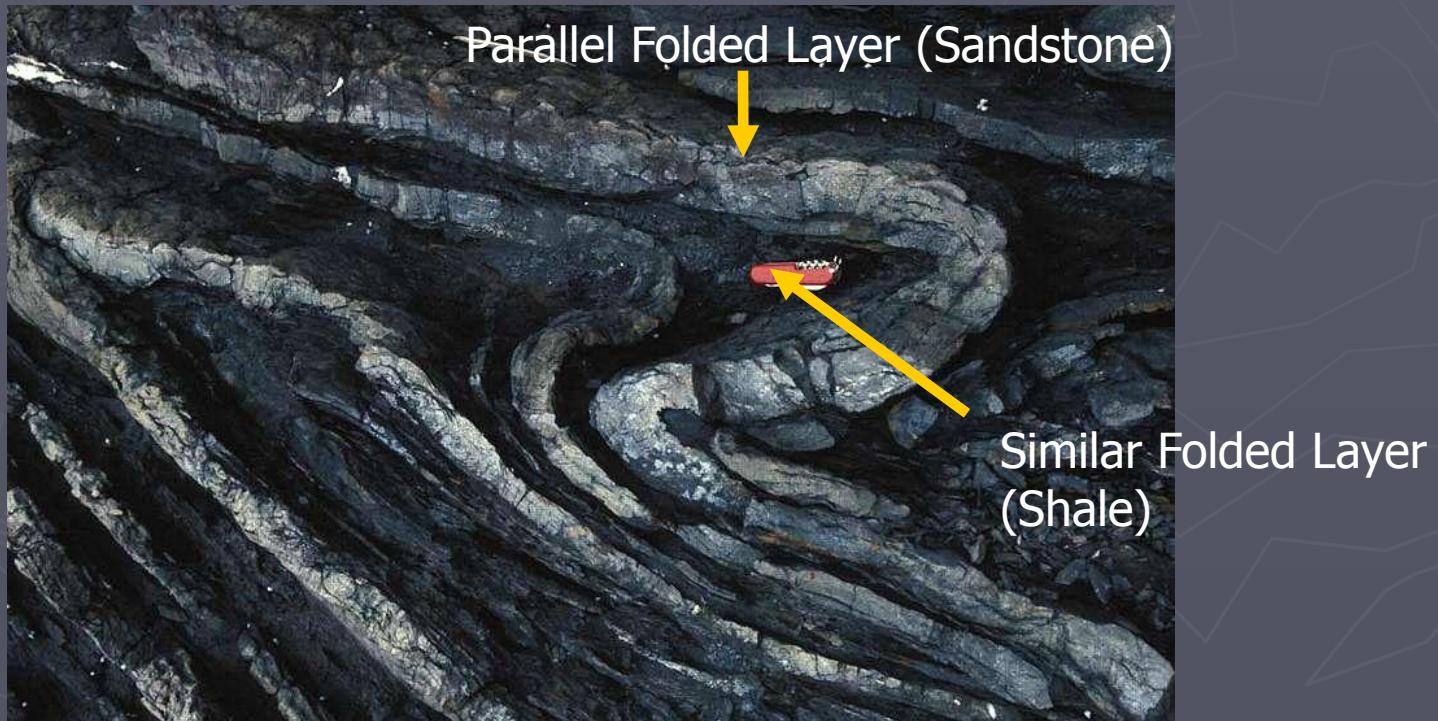
FOLD CLASSIFICATION BY LAYER THICKNESS

- ▶ **SIMILAR FOLDS:** maintain layer thickness parallel to the axial plane (hinge thickens and limbs thin)
- ▶ Rock must have flowed during deformation
- ▶ Typical of high-temperature deformation



FOLD CLASSIFICATION BY LAYER THICKNESS

- ▶ Parallel and similar folds may coexist in the same outcrop
- ▶ More competent layers such as sandstone, limestone or granite will tend to form parallel folds
- ▶ Less competent layers such as shale or schist will tend to form similar folds

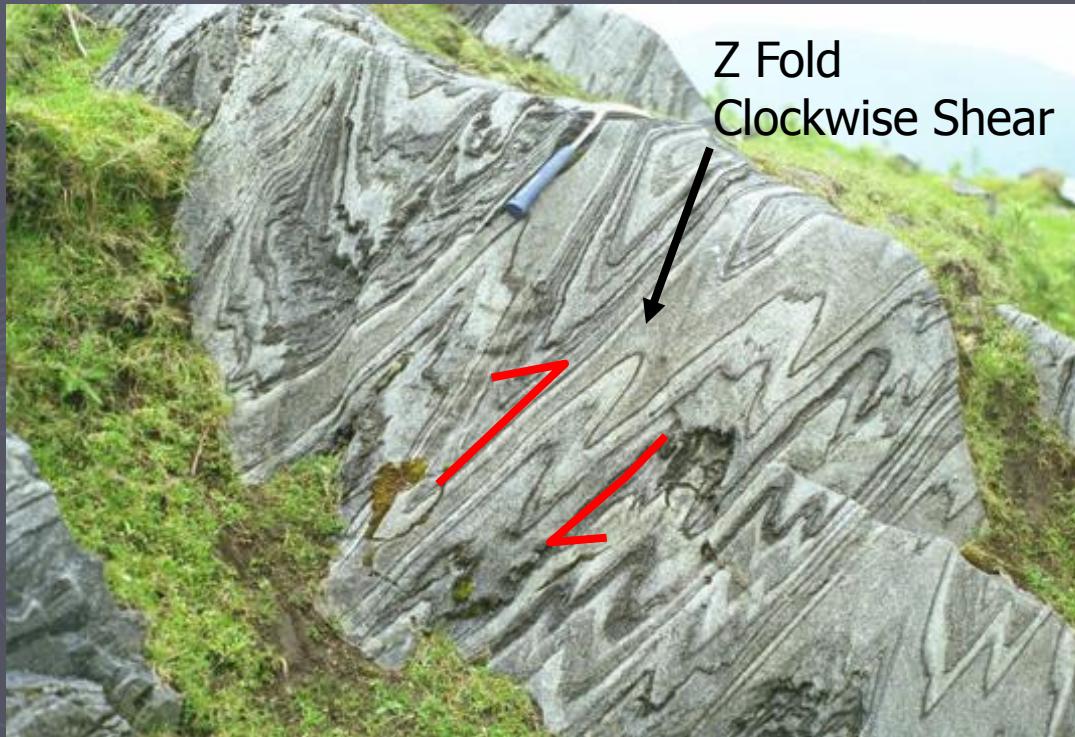


Classify the Fold



SPECIAL FOLDS: ASYMMETRIC FOLDS

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



SPECIAL FOLDS: CHEVRON FOLDS

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



SPECIAL FOLDS: KINK FOLDS

- ▶ Characterized by planar limbs and a narrow hinge zone and asymmetrical form



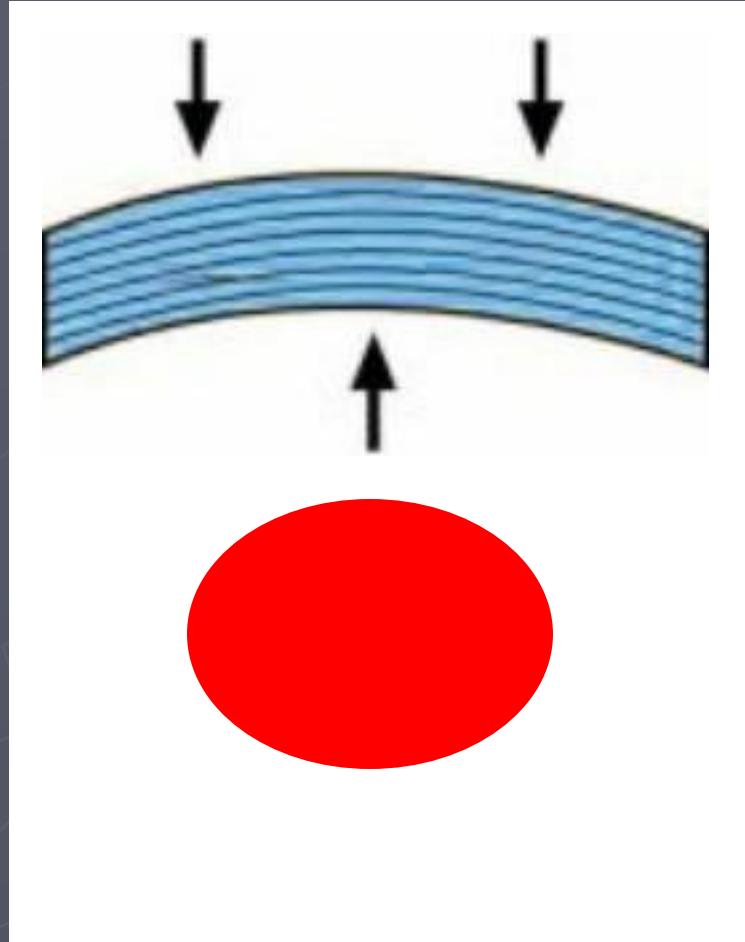
SPECIAL FOLDS: PTYGMATIC FOLDS

- ▶ Disharmonic in nature: Shape or wavelength changes from one layer to another
- ▶ Indicate that the viscosity of the folded layer was much greater than that of the matrix



FOLDING TYPES

- ▶ **BENDING:** folding that occurs when pairs of forces are applied to a layer
 - For example, regionally gravity provides a downward force, but above a rising pluton there is an upward force
 - Produces a bend



FOLDING TYPES

- ▶ ***BUCKLING***: folding that occurs when compression is applied perpendicular to a layer
 - Regional horizontal compression forms such folds

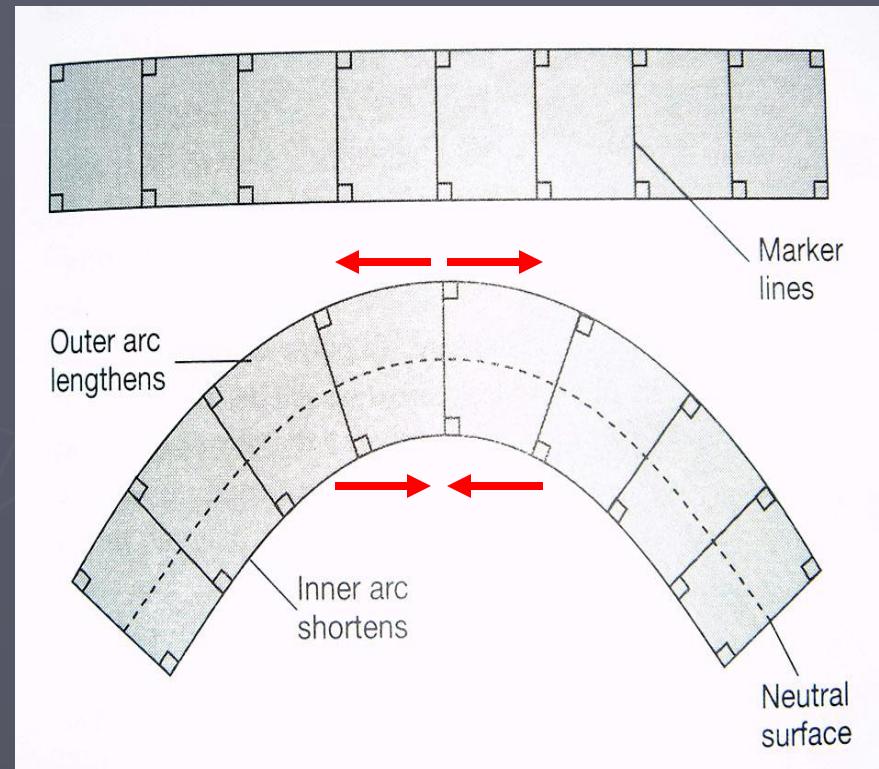


FOLDING MECHANISMS

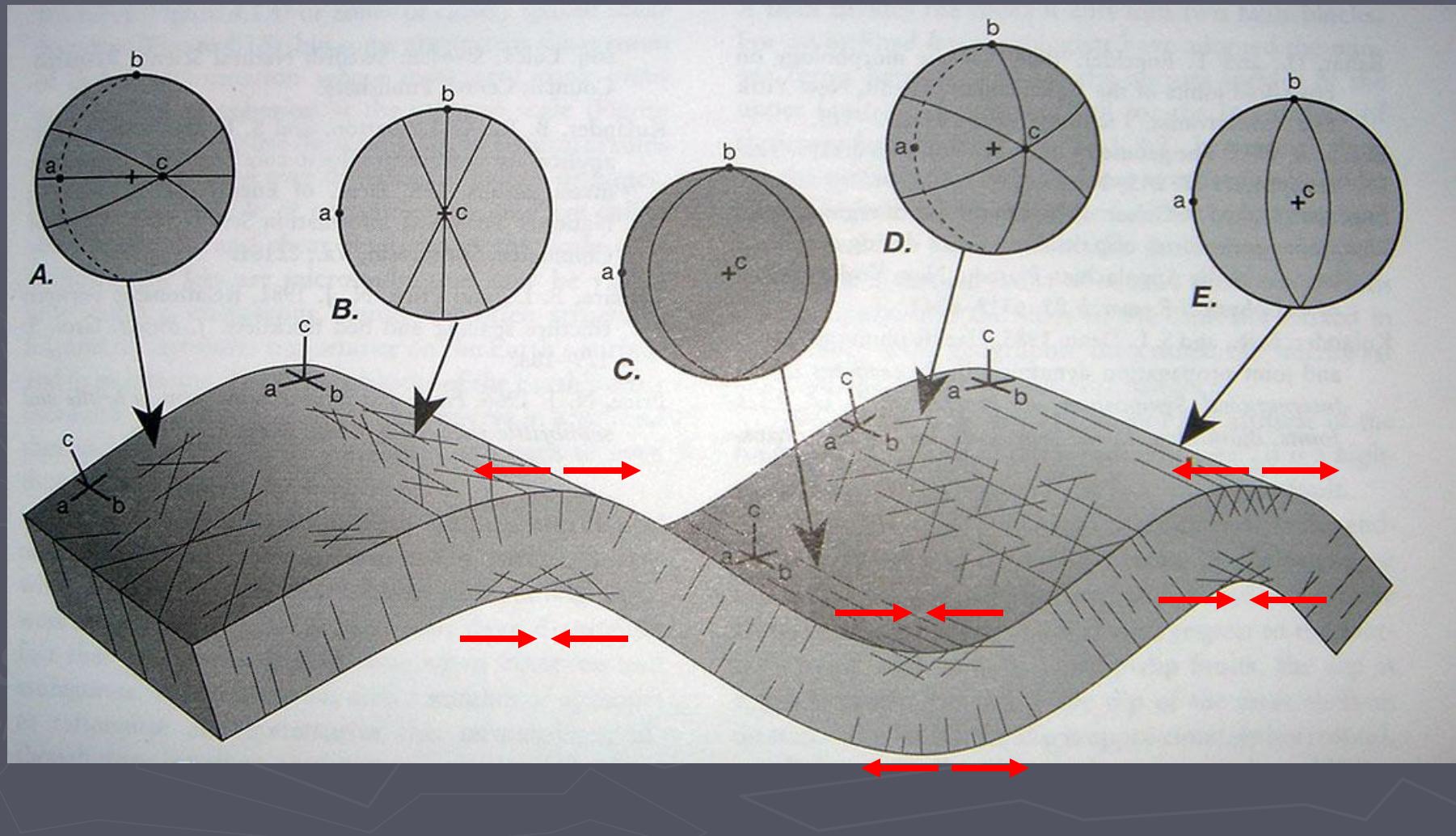
► *ORTHOGONAL FLEXURE:*

the lines that were perpendicular to the layer before folding remain perpendicular after folding

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

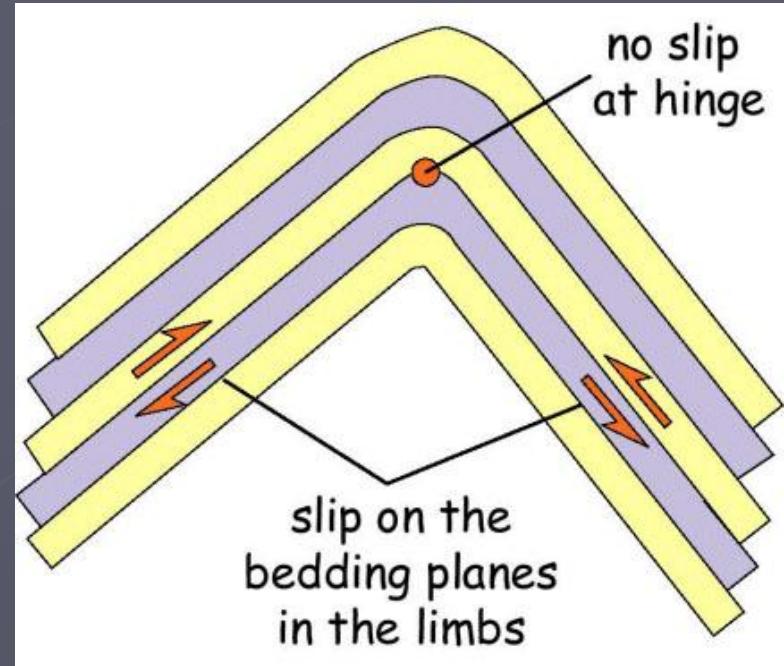


FRACTURES ASSOCIATED WITH ORTHOGONAL FOLDING



FOLDING MECHANISMS

- ▶ ***FLEXURAL SLIP***: Layers in a fold slip past each other
 - Like folding a deck of cards
 - Individual layers remain the same length
 - Movement between layers along each limb
 - Occurs in interbedded strata where the layers have differing competence
 - Layers will commonly display slickensides



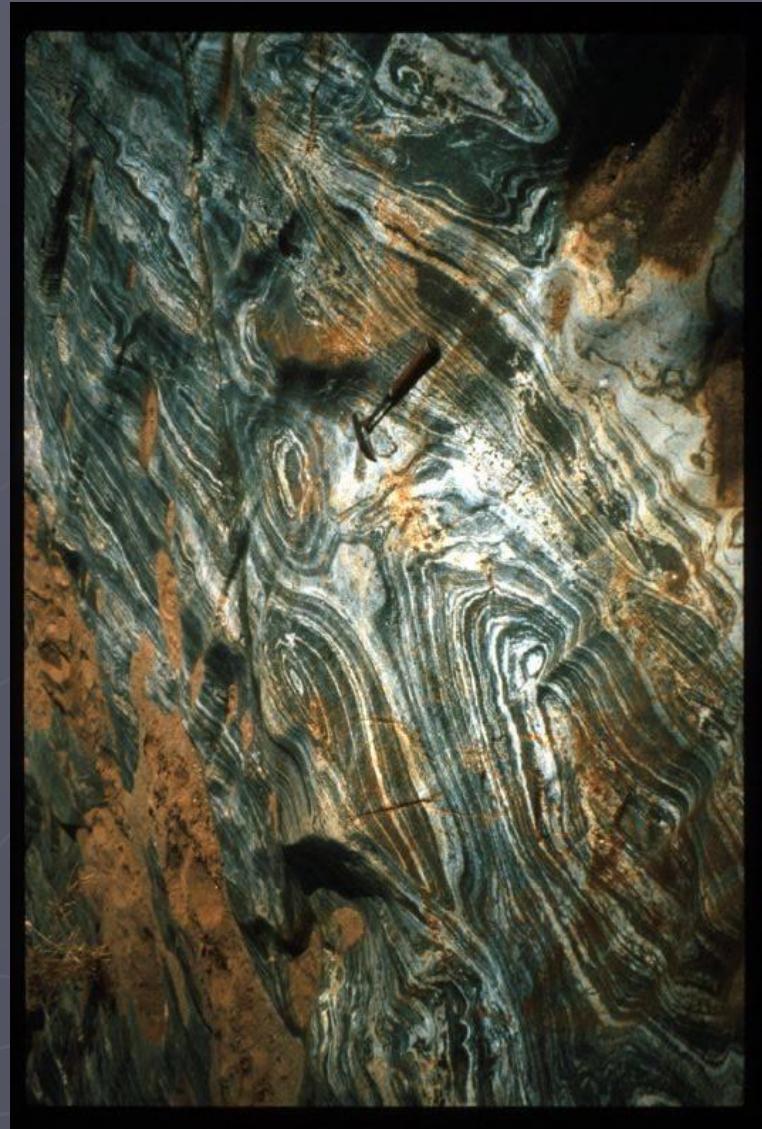
FOLDING MECHANISMS

- ▶ *PASSIVE FLOW*: flow of material within layers in response to stress
 - Forms in incompetent layers
 - Forms similar folds



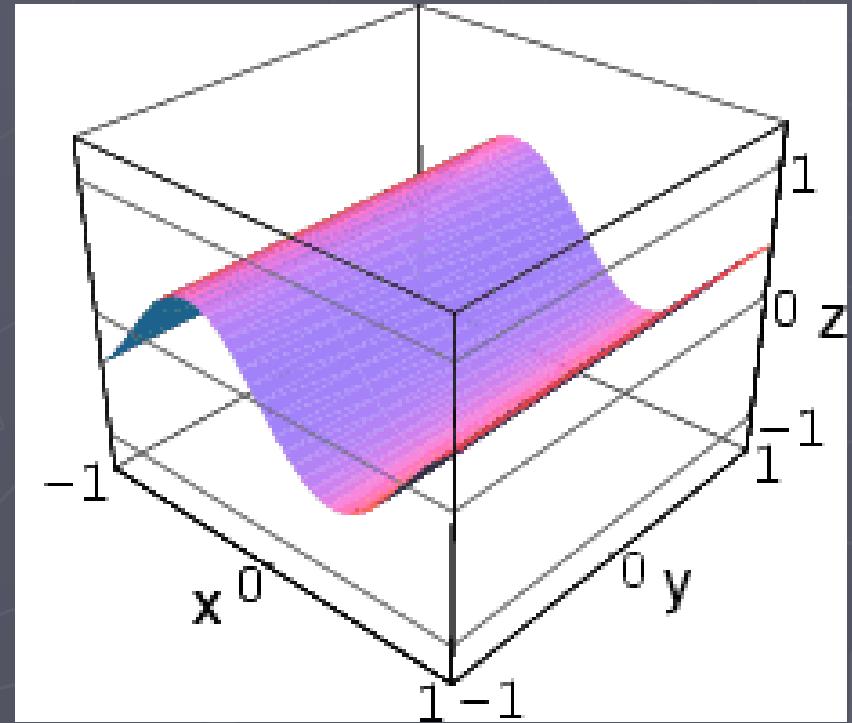
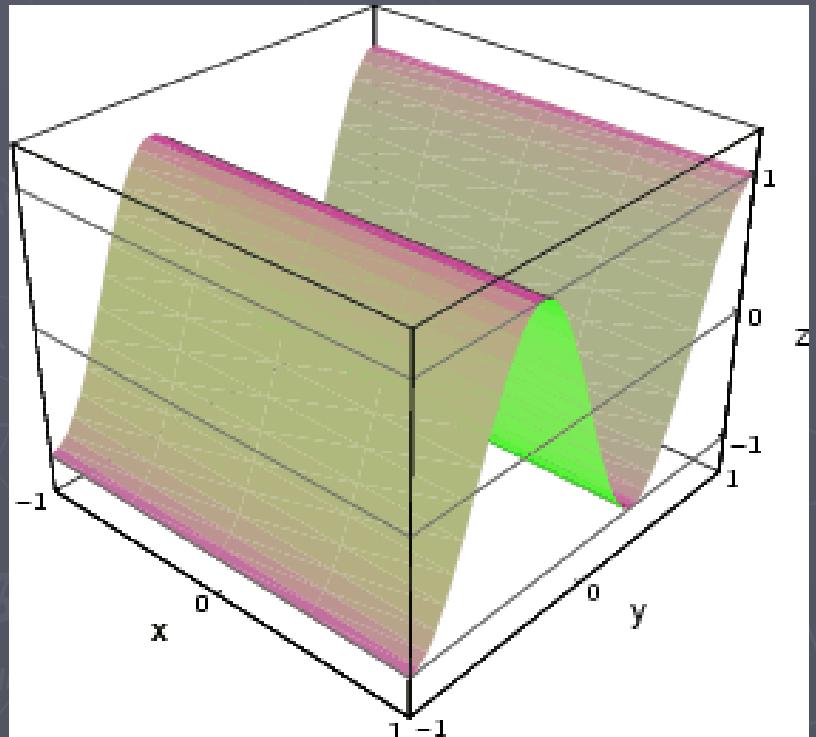
FOLD INTERFERENCE PATTERNS

- ▶ Multiple episodes of deformation may result in the refolding of folds
- ▶ Three distinct interference patterns can develop depending on the relative orientations of the folding in each event

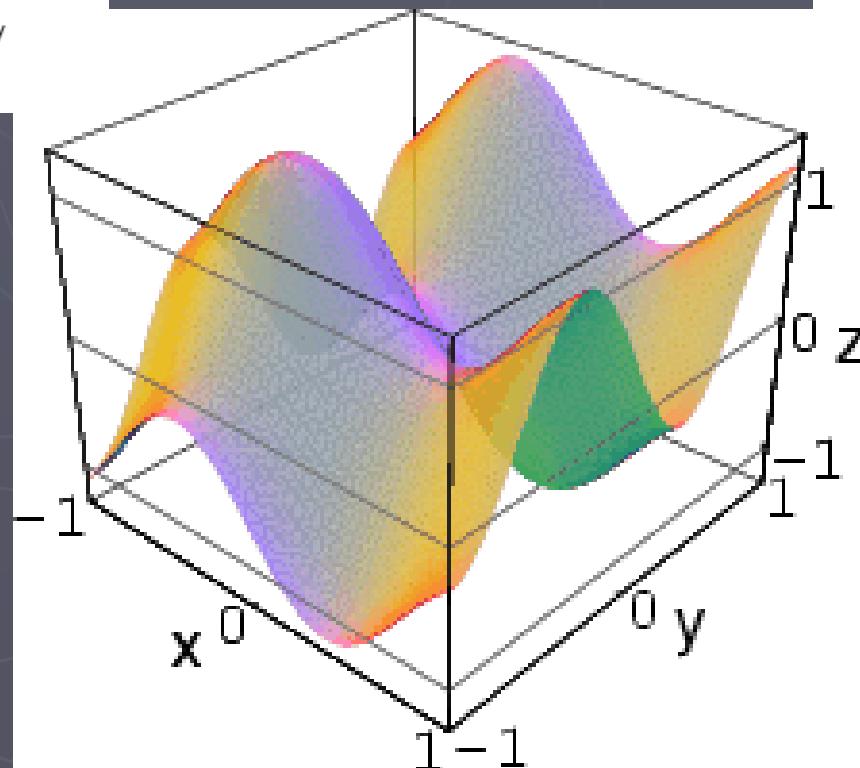
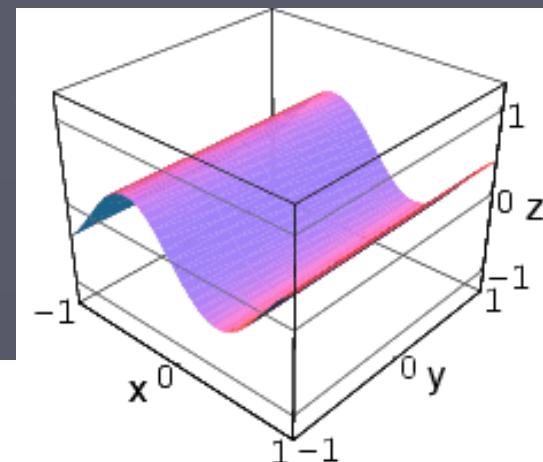
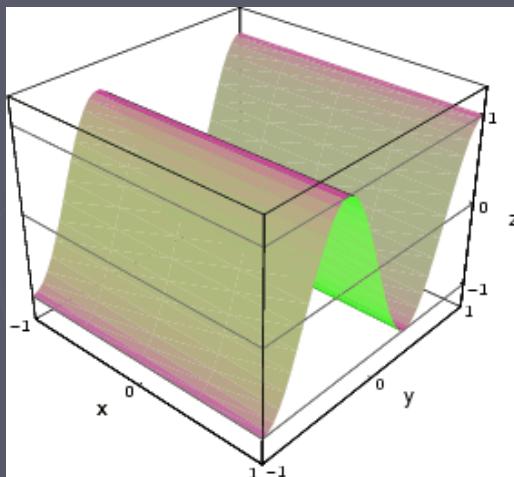


TYPE 1 EXAMPLE

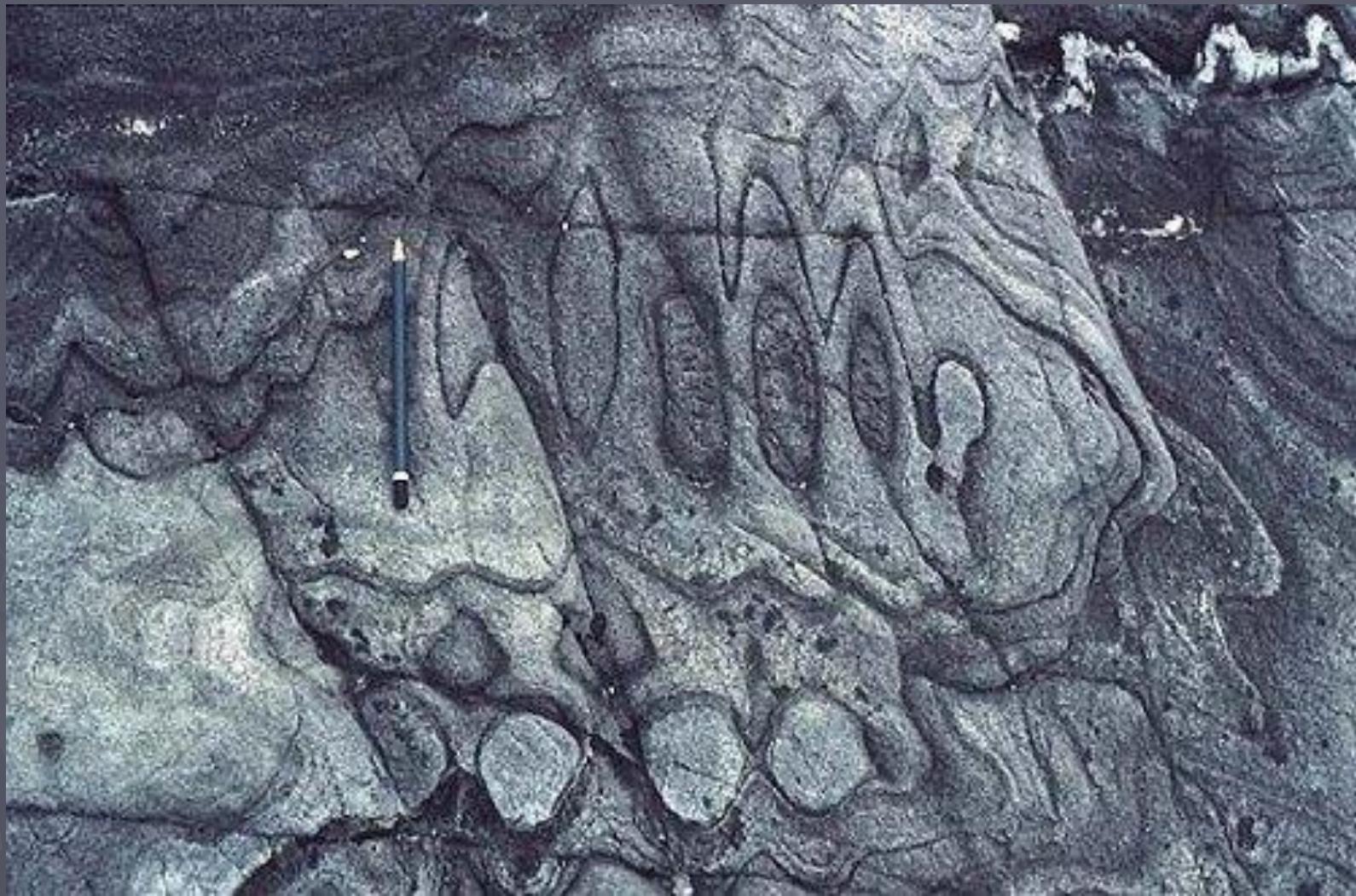
- ▶ F1: Vertical Axial Plane, Horizontal Fold Axis
- ▶ F2: Vertical Axial Plane, Horizontal Fold Axis



TYPE 1 EXAMPLE

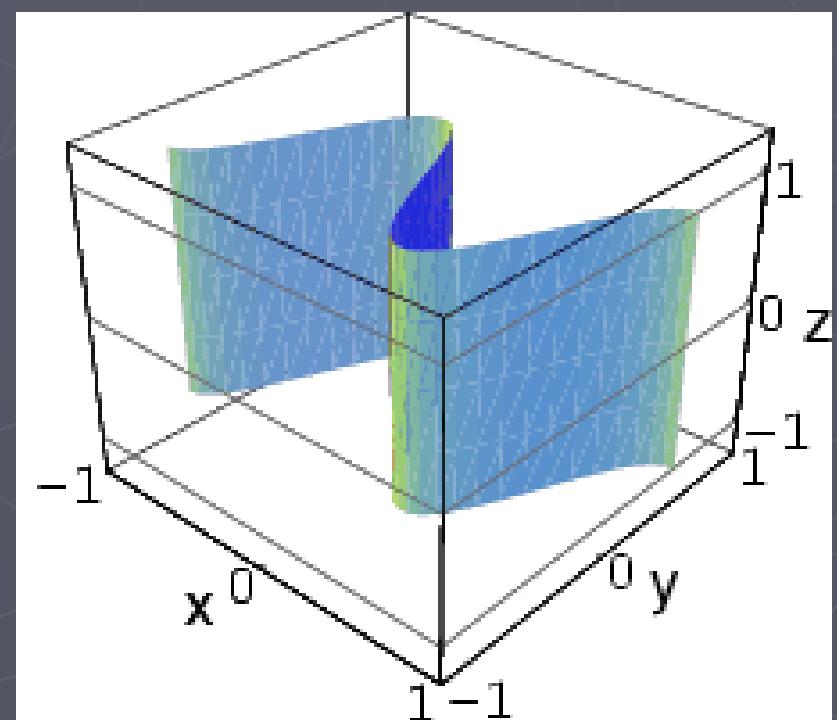
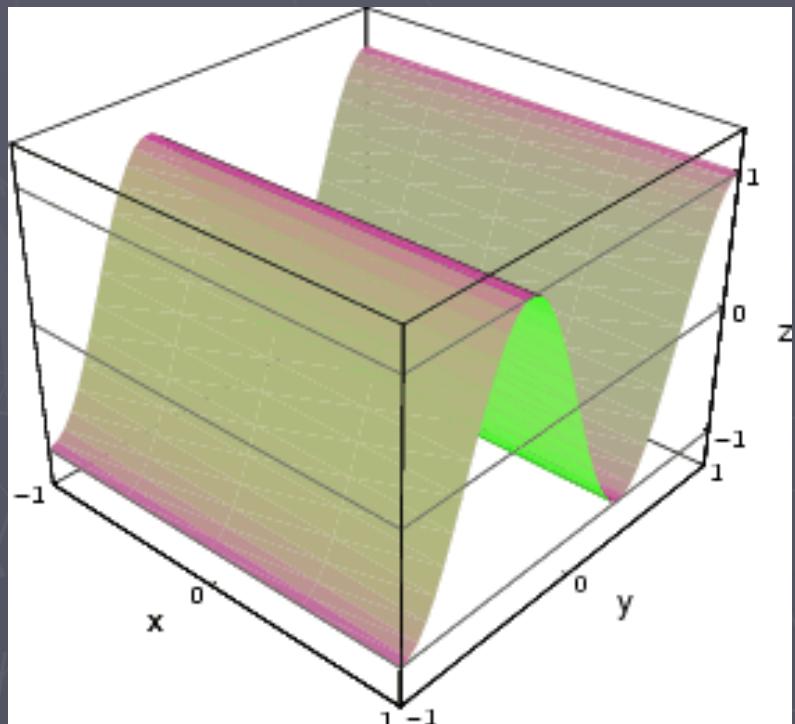


TYPE 1 FOLD INTERFERENCE

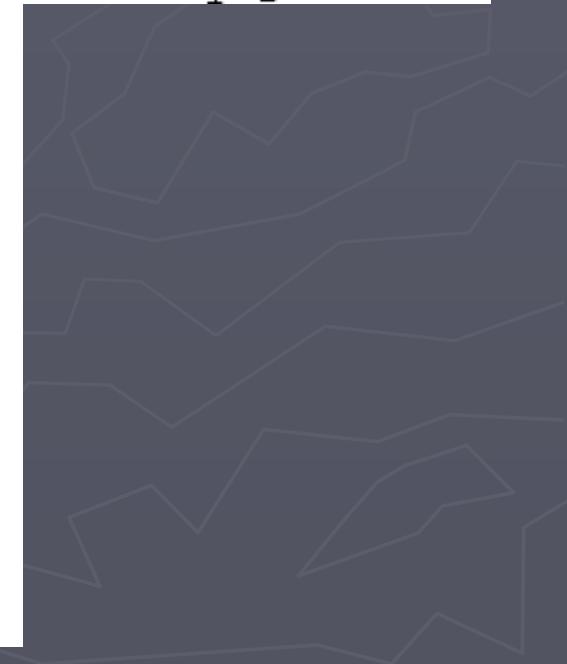
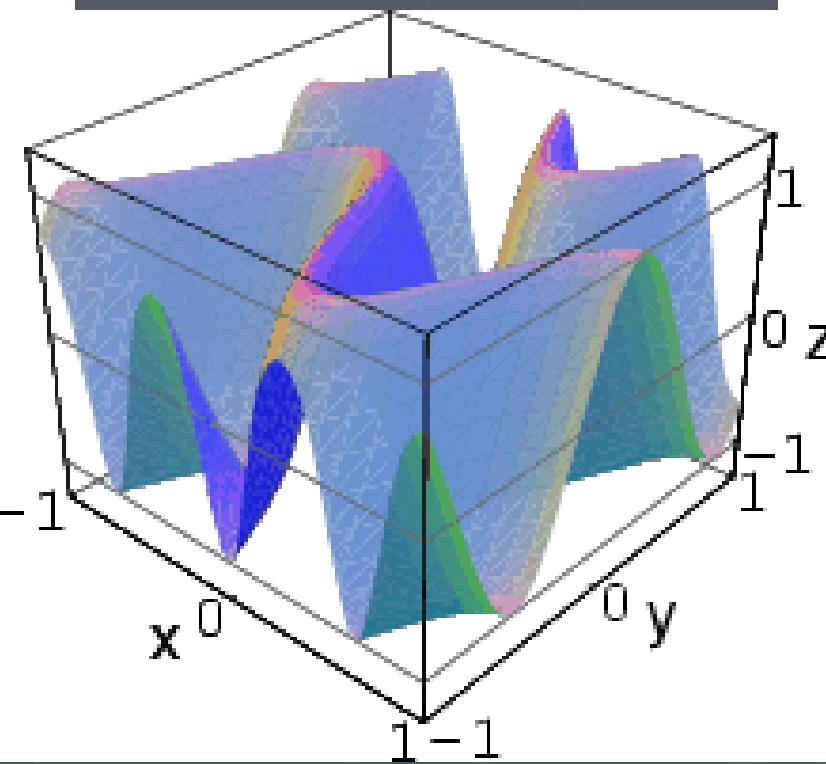
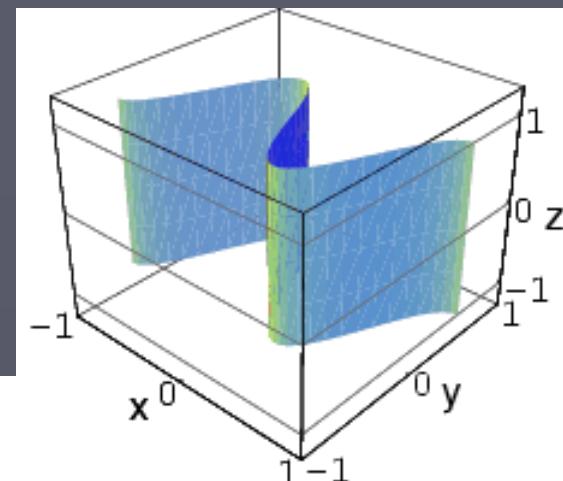
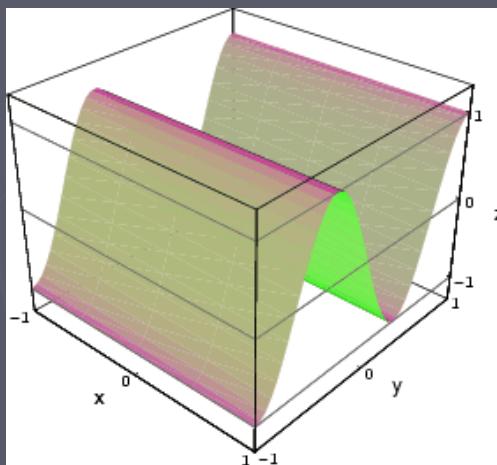


TYPE 2 EXAMPLE

- ▶ F1: Vertical Axial Plane, Horizontal Fold Axis
- ▶ F2: Vertical Axial Plane, Vertical Fold Axis



TYPE 2 EXAMPLE

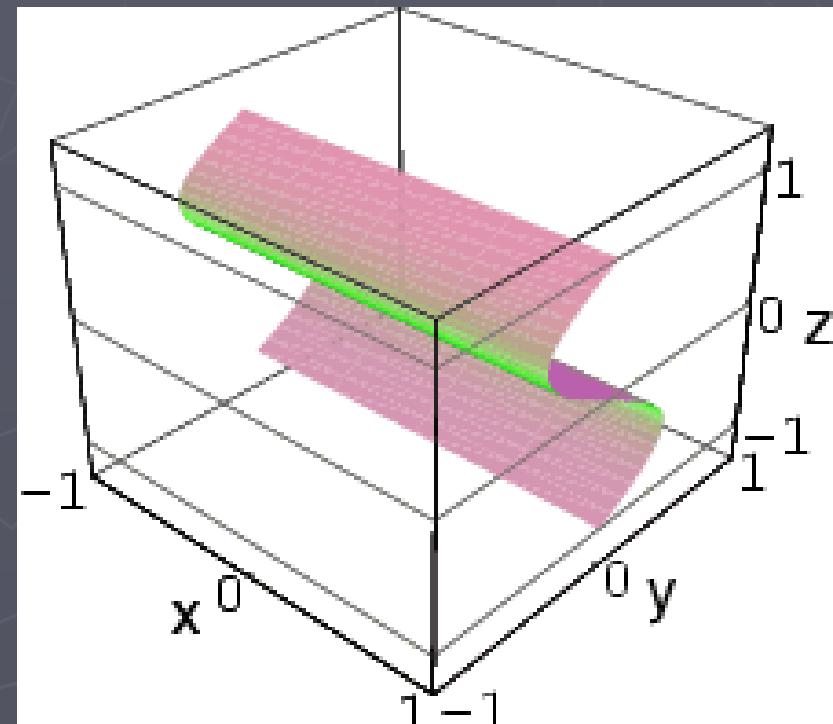
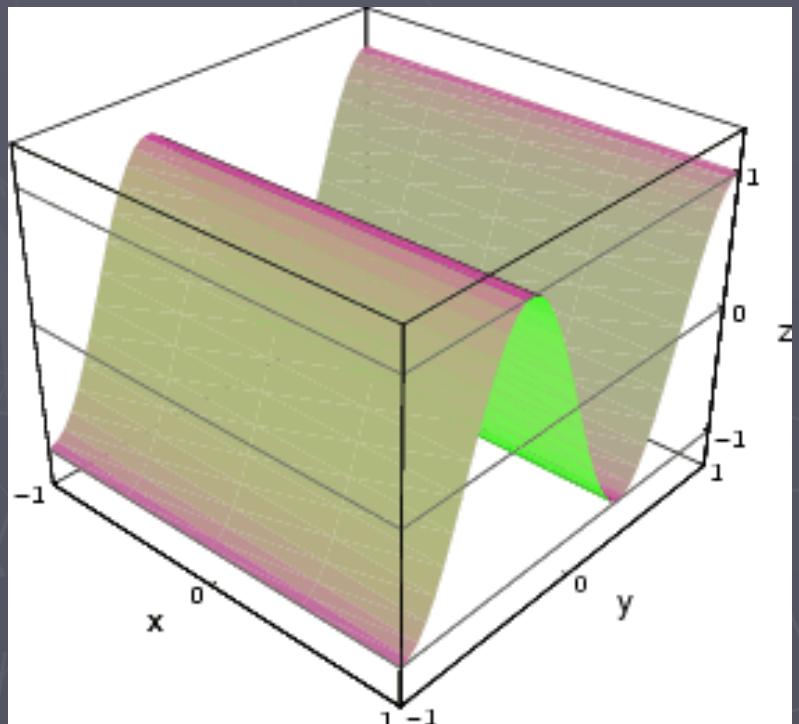


TYPE 2 FOLD INTERFERENCE

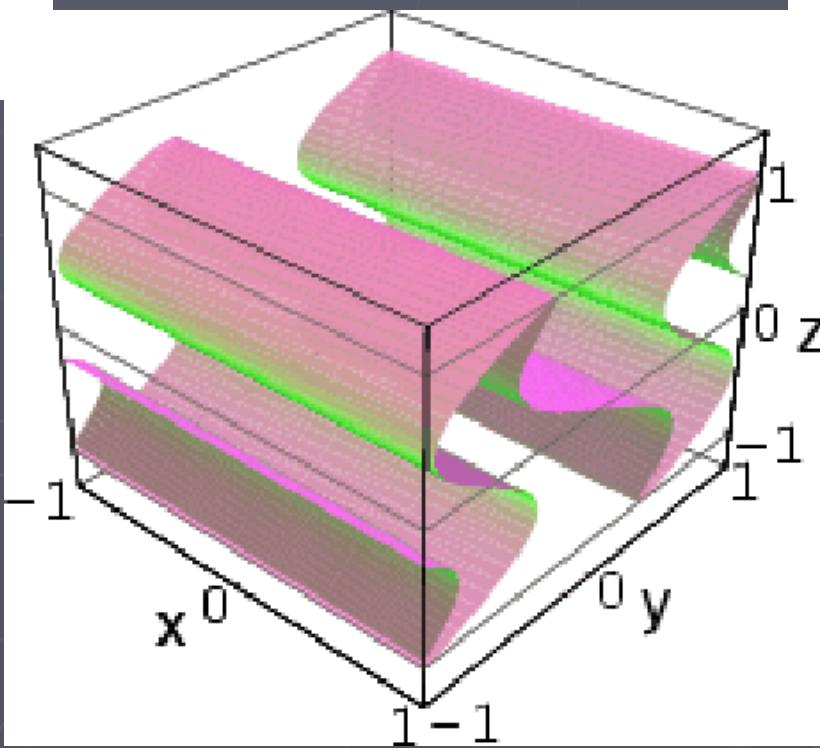
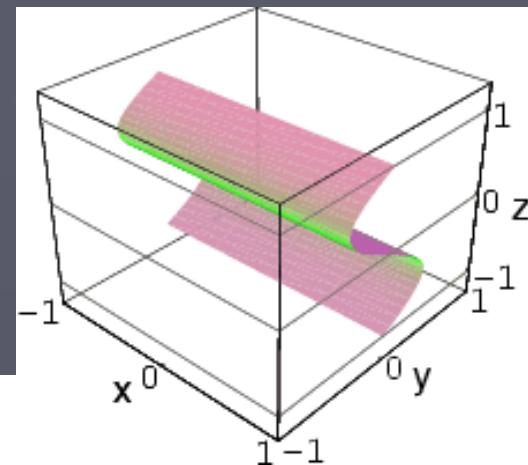
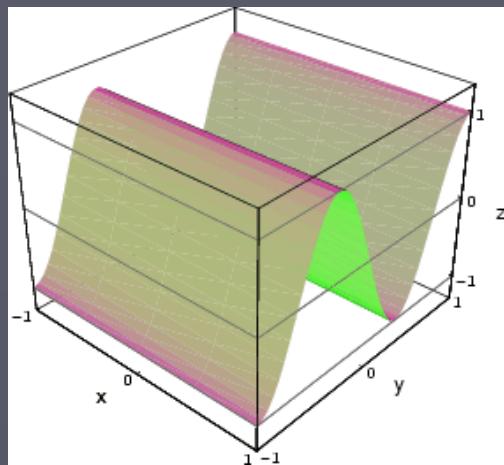


TYPE 3 EXAMPLE

- ▶ F1: Vertical Axial Plane, Horizontal Fold Axis
- ▶ F2: Horizontal Axial Plane, Horizontal Fold Axis



TYPE 1 EXAMPLE



TYPE 3 FOLD INTERFERENCE

