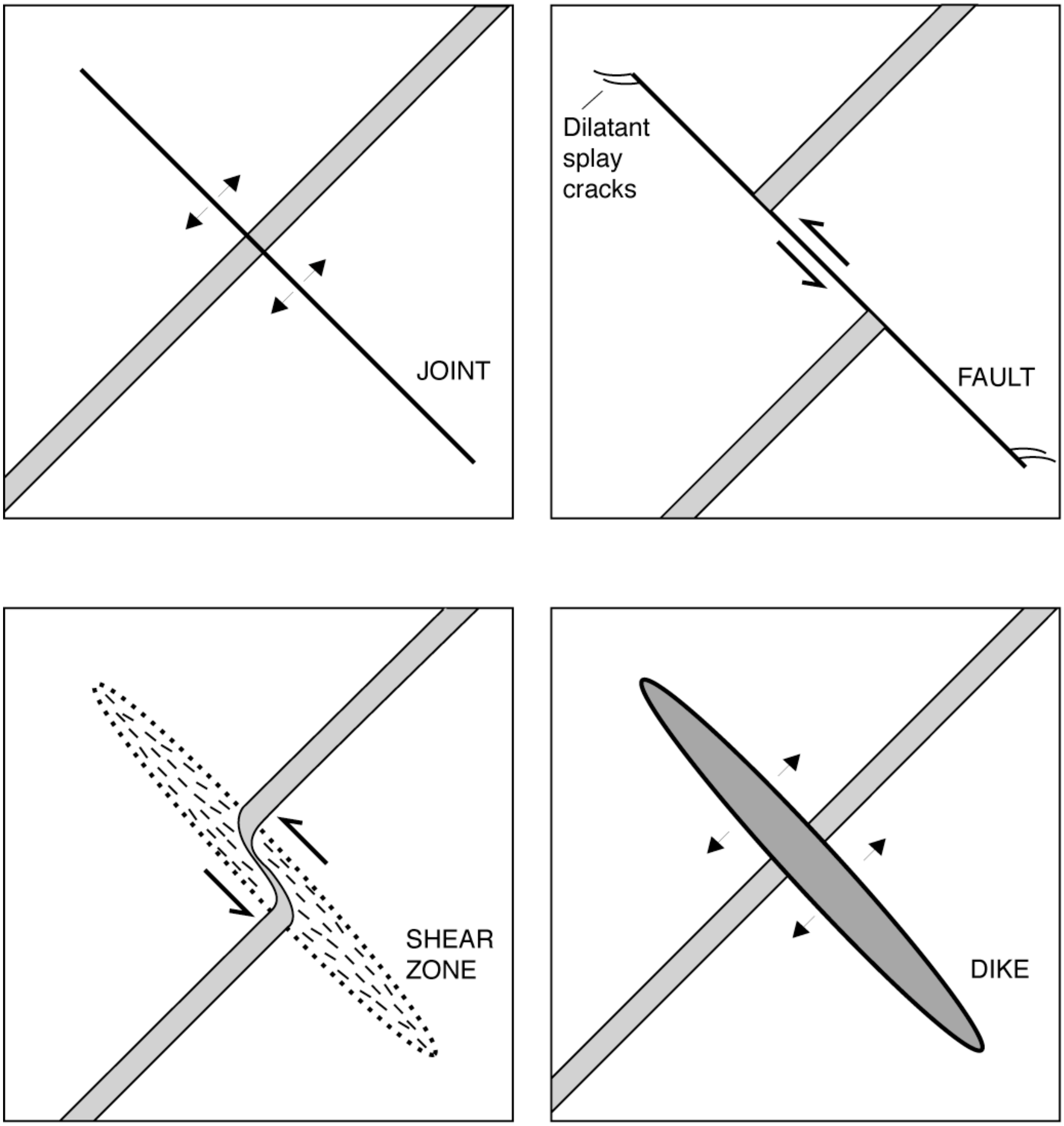
ROCK STRUCTURE ("FRACTURES AND FOLDS") (2)

I Main Topics
- A Planar geologic structures (mostly fractures)
- B Folds
- C Fabrics: grain-scale structure

II <u>Planar geologic structures (mostly fractures)</u>
- A Fractures/classification: structural discontinuities (all rock types).
- • <u>A fracture is classified according its kinematics</u> (i.e., by the relative displacement of points that were originally neighbors on opposing faces of a fracture) and not by genesis or geometry.
- • Fractures commonly occur in parallel sets and thus impart anisotropy (directional variability) to rocks.
- • Exceedingly important in crustal mechanics and fluid flow
  - 1 Joints and dikes: opening mode fractures
  - 2 Faults and fault zones: shearing mode fractures
    - a Geologic classification of faults
    - • Based on orientation of slip vector (vector joining offset neighboring points) relative to the strike and dip of a fault
    - b **Strike-slip fault**: slip vector is predominantly horizontal (i.e., parallel or anti-parallel to the line of strike)
      - 1 Right lateral: in map view <u>across</u> a fault, a marker is offset to the right
      - 2 Left lateral: in map view across a fault, a marker is offset to the right
    - c Dip-slip fault: slip vector is parallel (or anti-parallel) to dip
      - 1 **Normal fault**: hanging wall ("upper face" moves down relative to footwall ("lower face")
      - 2 **Thrust fault**: hanging wall moves up relative to footwall
    - D Oblique-slip: combination of strike slip and dip slip
- B Fractures/Geometry
  - 1 Thin relative to their in-plane dimensions (~1:1000+)
  - 2 Bounded in extent
  - 3 Grossly planar (usually)

FOUR PLANAR GEOLOGIC STRUCTURES Fig. 2.1



For joints and dikes (opening mode fractures) the relative displacement of originally neighboring points on opposing walls is perpendicular to the fracture

For shear zones and faults, the relative displacement of neighboring points is parallel to the feature

Deformation (displacement) is discontinuous across a fault

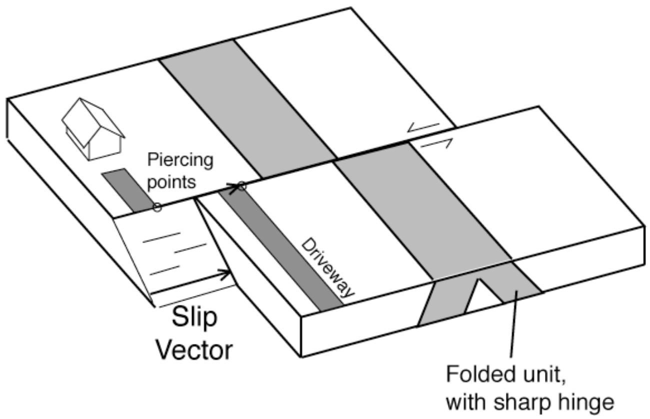
Deformation (displacement) is continuous across a shear zone

Fig. 2.2

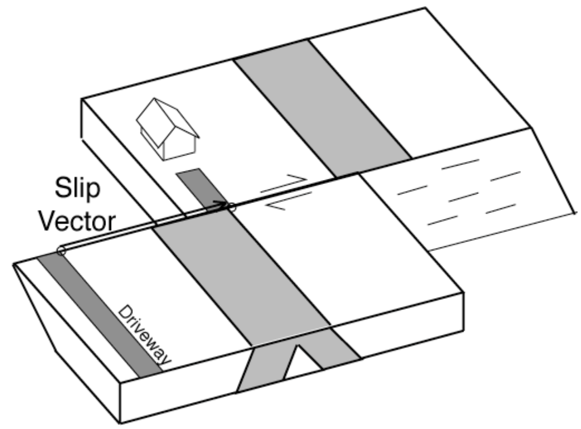
Geologic Classification of Faults

Strike-slip Faults

Left lateral

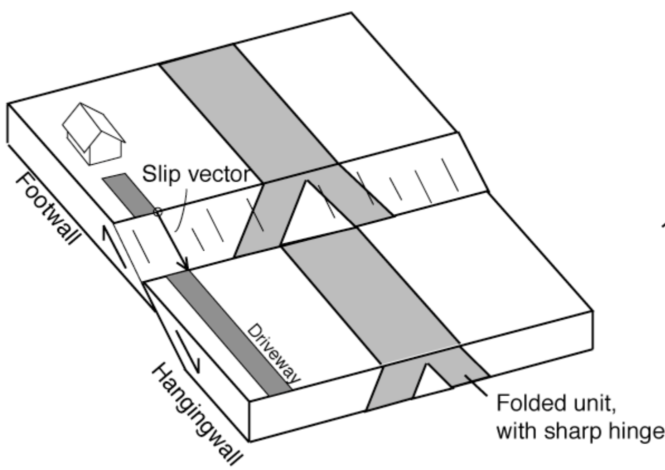


Right lateral



Dip-slip Faults

Pure normal slip



Pure reverse (thrust) slip

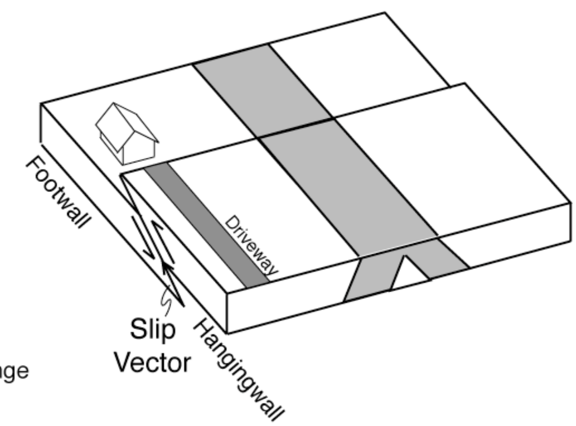
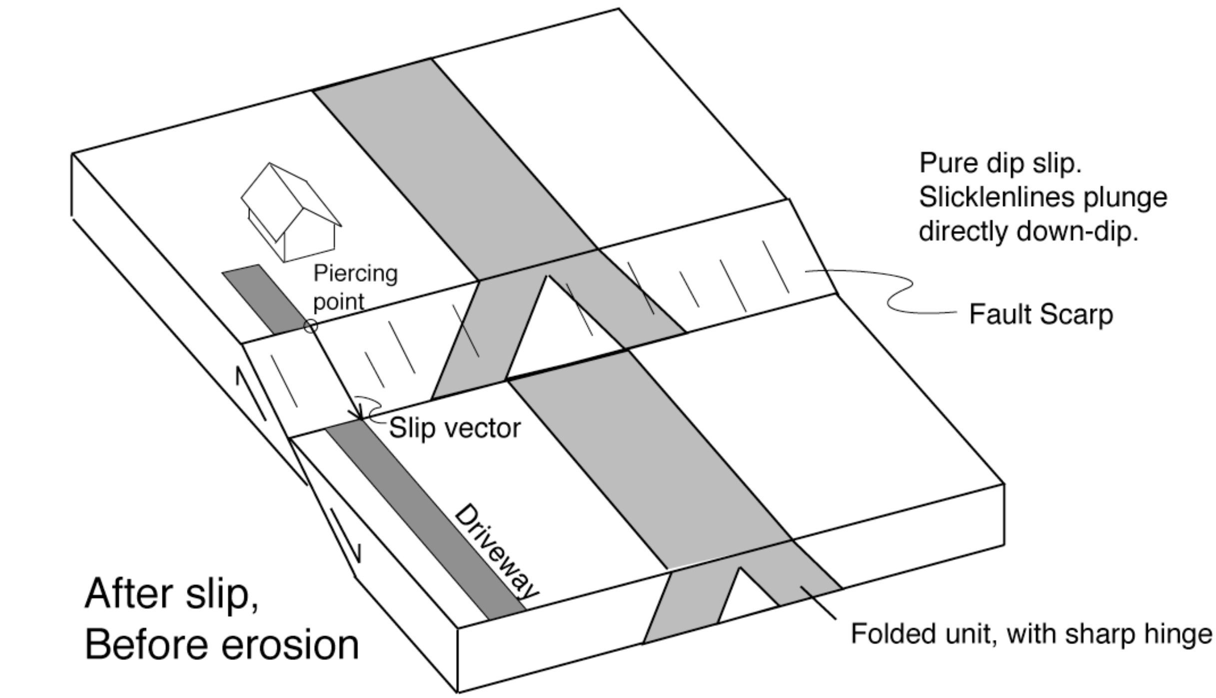
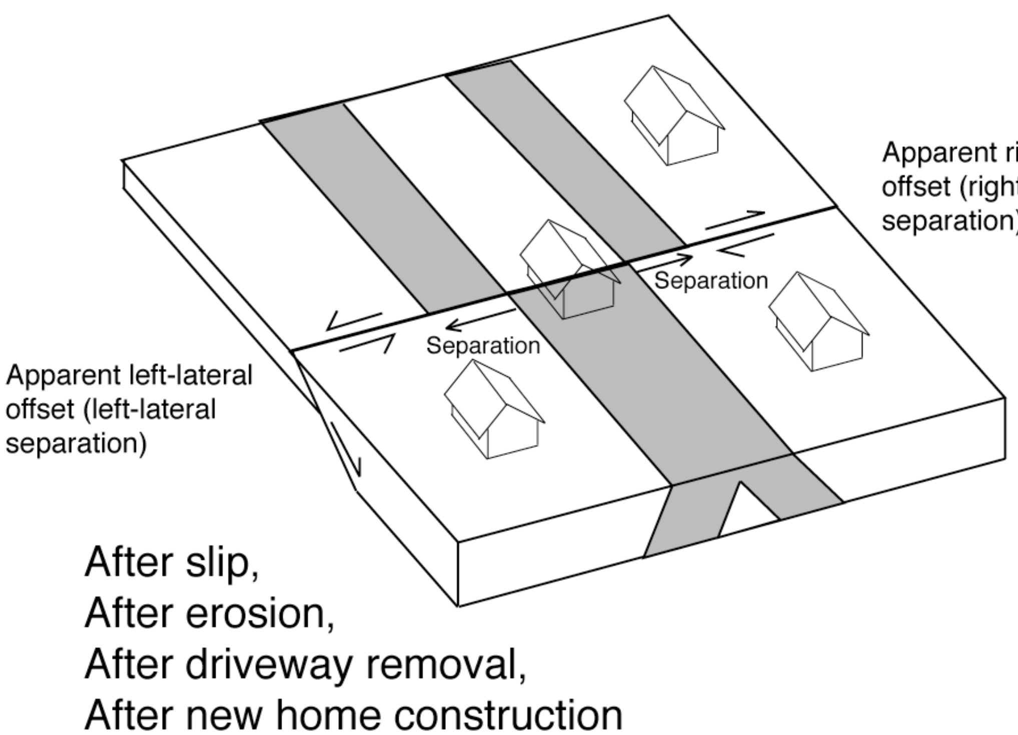


Fig. 2.3

Contrast between slip and separation





C Shear zones
1 Thin structures across which deformation is continuous but where the rate of displacement parallel to the structure changes rapidly with respect to distance perpendicular to the structure
2 Rock within shear zones commonly is foliated
3 Shear zones common in plutonic & metamorphic rocks
D Bedding planes (sedimentary rocks & volcanic rocks)
1 Sedimentological discontinuities
2 Some individual bedding planes extend for tens of km
3 Bedding planes, like joints, can slip and become faults

<u>III Folds</u>

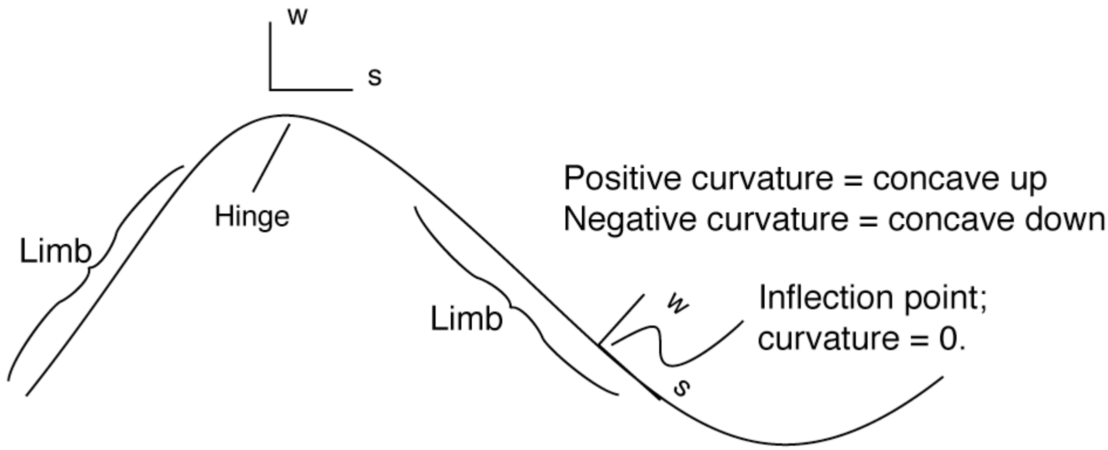
A Surfaces which have experienced, at least locally, a change in their curvature (rate at which a unit tangent or a unit normal to a surface changes with respect to distance along a surface
B Most readily identified in rocks that are layered or bound by parallel discontinuities; folds occur in all rocks, *including plutonic rocks*!
C Folding commonly causes bedding planes to slip
D Historical 2-D conceptualization of folds (see p. 6-10)
1 Fold classification factors
a Relative curvature of inner and outer surfaces of a fold
b Direction of opening of a fold (i.e., direction of curvature vector)
c Axial surface orientation (axial surface connects points of tightest curvature)
d Fold axis orientation (fold can be "generated" by fold axis)
1 Common types of folds
a Anticlines
i Oldest rocks in center of fold
ii Usually "A-shaped" (i.e., they open down)
b Synclines
i Youngest rocks in center of fold
ii Usually "U-shaped" (i.e., they open down)
E Emerging 3-D conceptualization of folds (see p. 11-14)

<u>IV Fabrics</u>: grain-scale structure (metamorphic rocks & igneous rocks)

A Foliation: preferred alignment of minerals (e.g., mica) parallel to a plane;
B Lineation: preferred alignment of minerals parallel to a line;

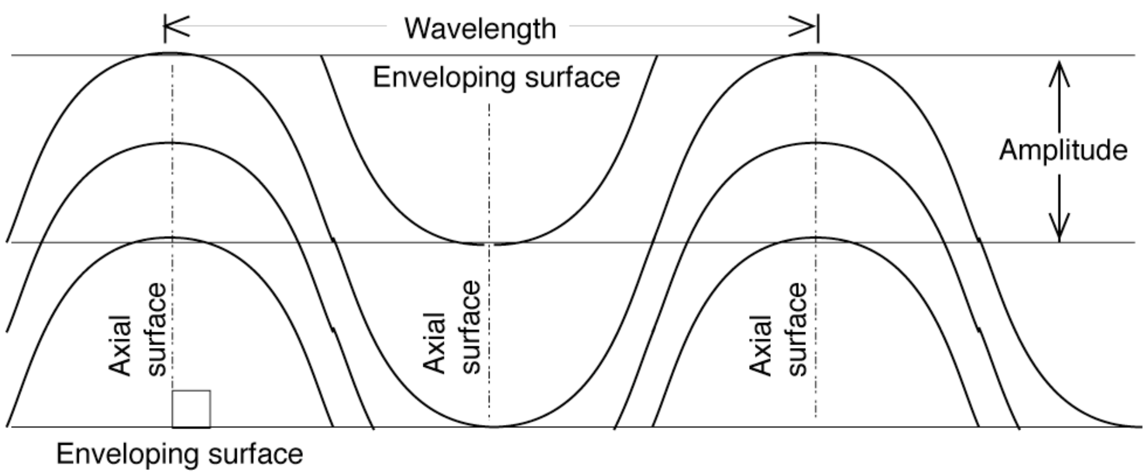
NOMENCLATURE FOR FOLDS

Fig. 2.4

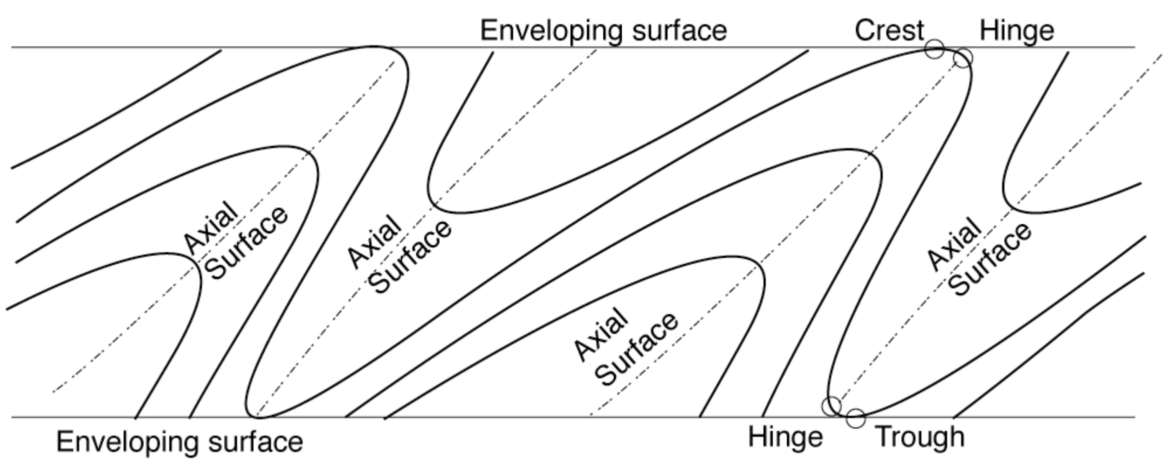


Radius of curvature is small(est) at the hinge, larg(est) on the limbs

Symmetrical Folds

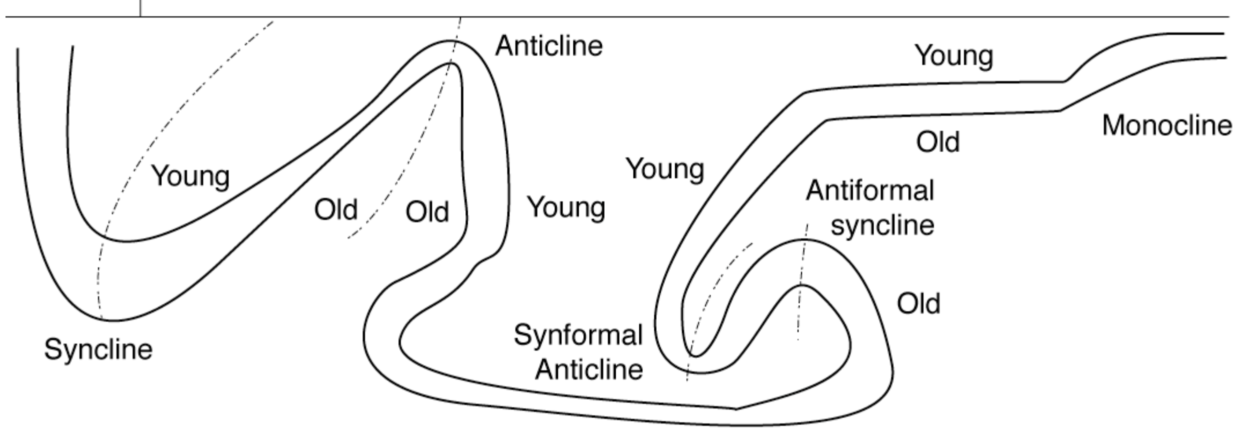


Asymmetrical Folds



NOMENCLATURE FOR FOLDS

Fig. 2.5



Syncline: fold where rocks become younger towards axial surface

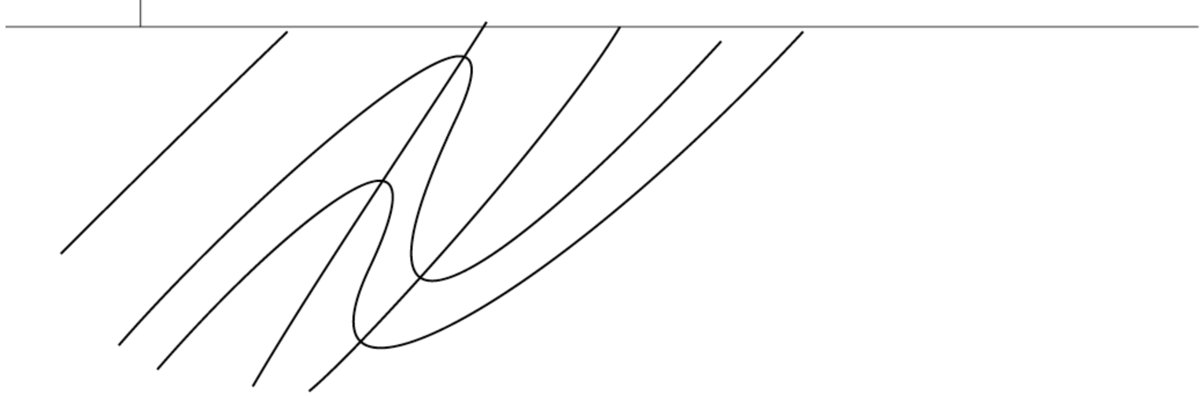
Anticline: fold where rocks become older towards axial surface

Synform: fold where limbs dip towards axial surface

Antiform: fold where limbs dip way from axial surface

Monocline: gentle anticline-syncline pair with horizontal outer limbs

Overturned folds



Overturned syncline: one limb of syncline is overturned

Overturned anticline: one limb of anticline: is overturned

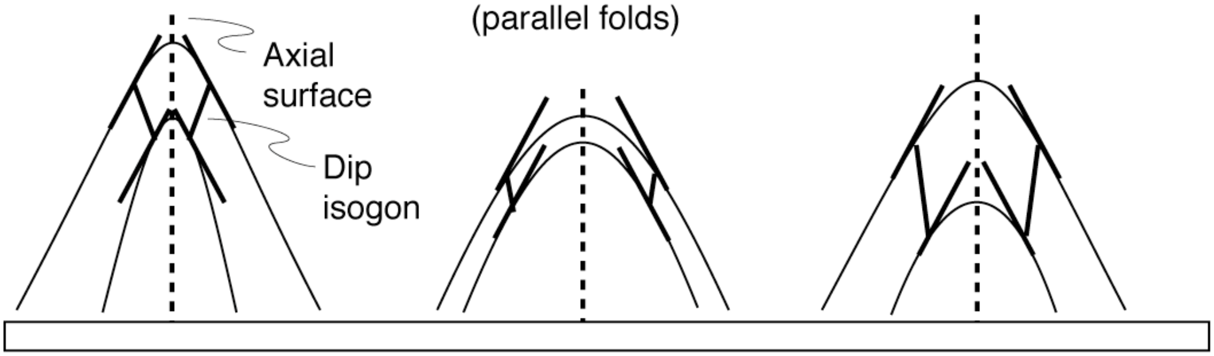
Ramsay's Fold Classification

Fig. 2.6

Dip Isogon: a line that connects points of equal dip on the top and bottom of a folded layer

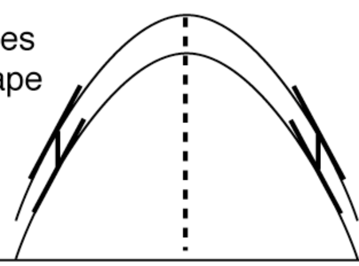
Class 1: Dip isogons converge towards axial surface; $C_{inner} > C_{outer}$

1A	1B	1C
Limbs thicker than hinges	Layer thickness is constant (parallel folds)	Limbs thinner than hinges



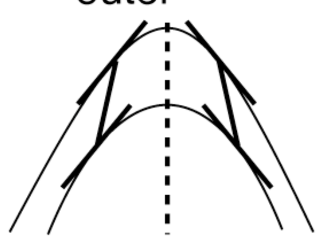
Class 2: Dip isogons parallel axial surface (similar folds); $C_{inner} = C_{outer}$

Inner and outer fold surfaces have exactly the same shape



Translate outer fold surface parallel to axial surface to match inner fold surface

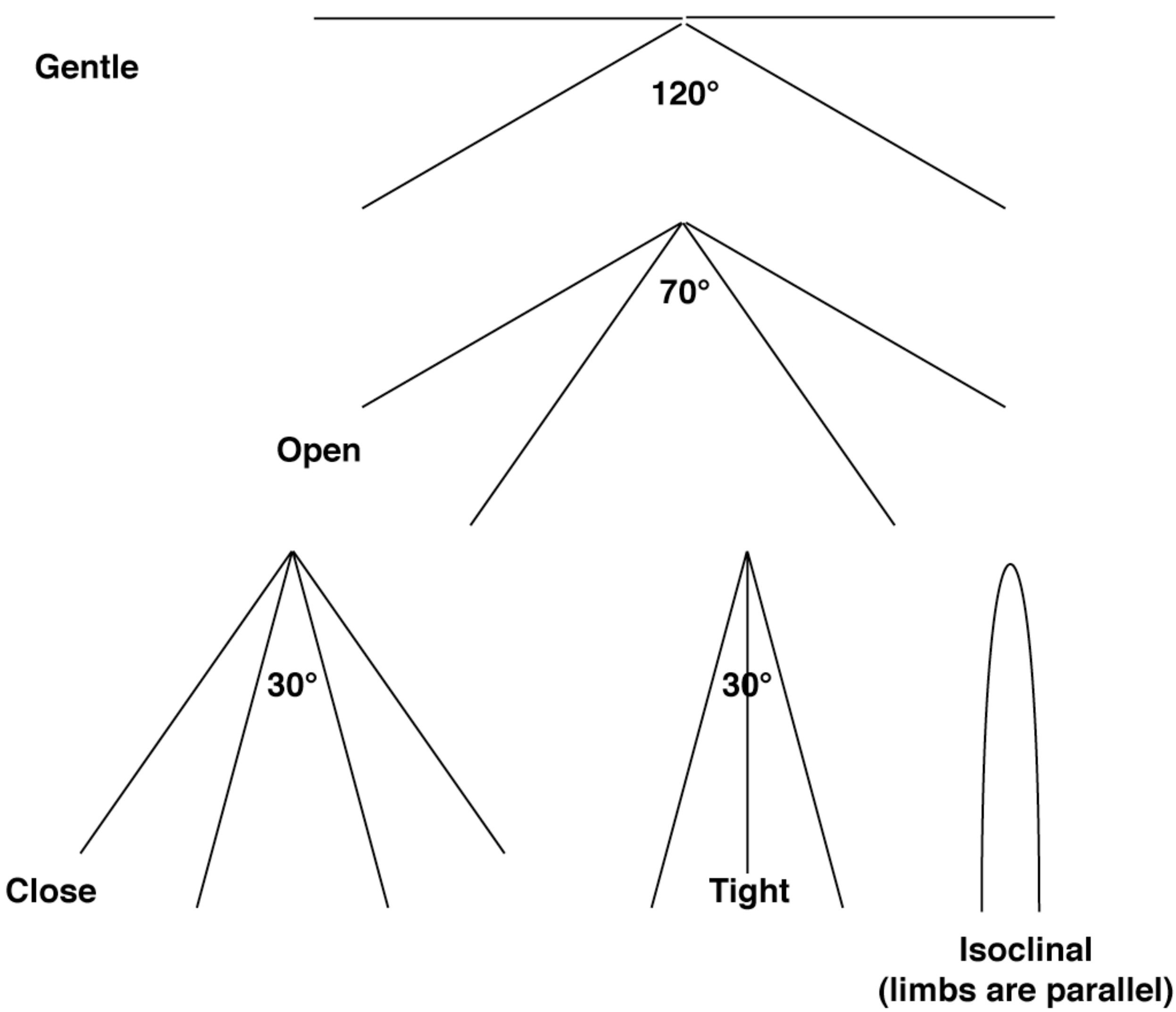
Class 3: Dip isogons diverge from axial surface; $C_{inner} < C_{outer}$



Class 3 conditions can't extend "forever" otherwise the inner and outer fold surfaces would cross

Terms for Describing the Tightness of Folds Fig. 2.7

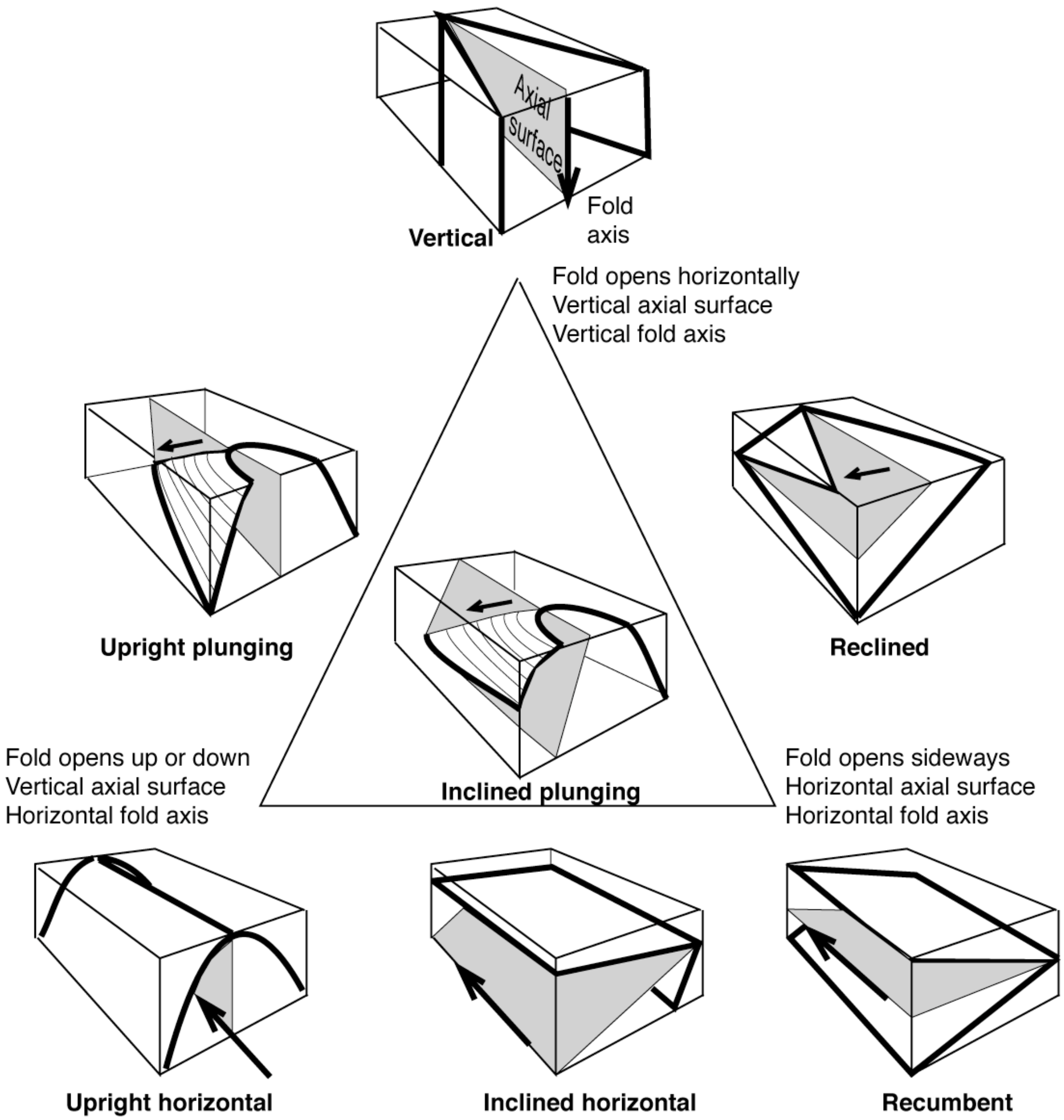
Interlimb angle	Description of fold
180° - 120°	Gentle
120° - 70°	Open
70° - 30°	Close
30° - 0°	Tight
"0°"	Isoclinal
Negative	Mushroom



Fold Classifications Fig. 2.8

(modified from Ragan, 1973, Figure 7.10)

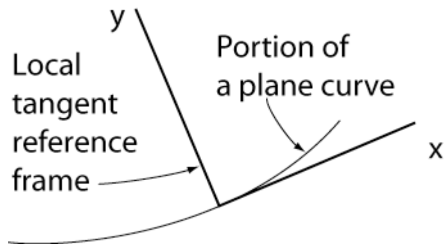
Based on direction of fold concavity, axial suface orientation, and fold axis orientation



First modifier (e.g., "upright") describes orientation of axial surface
Second modifier (e.g., "horizontal") describes orientation of fold axis

Curvature at a point along a curved surface

A Local equation of a plane curve in a tangential reference frame



At x= 0, y = 0.

At x= 0, y' = 0.

Express the plane curve as a power series of linearly independent terms:

1 $y = \left[...+ C_{-2}x^{-2} + C_{-1}x^{-1}\right] + \left[C_0 x^0\right] + \left[C_1 x^1 + C_2 x^2 + C_3 x^3 + ...\right]$.

As y is finite at x= 0, all the coefficients for terms with negative exponents must be zero. At x= 0, all the terms with positive exponents equal zero. Accordingly, since y = 0 at x = 0, C_0 = 0. So equation (1) simplifies:

2 $y = C_1 x^1 + C_2 x^2 + C_3 x^3 + ...$.

The constraint y' = 0 at x = 0 is satisfied at x = 0 only if C_1 = 0

3 $y' = C_1 x^0 + 2C_2 x^1 + 3C_3 x^2 + ... = 0$.

4 $y = C_2 x^2 + C_3 x^3 + ...$. Now examine the second derivative:

5 $y'' = 2C_2 + 6C_3 x^1 + ...$. Only the first term contributes as x → 0, hence

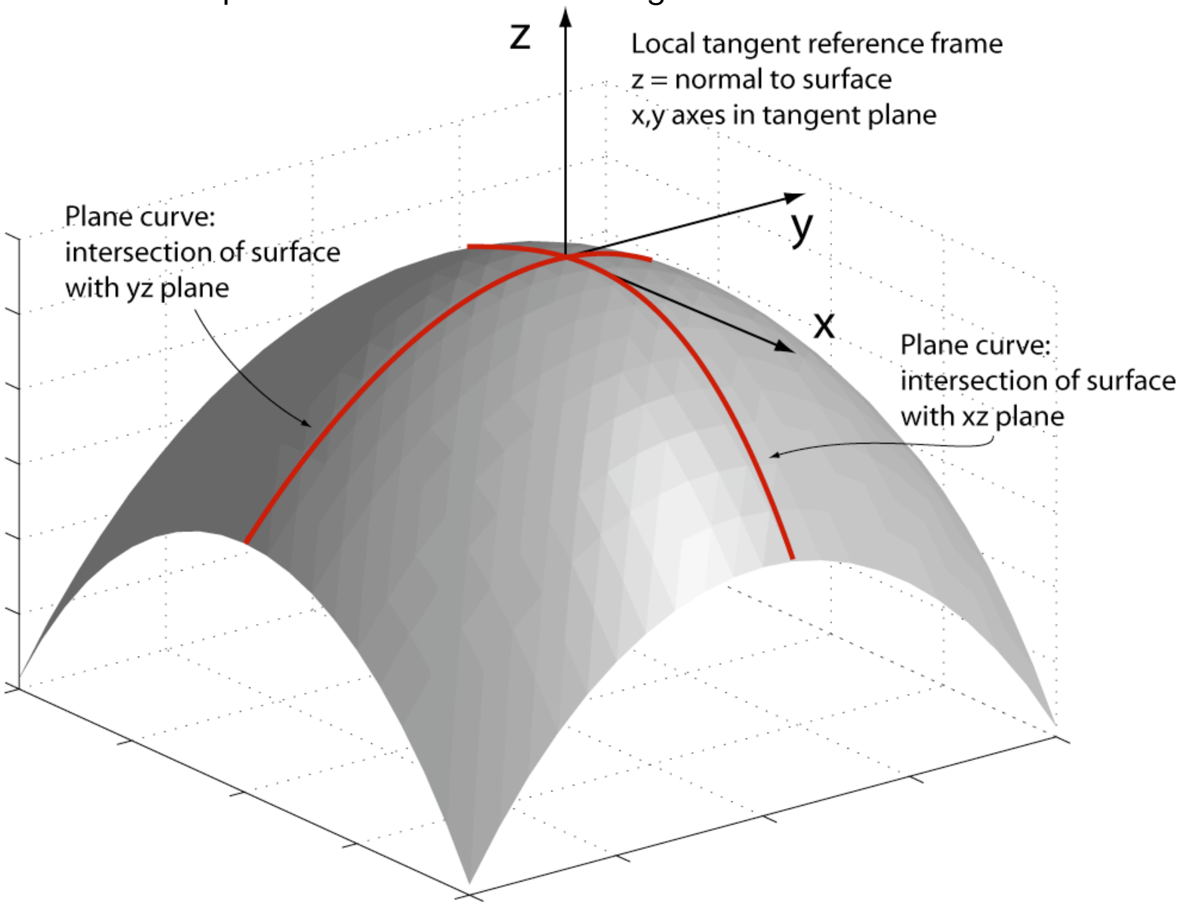
6 $\lim_{x \to 0} y = C_2 x^2$.

<u>So near a point of tangency all plane curves are second-order (parabolic).</u>

At x = 0, x is the direction of increasing distance along the curve, so

7 $\lim_{x \to 0} K = \left|y(s)''\right| = \left|y(x)''\right| = 2C_2$

B <u>Local equation of a surface in a tangential reference frame</u>



In this local reference frame, at (x= 0, y = 0), z = 0, ∂z/∂x = 0, ∂z/∂y = 0.

Plane curves locally all of second order pass through a point on a surface z = f(x,y) and contain the surface normal, so any continuous surface is locally 2nd order. The general form of such a surface in a tangential frame is

8 $z = Ax^2 + Bxy + Cy^2$,

where at (x= 0, y = 0), z = 0, and the xy-plane is tangent to the surface. This is the equation of a paraboloid: <u>near a point all surfaces are second-order elliptical or hyperbolic paraboloids.</u>

Example: curve (*normal section*) in the arbitrary plane y = mx

9 $\lim_{x\to 0, y\to 0} z = Ax^2 + Bx(mx) + C(mx)^2 = \left(A + Bm + Cm^2\right)x^2$.

The curves of maximum and minimum curvature are orthogonal (Euler, 1760).

Fold nomenclature and classification schemes

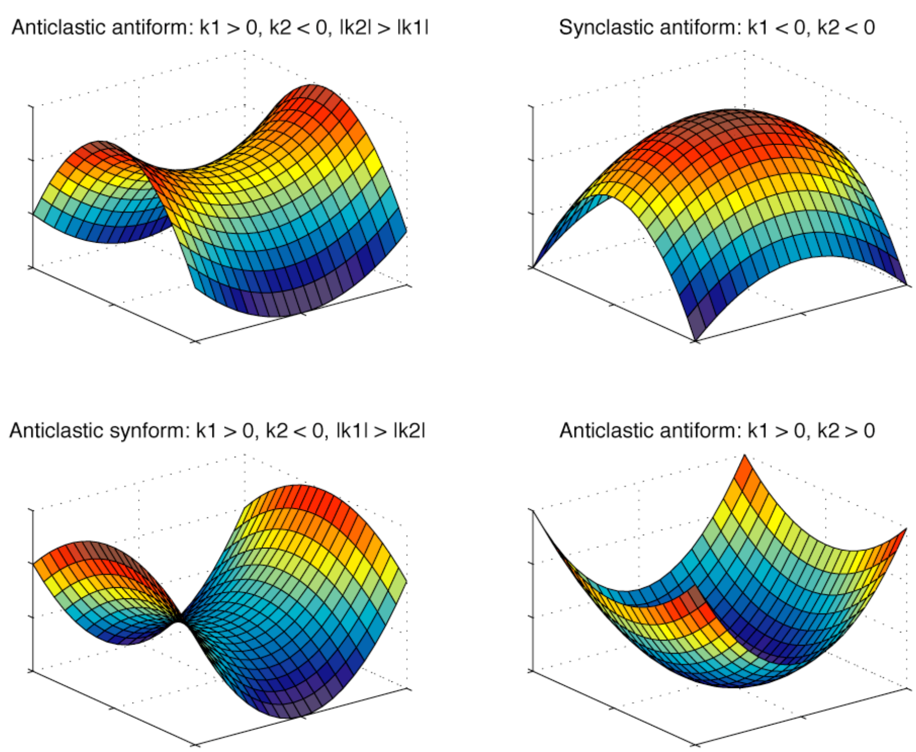
A Emerging fold terminology and classification

1 Classification of Lisle and Toimil, 2007*)

	K < 0 (Anticlastic) Principal curvatures have opposite signs	K > 0 (Synclastic) Principal curvatures have same signs
H < 0 (∩) antiform	Anticlastic antiform $k_1 > 0$, $k_2 < 0$, $\lvert k_2 \rvert > \lvert k_1 \rvert$ “Saddle on a ridge”	Synclastic antiform $k_1 < 0$, $k_2 < 0$
H > 0 (∪) synform	Anticlastic synform $k_1 > 0$, $k_2 < 0$, $\lvert k_1 \rvert > \lvert k_2 \rvert$ “Saddle in a valley”	Synclastic synform $k_1 > 0$, $k_2 > 0$

- * Lisle and Toimil (2007) consider convex curvatures as positive

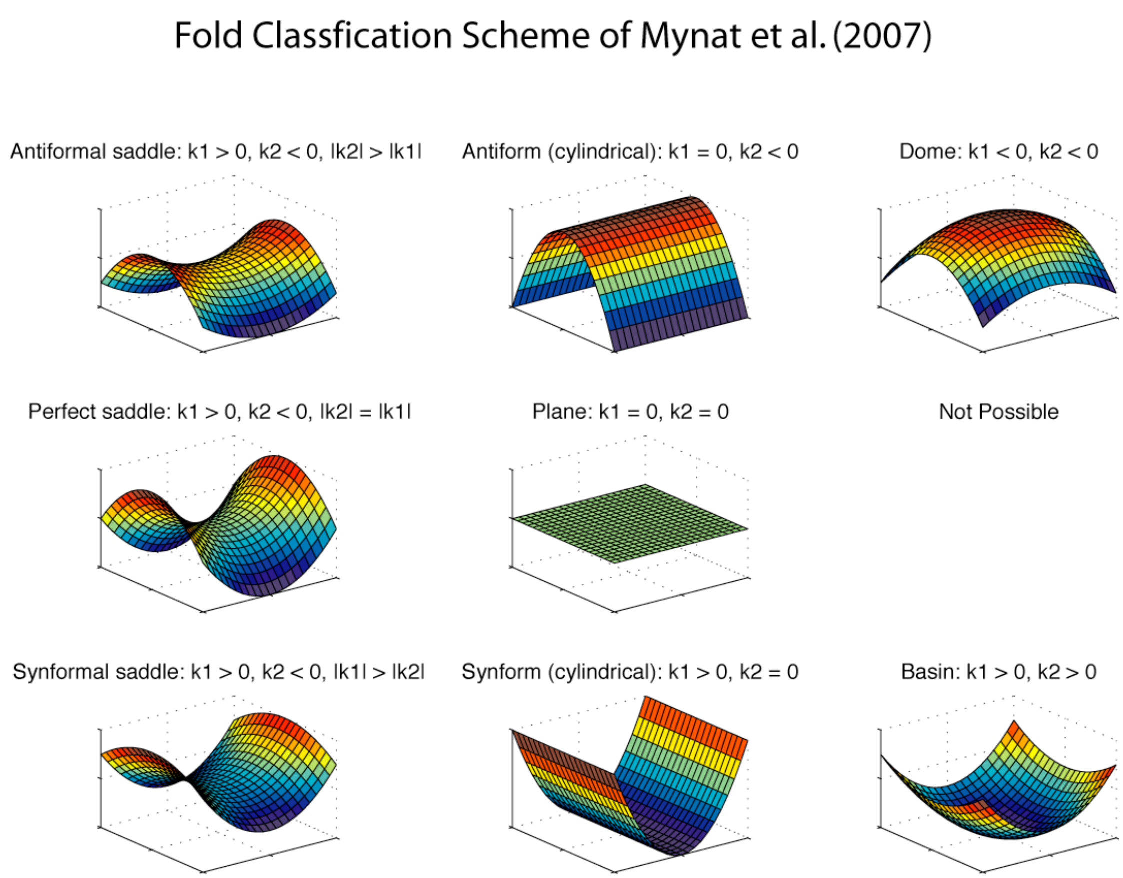
Fold Classfication Scheme of Lisle and Toimil (2007)



2 Classification of Mynatt et al., 2007

	K < 0 (saddle) Principal curvatures have opposite signs	K = 0	K > 0 (bowl or dome) Principal curvatures have same signs
H < 0 (∩) Antiform	Antiformal saddle $k_1 > 0$, $k_2 < 0$, $\lvert k_2 \rvert > \lvert k_1 \rvert$ "Saddle on a ridge"	Antiform $k_1 = 0$, $k_2 < 0$	Dome $k_1 < 0$, $k_2 < 0$
H = 0	Perfect saddle $k_1 > 0$, $k_2 < 0$, $\lvert k_2 \rvert = \lvert k_1 \rvert$	Plane $k_1 = 0$, $k_2 = 0$	Not possible
H > 0 (∪) Synform	Synformal saddle $k_1 > 0$, $k_2 < 0$, $\lvert k_1 \rvert > \lvert k_2 \rvert$ "Saddle in a valley"	Synform $k_1 > 0$, $k_2 = 0$	Basin $k_1 > 0$, $k_2 > 0$

- Mynatt et al., (2007) consider convex curvatures as positive



APPEARANCES OF PLANAR AND LINEAR FABRICS Fig. 2.9
(More than one view is commonly needed!)