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

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

II Planar geologic structures (mostly fractures)
   A Fractures/classification: structural discontinuities (all rock types).
      • A fracture is classified according its kinematics (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 across 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.
Geologic Classification of Faults

Strike-slip Faults

Left lateral

Right lateral

Folded unit, with sharp hinge

Dip-slip Faults

Pure normal slip

Pure reverse (thrust) slip

Footwall

Hangingwall

Folded unit, with sharp hinge
Contrast between slip and separation

After slip, Before erosion

Pure dip slip. Sticklenlines plunge directly down-dip.

Fault Scarp

Piercing point

Slip vector

Folded unit, with sharp hinge

After slip, After erosion, After driveway removal, After new home construction

Apparent right-lateral offset (right-lateral separation)

Apparent left-lateral offset (left-lateral 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

III  **Folds**
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)

IV  **Fabrics**: 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

Positive curvature = concave up
Negative curvature = concave down

Inflection point; curvature = 0.

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

Symmetrical Folds

Wavelength

Amplitude

Asymmetrical Folds

Enveloping surface

Crest

Hinge

Trough
NOMENCLATURE FOR FOLDS

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

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; $C_{inner} > C_{outer}$

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

Class 3: Dip isogons diverge from axial surface; $C_{inner} < C_{outer}$
Terms for Describing the Tightness of Folds

**Interlimb angle**
- 180° - 120°
- 120° - 70°
- 70° - 30°
- 30° - 0°
- "0°"

**Description of fold**
- Gentle
- Open
- Close
- Tight
- Isoclinal

Mushroom

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**Diagram**

Gentle

120°

Open

70°

Close

30°

Tight

30°

Isoclinal

(limbs are parallel)
Fold Classifications
(modified from Ragan, 1973, Figure 7.10)
Based on direction of fold concavity, axial surface 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

Express the plane curve as a power series of linearly independent terms:
1. \[ y = \left[ ... + C_{-2}x^{-2} + C_{-1}x^{-1} \right] + \left[ C_0x^0 \right] + \left[ C_1x^1 + C_2x^2 + C_3x^3 + ... \right]. \]

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. \[ y = C_1x^1 + C_2x^2 + C_3x^3 + ... . \]

The constraint \( y' = 0 \) at \( x = 0 \) is satisfied at \( x = 0 \) only if \( C_1 = 0 \)
3. \[ y' = C_1x^0 + 2C_2x^1 + 3C_3x^2 + ... = 0. \]

Now examine the second derivative:
4. \[ y'' = 2C_2 + 6C_3x + ... . \]
   Only the first term contributes as \( x \to 0 \), hence
5. \[ \lim_{x \to 0} y'' = 2C_2. \]

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

At \( x = 0 \), \( x \) is the direction of increasing distance along the curve, so
6. \[ \lim_{x \to 0} K = \frac{|y''(x)|}{|y'(x)|} = |y'(x)| = 2C_2 \]
B Local equation of a surface in a tangential reference frame

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

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

\[ z = Ax^2 + Bxy + Cy^2, \]

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

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

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

The curves of maximum and minimum curvature are orthogonal (Euler, 1760).
### Fold nomenclature and classification schemes

#### A Emerging fold terminology and classification

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>K &lt; 0</strong> (Anticlastic)</td>
<td>Principal curvatures have opposite signs</td>
</tr>
<tr>
<td><strong>K &gt; 0</strong> (Synclastic)</td>
<td>Principal curvatures have same signs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>H &lt; 0 (∩) antiform</th>
<th>Anticlastic antiform</th>
<th>Synclastic antiform</th>
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</thead>
<tbody>
<tr>
<td>( k_1 &gt; 0, k_2 &lt; 0,</td>
<td>k_1 &gt; 0, k_2 &lt; 0,</td>
<td>k_1 &lt; 0, k_2 &lt; 0</td>
</tr>
<tr>
<td>(</td>
<td>k_2</td>
<td>&gt;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>H &gt; 0 (∪) synform</th>
<th>Anticlastic synform</th>
<th>Synclastic synform</th>
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</tr>
<tr>
<td>(</td>
<td>k_2</td>
<td>&gt;</td>
</tr>
</tbody>
</table>

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

Fold Classification Scheme of Lisle and Toimil (2007)

- Anticlastic antiform: \( k_1 > 0, k_2 < 0, |k_2| > |k_1| \)
- Synclastic antiform: \( k_1 < 0, k_2 < 0 \)
- Anticlastic synform: \( k_1 > 0, k_2 < 0, |k_1| > |k_2| \)
- Anticlastic antiform: \( k_1 > 0, k_2 > 0 \)
## 2 Classification of Mynatt et al., 2007

<table>
<thead>
<tr>
<th></th>
<th>$K &lt; 0$ (saddle)</th>
<th>$K = 0$</th>
<th>$K &gt; 0$ (bowl or dome)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Principal curvatures have opposite signs</td>
<td></td>
<td>Principal curvatures have same signs</td>
</tr>
<tr>
<td>$H &lt; 0$ ($\cap$)</td>
<td>Antiformal saddle</td>
<td>Antiformal</td>
<td>Dome</td>
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<tr>
<td>Antiform</td>
<td>$k_1 &gt; 0$, $k_2 &lt; 0$, $</td>
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<td>&gt; lk_1$</td>
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<tr>
<td>$H = 0$</td>
<td>Perfect saddle</td>
<td>Plane</td>
<td>Not possible</td>
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- Mynatt et al., (2007) consider convex curvatures as positive

Fold Classification Scheme of Mynat et al. (2007)
APPEARANCES OF PLANAR AND LINEAR FABRICS

(More than one view is commonly needed!)

**Planar Fabric**
All elements parallel the fabric plane
Elements do not parallel a common line

**Linear Fabric**
All elements parallel a common line
Elements do not parallel a common plane

Planar elements
Plane of fabric

Linear elements

Mixed linear and planar elements

Lineation direction