**Rock Deformation (Chapter 9)**

Rocks may deform in variety of ways in responses to stresses, largely imposed by plate tectonic processes. The record of rock deformation, in the form of macroscopic features such as folds and faults, provides valuable information on the tectonic history of an area. Whether rocks respond to these differential stresses by folding or faulting is determined by the pressure, temperature, composition of the rock and the rate at which the stresses are applied. We will examine the major types of folds and faults, as well as the relationship of these features to the tectonic settings in which they occur.

Stress and Strain

- stress (force/area) results in strain (change in size, shape, position)
- stress at a point may be described in terms of three principal stresses
  - $\sigma 1 > \sigma 2 > \sigma 3$ (convention is that compression is positive so that the $\sigma 3$ is the least compressive stress = tension)
- hydrostatic stress versus differential stress (three general types)
  1. compressive - $\sigma 1 > \sigma 2 = \sigma 3$ convergent margins
  2. tensional - $\sigma 1 = \sigma 2 > \sigma 3$ divergent margins
  3. shearing - transform margins

Brittle versus Ductile Deformation: Stages of Deformation

1. Elastic deformation
2. Ductile deformation
3. Failure

Brittle-Ductile Transition and Lithospheric Plates

Strike and Dip as representation of deformed planar layers

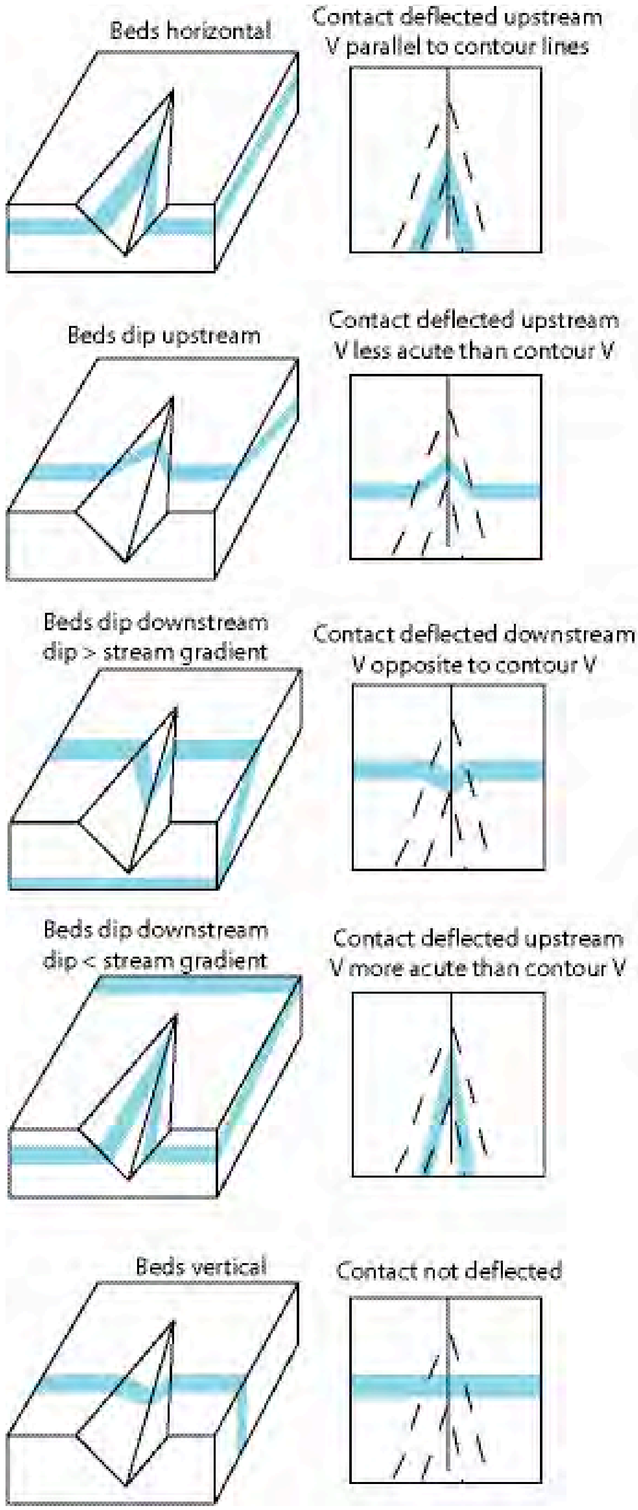
Fault terminology and types of faults

- hanging wall versus footwall
- fault types and relationship to principal stresses
- determining slip on a fault
- oceanic transform faults

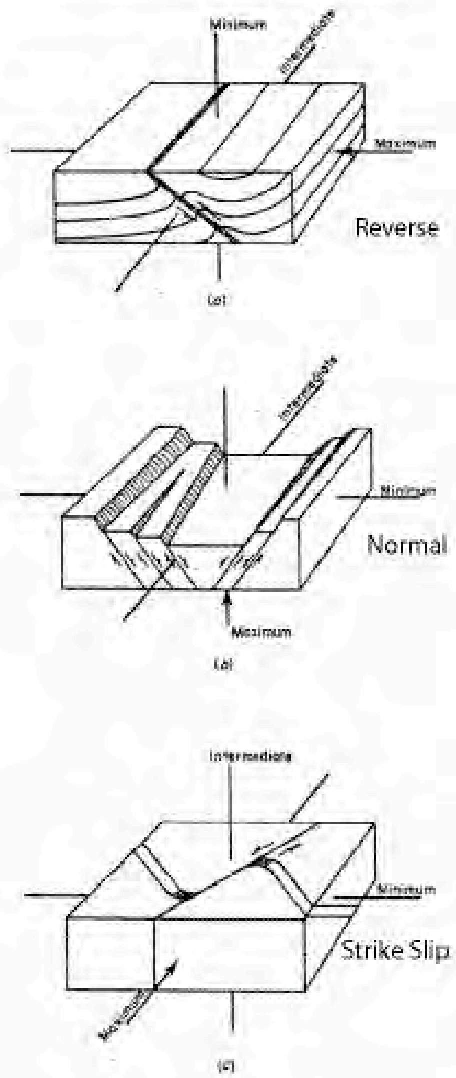
Fold terminology

- fold axis, axial plane (surface), fold limbs
- anticline versus syncline
- representation of folds in map view and cross section
- topographic expression of folds

Law of “V”s for contacts between planar beds




Relationship of faults
and principal stress directions



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## Stress and strain revisited

*stress* = force/area [N/m2 = Pa]
result of stress is *strain* (change in size, shape, position)

One dimensional case: Hooke's law
strain = K * stress = change length/length

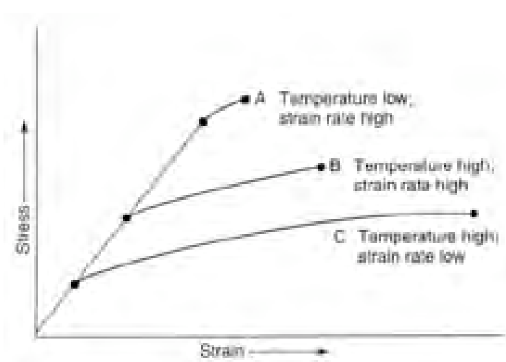
Three dimensional case:
stress at a point: $\sigma1 > \sigma2 > \sigma3$
principal stresses are eigenvalues of 2nd rank stress tensor (shear = 0)
normal and shear stresses

*hydrostatic*: $\sigma1 = \sigma2 = \sigma3$
*differential*:
$\sigma1 > \sigma2 = \sigma3$ (axial compression)
$\sigma1 = \sigma2 > \sigma3$ (axial tension)
$\sigma1 > \sigma2 > \sigma3$ (general)

importance: we'll see later that faulting develops at particular angle to $\sigma1$
also, fault orientation and displacement used to infer stress

## Response of rocks to differential stress

Stages of deformation of geologic materials
1) elastic deformation (recoverable)
inflection point is elastic limit
2) ductile deformation
3) failure (fracture)




Factors determining type of deformation
1) pressure
2) temperature

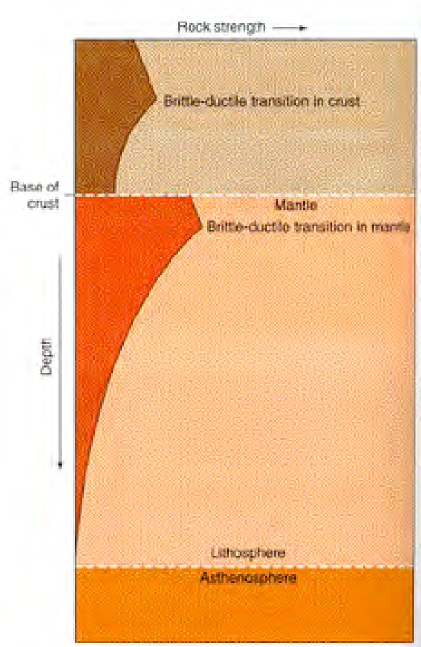
3) strain rate
4) composition
e.g. salt (density = 2.2, flows at 100-200C)
development of salt domes and importance for oil exploration

more typical minerals (Q,Feld) ductile at temperatures of 300-400C

importance of water

**Brittle-ductile transition in the lithosphere**

Of the determining factors for rheology, temperature is perhaps the most important. This is most evident in how the lithosphere and crust respond to deformation.




reduction in strength of crust at 15-20 km << softening of Q, Feld
in upper mantle, Ol, Px are stronger materials
strength again decreases with depth
asthenosphere = depth at which brittle deformation ceases

oceanic lithosphere
examine a cross section of oceanic lithosphere
> crust generated at ridge crest (NB: constant thickness)
> given strong role of temperature, predict that lith. thickness varies
> thickness (as well as depth) proportional to sqrt(age)

Is continental lithosphere likely to be thicker or thinner than oceanic? why?

**Strike and Dip**

From field trip, you should already be familiar with the concept of strike and dip.

*strike* = azimuth of horizontal line within a plane (note 0-360 convention)
*dip* = angle of plane with horizontal, measured perpendicular to strike

conventions for plotting strike/dip on a map

**Fault types**

Evidence of brittle deformation (joints, fractures as well)

1) *Normal* faults
   general terminology
      *hanging wall*
      *footwall*
   stress: tension (setting: ridge crest, continental rifting)
   relationship to max stress (fault at 30° to $\sigma1$, $\sigma3$ horizontal)
   so normal faults typically have steep dip (about 60°)

   special types: graben, horst (ridge crest), half grabens
   why might angle of listric normal fault change with depth?

2) *Reverse* faults
   stress field: compression ($\sigma1$ horizontal, $\sigma3$ vertical)
   setting: convergent margins
   angle of reverse faults typically low (recall 30° from sigma 1)
   *thrust* faults (dip < 15°)
   important in mountain belts
   geologic map signature: older rocks onto younger rocks

3) *Strike slip* faults
   generally high angle faults
   left lateral vs right lateral
   orientation of $\sigma1$ and $\sigma3$ (both horizontal)

   expression of strike slip faults
      pull apart basins and uplift
      folds

*Oblique* faults
   general case: typically motion on fault is not purely one of endmembers

*Determining slip on a fault*

marker beds: planar features give part of the slip
piercing points: e.g. channels give actual slip
slickensides

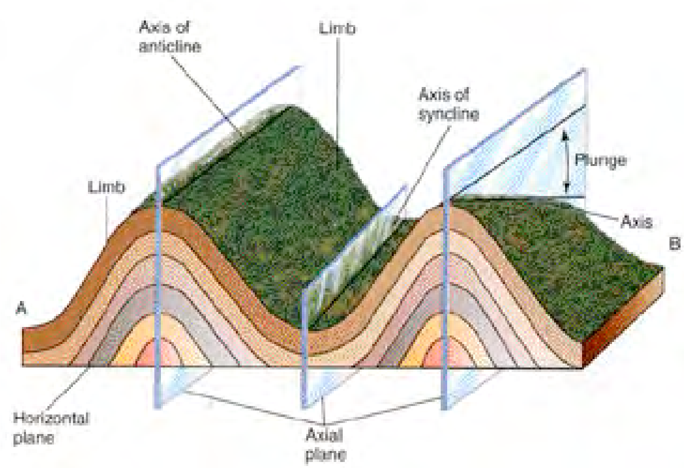
*Transforms* - a special type

sketch a transform
isochrons - from magnetic anomalies
sense of motion based on the above types apparently strike slip
but actual motion at ridge ...

*transform fault* - name from transformation of sense of motion
*fracture zone* - scar of transform fault
discussed earlier role of temperature in determining depth of seafloor
what would you expect the depth change to be across FZ?

**Types of folds (ductile deformation)**

Some terminology
fold limb
axial plane = most nearly divides fold into symmetric parts
axis of fold = median line (in axial plane)




Anticlines and synclines
block diagram
associated map view
role of dip in determining outcrop thickness

Signatures of plunging folds

Topography and the expression of folds
resistant units form ridges

drainages affected

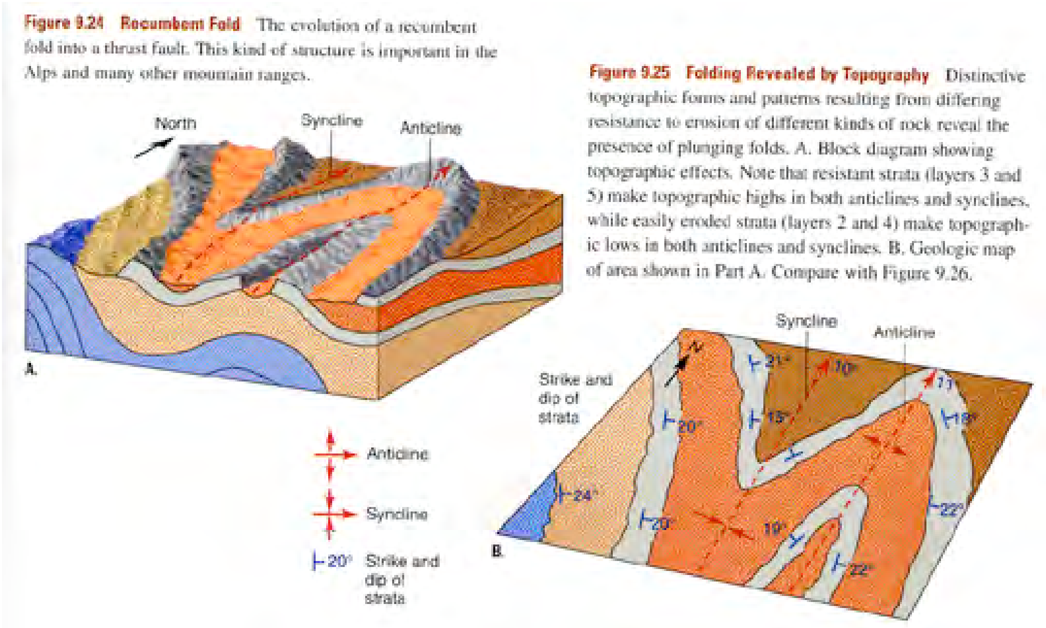



**Figure 9.24 Recumbent Fold** The evolution of a recumbent fold into a thrust fault. This kind of structure is important in the Alps and many other mountain ranges.

**Figure 9.25 Folding Revealed by Topography** Distinctive topographic forms and patterns resulting from differing resistance to erosion of different kinds of rock reveal the presence of plunging folds. A. Block diagram showing topographic effects. Note that resistant strata (layers 3 and 5) make topographic highs in both anticlines and synclines, while easily eroded strata (layers 2 and 4) make topographic lows in both anticlines and synclines. B. Geologic map of area shown in Part A. Compare with Figure 9.26.

**Geologic maps and the law of "V"s**

Some important information can be gleaned from geologic maps simply by looking at the relationship between planar geologic contacts and streams (the other law of "V"s).

a. Signature of horizontal beds
b. Signature of vertical beds
c. Dipping beds

Older beds dip toward younger beds.
Contacts migrate in direction of dip at lower elevations.