

**Geological Structures**

**Geological structures = rock deformation resulted from the change in stress through geological time.**

Why change in stress?  
**Tectonic processes are responsible for the change in stress**



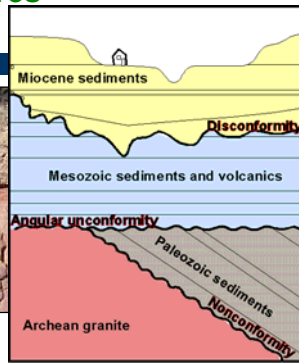
**Geological Structures**

**Common structures**

1. Faults
2. Folds
3. Joints
4. Unconformities



## Common Structures - Unconformities



## Stress

- Stress is the force applied to each unit area in a particular direction
- Vector quantity
- Measured in pascals,  $N/m^2$
- Normal stress
- Shear stress

## Geological Structures

### Implications

1. Tectonic history
2. Mineral exploration
3. Gas and oil exploration
4. Geotechnical engineering

## Type of Stresses

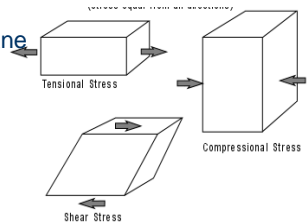
### Normal stress

Perpendicular to plane

- Extensional stress
- Compressional stress

### Shear stress

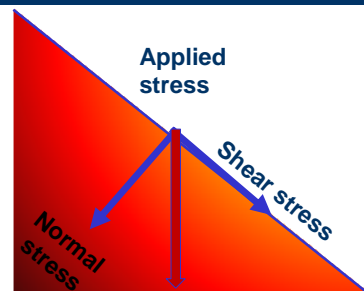
Parallel to plane



## Stress and Strain

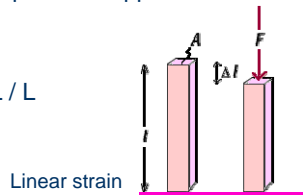
The concepts of **stress**, **strain** and **material behavior** are fundamental to the understanding of geological structures including faults and folds

## Reality: Stress Decomposition



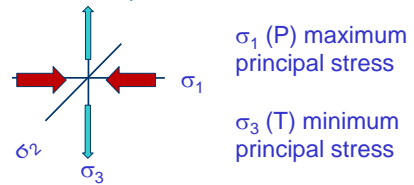
## Strain

- When rocks deform they are said to **strain**
- A strain is a change in size, shape, or volume of a material in response to applied stress
- Strain is given in fraction, no unit
- Linear strain =  $\Delta L / L$



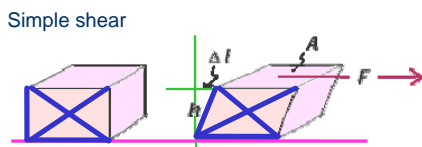
## Principal Stress Directions

The stress state at any given point can be described by a system of **three principal stresses**, normal to each other and along which there are no shear stress components.

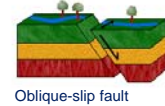
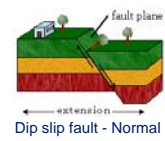
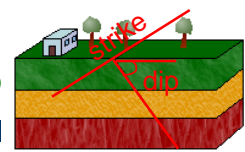


## Shear Strain

- Causes rotation
- Changes in angular relation
- Shear strain differs in different directions

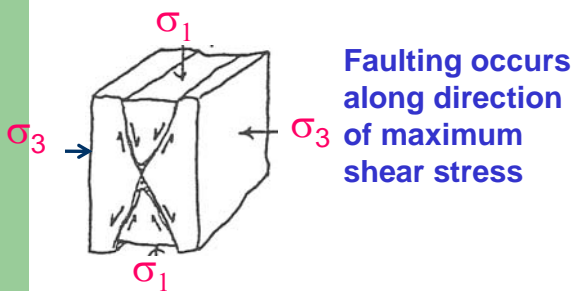


## Strike, Dip and Slip

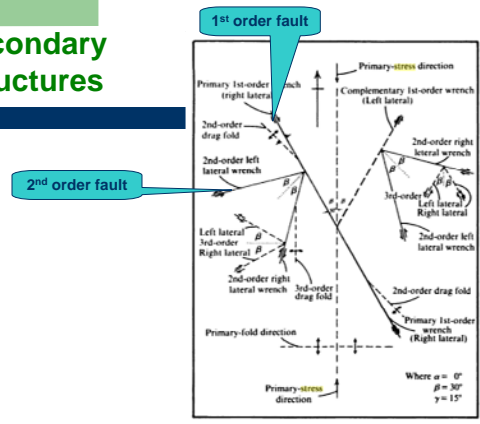


Pictures courtesy of IRIS

## Relationship between principal stresses and faults



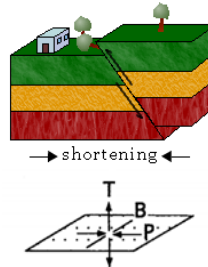
## Secondary Structures



## Classification of Faults

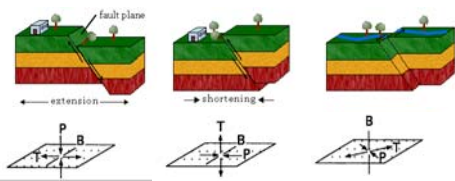
- **Dip-slip fault**
  - Normal fault
  - Reverse fault
  - Thrusting fault
  - Listric normal fault
- **Strike-slip fault**
  - Right-lateral strike slip
  - Left-lateral strike slip
- **Oblique-slip fault**

## Reverse Fault



- Maximum principal stress  $\sigma_1$  horizontal
- Minimum principal stress  $\sigma_3$  vertical

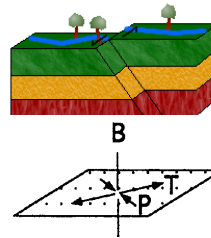
## Fault and Stress



P: maximum  
B: intermediate  
T: minimum

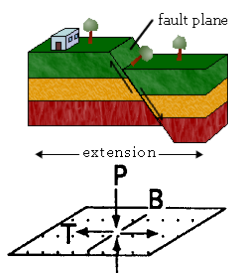
**Normal**      **Reversed**      **Strike-slip**

## Strike-slip Fault



- Both maximum and minimum principal stresses horizontal
- Intermediate principal stress  $\sigma_2$  vertical

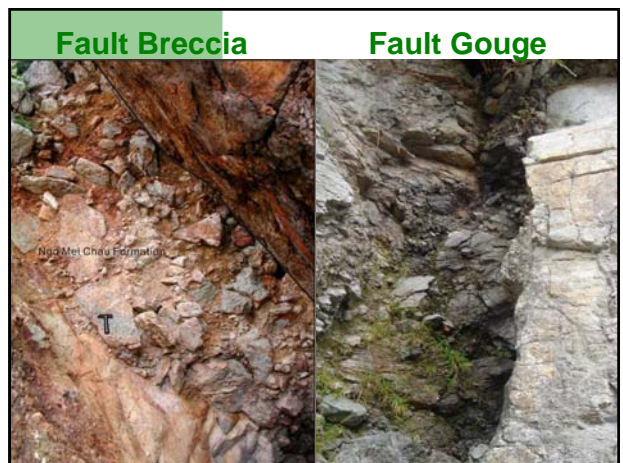
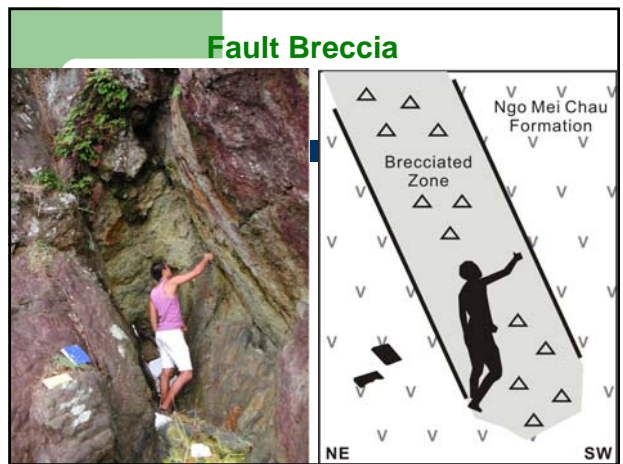
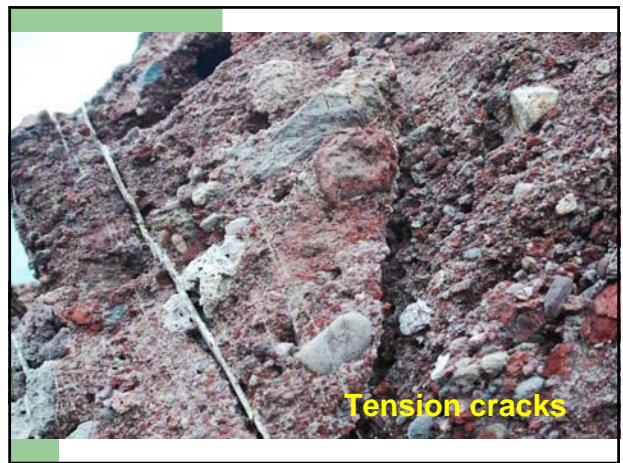
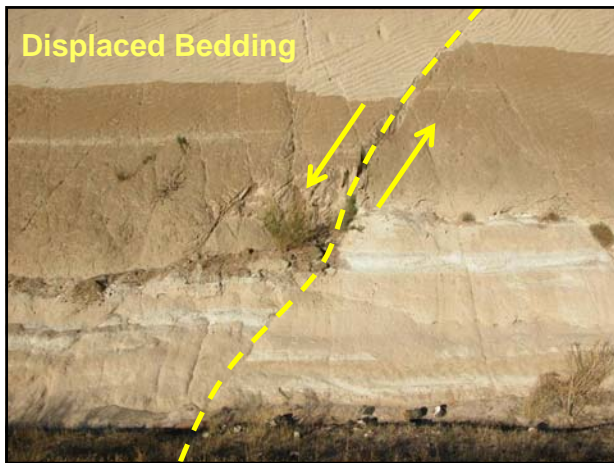
## Normal Fault

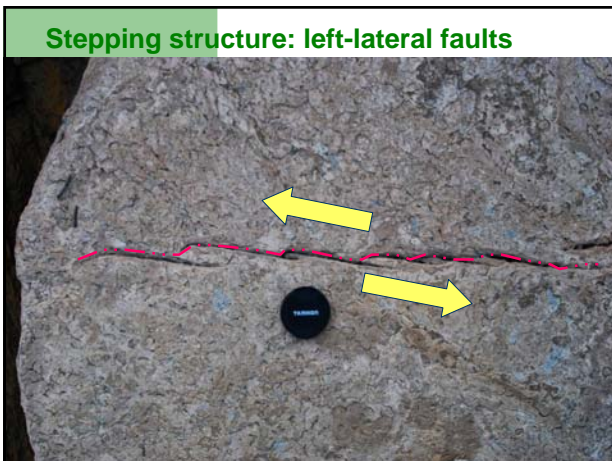
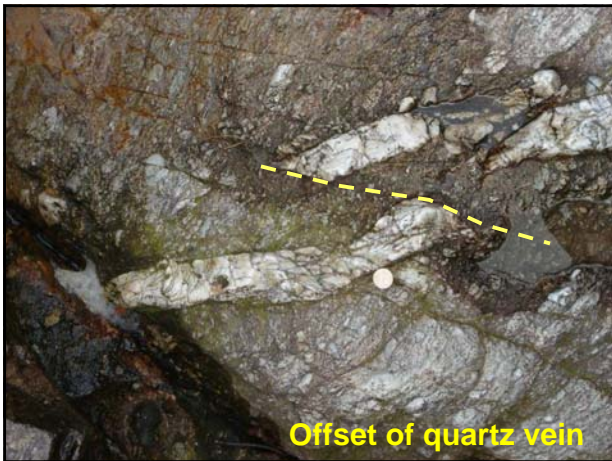


- Maximum principal stress  $\sigma_1$  vertical
- Minimum principal stress  $\sigma_3$  horizontal

## Field Evidence for Faults

- Offsets & sheared pebbles
- Fault breccia
- Fault gouge
- Quartz veins
- Mineralization and bleached zones
- Cleavages and Riedels
- Fault-related landforms

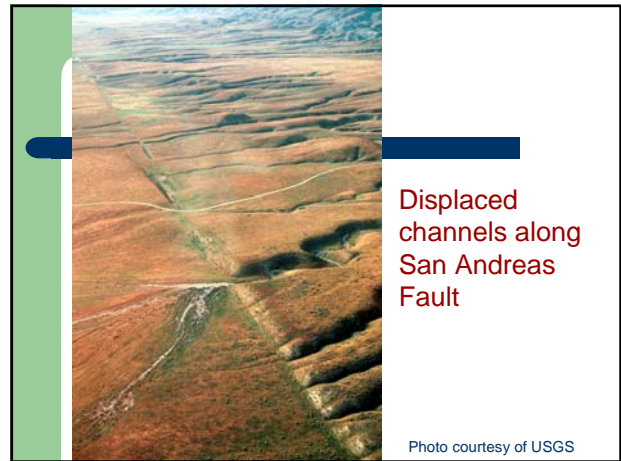






## Fault-related landforms

- Linear depressions
- Displaced stream channels
- Fault scarps
- Springs & ponds
- Raised terraces and waterfalls

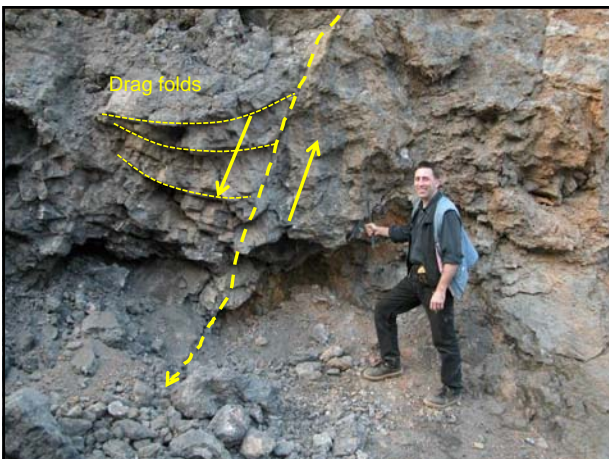
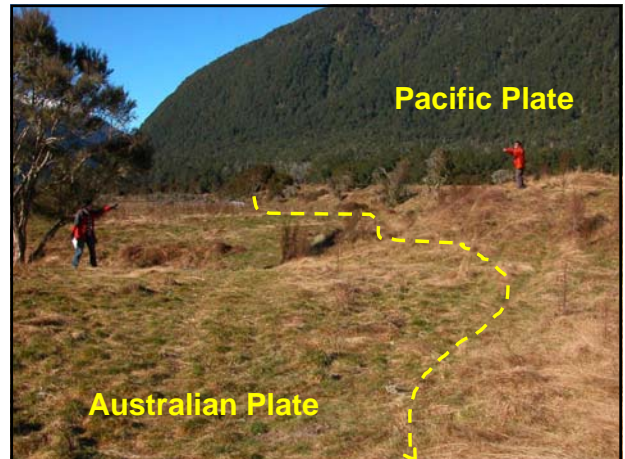




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Earthquake & Landform  
- waterfall  
Waterfalls can form in  
matters of seconds





### Northern Tibet: Triangular facets are fault scarps



### Polished surface



### Horst-and-Graben



USGS Horst & Graben

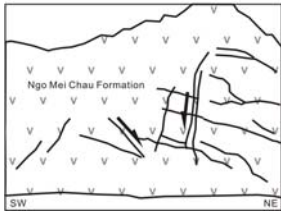
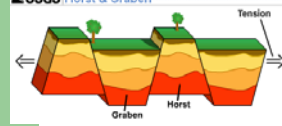


Illustration courtesy of USGS



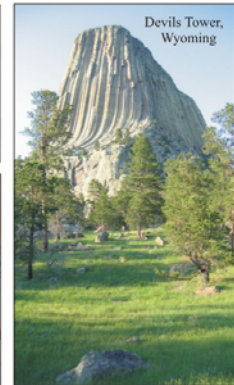
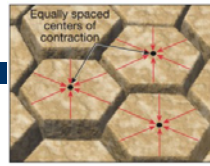
### Horst-and-Graben



## Joints

- Cooling joints
- Tension joints

## Columnar Joint



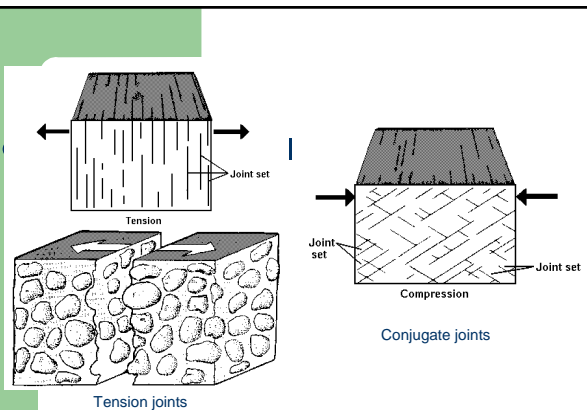
## Cooling joints: Ninepin Islands



## Columnar Joint

As solidifying material contracts, because the whole volume of rock is contracting, evenly-spaced centers of contraction develop.

Cracks open up to accommodate that contraction. This makes a honeycomb-style pattern, because 3 crack orientations is the minimum number necessary to allow contraction in every direction.





**Brittle materials fracture without suffering any significant plastic deformation. Plastic deformation is not recoverable, i.e. the change is permanent.**

Source: [http://wapi.isu.edu/envgeo/EG2\\_earth/brittle\\_deformation.htm](http://wapi.isu.edu/envgeo/EG2_earth/brittle_deformation.htm)



**Brittle vs Ductile Deformation**

**Material Behavior**

**Brittle vs Ductile Deformation**

Brittle deformation: material deform by rupturing, e.g. joints, faults

Ductile deformation: material deform by bending, flowing or with deformation spread over a zone of numerous closed microscopic scale fractures, e.g. fold, shear zone

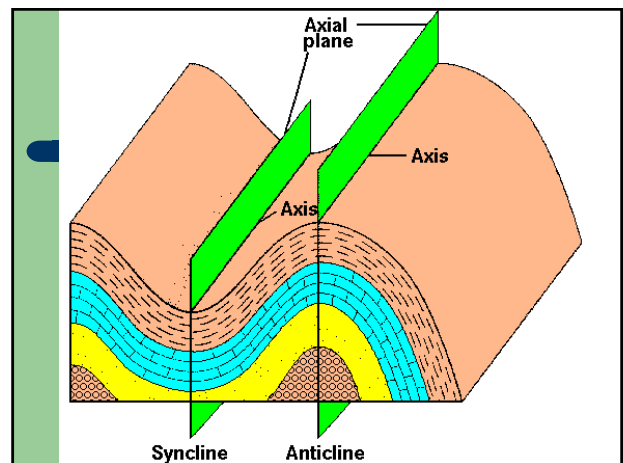
## Brittle vs Ductile Deformation

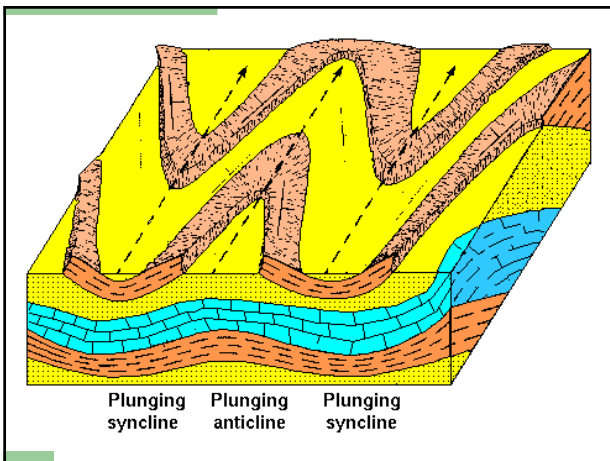
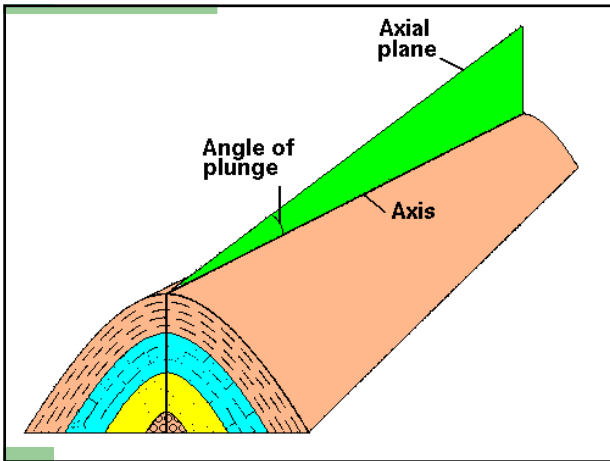
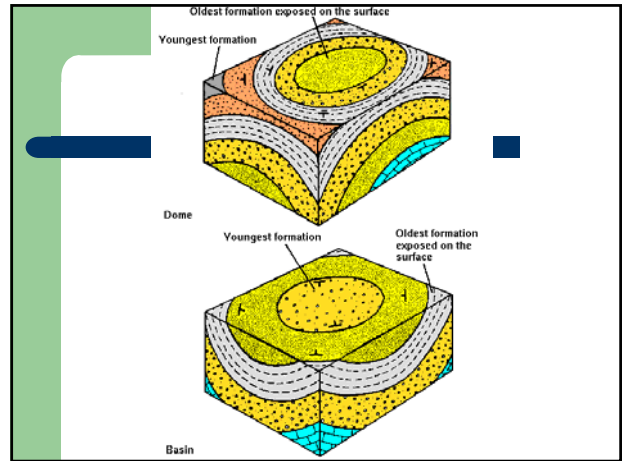
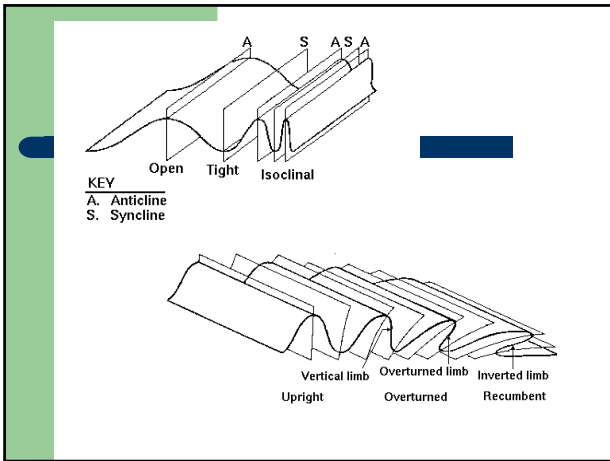
### Factors

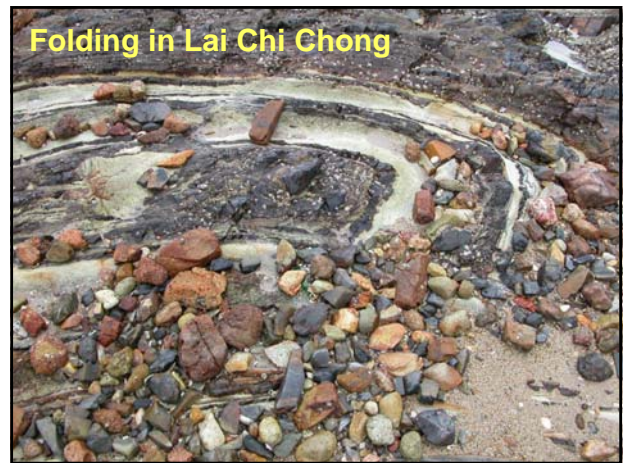
1. Material composition and properties
2. Temperature
3. Pressure
4. Strain rate & time
5. Presence of fluid

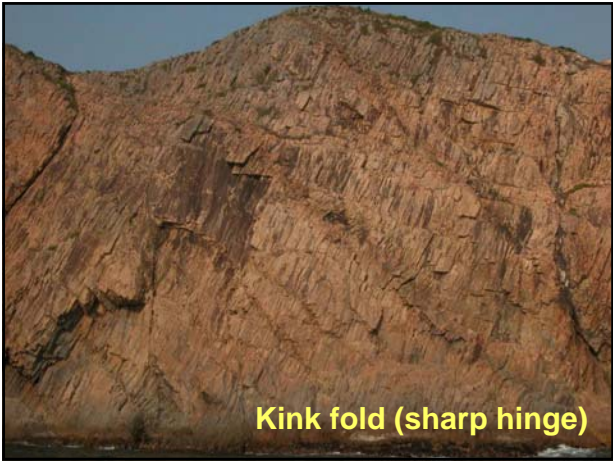


## Folds: Description and Classification

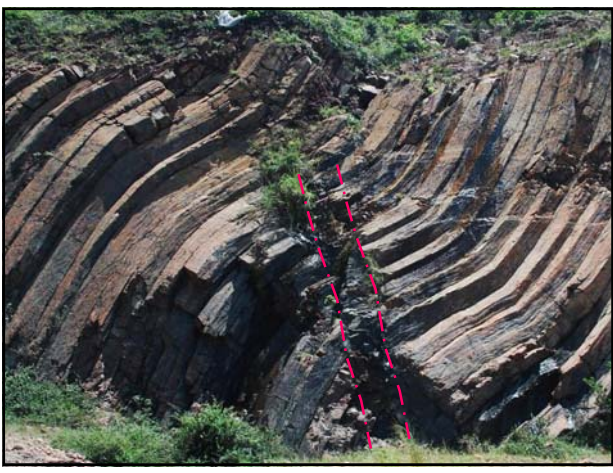








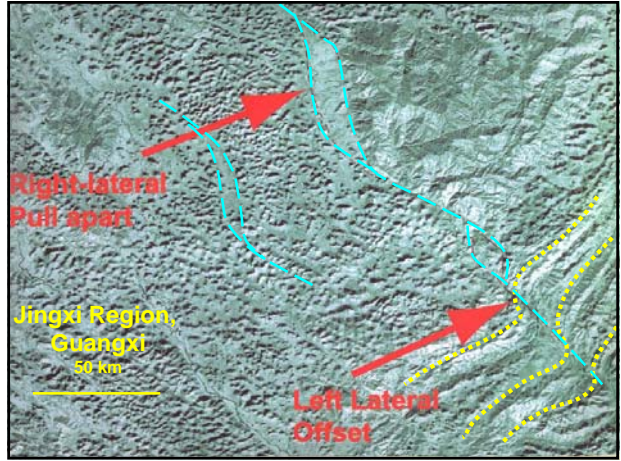
Kink fold (sharp hinge)



Folds - Regional Scale



Ptygmatic folds in migmatite



Right-lateral Pull apart

Left Lateral Offset

