

**Cairo University  
Faculty of Engineering  
Public Works Department  
Soil Mechanics and Foundations Research Laboratory**

# Engineering Geology

Lecturer:

**Dr. Sherif Akl**

# Acknowledgement

- Herbert Einstein
- Andy Link
- Dayanthie Weeraratne
- James M. Hayden
- Mihai Ducea
- University of Arizona, Geosciences Department, Website
- Vincent Salters
- Mustafa Hariri (KFUPM)
- Jian Zhao (EPFL)

# Introduction to Structural Geology

Lecture 3

# Outline

- There are forces acting constantly on the earth's crust. Where do they come from?
- How does different formations react to these forces
  - Ductile Deformation
  - Brittle Deformation
- An engineering problem using stereonet

# Definition

Structural geology is the study of the deformation of rocks and its effects.

- Basically rock deforms (folds on itself) until a brittle failure occurs (fracture)

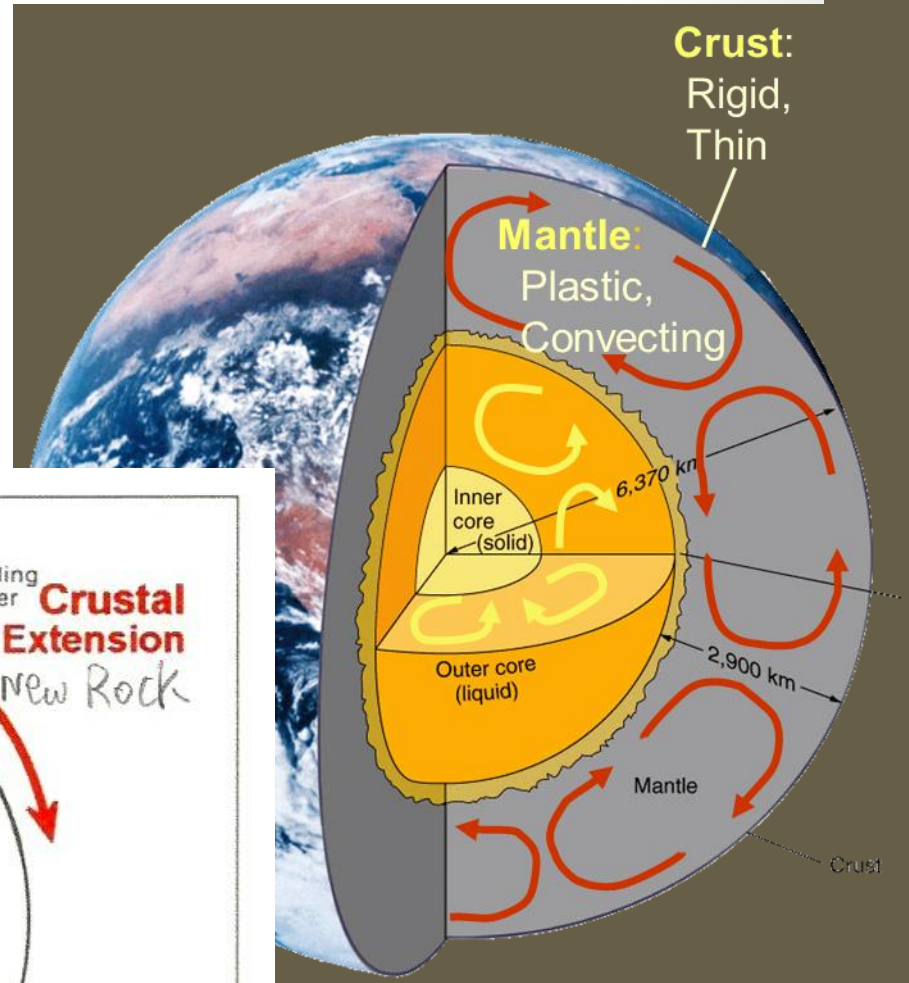
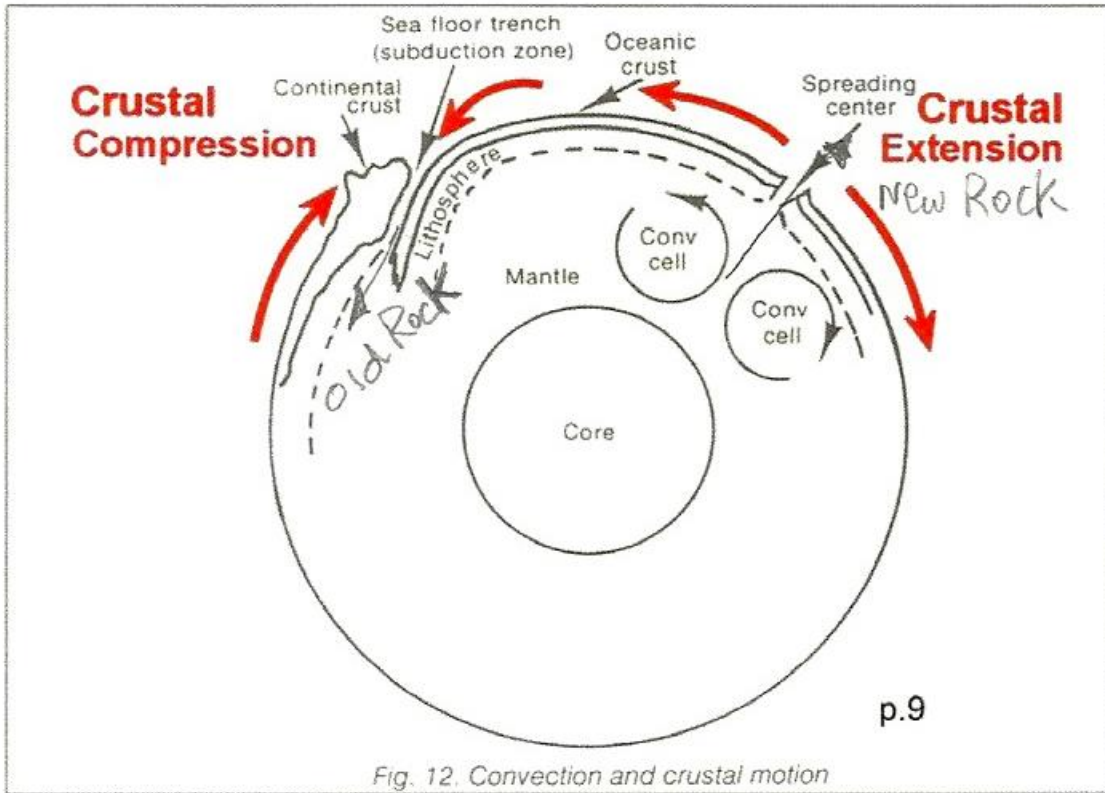
# Plate Tectonics

**From where do the forces that produce structures come?**  
**Plate tectonics**

## **Plate Tectonics**

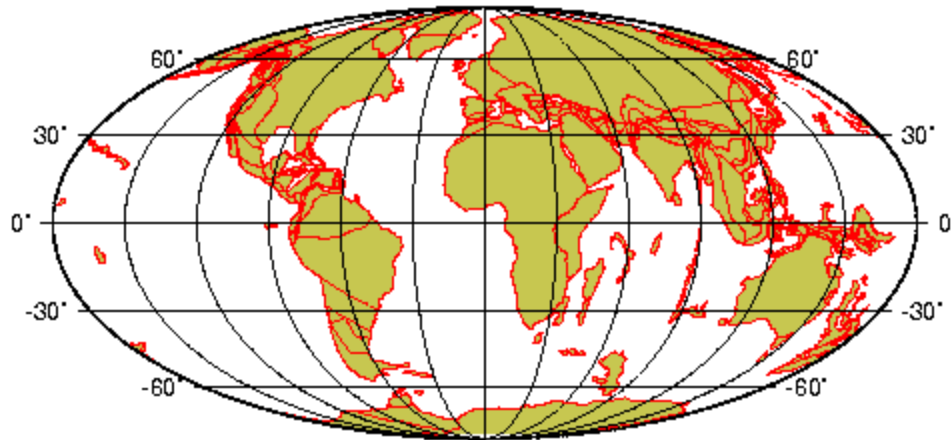
The division of the lithosphere into a number of rigid plates that move horizontally across the earth's surface. Plates interact with one another at their margins, causing seismic and tectonic activity at their margins

# Plate Tectonics

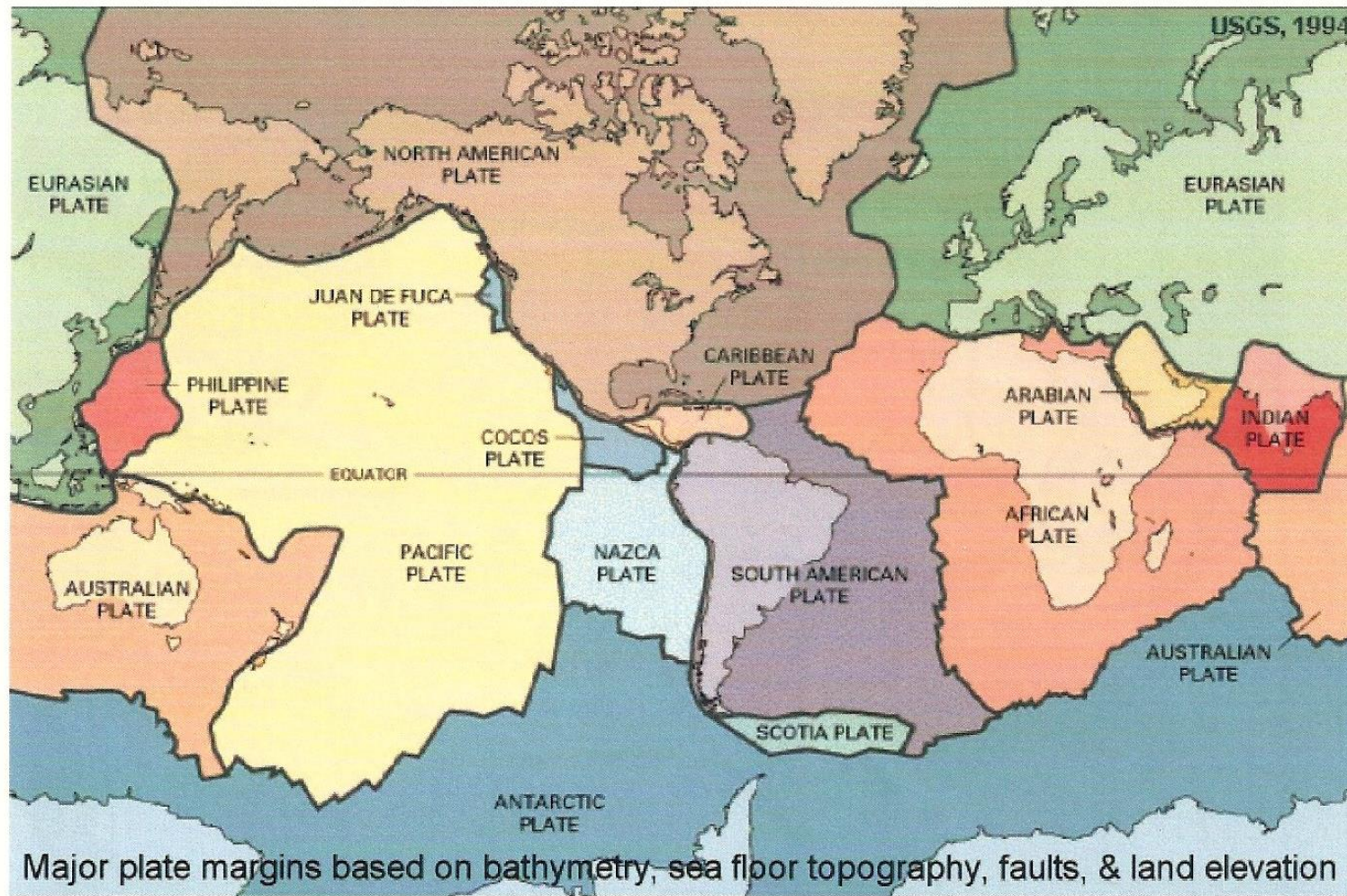


# Plate Tectonics

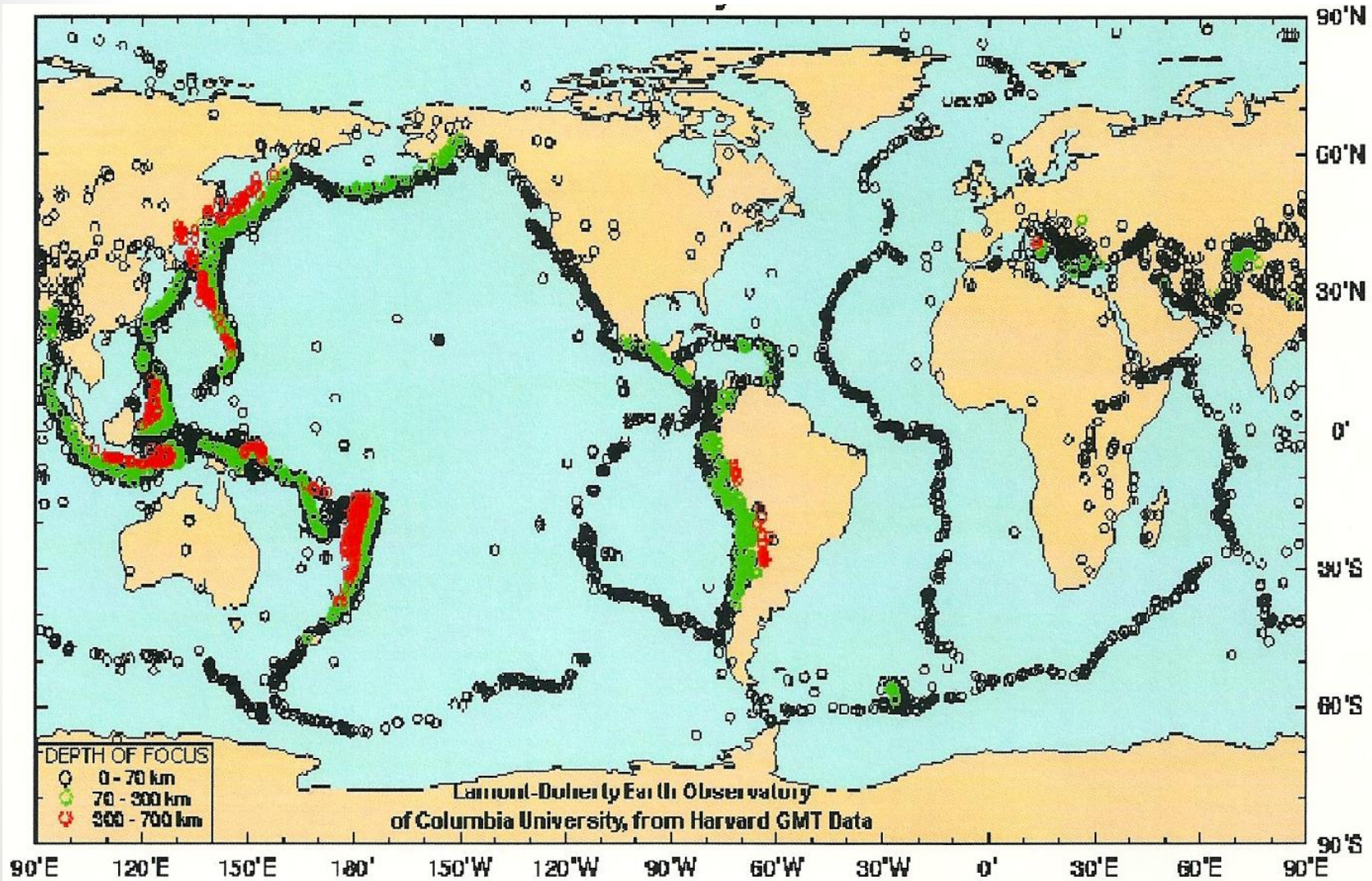
- Pangea --- one continent
- Plates move 1-15 cm/year
- Continuous change through millions of years



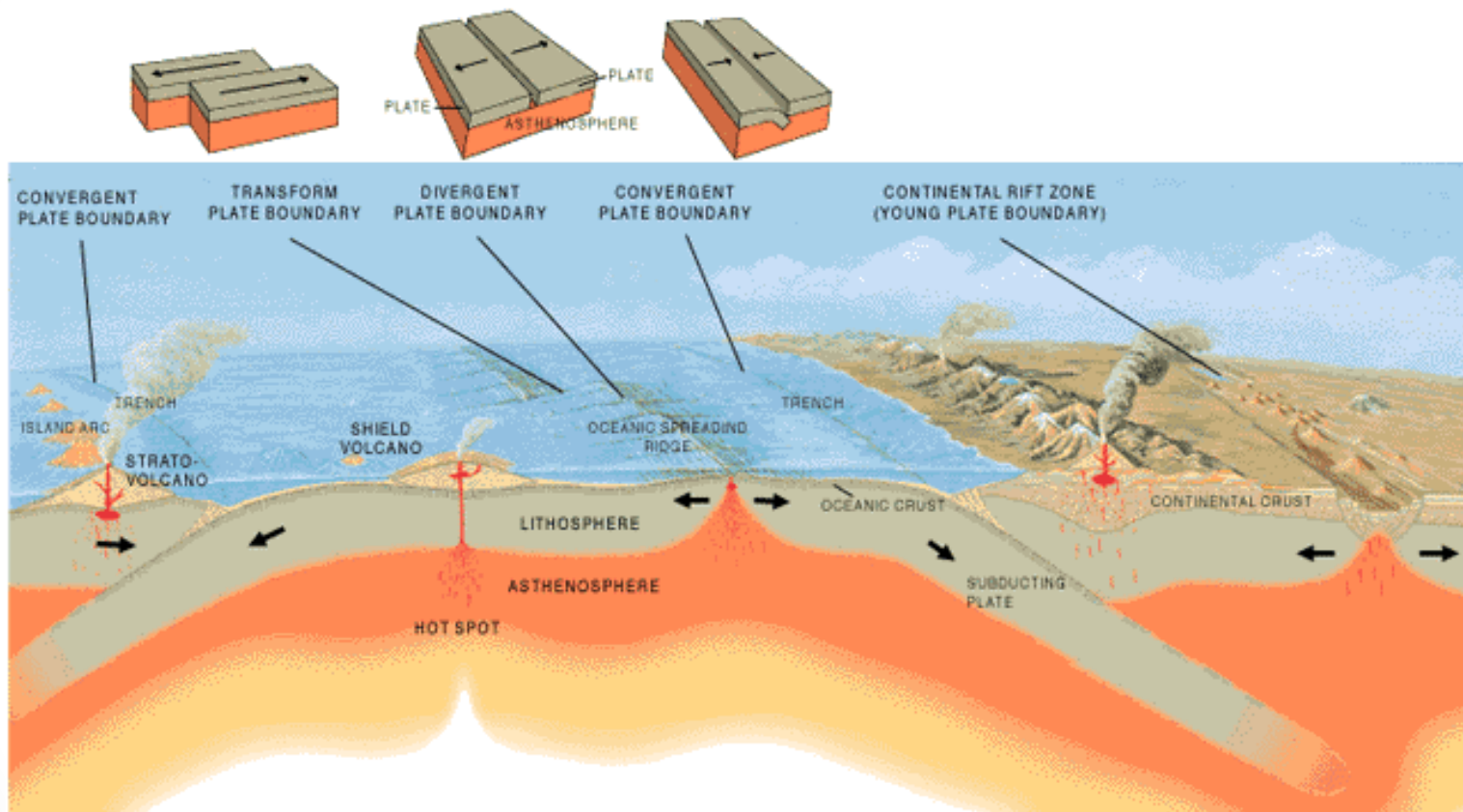
# Tectonic Plates



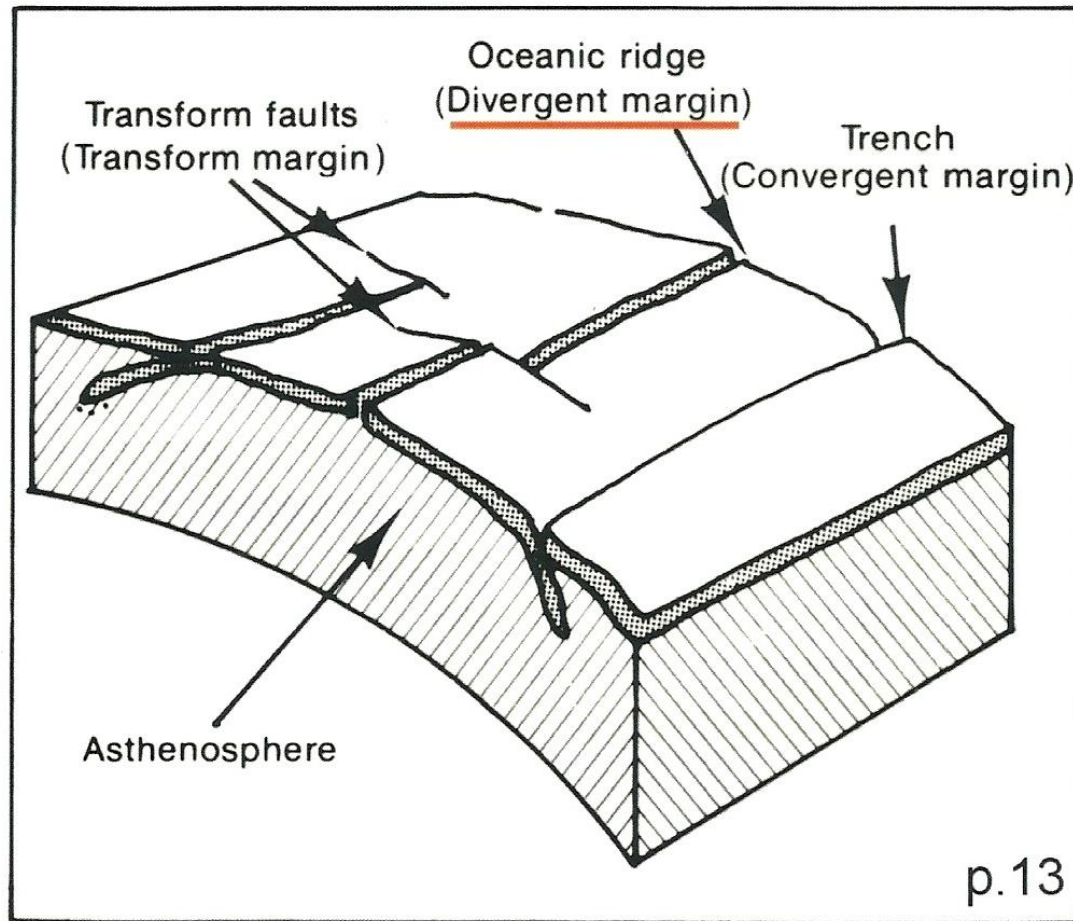
# Tectonic Plates



# Margin Types

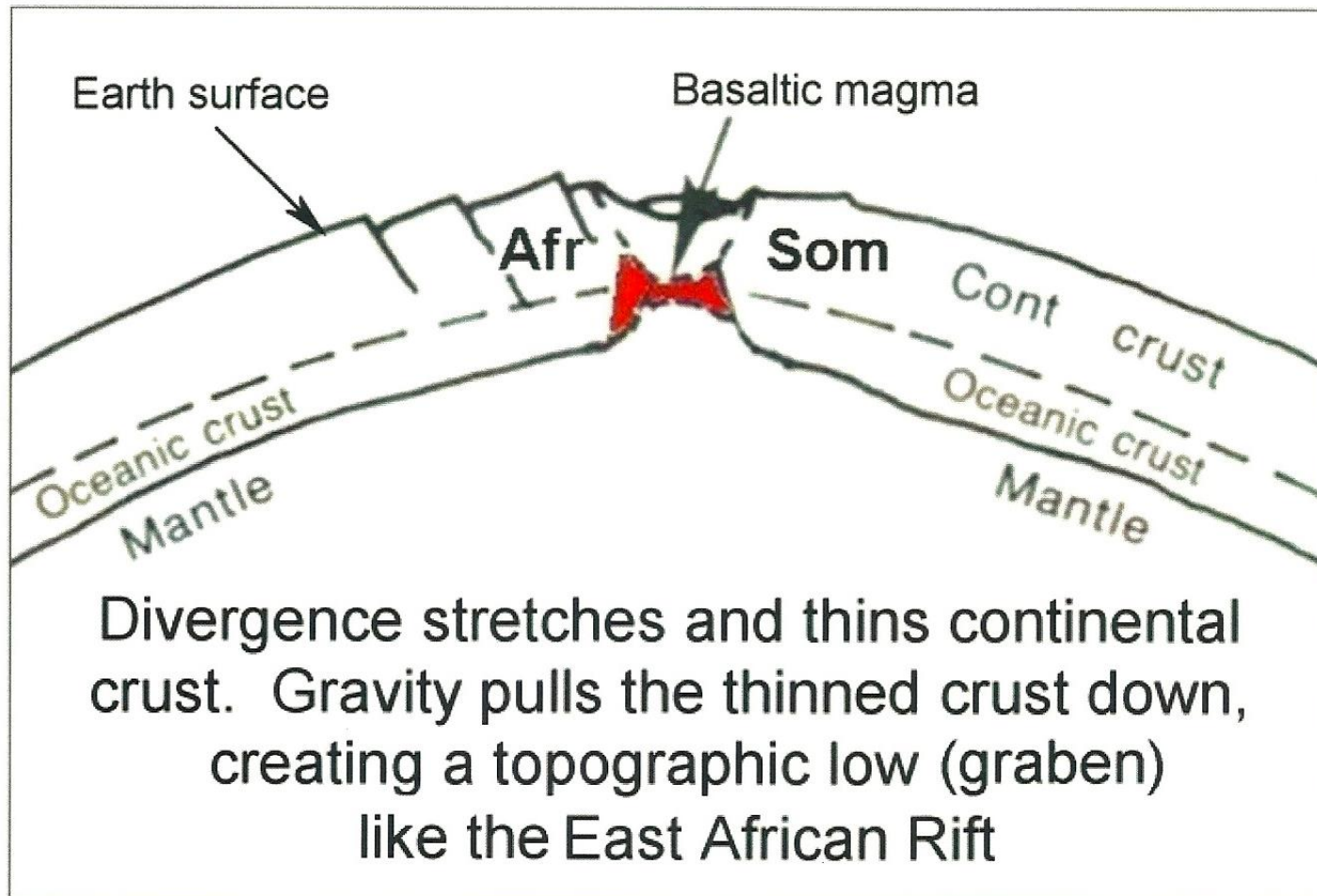


# Divergent Margin

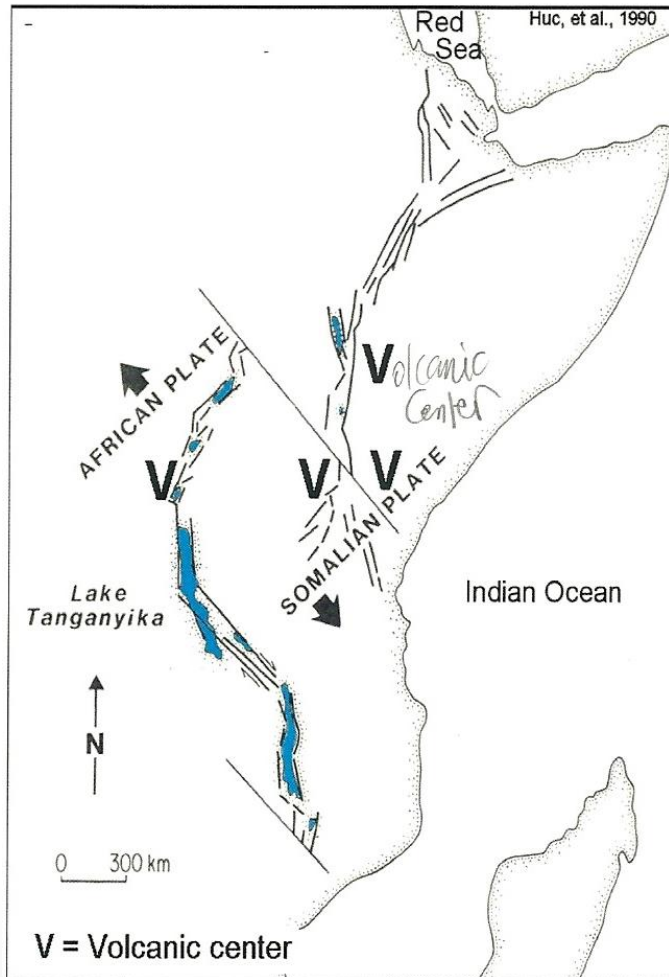


Consider divergent plate margins.

# Divergent Margin



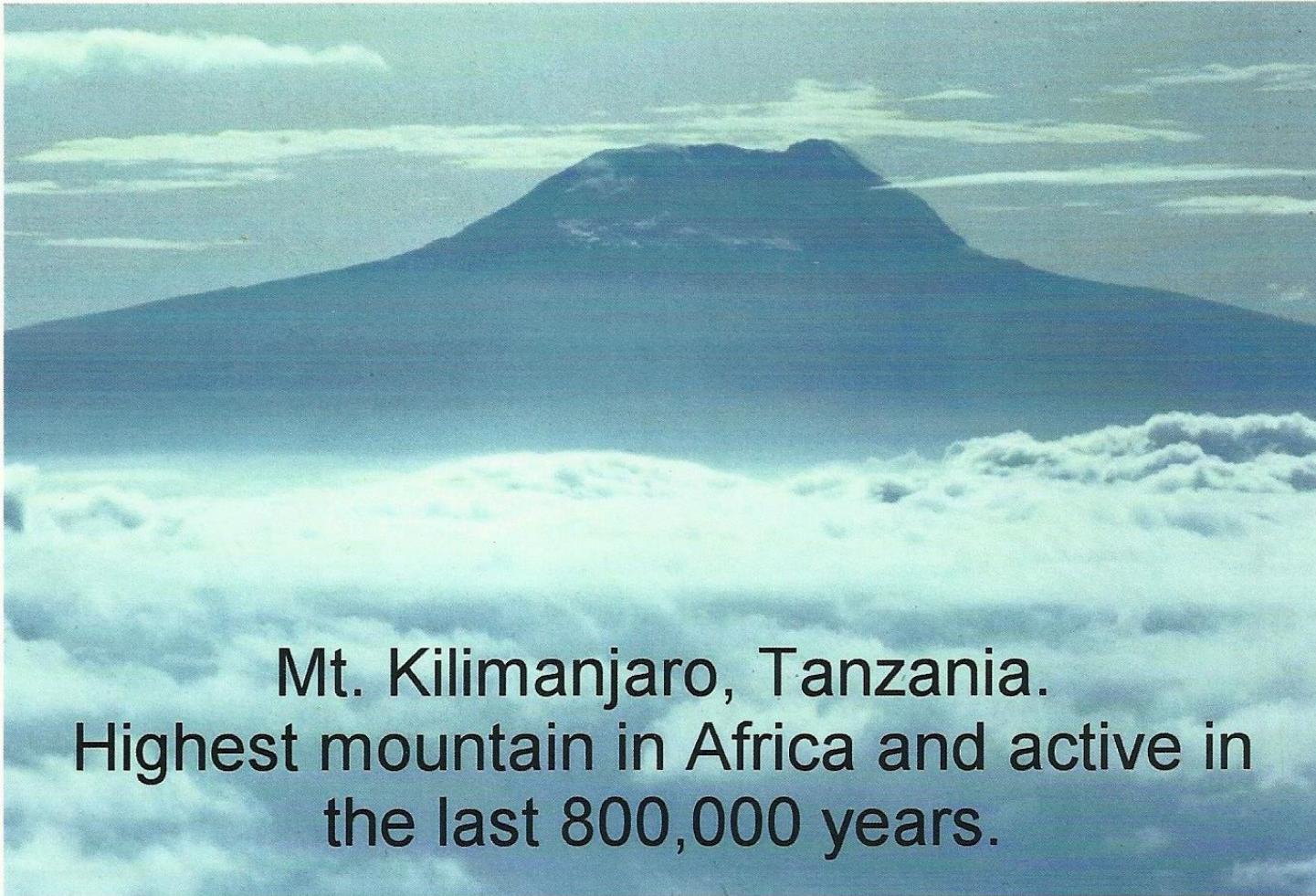
# Divergent Margin



East African Rift with volcanic centers.

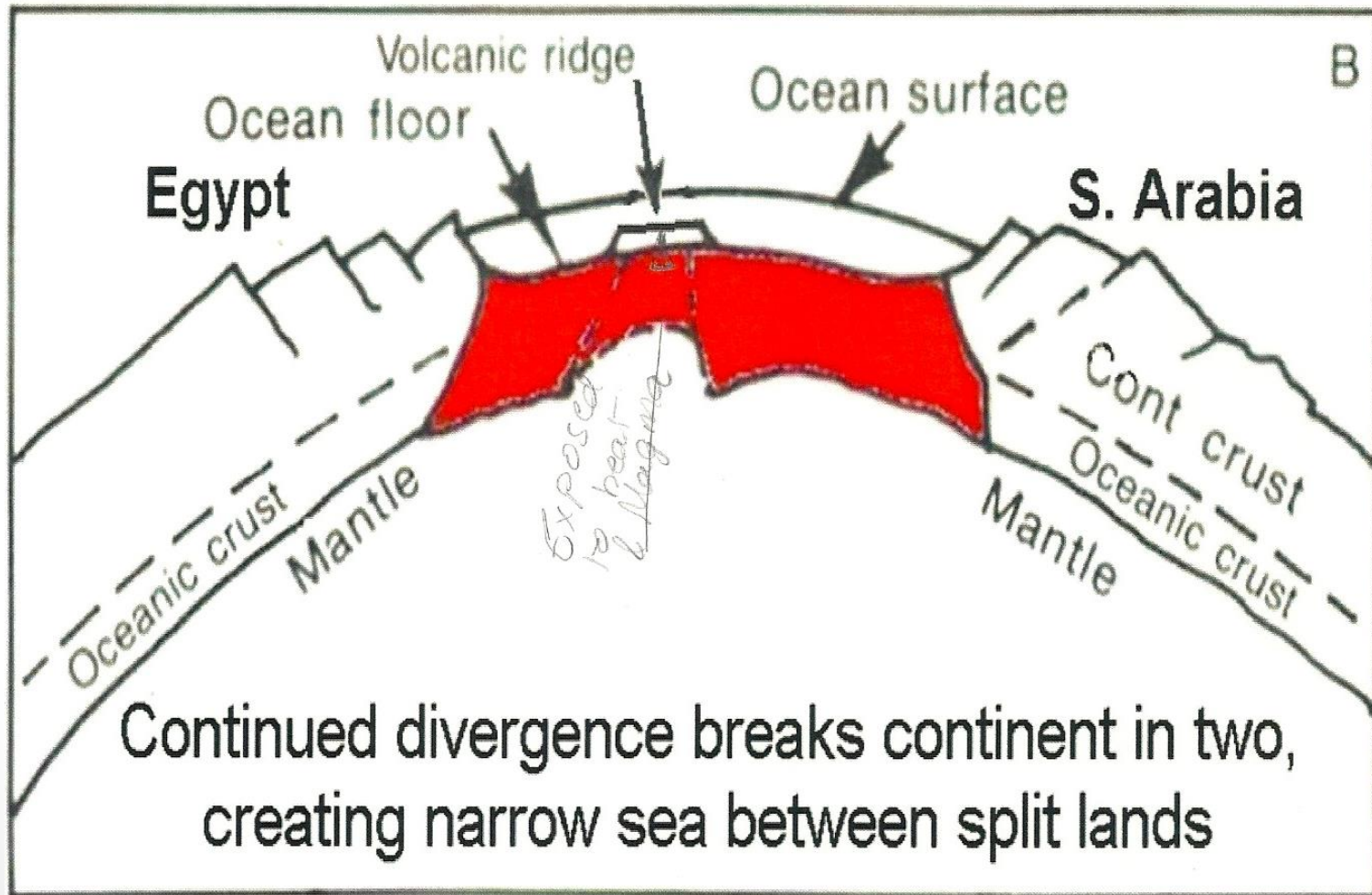
Note the offset along a transform fault. If splitting of the African continent continues, the rift will eventually subside enough such that the rift floor will reach and then fall below sea level. The rift will then be flooded, producing a narrow sea between the African and Somali plates like the Red Sea today.

# Divergent Margin

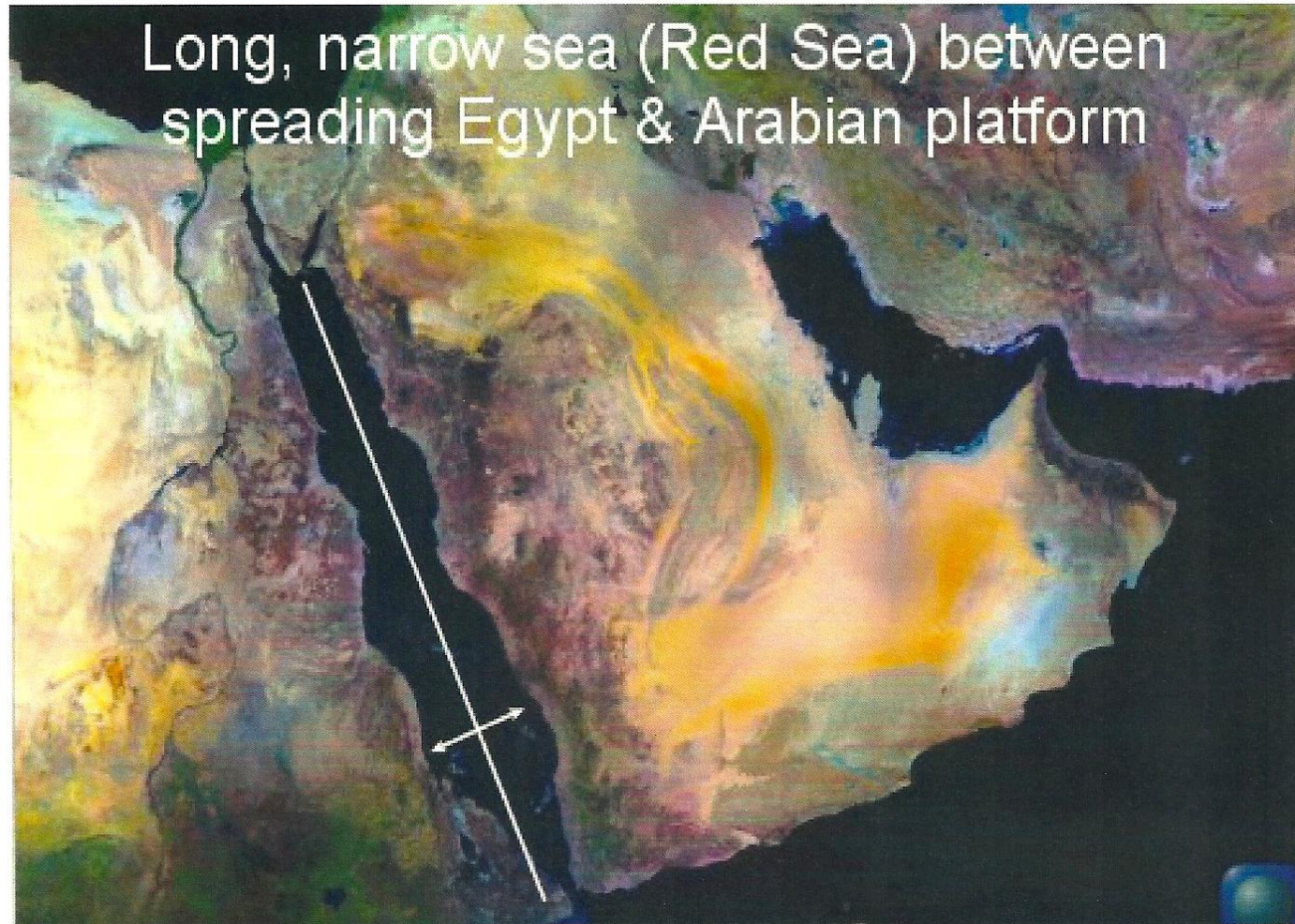


Mt. Kilimanjaro, Tanzania.  
Highest mountain in Africa and active in  
the last 800,000 years.

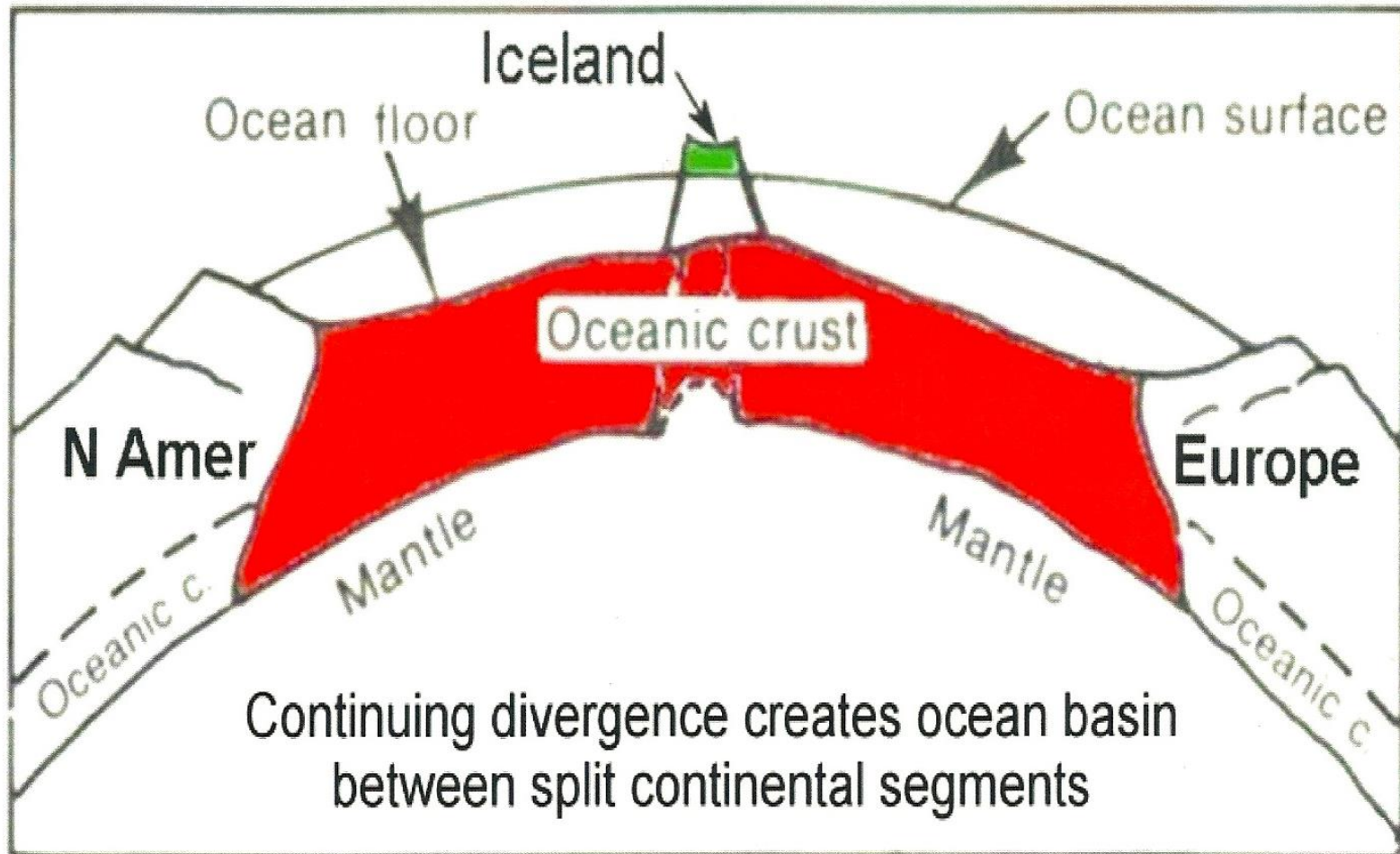
# Divergent Margin



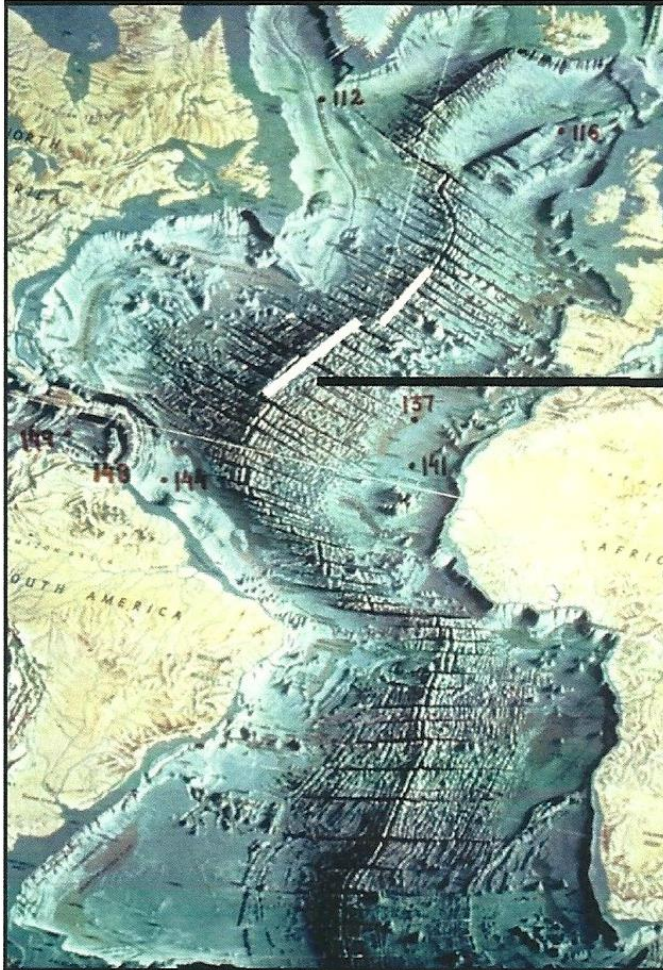
# Divergent Margin



# Divergent Margin



# Ridges

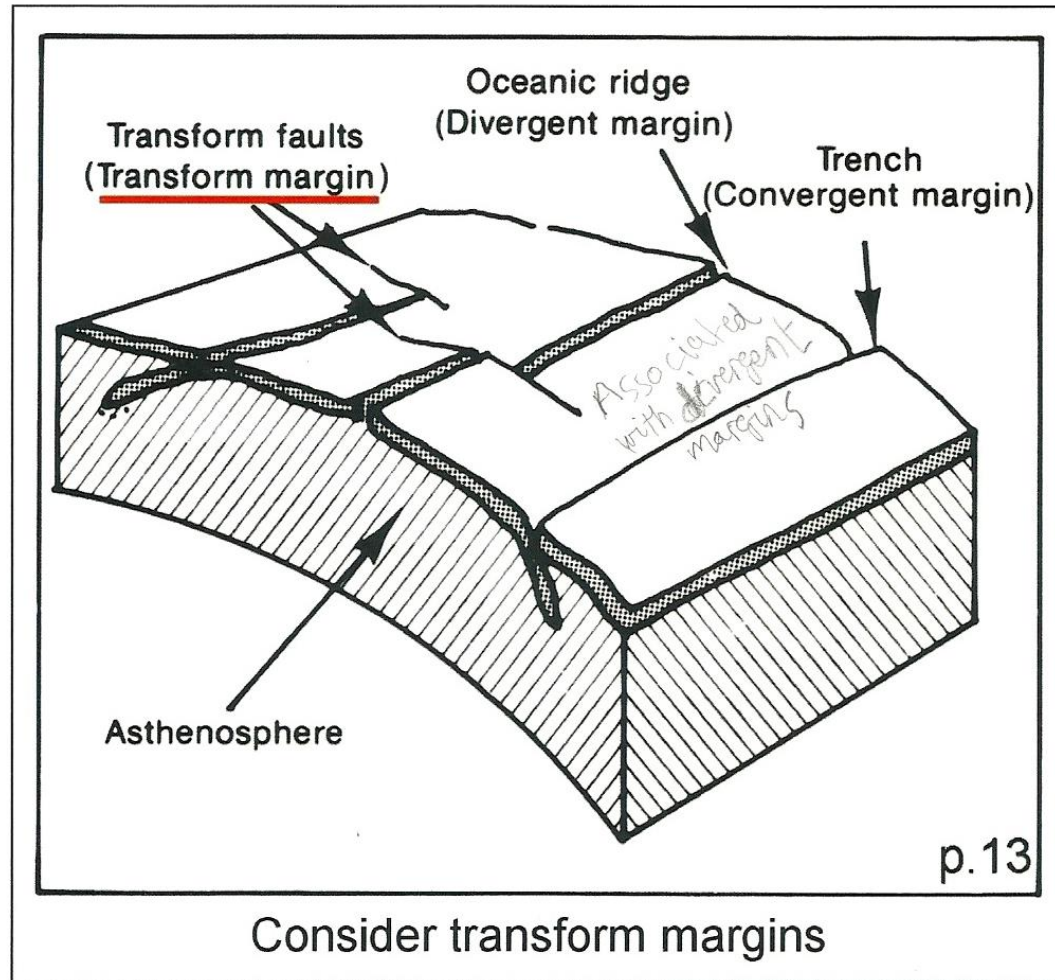


Atlantic Basin topography

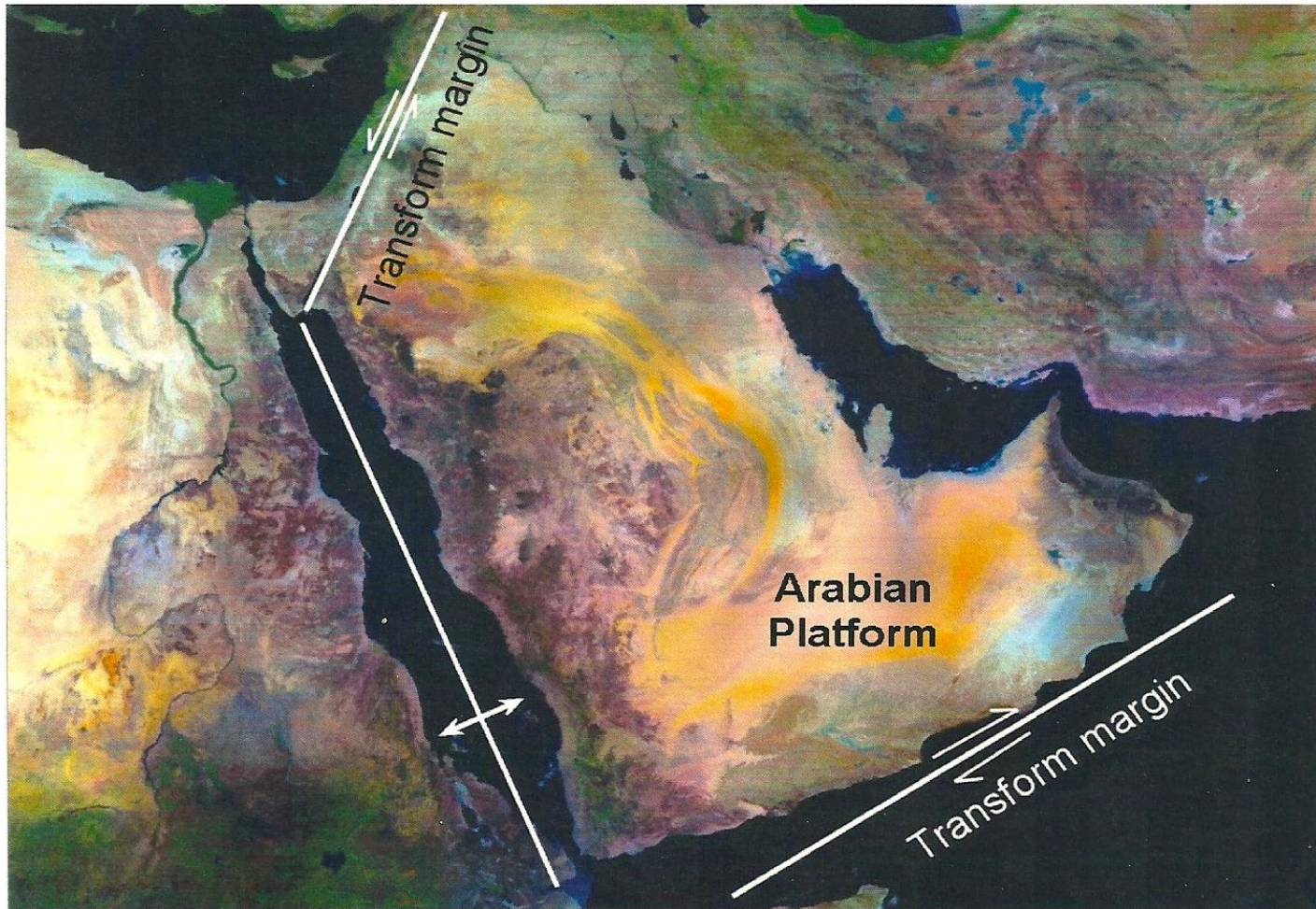
Mid-Atlantic Ridge is a topographic high. The ridge extends the full length of the ocean basin before curving eastward under Africa.

*Shallowest - Youngest Rock*

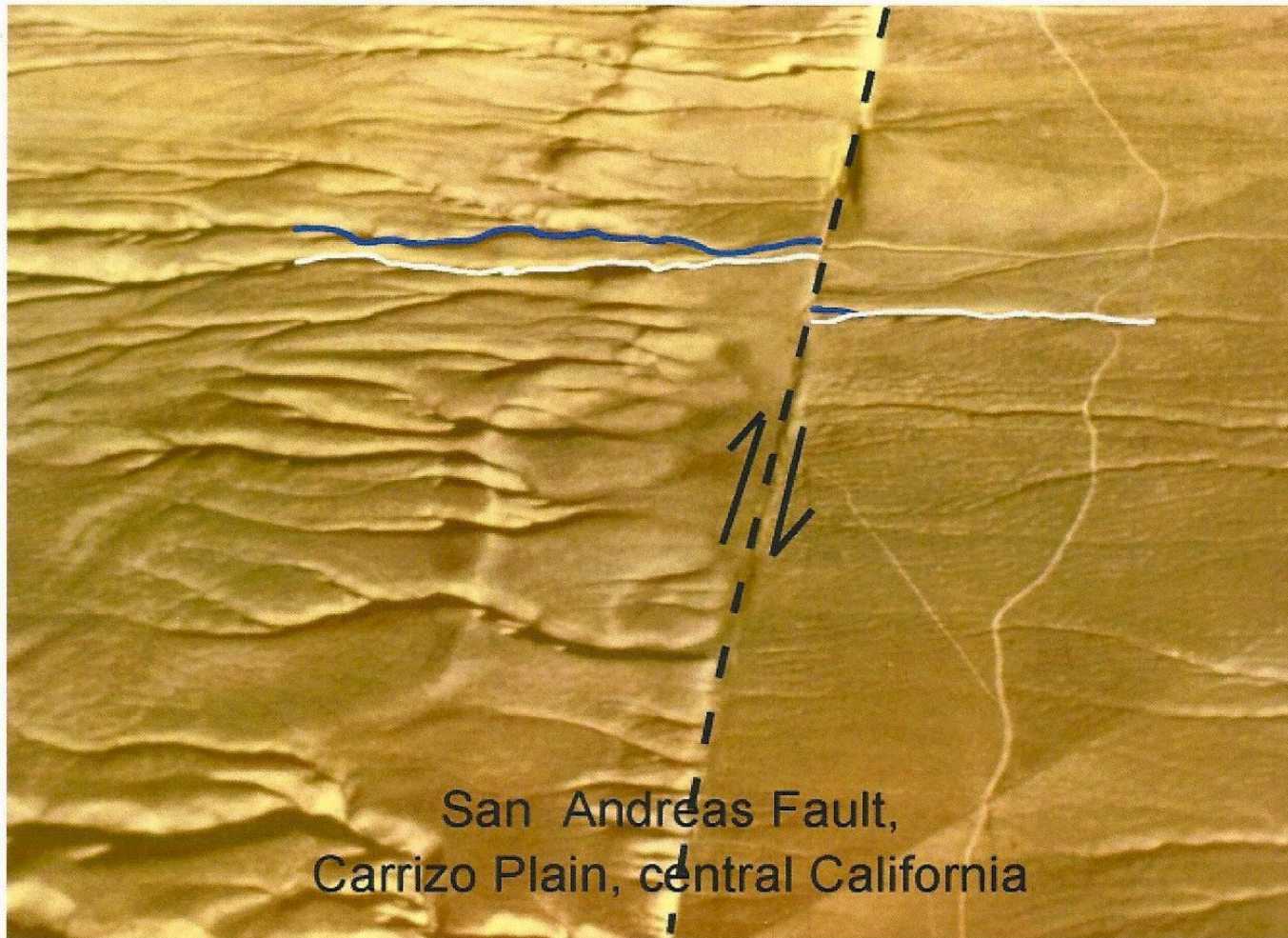
# Transform margin



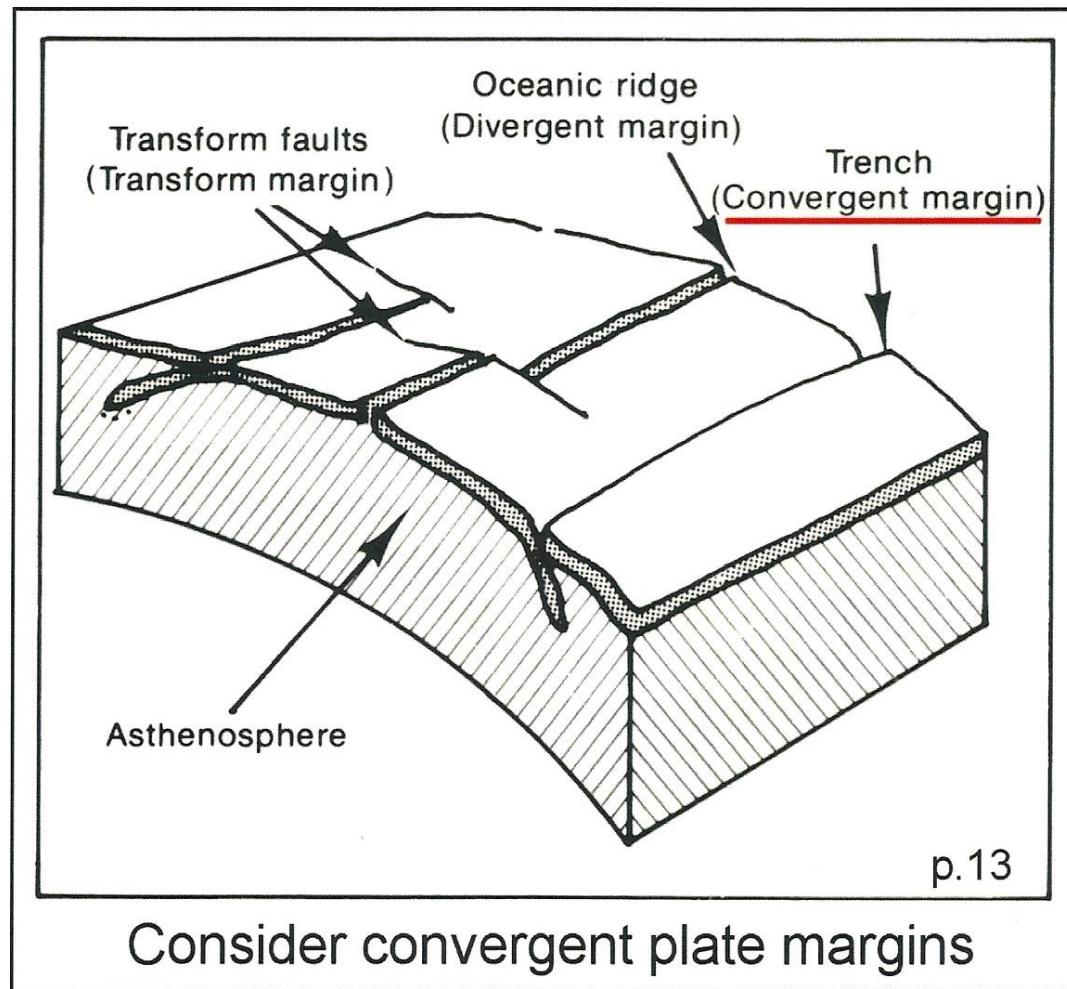
# Transform Margin



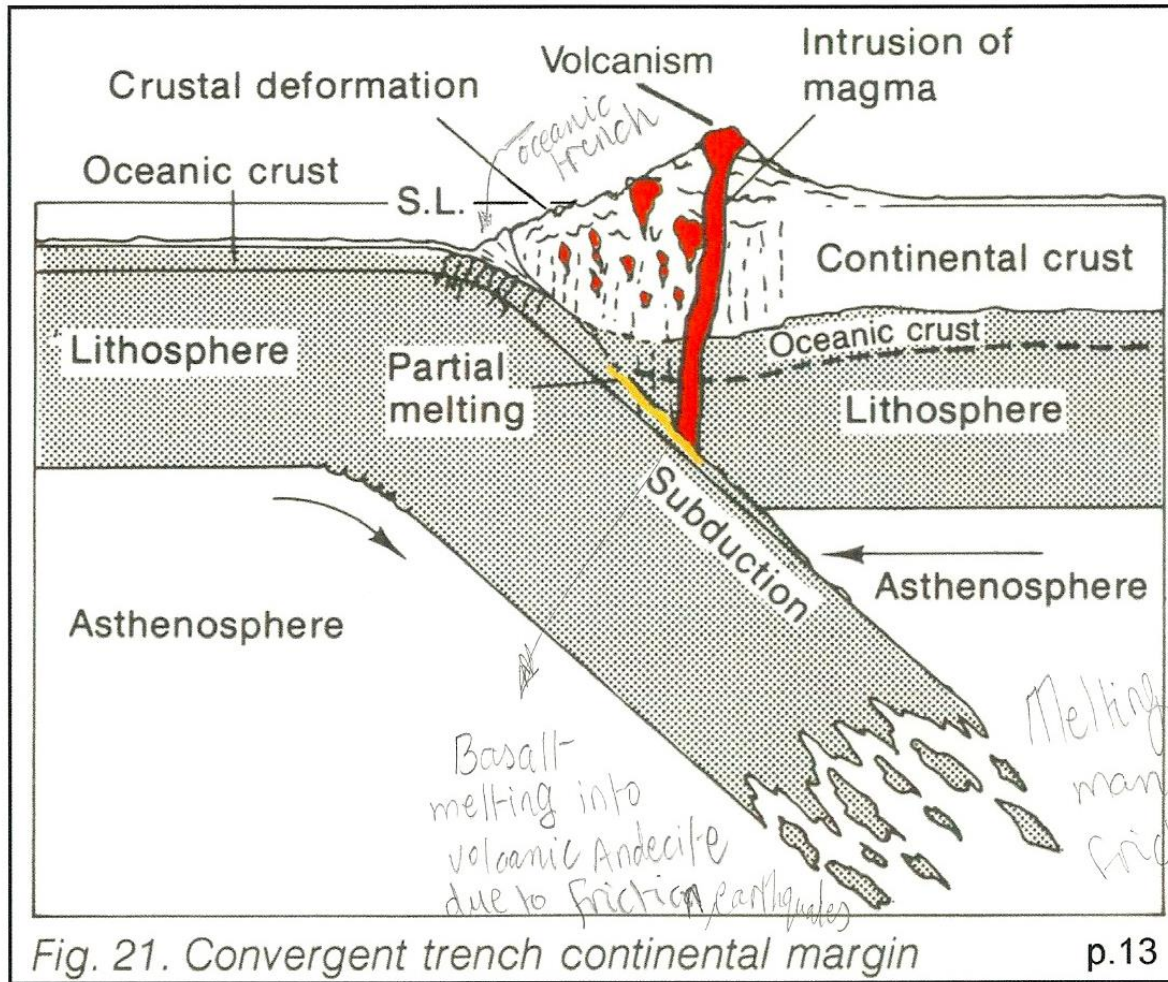
# Transform Margin



# Convergent Margin



# Convergent Margin



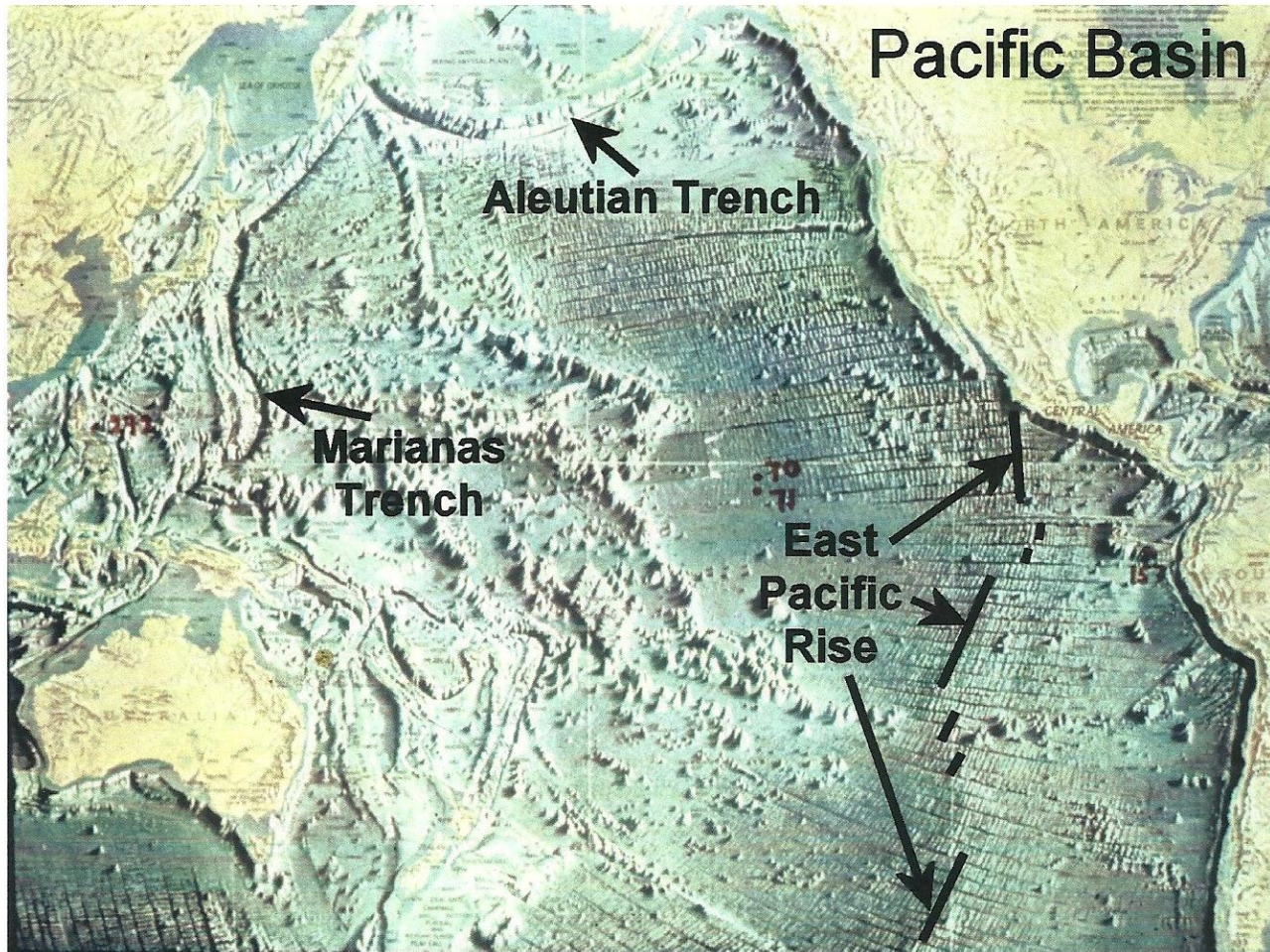
# Convergent Margin



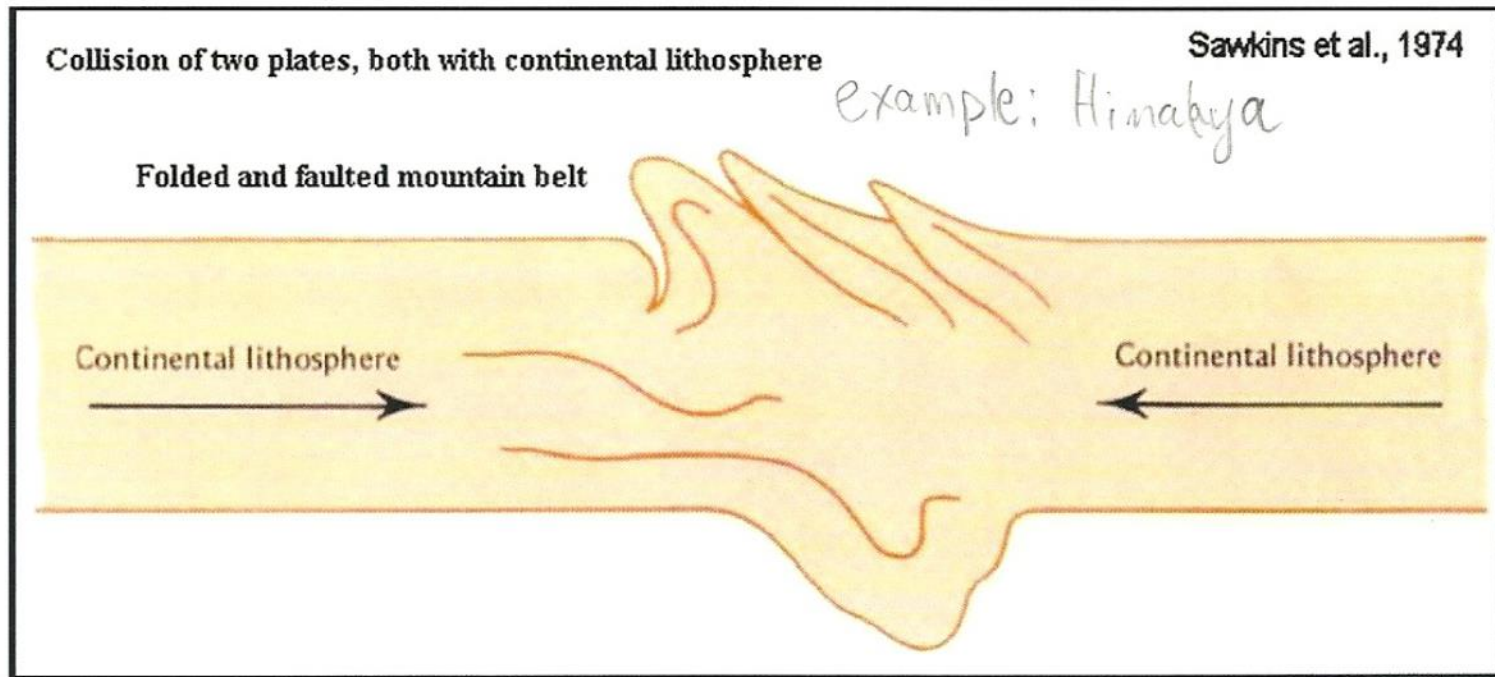
Peter K. Link

Krakatau volcano, Sunda Strait, Indonesia

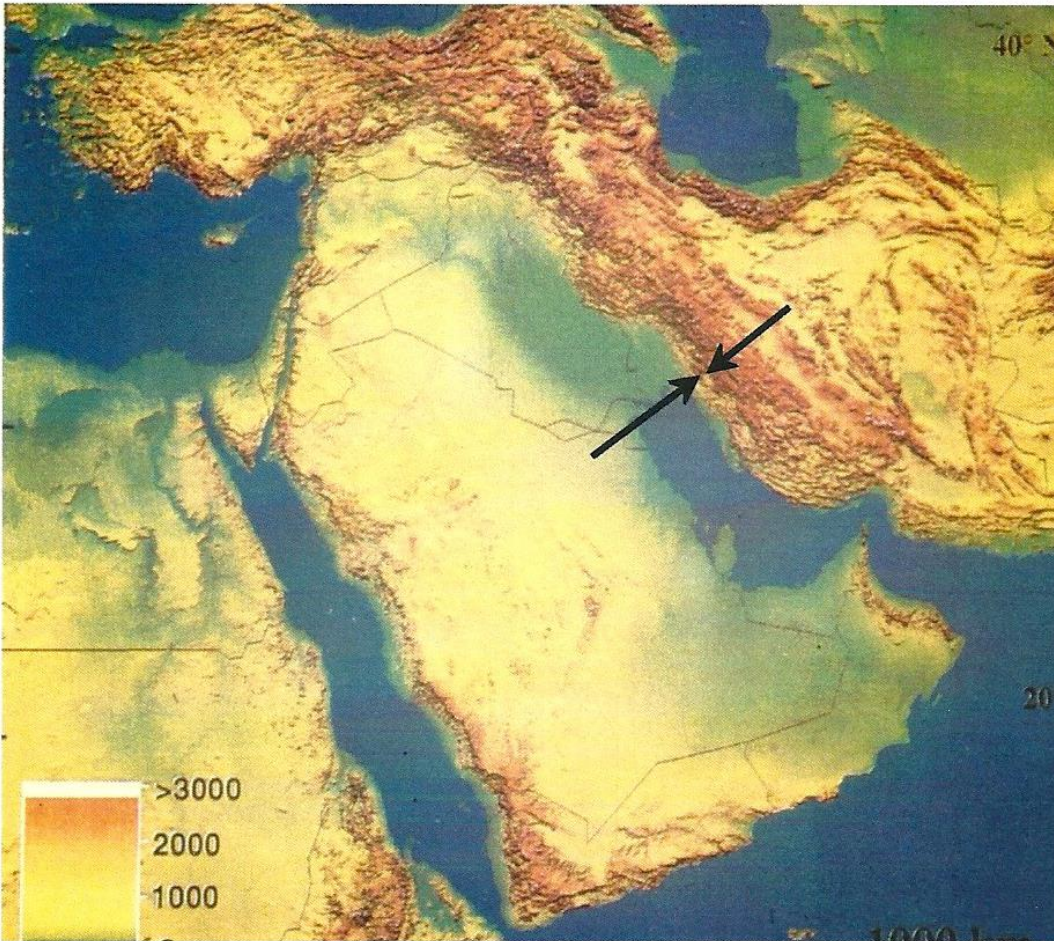
# Trenches



# Convergent Margin



# Convergent Margin



## Middle East

Spreading in the Red Sea is pushing the Arabian Peninsula NE into SW Asia, with the collision pushing the Zagros Mtns. up and forcing the Arabian (Persian) Gulf down.

# Convergent Margin

Himalaya Mtns., Nepal



Nuptse  
25,850'  
7906m

Everest  
29,035'  
8850m

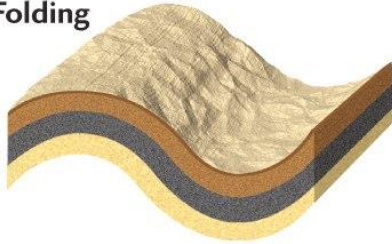
Lhotse  
27,890'  
8501m

# How does rock react?

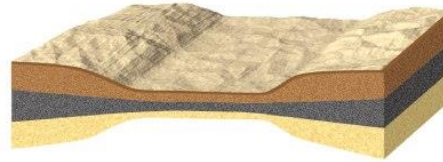
## Secondary structures

Ductile materials undergo smooth, continuous plastic deformation and do not spring back to their original shape when the deforming force is released.

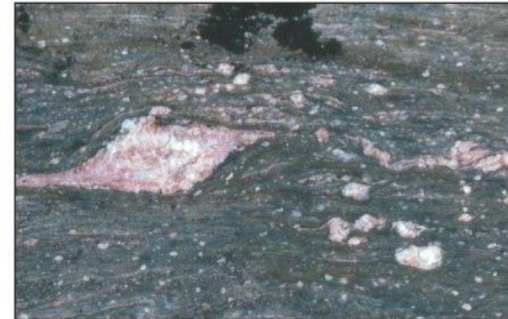
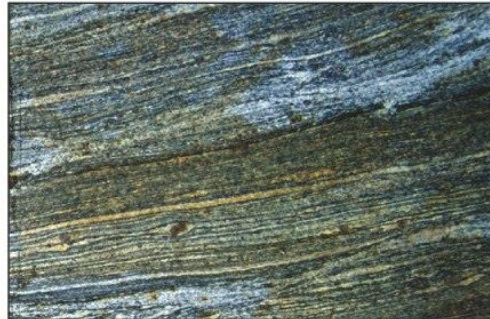
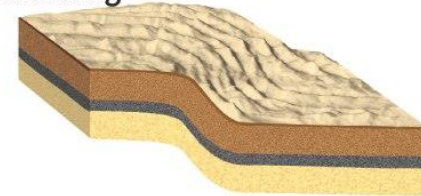
Folding



Stretching



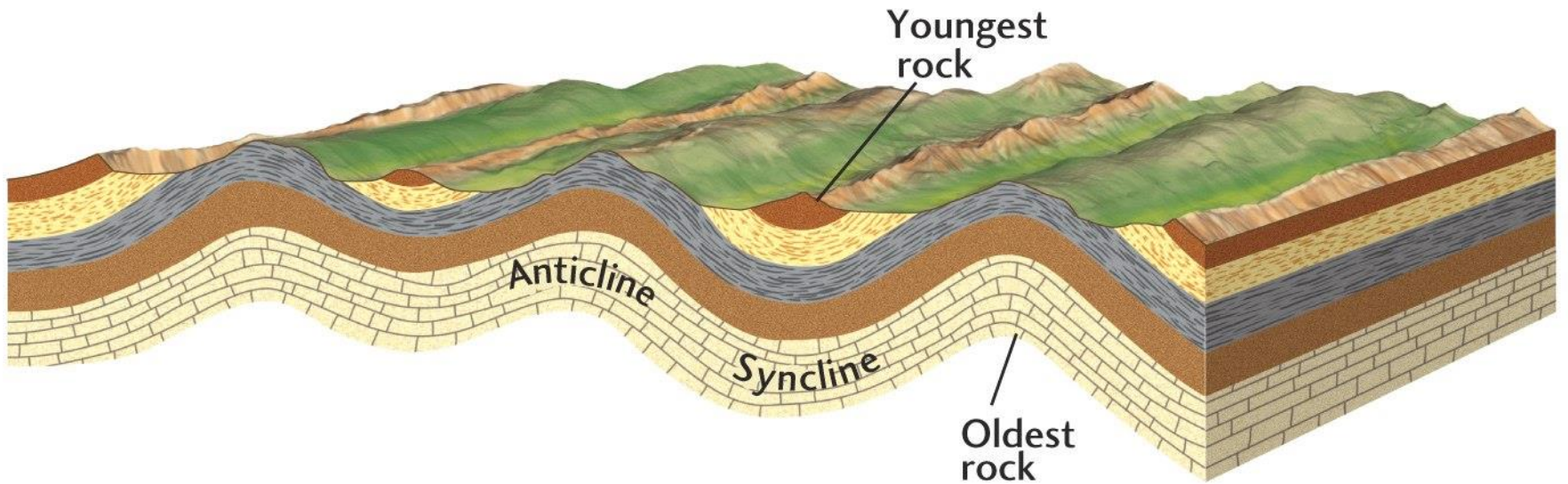
Shearing



# Folding of Rocks

- Produced by horizontal or vertical forces
- Scale can be from cm to 100's of km

ROCK FOLDING IS INFLUENCED BY THE TYPE OF ROCK AND THE COMPRESSIVE FORCES

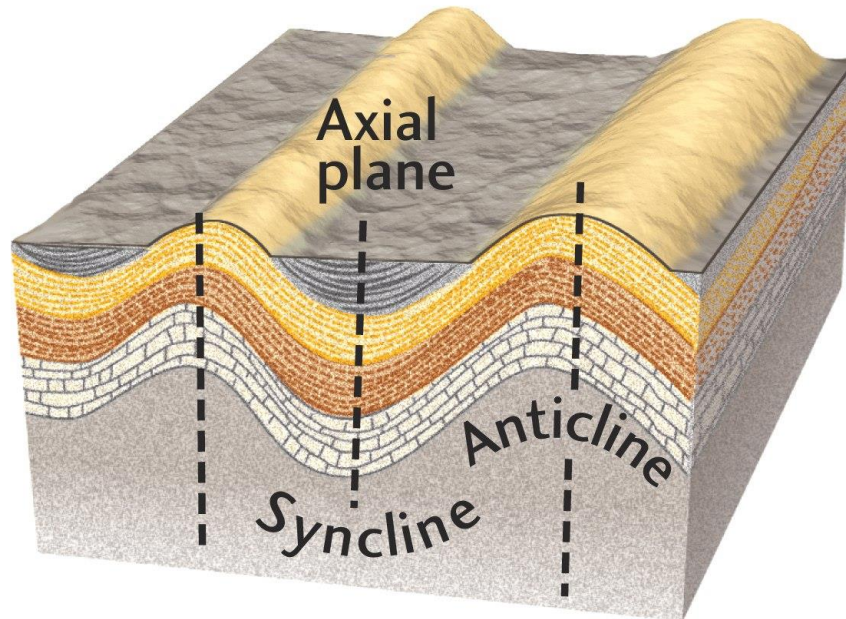


# Fold

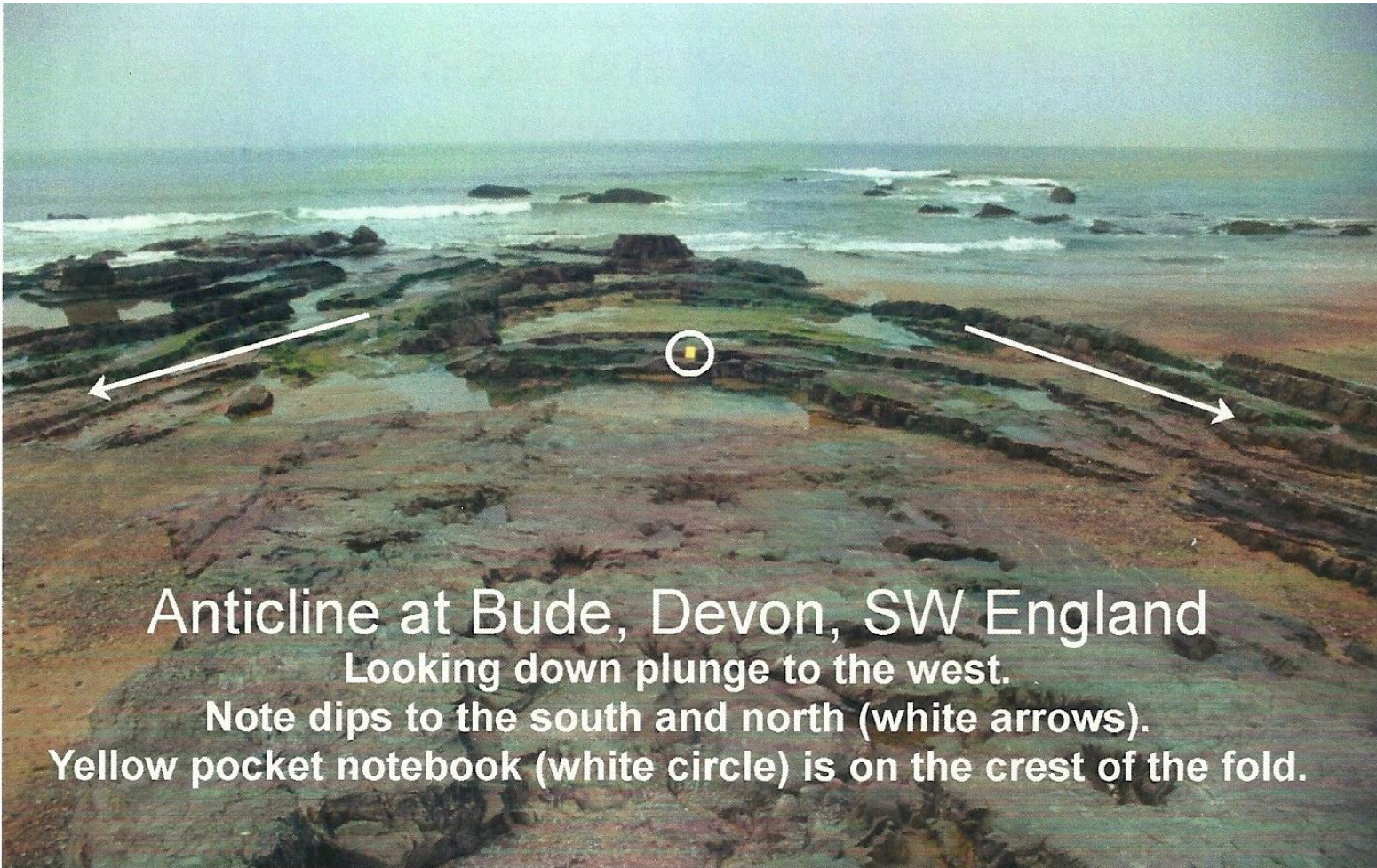
**syncline:** a sequence of folded rocks with the youngest rocks on the inside of the fold

**anticline:** a sequence of folded rocks with the oldest rocks on the inside of the fold

## Symmetrical folds



# Examples



**Anticline at Bude, Devon, SW England**

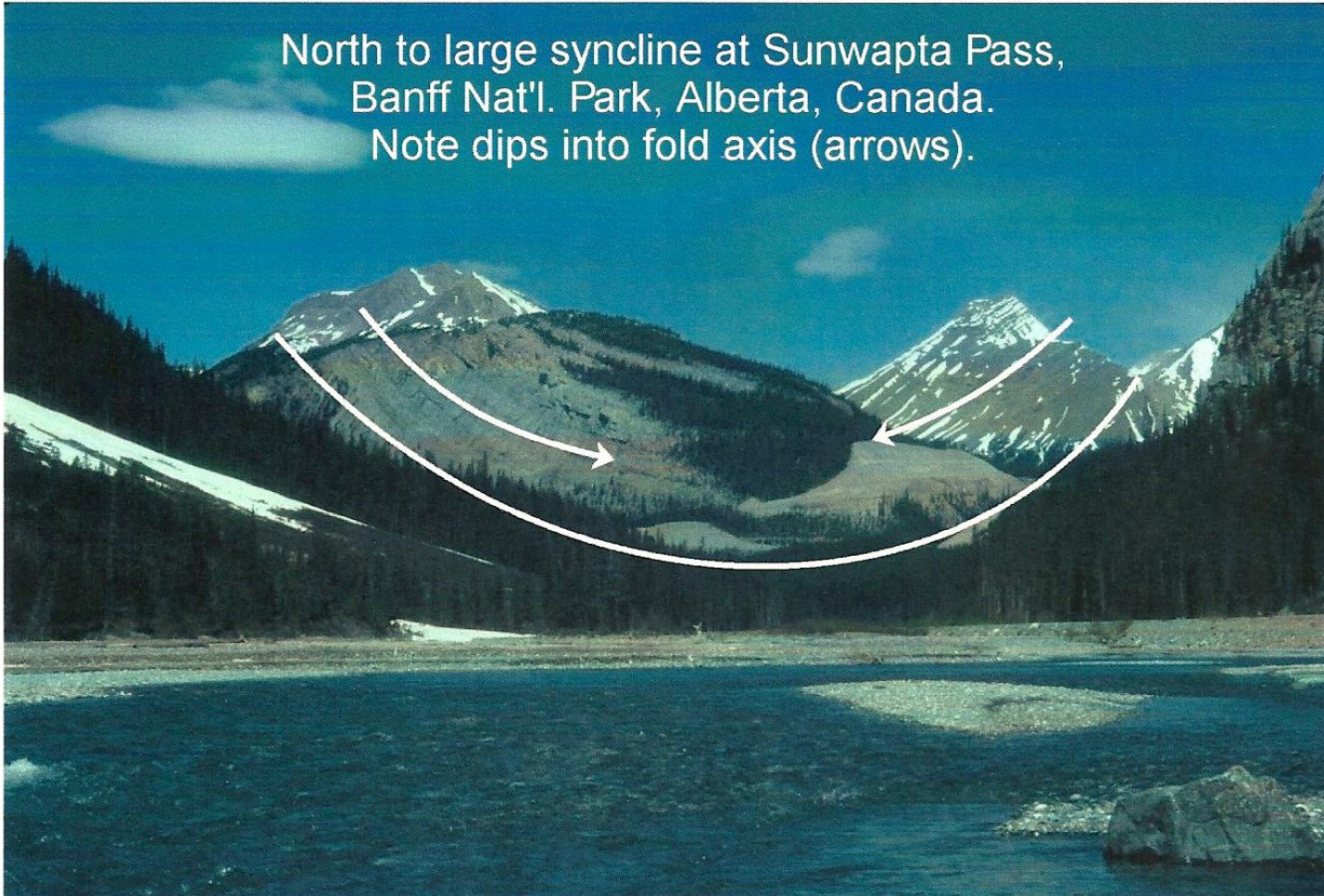
**Looking down plunge to the west.**

**Note dips to the south and north (white arrows).**

**Yellow pocket notebook (white circle) is on the crest of the fold.**

# Example

North to large syncline at Sunwapta Pass,  
Banff Nat'l. Park, Alberta, Canada.  
Note dips into fold axis (arrows).



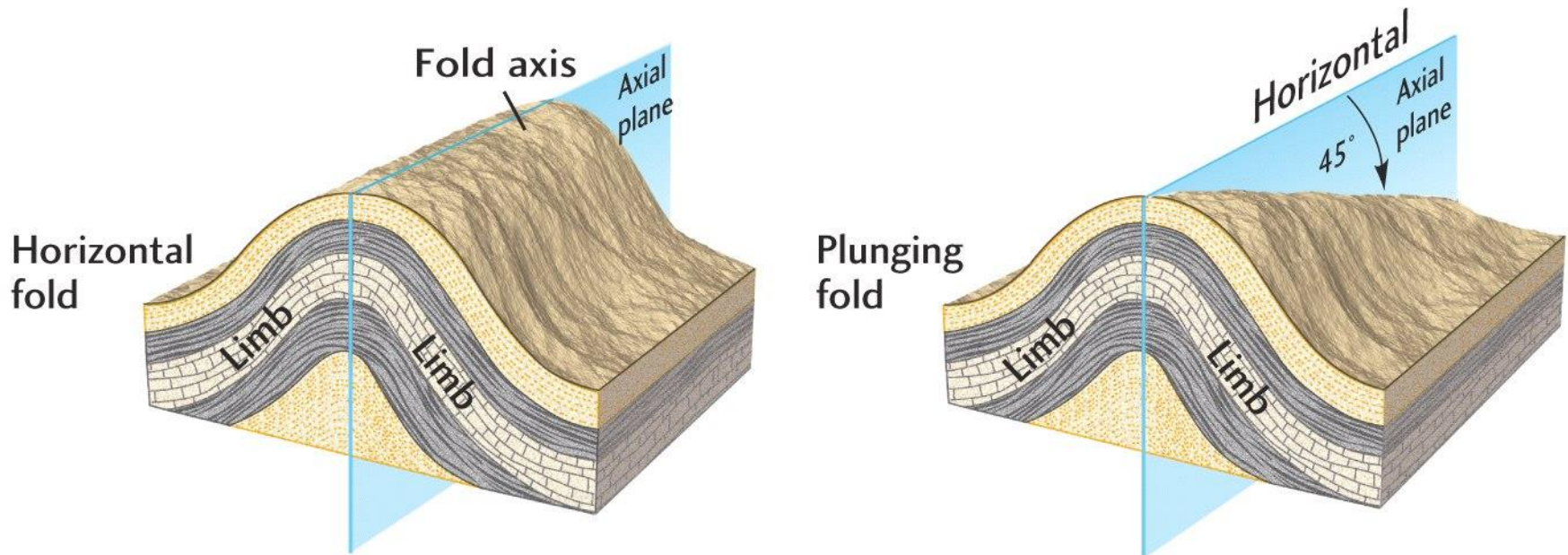
# Fold Terminology

**axial plane:** the plane of mirror symmetry dividing the fold into two limbs

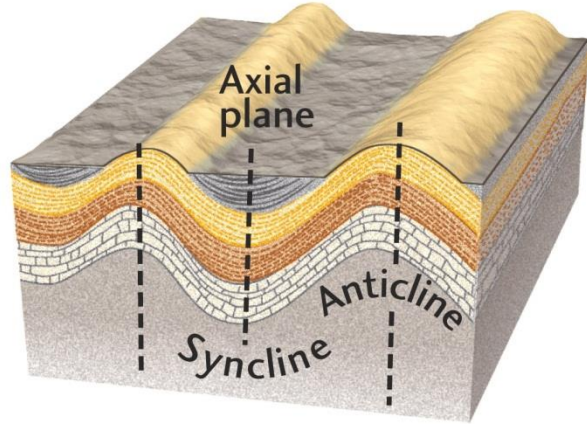
**axis:** the line formed by the intersection of the axial plane and a bedding plane

**horizontal fold:** fold where the axis is horizontal

**plunging fold:** fold where the axis is not horizontal



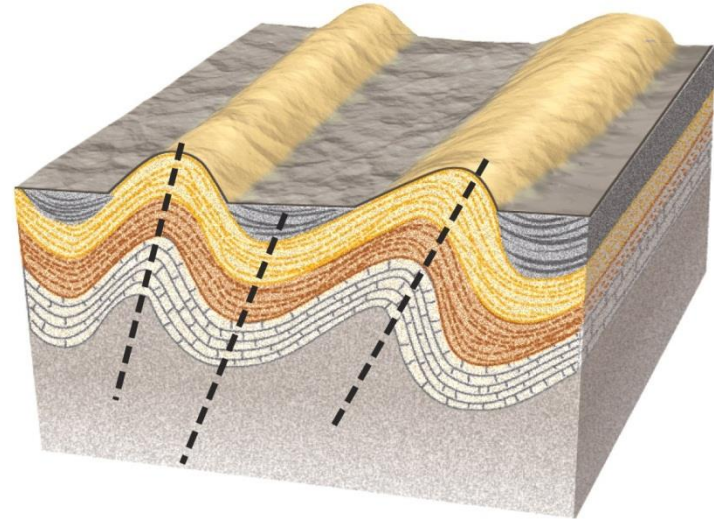
## Symmetrical folds



Beds dip away symmetrically from the axial plane

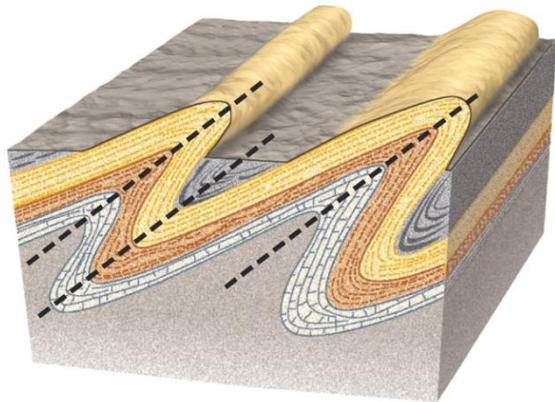
Beds on one side of the axial plane dip steeper than those on the other side

## Asymmetrical folds

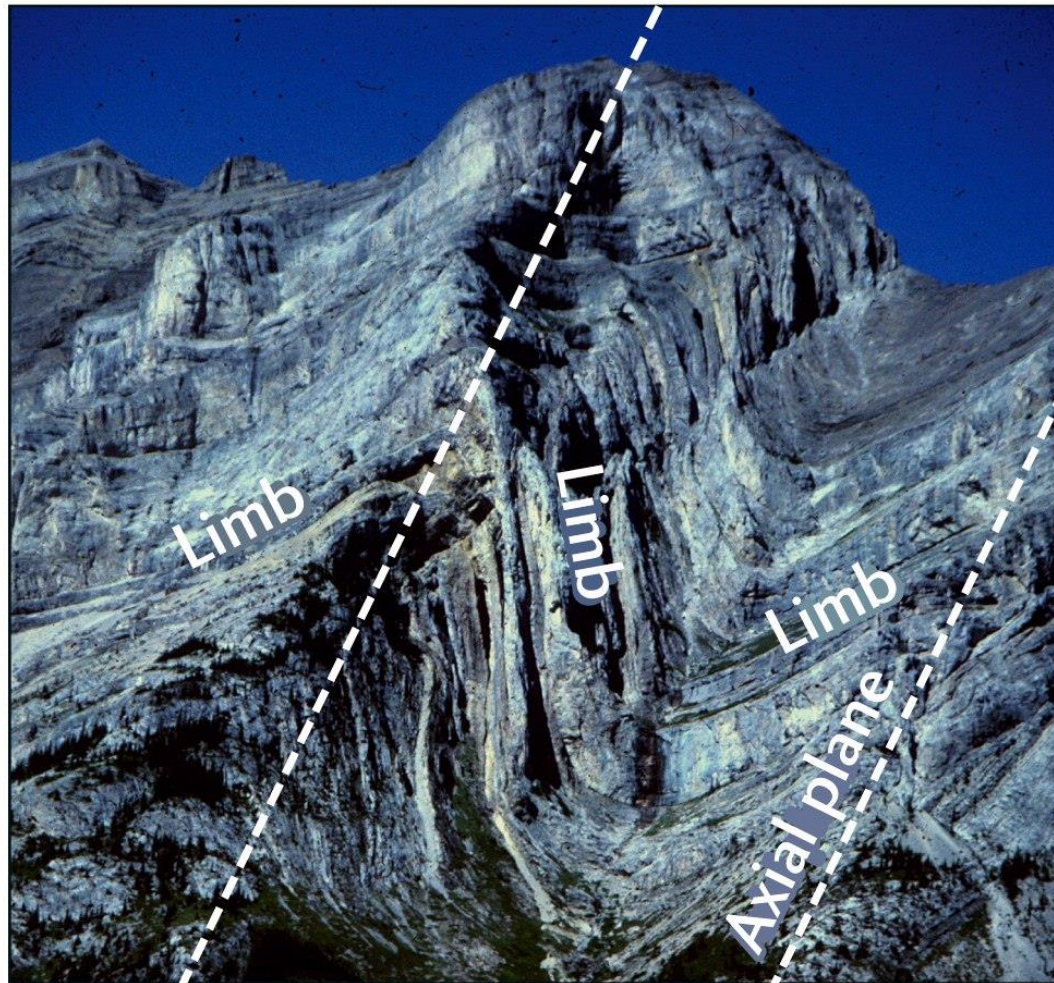


Both limbs dip in the same direction

## Overtured folds



# Asymmetric Folds



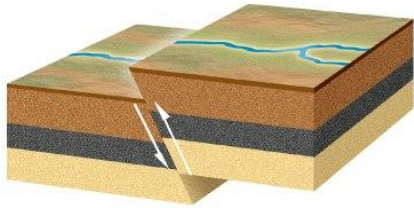
# Overturning Folds



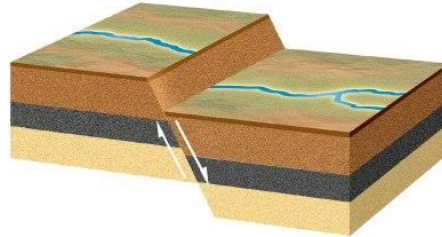
# When failure is reached.

Brittle materials change a little and then break suddenly.

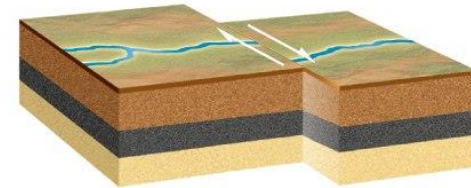
Reverse faulting



Normal faulting



Strike-slip faulting



# Fracture as a Discontinuity

It is defined by Twiss and Moores (1992) as “*..surfaces along which rocks or minerals have broken; they are therefore surfaces across which the material has lost cohesion*”

## *Characteristics:*

- *fractures have two parallel surfaces that meet at the fracture front*
- *these surfaces are approximately planar*
- *the relative displacement of originally adjacent points across the fractures is small compared to the fracture length.*

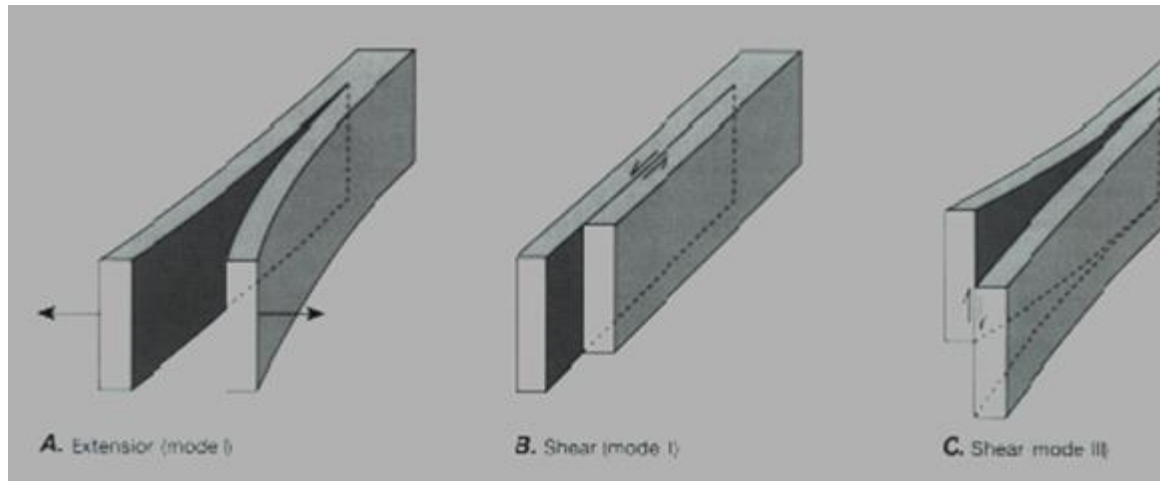
## Other Discontinuities:

- Weathered Zones
- Hydrothermally altered zones
- Solution cavities (ex: karst)

# Fracture Mechanics

## The term fracture encompasses both joints and faults.

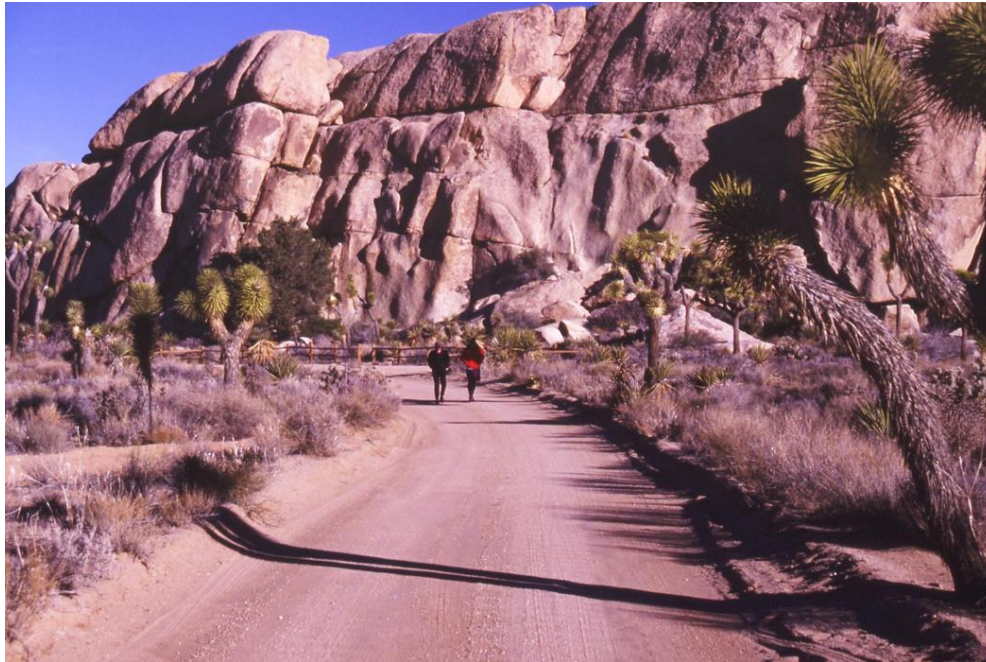
- **Mode I fractures (joints)** it is the extensional fractures and formed by opening with no displacement parallel to the fracture surface.
- **Mode II and Mode III are shear fractures (Faults)** one of them is strike-slip and the other is dip-slip



# Fracture, Joint and Fault

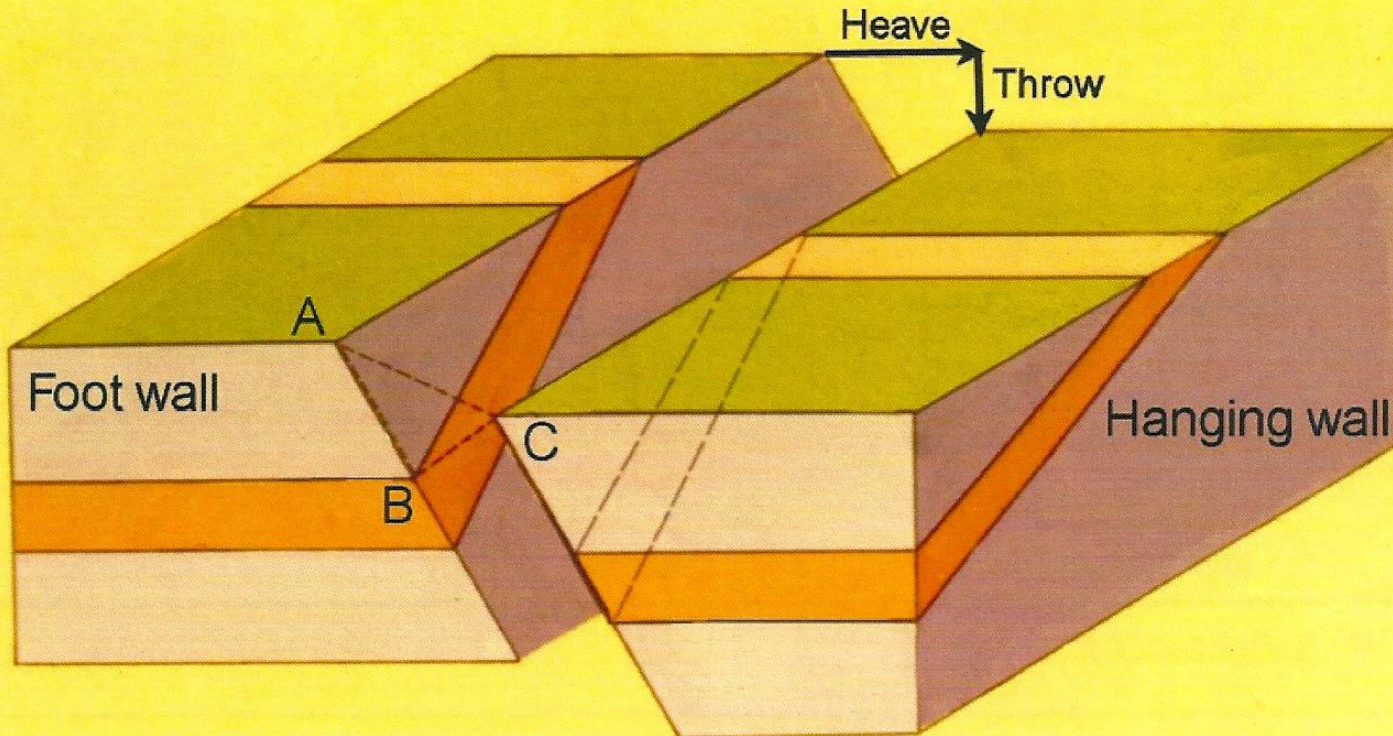
**JOINTS:** are fractures along which there has been no appreciable displacement parallel to the fracture and only slight movement normal to the fracture plane.

*Joints are most common of all structures present in all settings in all kind of rocks as well as consolidated and unconsolidated sediment*



# Faults

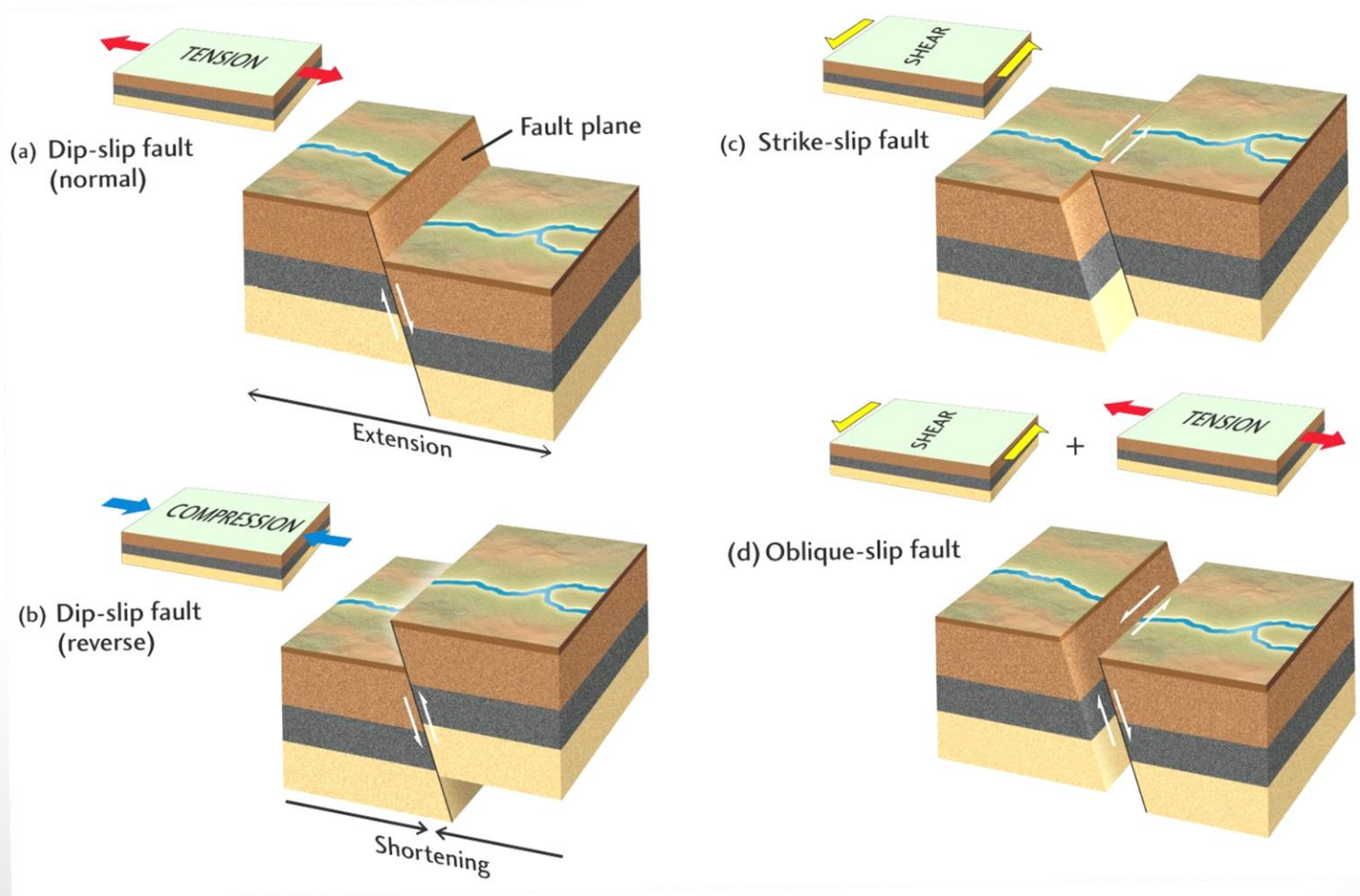
AB = Dip slip  
BC = Strike slip  
AC = Net slip



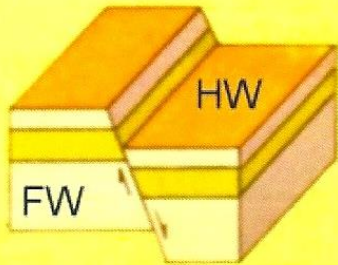
# Faults

Produced in shear stresses and involve a lot of differential movement

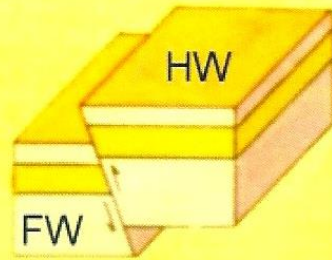
- Normal Fault
- Thrust Fault
- Strike Slip Fault



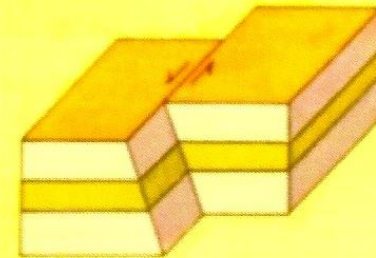
# Faults



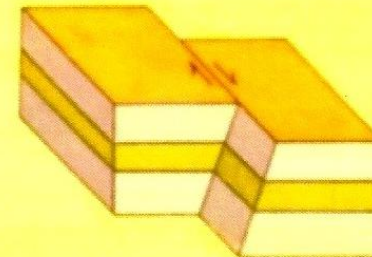
Normal fault



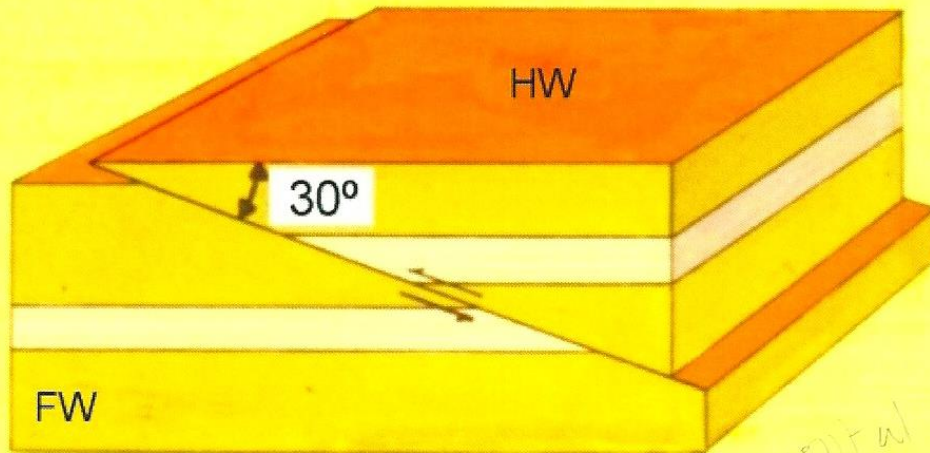
Reverse fault



Left lateral  
strike slip fault



Right lateral  
strike slip fault



Thrust fault

Faults with vertical movement

*low angle fault*

Faults with  
horizontal movement

# Effect of Stress State

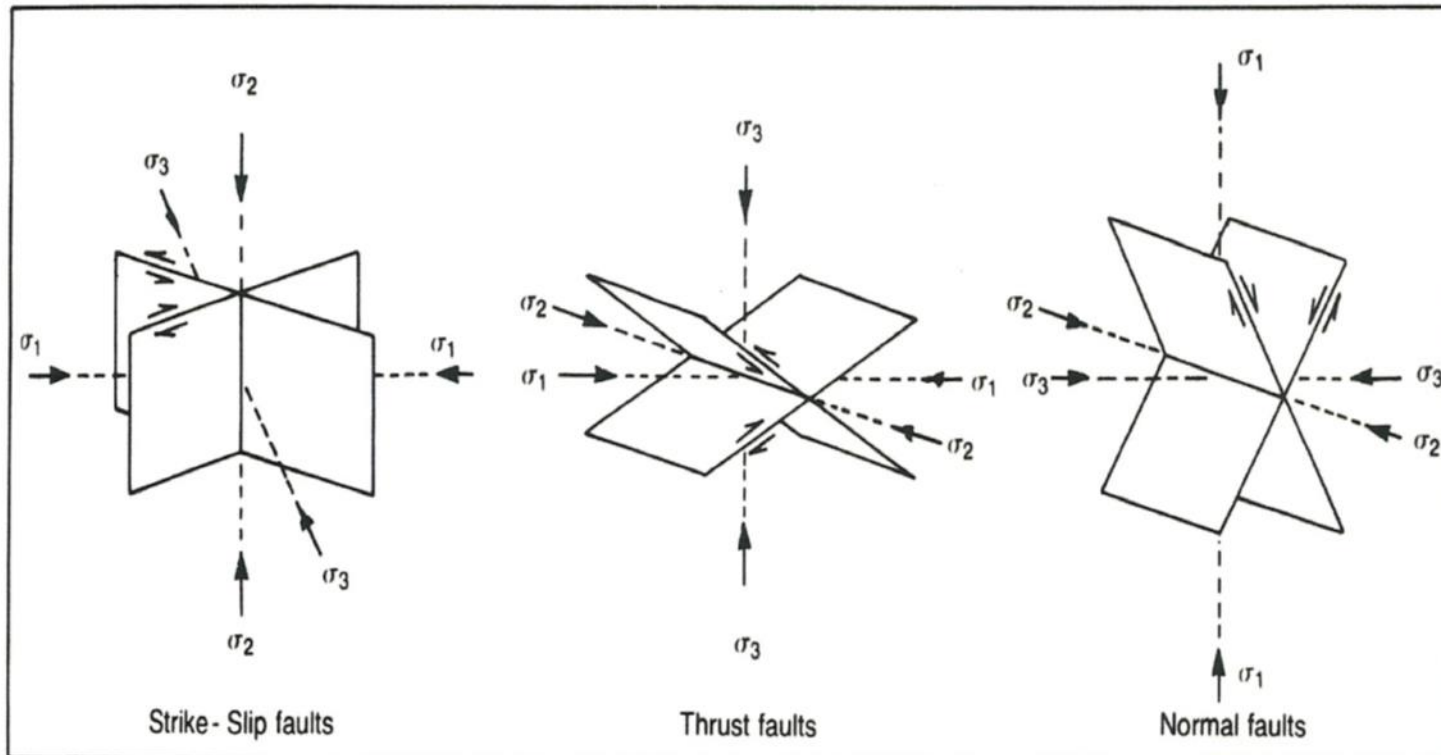
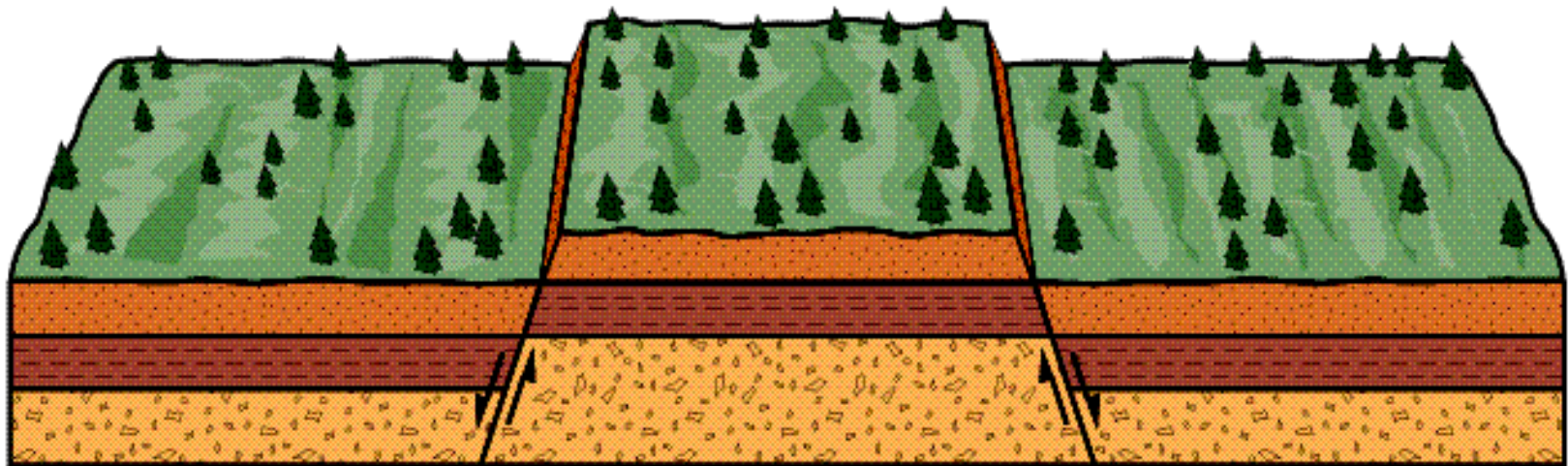


Fig. 286. Fault classification

# Graben, Horst Faults

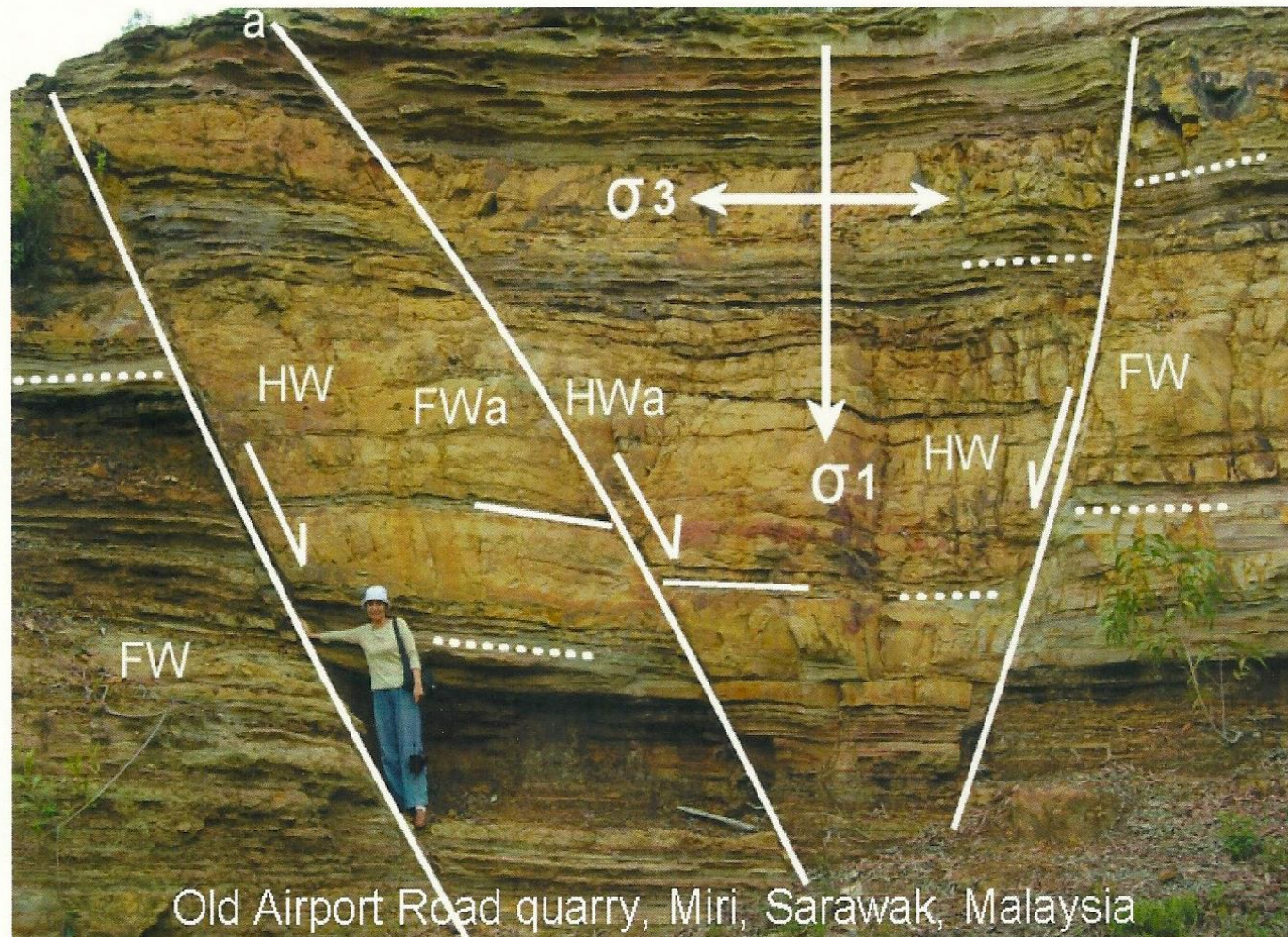


**Graben**

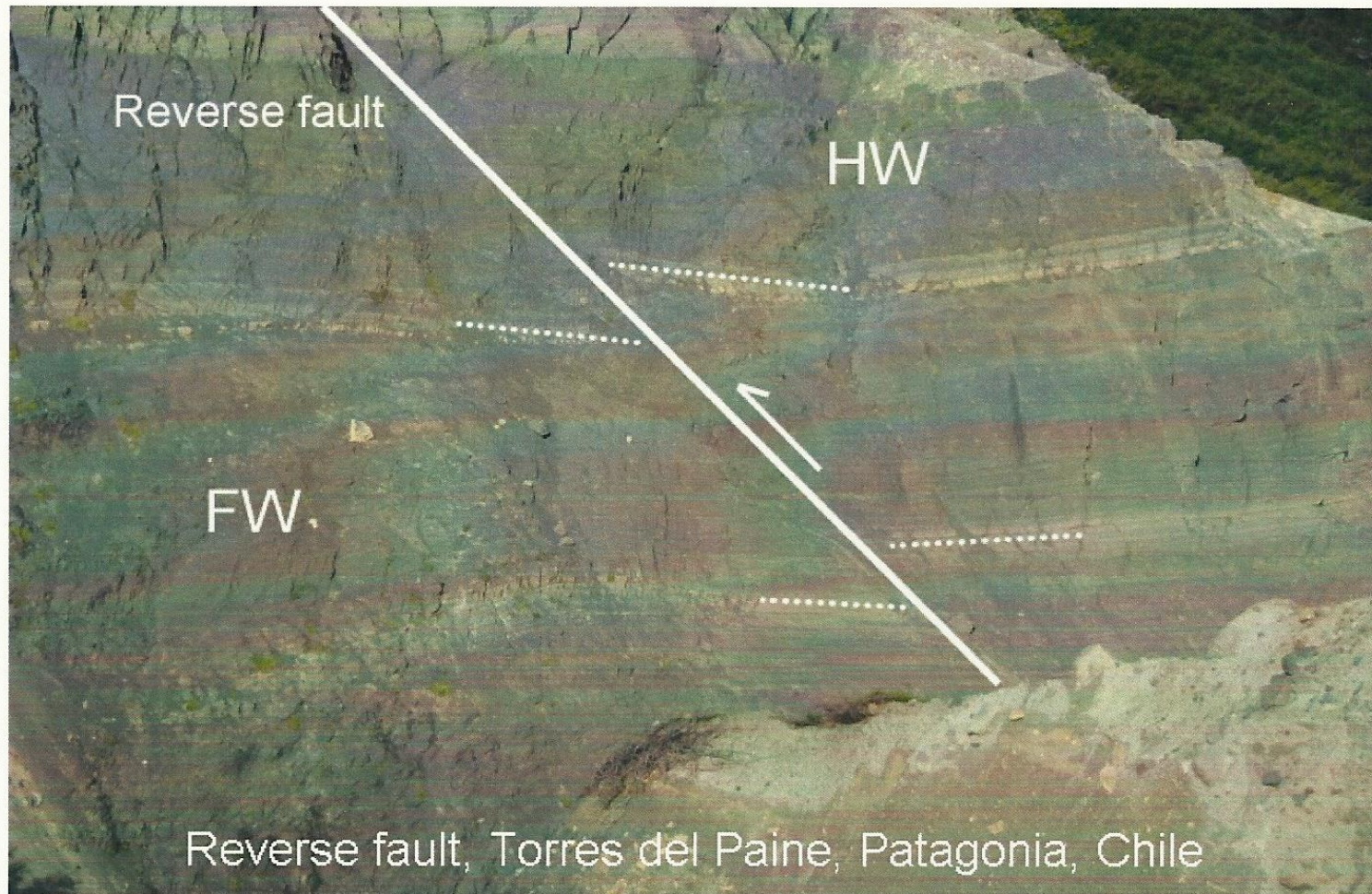


**Horst**

# Example: Cluster Faults



# Example: Reverse Faults



# Example: Horst



# Physical Characteristics

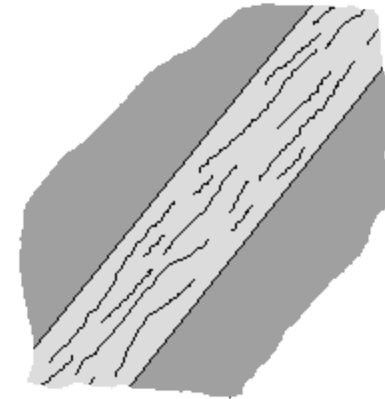
1. length
2. Planar or near planar surfaces (Strike and Dip)
3. Width
4. Relative Movement
5. Disturbed Material (Fault Material)

# Fault Zone Materials

- Breccia
- Gouge
- Character of Parent rock
- Adjacent Competent and Incompetent Rocks



Breccia



Gouge

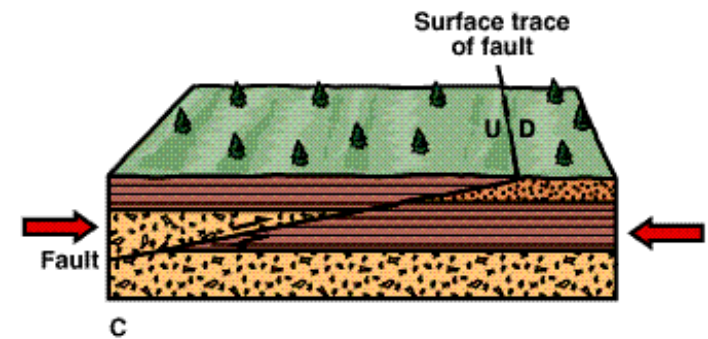
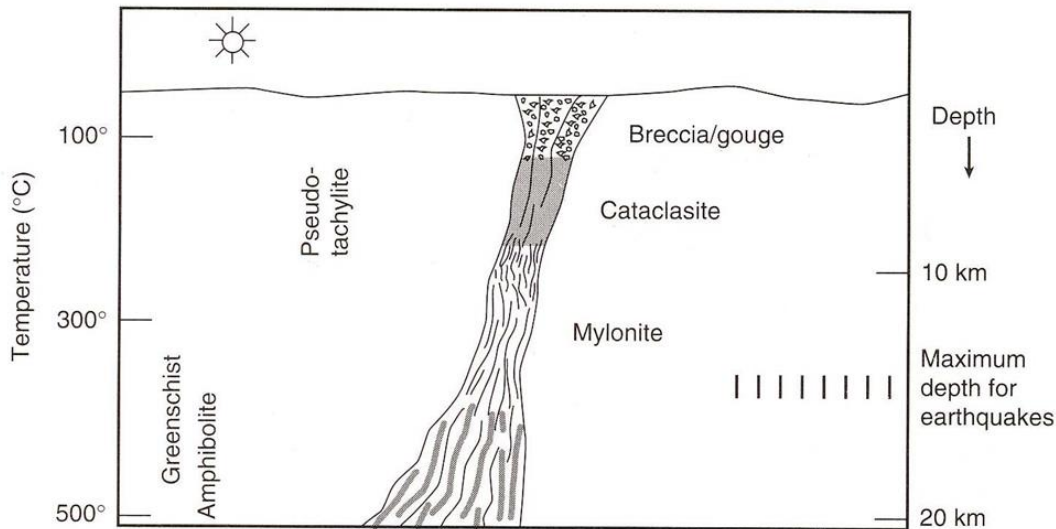


Figure 8.25 Change in fault character with depth for a steeply dipping fault.

# Breccia



# Factors Affecting Fault Material

- Distance of displacement and duration of faulting
- Erosion by water flow
- Chemical Weathering
- Hydrothermal process
- Solution
- Cementation/ Resedimentation

# Observing Faults

- Surveying
- Seismographs
- Microseisms
- Fresh fault Scarp (confusion with erosion)
- Sag pond
- Offset stream course

## Fault Movement:

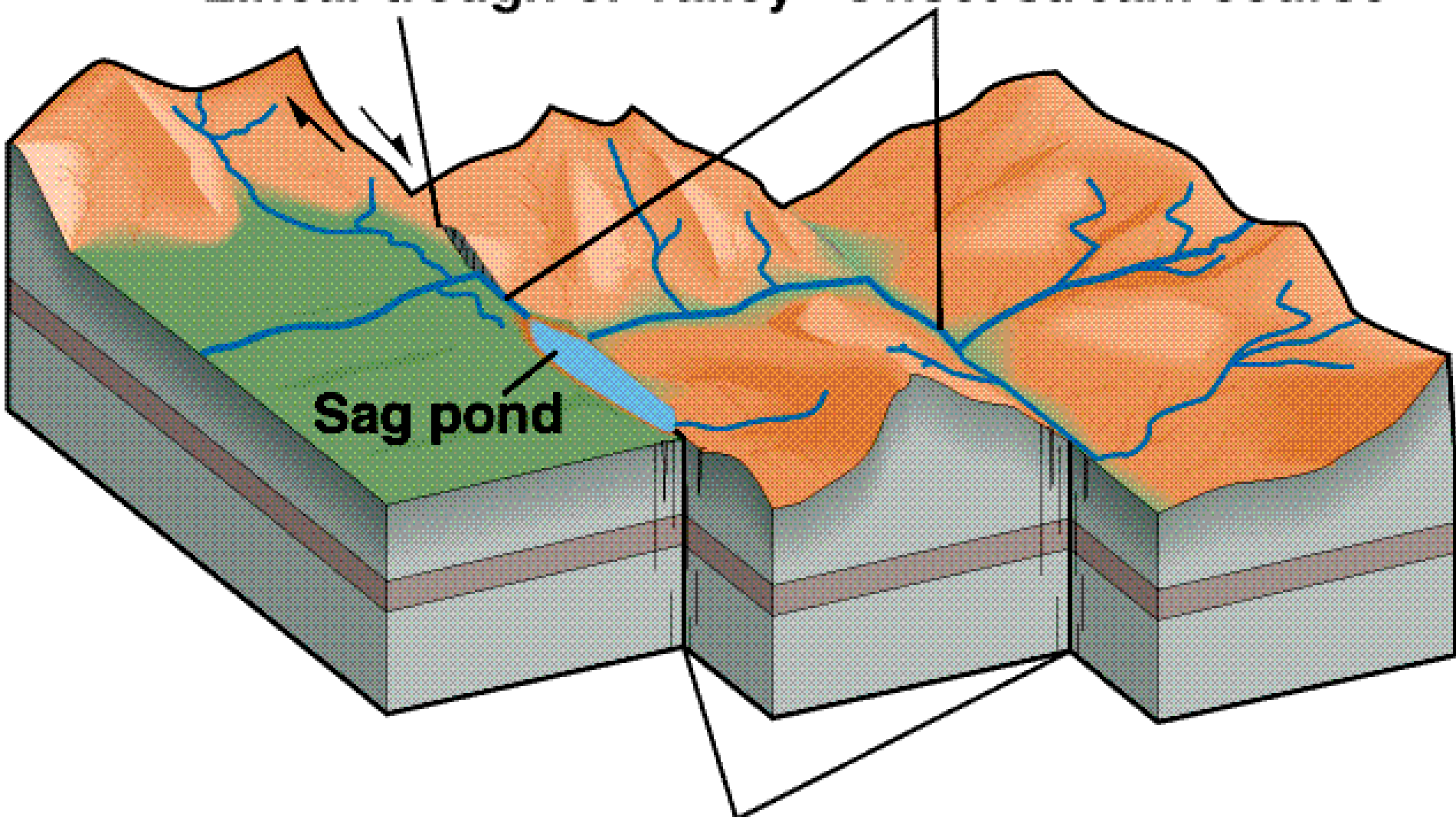
- Instantaneous
- Creep
- Active Fault
- Inactive Fault



Armenia 1988 Earthquake

# Right-Lateral Strike-Slip Fault

Linear trough or valley      Offset stream course



Sag pond

Active fault traces

# Engineering Implications: Dams

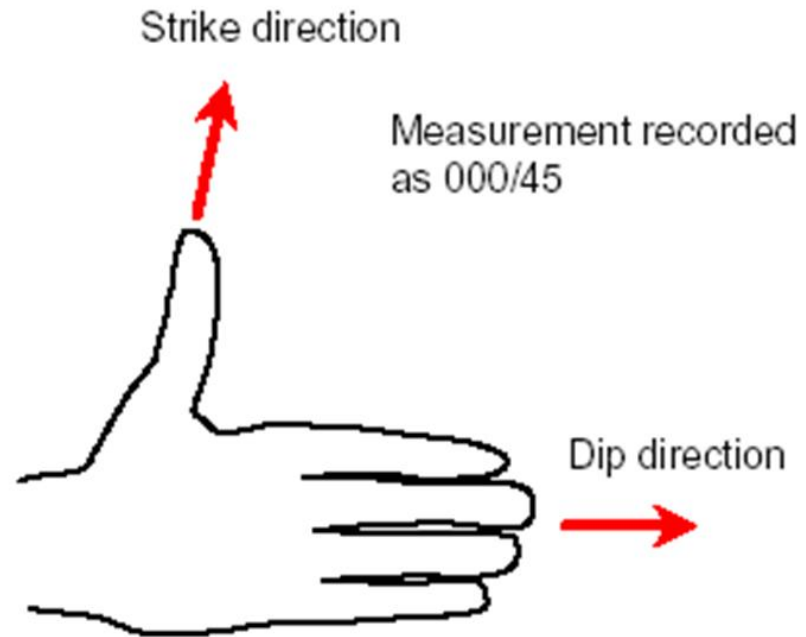
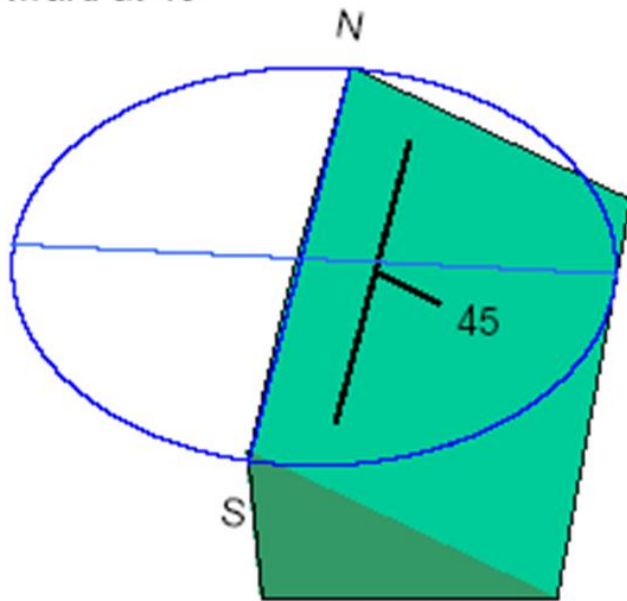
- River path
- Permeable Zones
- Build Up pressure
- Fault Material are more deformable
- Variability in Foundation Rock

# Engineering Implications: Tunnels

- Method and Direction of Driving
- Considering Alignment
- Water pressure on tunnel lining (Harlem River)

# Remember Strike and Dip

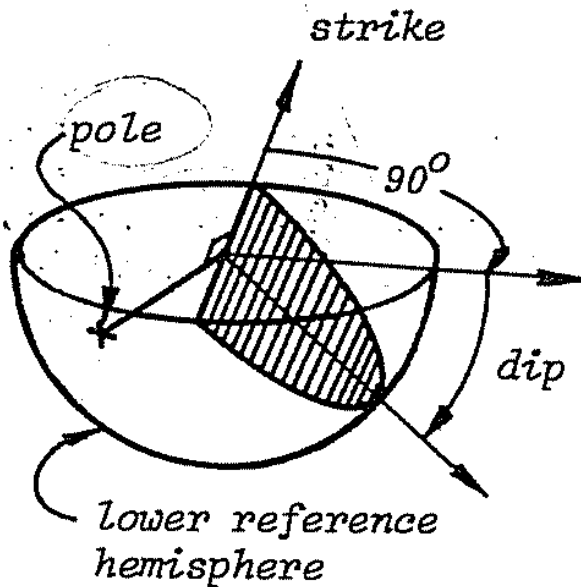
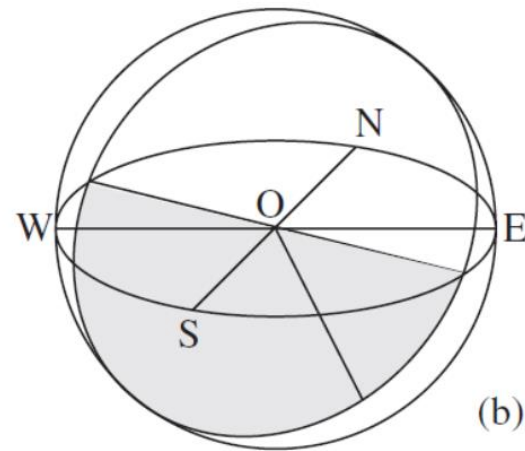
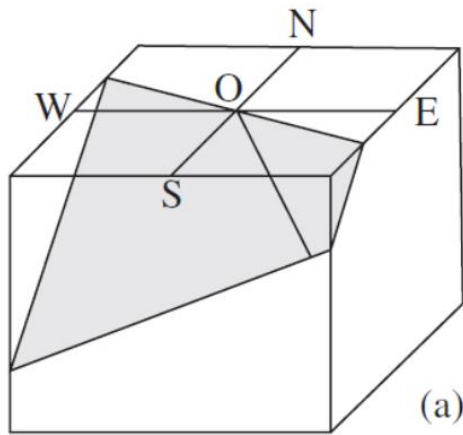
Bedding plane striking N-S and dipping eastward at 45



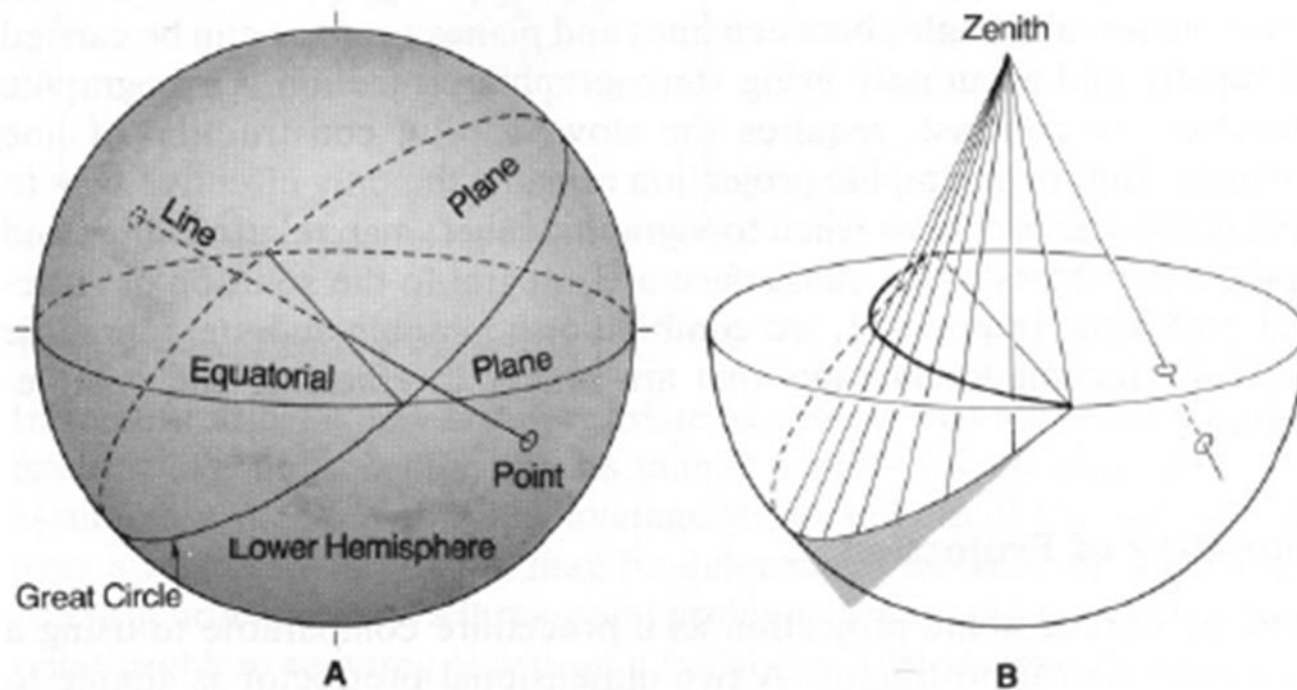
# Stereonet

- **Stereonet** are used for plotting and analyzing 3-D orientations of lines and planes in 2-D space
- It is **MUCH** more convenient than using Cartesian space (x-y-z coordinates) for graphically representing and analyzing 3-D data

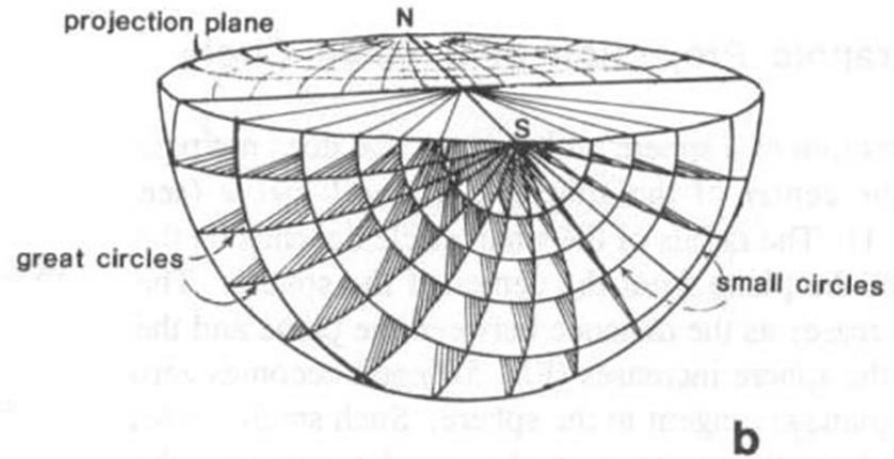
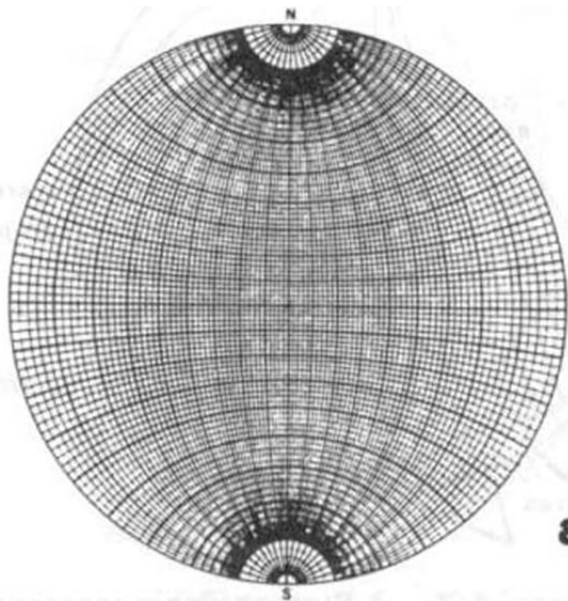
# Reference Sphere



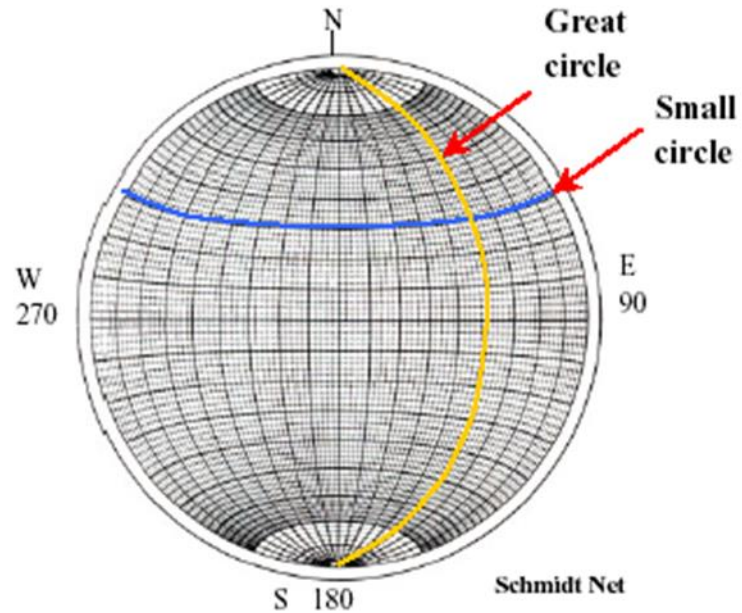
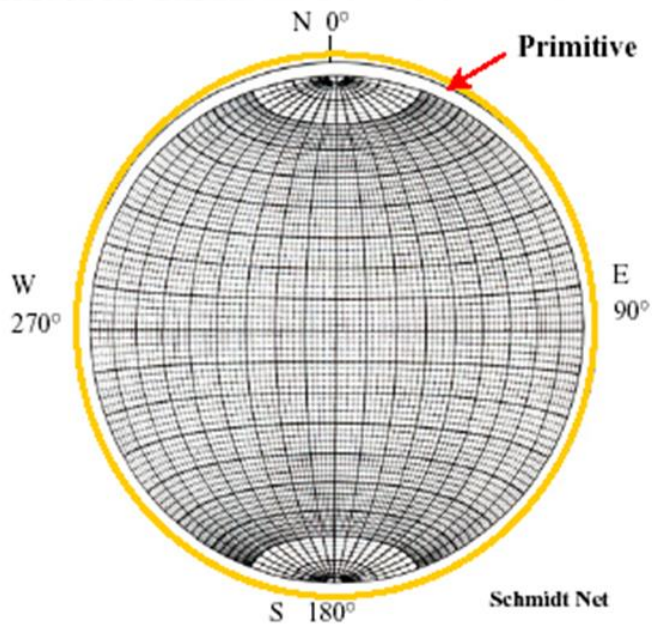
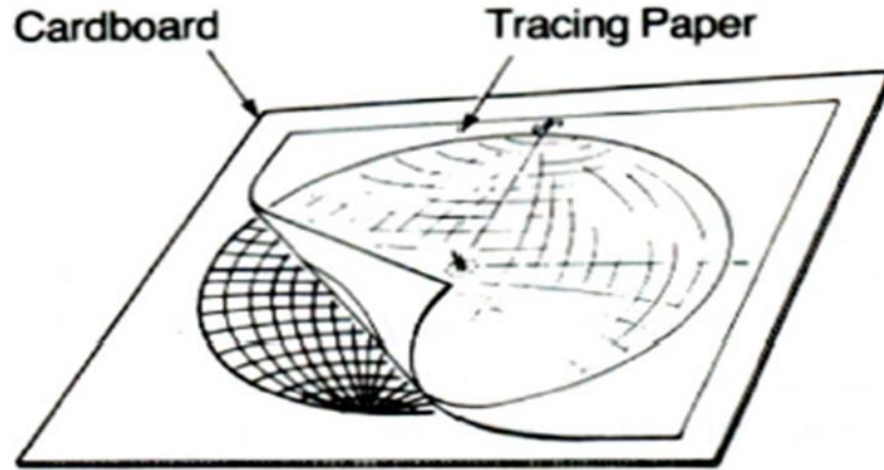
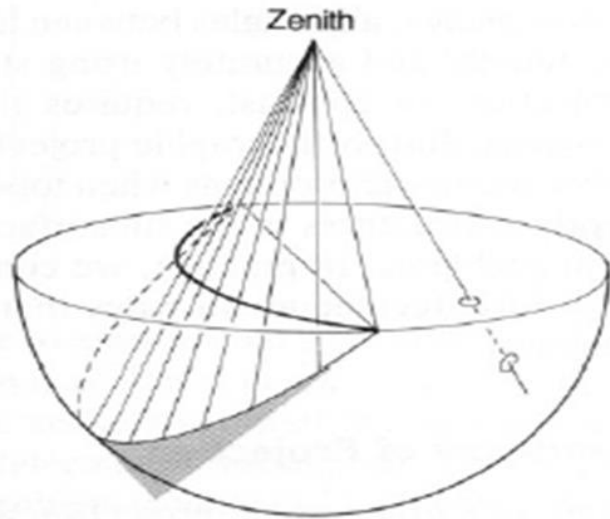
# Stereonets Projection

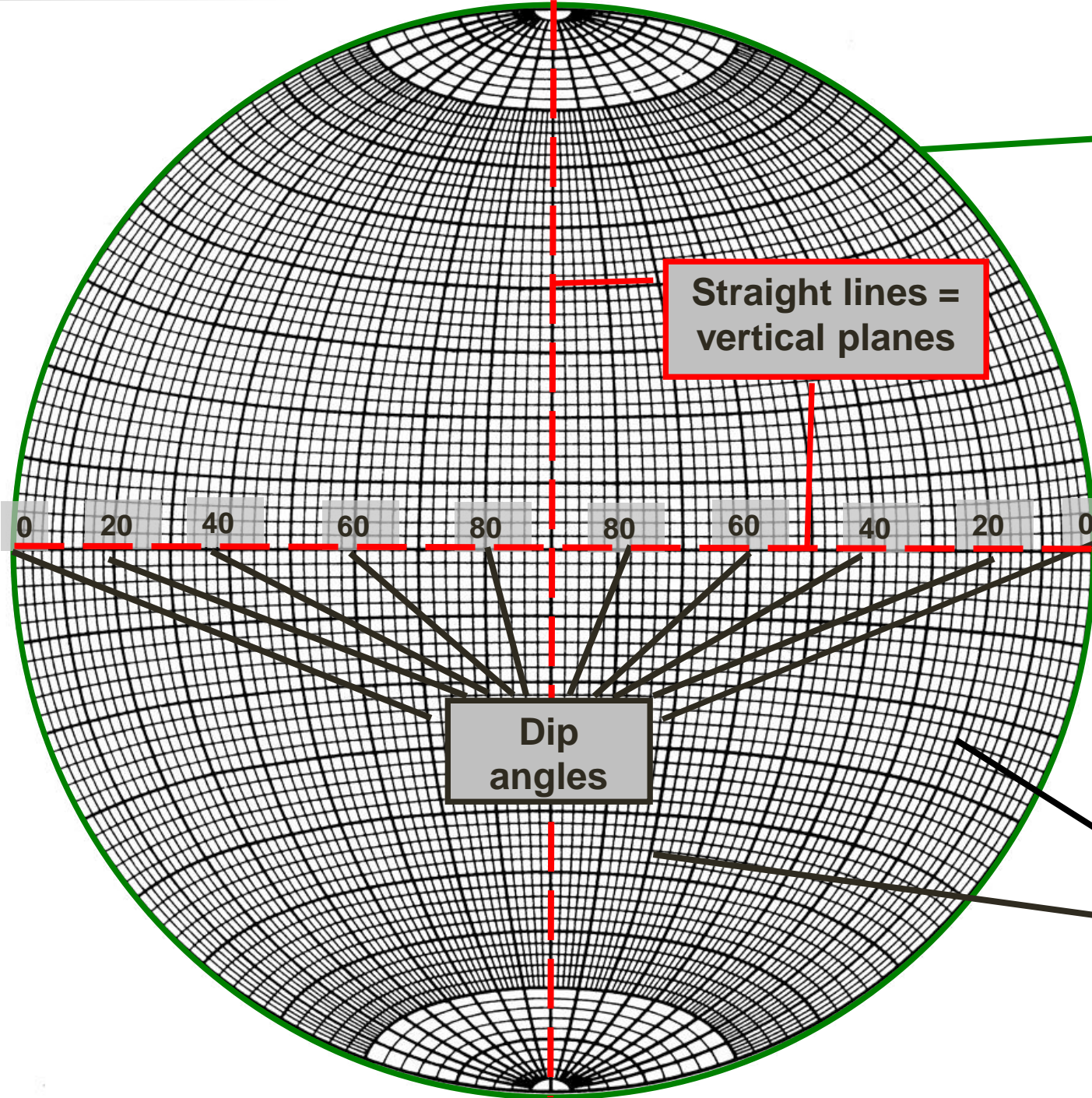


# Stereonet Grid



# Using Stereonet





Equatorial  
circle =  
horizontal  
plane

Straight lines =  
vertical planes

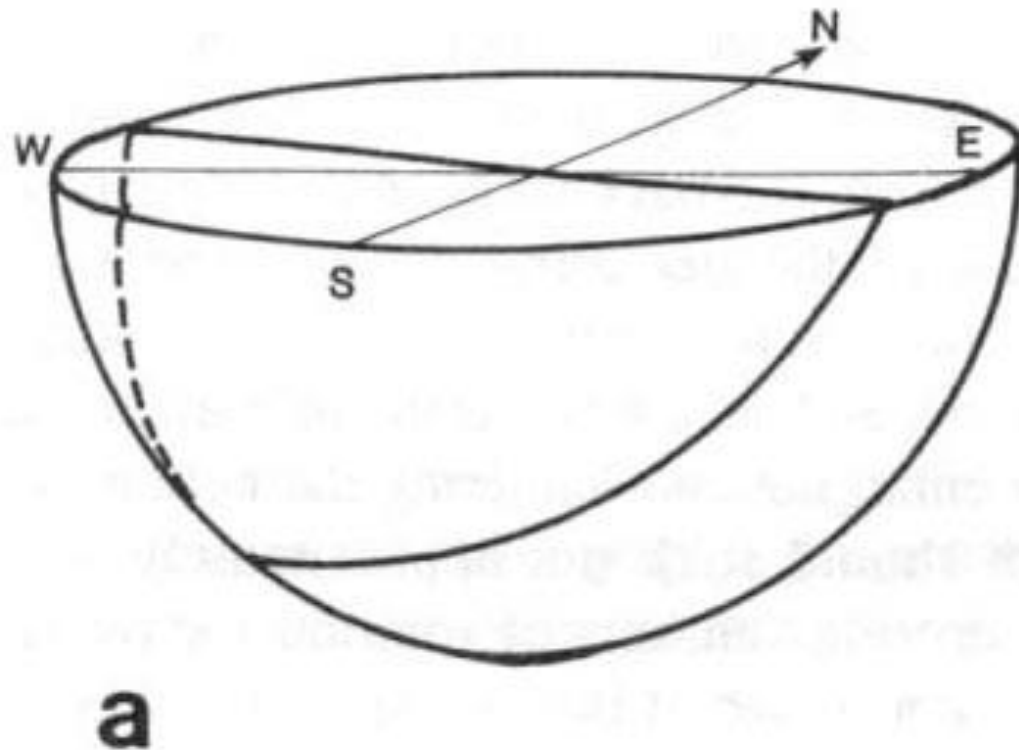
0 20 40 60 80 80 60 40 20 0

Dip  
angles

Great circles  
= inclined  
planes

# How to plot a plane?

***Suppose a sandstone layer has strike and dip N80W 40S***

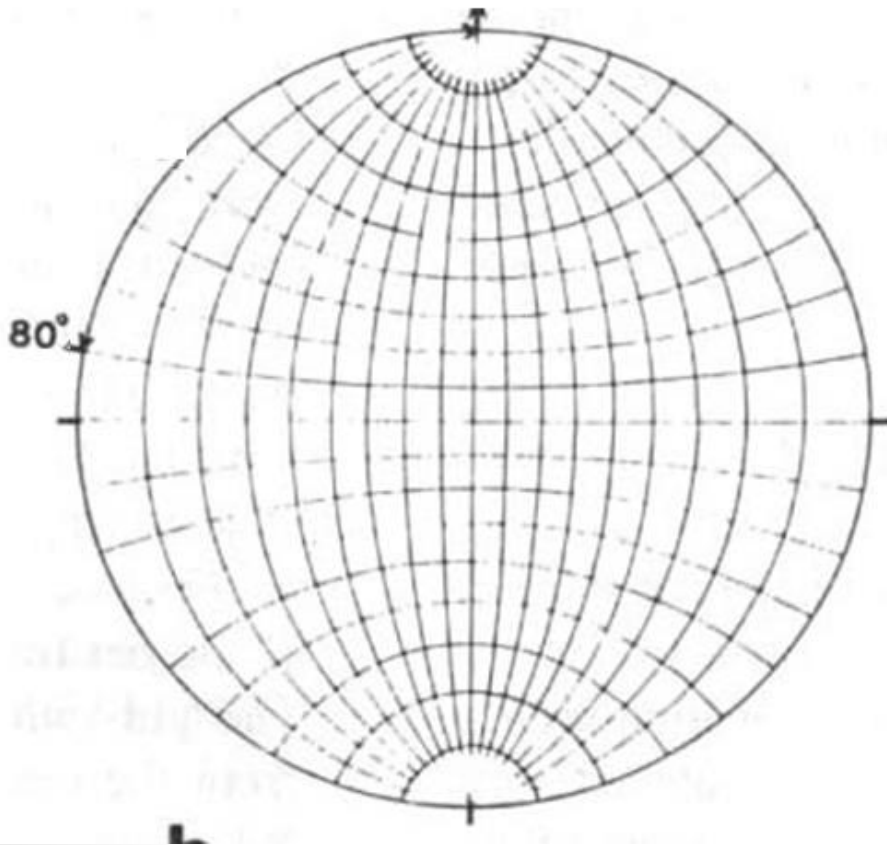


***Visualize the plane  
in space and  
the way it cuts  
the sphere.***

# Plotting a Plane using the Stereonet

*The layer is N80W, 40S*

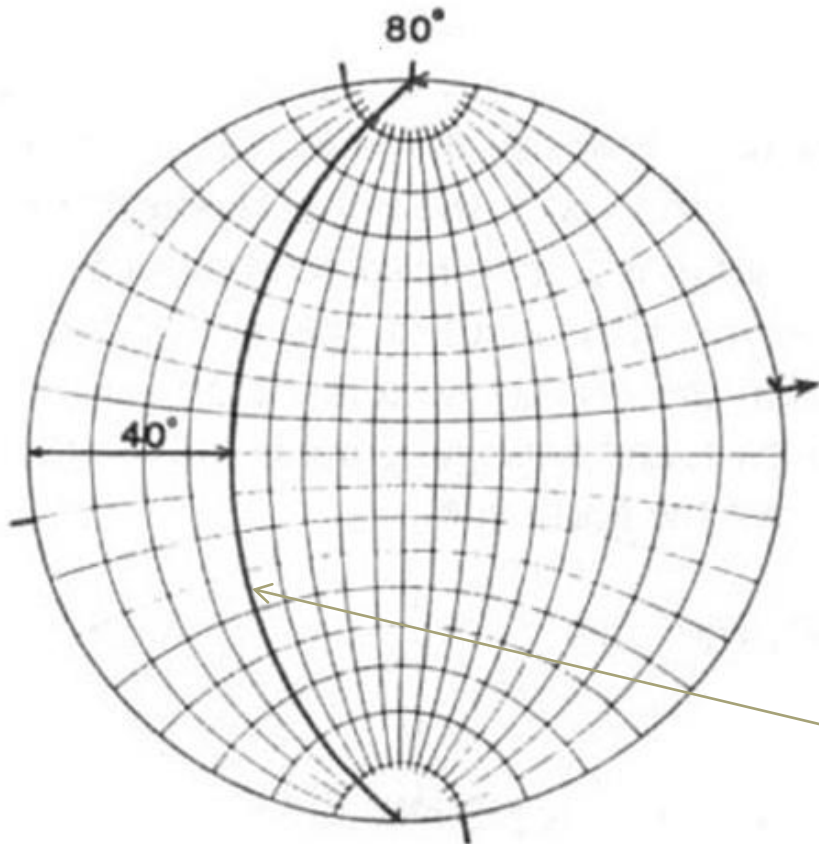
*Place the overlay on the net and mark N, S, E, & W on the overlay.*



*With the overlay positioned with N at 0°, Count 80° CCW to N80W and place a tick mark showing the position of the strike.*

# Plotting a Plane using the Stereonet

*The layer is N80W, 40S*



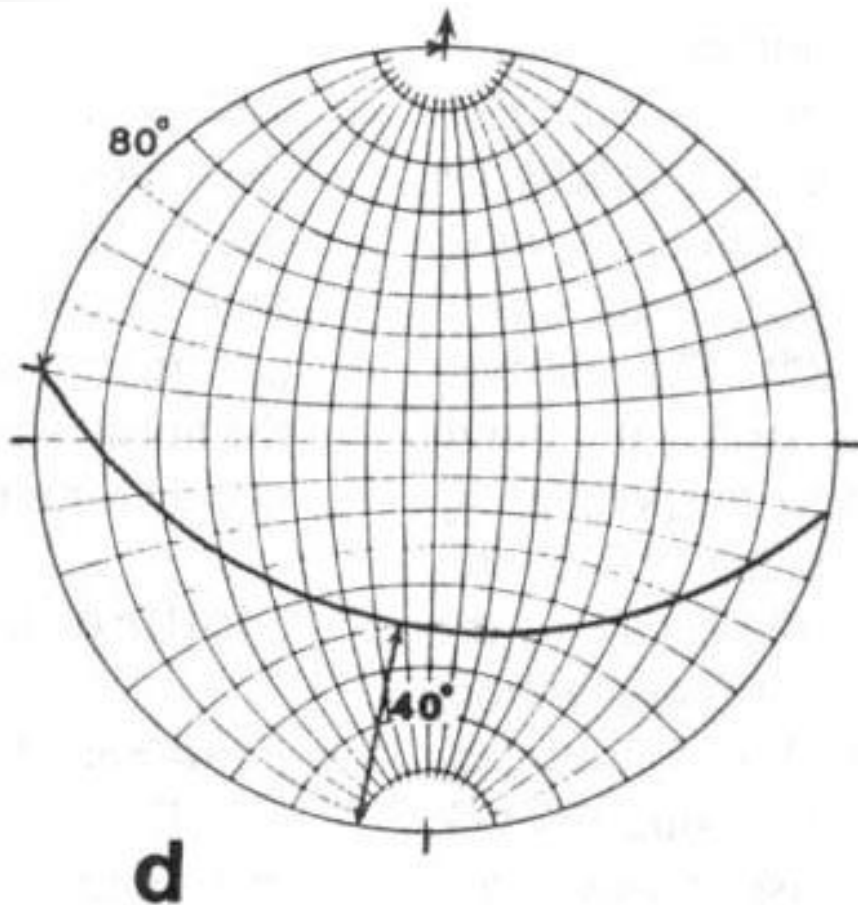
*Next, rotate the transparency so the strike is at 0. Now you can find the great circle with the same dip (40) as the layer by counting 40 from the primitive circle along the 90 – 270 diameter.*

*Make sure you count in from the primitive along the equator*

*Now trace that great circle on the transparency and you have the projection of the layer plotted.*

# Plotting a Plane using the Stereonet

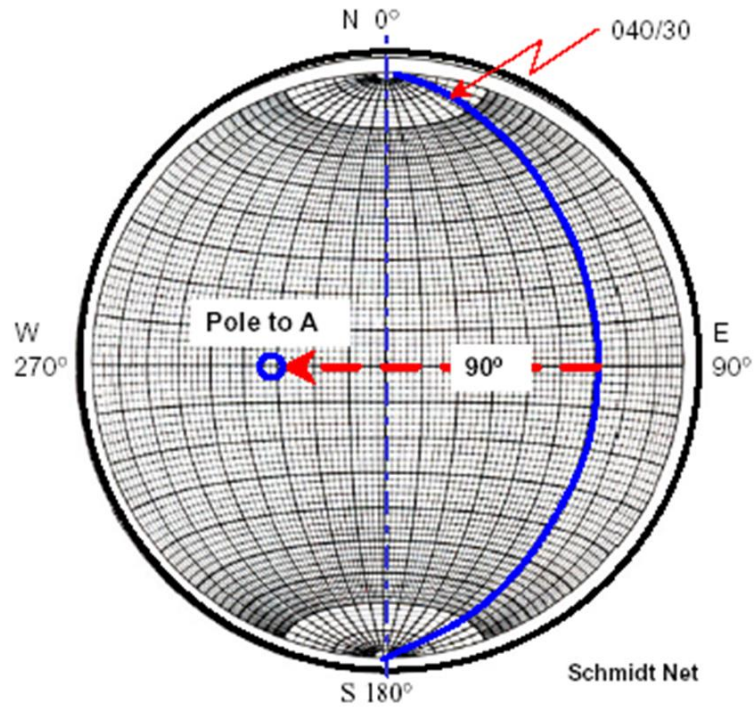
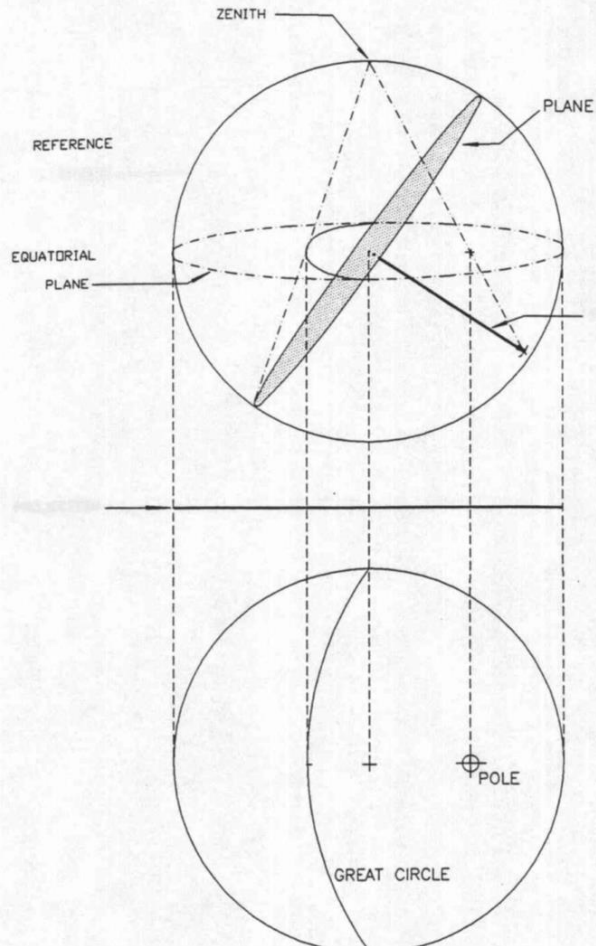
***The layer is N80W, 40S***



***Now, rotate the transparency back so North on the transparency coincides with 0 on the stereonet.***

***The plot now shows the projected position of the layer in space.***

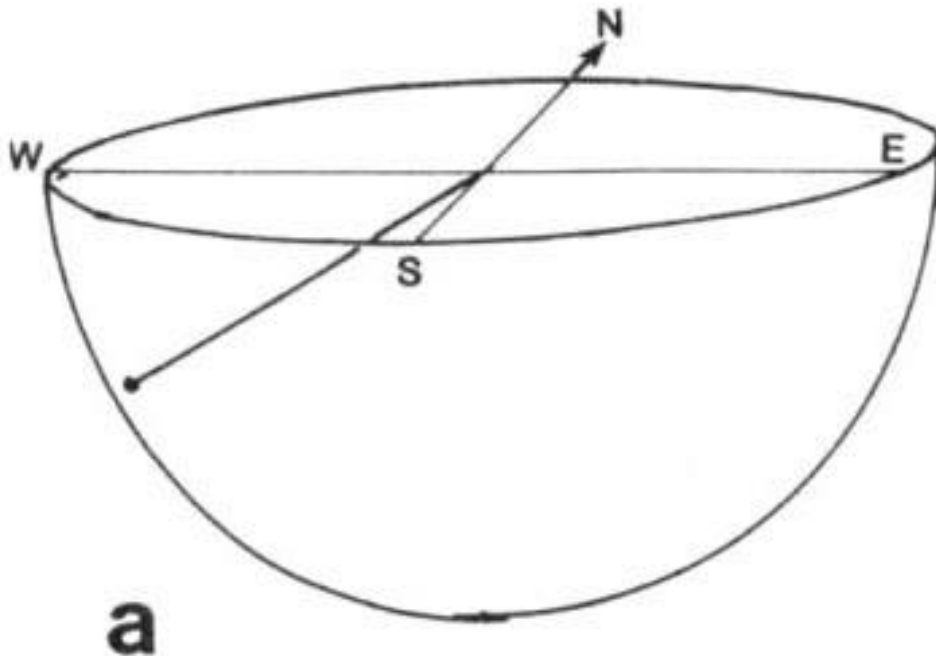
# Plotting the pole of a plane



# How to plot a line ?

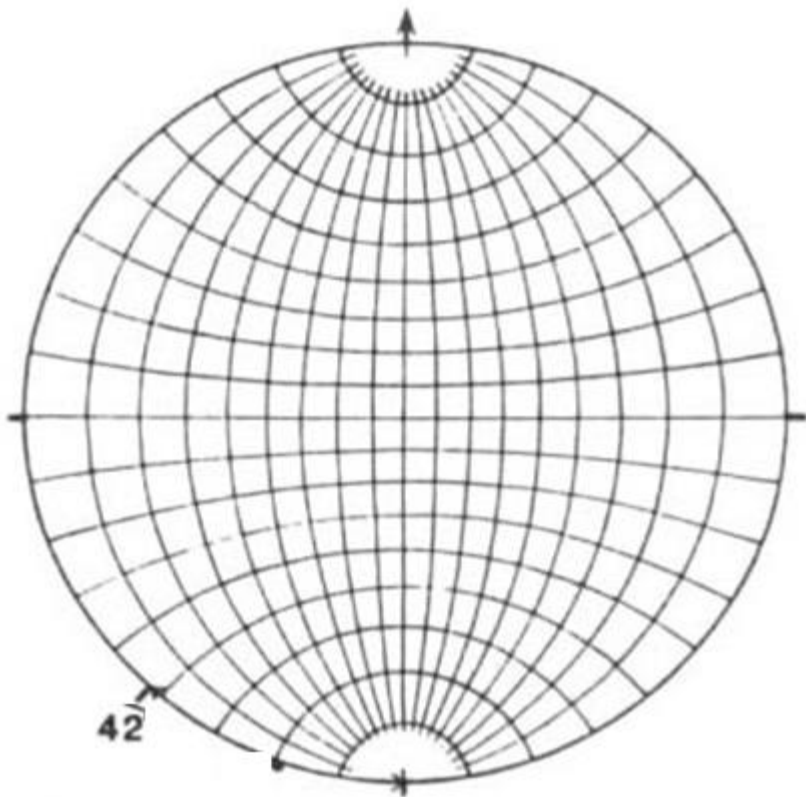
***The line is a fold axis at bearing (Trend) S42W, plunge angle 38°***

***Visualize the line in space plunging 38° to the SW***



# Plotting a Line using the Stereonet

*The line is a fold axis at S42W, 38°*

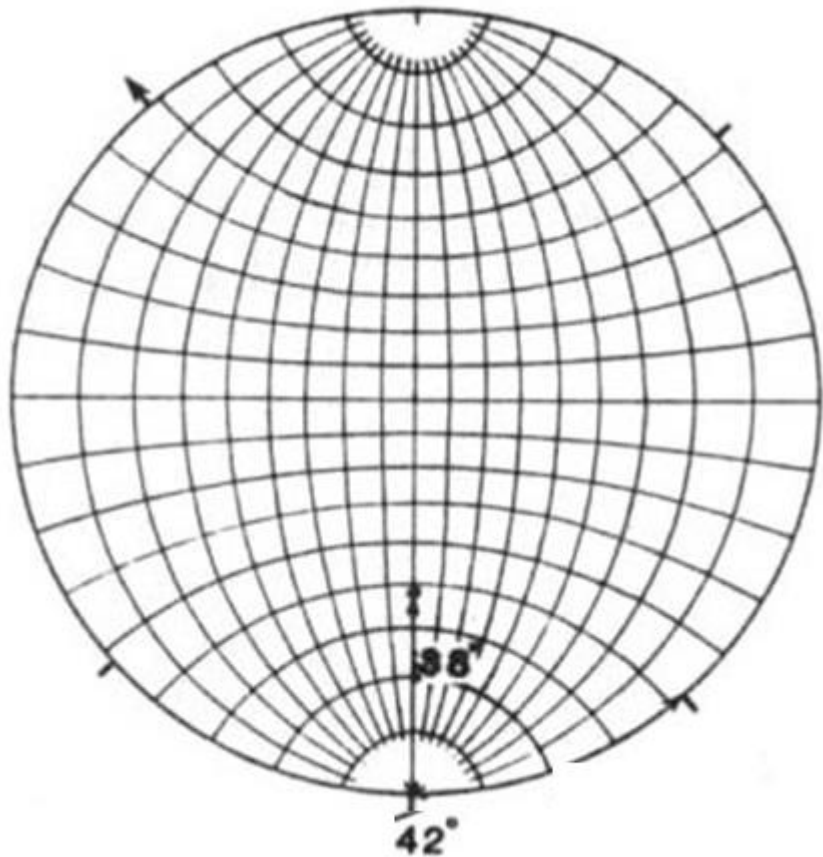


*Next, place the overlay on the net and mark N, S, E, & W on the overlay.*

*Locate S42W and make a tick mark at that position on the primitive circle.*

# Plotting a Line using the Stereonet

*The line is a fold axis at S42W, 38°*

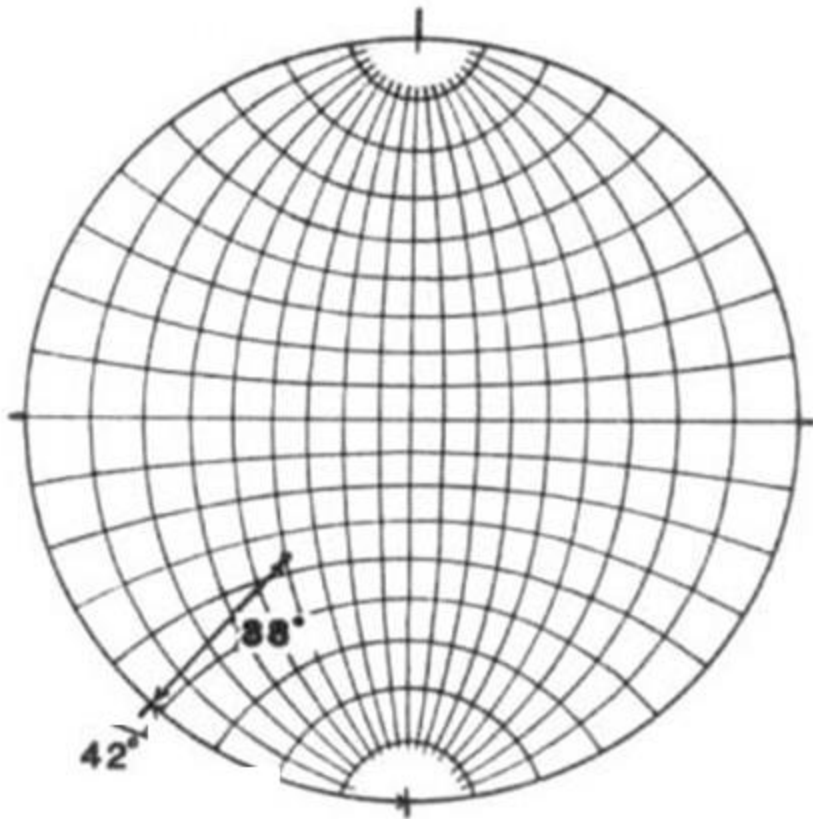


***Next, rotate the tick mark to either of the straight line axes of the net.***

***Measure 38° along the line from the primitive circle and put a dot. This is the projection of the point where the line penetrates the sphere.***

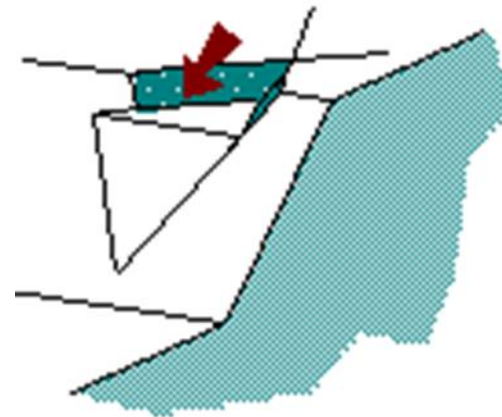
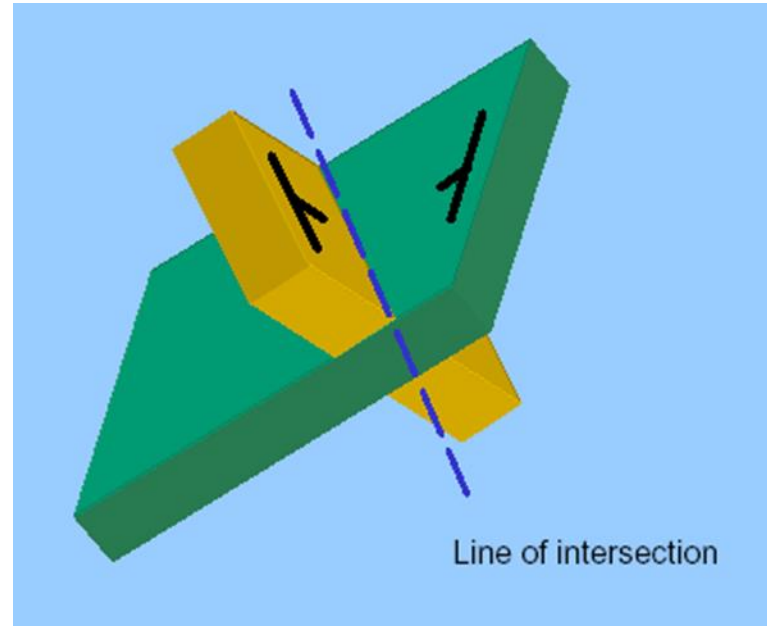
# Plotting a Line using the Stereonet

*The line is a fold axis at S42W, 38°*

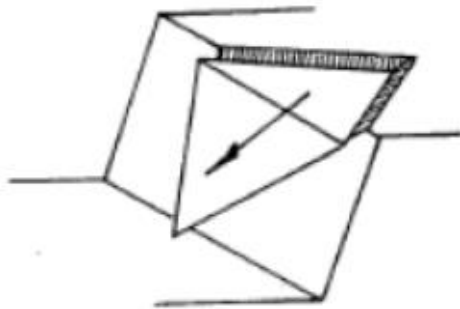


*Finally, rotate the transparency so that North coincides with 0 on the stereonet. Check to make sure your dot is in the SW quadrant.*

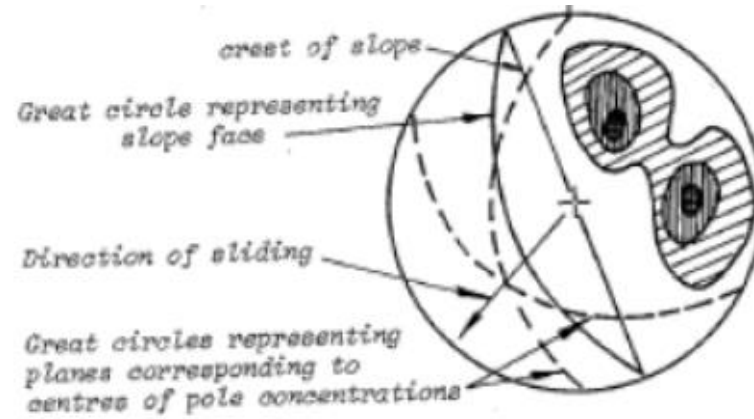
# Application to Rock mechanics



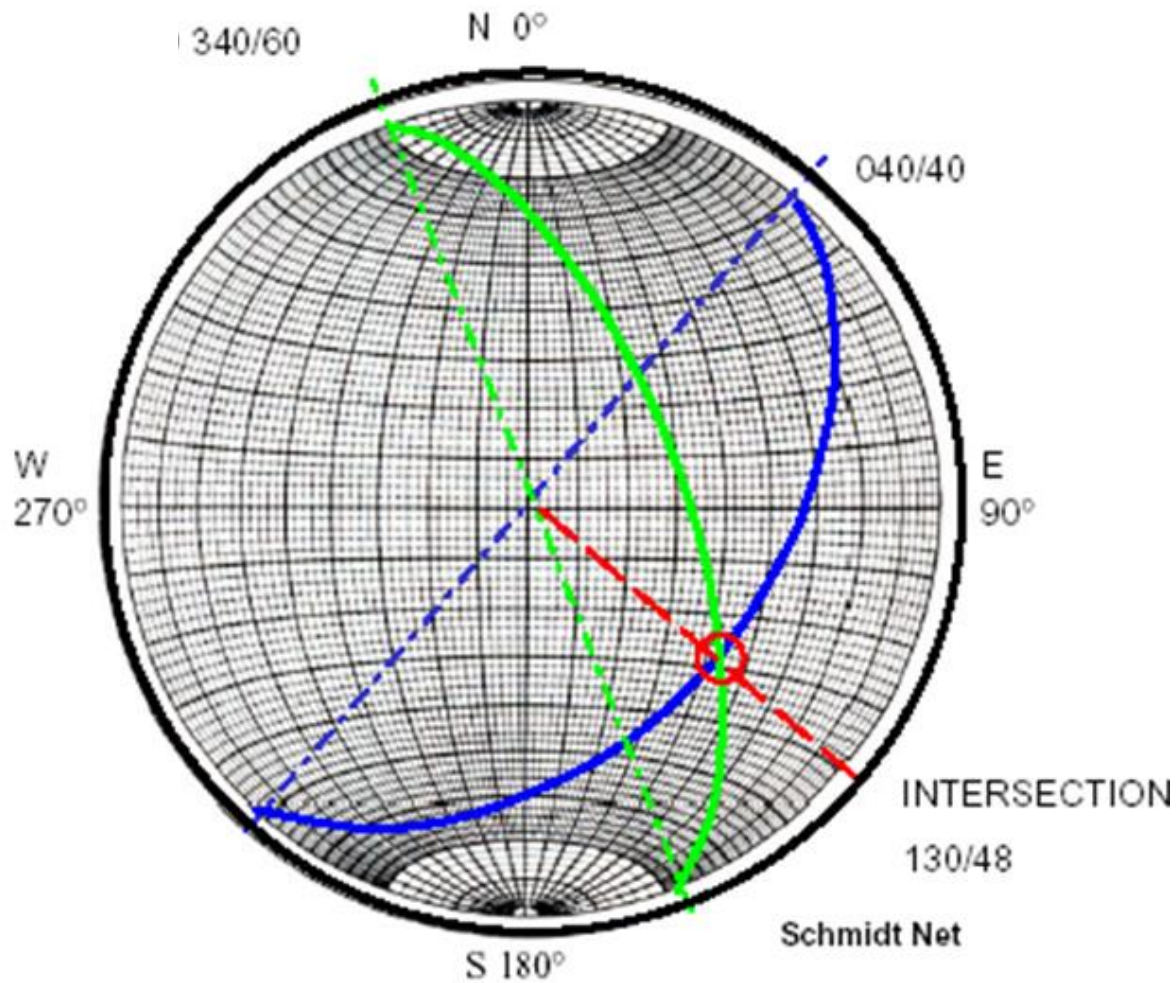
# Wedge failure



c. Wedge failure on two intersecting discontinuities.



# Wedge failure



THANK YOU