Chapter 10
Deformation of Rocks

Panamint Range, Death Valley National Park, California.

Chapter 10
Crustal Deformation

Topics covered -

- Stress and strain
- Mapping strike and dip
- Folds
- Faults
- Joints

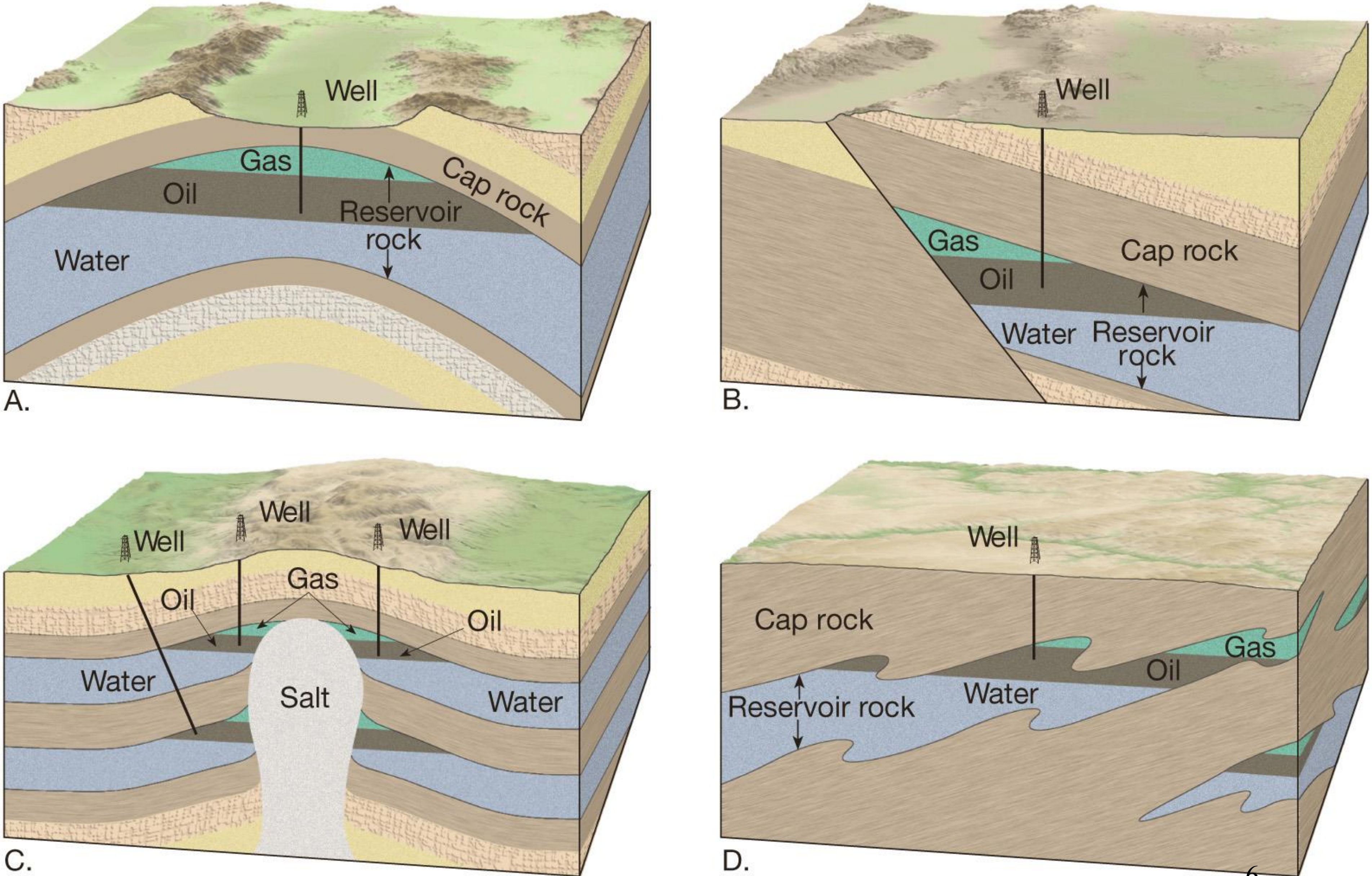
Why knowledge of folds and faults is important.

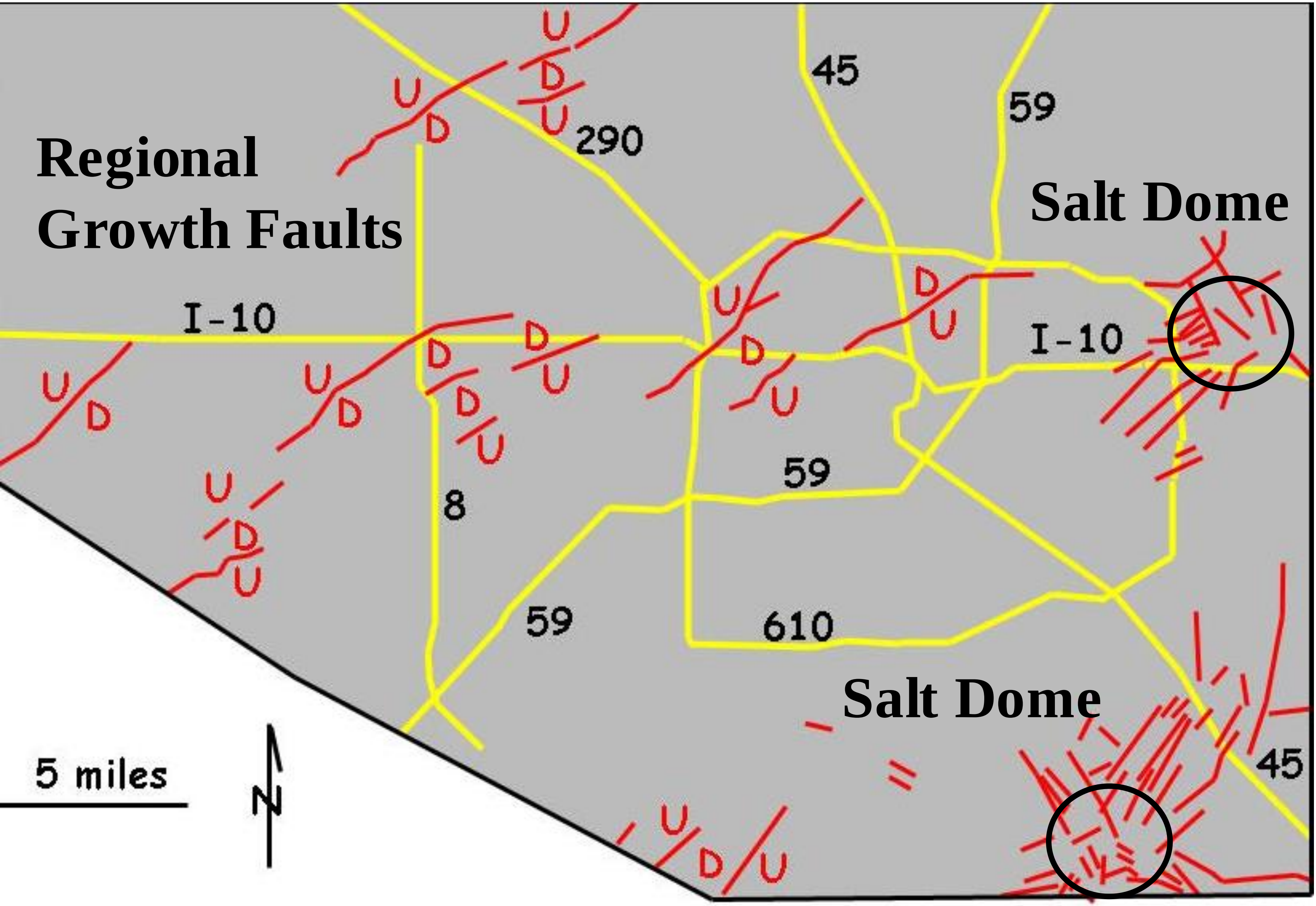
- orientation of folds and faults give
  - geologic setting
  - direction of forces that produces structures
- economic importance
  - oil and gas trapped by structures
  - must find faults so do not build structures there
  - ore deposits localized on faults

Why do oil companies spend a lot of money to find faults and folds?

Figure 21.7

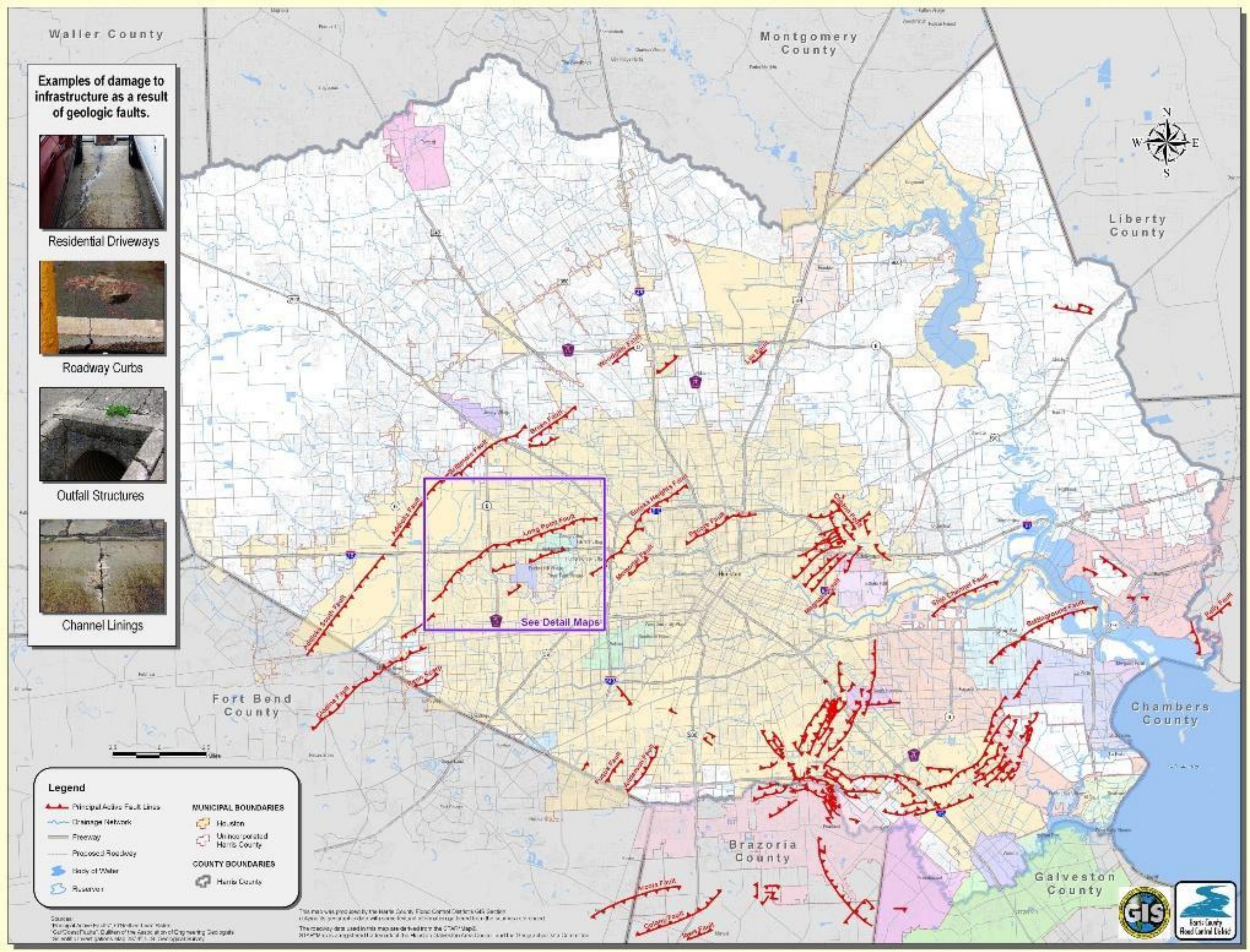
Folds and faults control location of oil



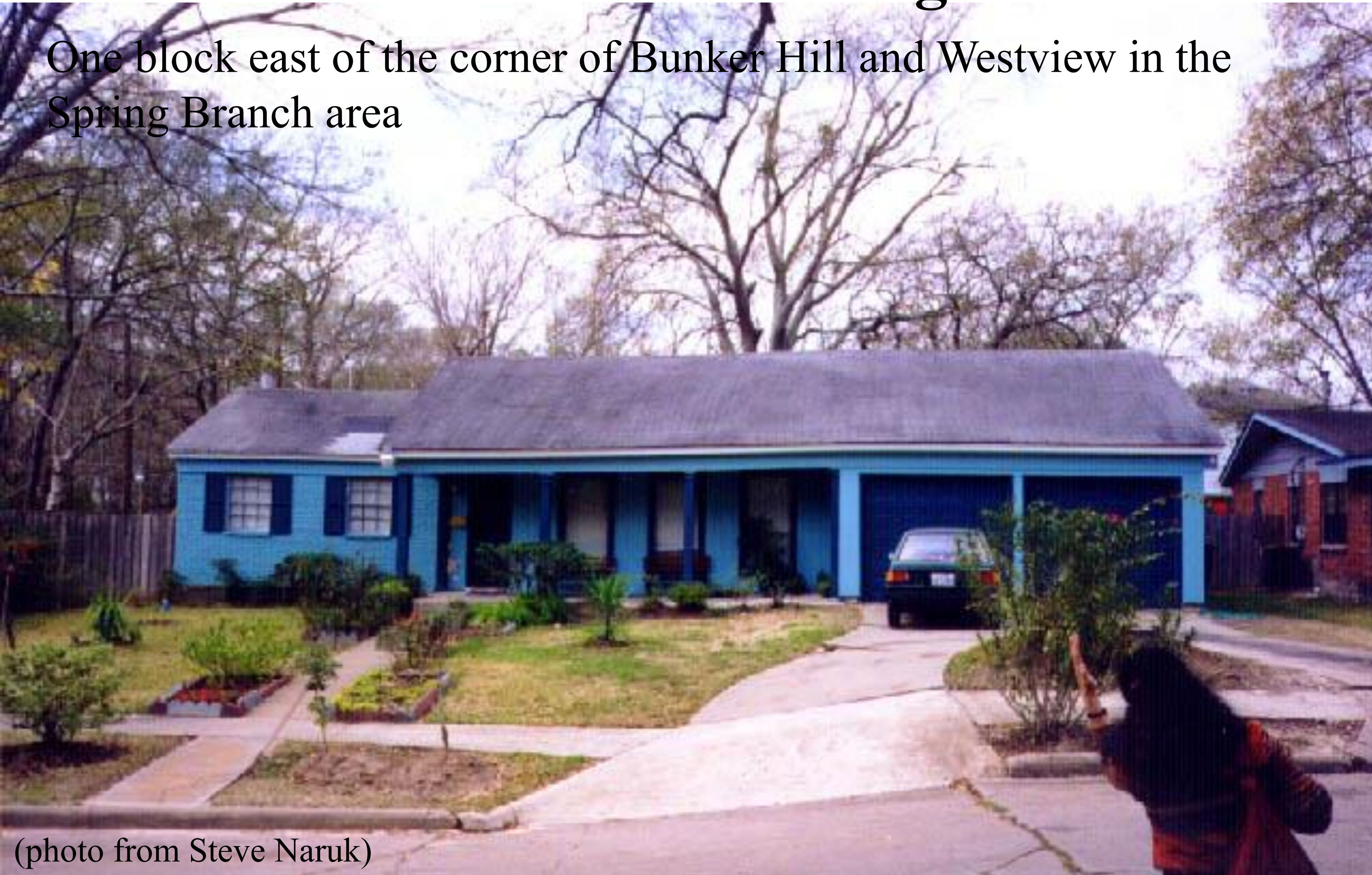


Houston Has It's Faults

Principal active faults in the Houston area (Harris County Flood Control District)



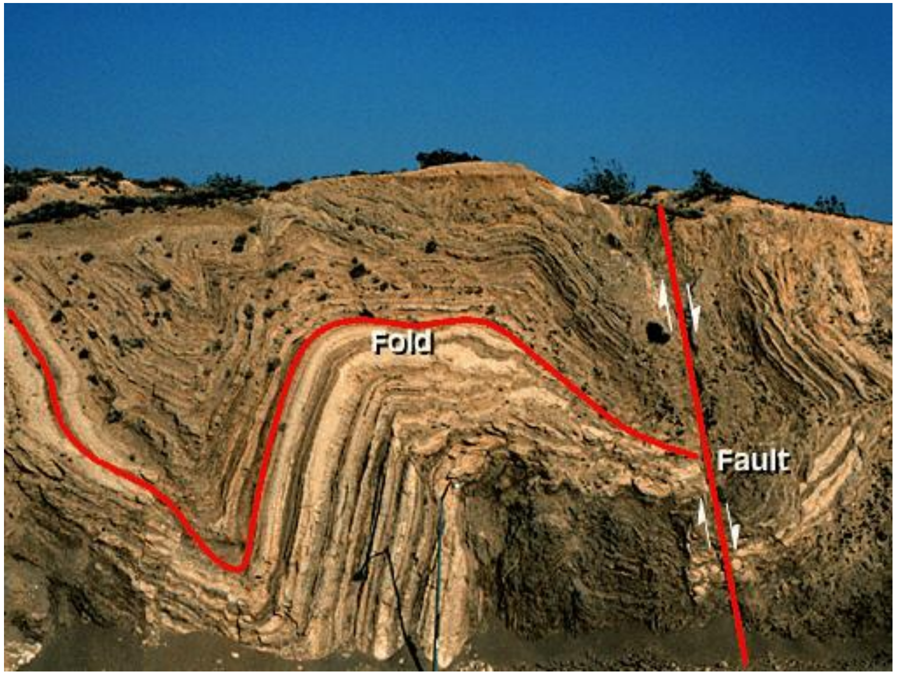
Faults in Houston can damage real estate



Memorial Area, Houston, Texas

Deformation of Rocks

- Deformation results in folding, flowing, fracturing
- <u>Folds</u> and <u>faults</u> are geologic structures in response to tectonic forces or <u>stress</u> on the rock
- Structural geology is the study of the deformation of rocks.

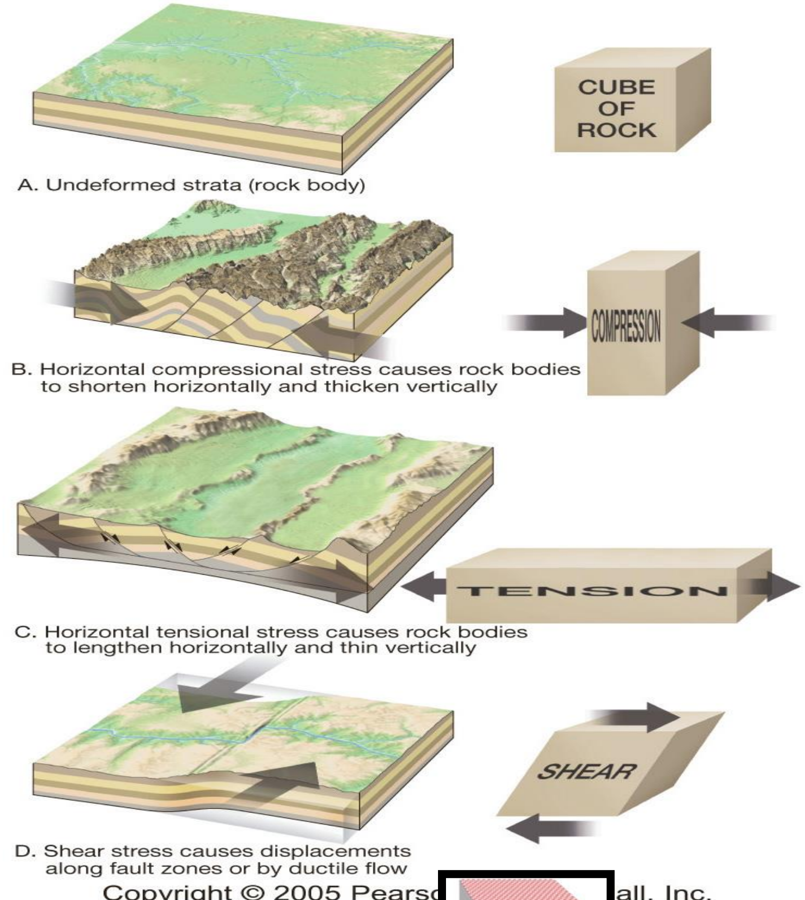


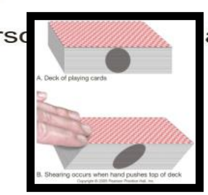
Stress and Strain

- Stress (tectonic forces)- is the amount of force acting on the rock
- Strain (deformation) – is the shape or volume changes caused by stress

Three Types of Differential Stress

- Differential stress is force applied unequally in different directions.
- <u>compressional</u> stress – forces push together
  - shorten the rock body reducing its volume
- <u>tensional</u> stress (extensional) – forces pull apart
  - elongate rock body
- <u>shear</u> stress – forces push toward but parallel to one another





Three Types of Deformation

- elastic deformation -not permanent because the elastic limit of the rock has not been exceeded so the rock rebounds when the stress is released

- ductile deformation (ductile flow) - when the rock bends or flows, this is permanent.

- brittle deformation (brittle failure) – when the rock fractures (breaks), this is permanent

Factors that determine if ductile or brittle deformation will occur (that is will the rock fold or fracture)

- depth-
  - brittle deformation occurs at shallower depths because the rock is cooler and pressures are lower so the rock will break more easily.
  - ductile deformation occurs at great depth where pressure and temperature are higher.

Continued - Factors that determine if ductile or brittle deformation will occur

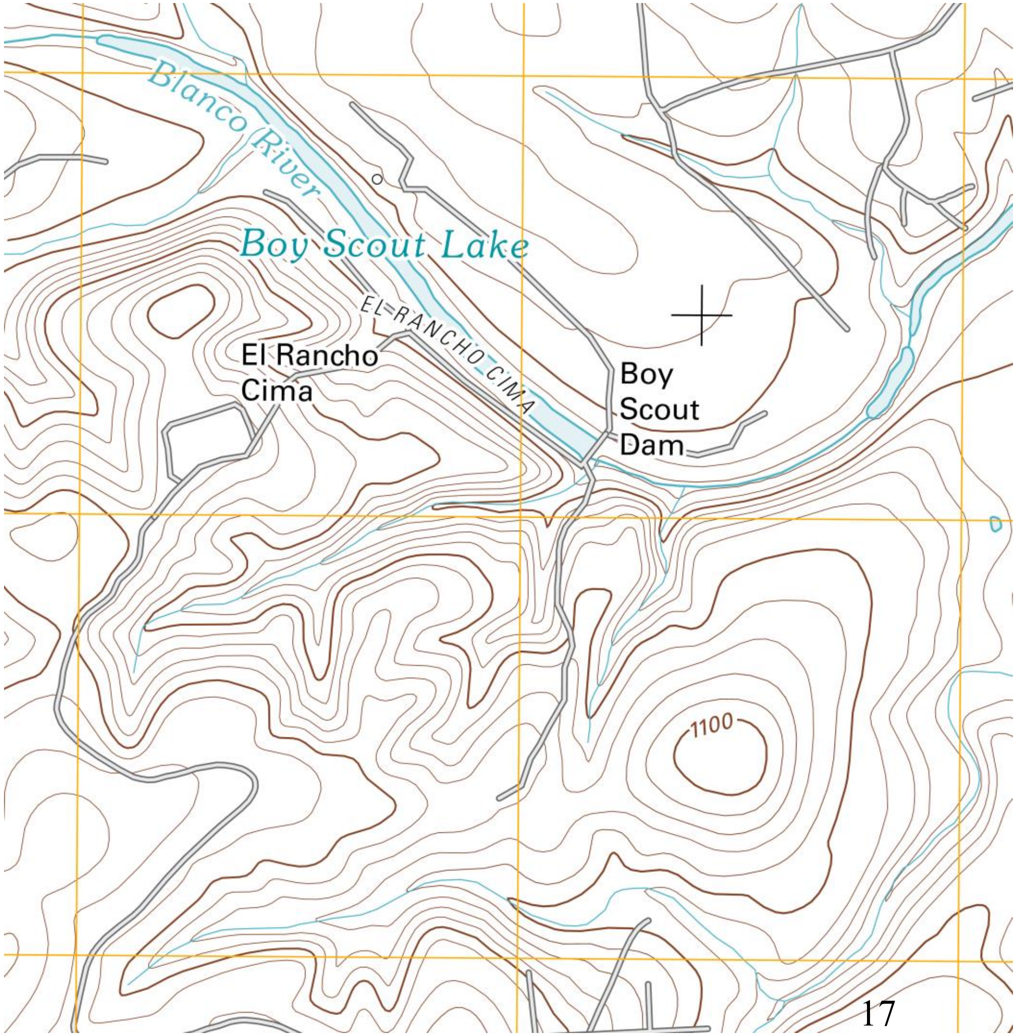
- rock type
  - brittle behavior is favored in granitic and basaltic rocks
    - Because they are composed of interconnected silicate minerals which have strong internal bonds
  - ductile behavior is favored in nonsilicate rich rocks or shale
    - because nonsilicate minerals have weaker bonds
    - because clays composing shale are weakly cemented
- time – brittle deformation occurs when forces acts quickly over short time, versus ductile deformation when forces acts slowly over long time

Mapping rock structure

s
- Locate outcrop - surface exposure of rock
  - Identify the rock type
- Measure strike and dip of folds, faults and rock layers
- Plot all the strike, dip and rock type information on a geologic map.

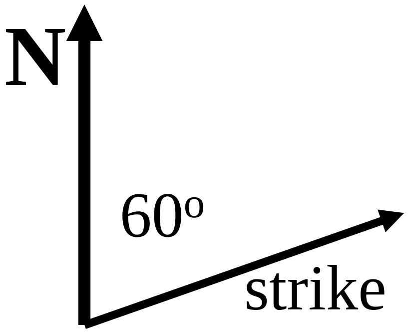
Topographic maps used as basemap

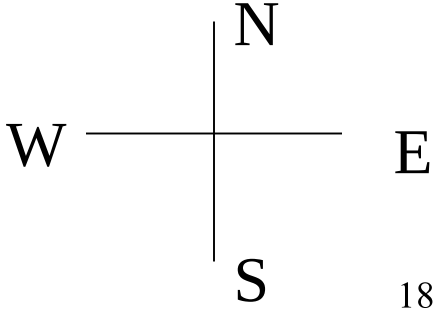
- Contour lines of constant elevation.
- Free Topographic Maps for all of the US can be downloaded from the United States Geological Survey web site http://store.usgs.gov/b2c_usgs/usgs/maplocator/(xcm=r3standardpitrex_prd&layout=6_1_61_76&uiarea=2&ctype=areaDetails&carea=%24ROOT)/.do



Strike

- Line produced by the intersection of a horizontal plane on the rock surface
  - if roll ball down rock surface it is the line perpendicular to the path the ball takes
- report as an angle relative to north
  - N60^{o}E = strike is 60^o east of north





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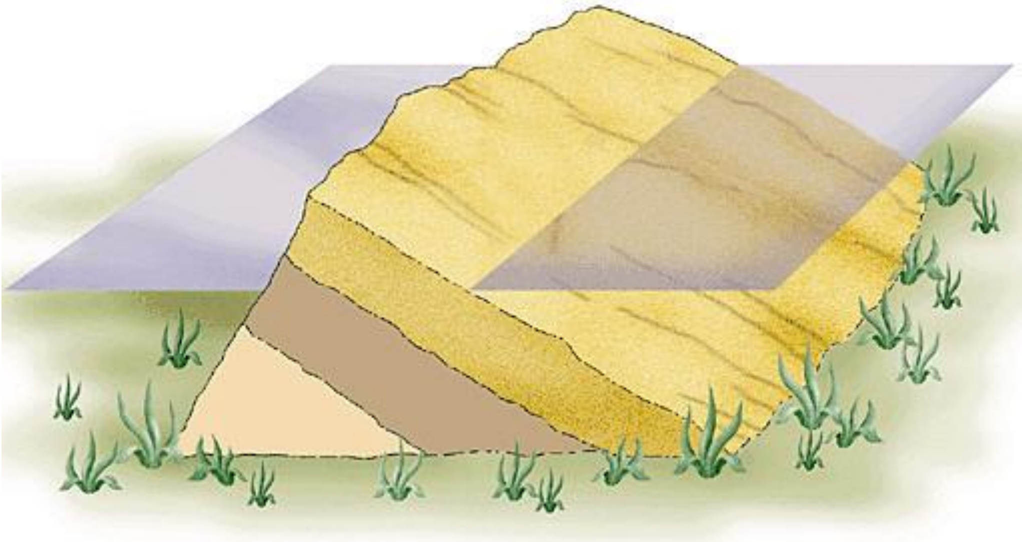

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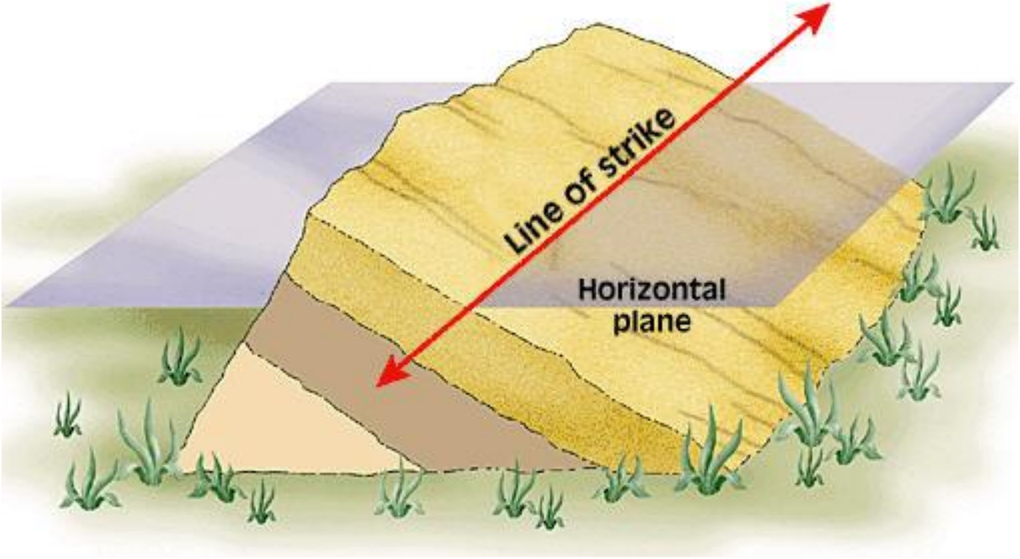

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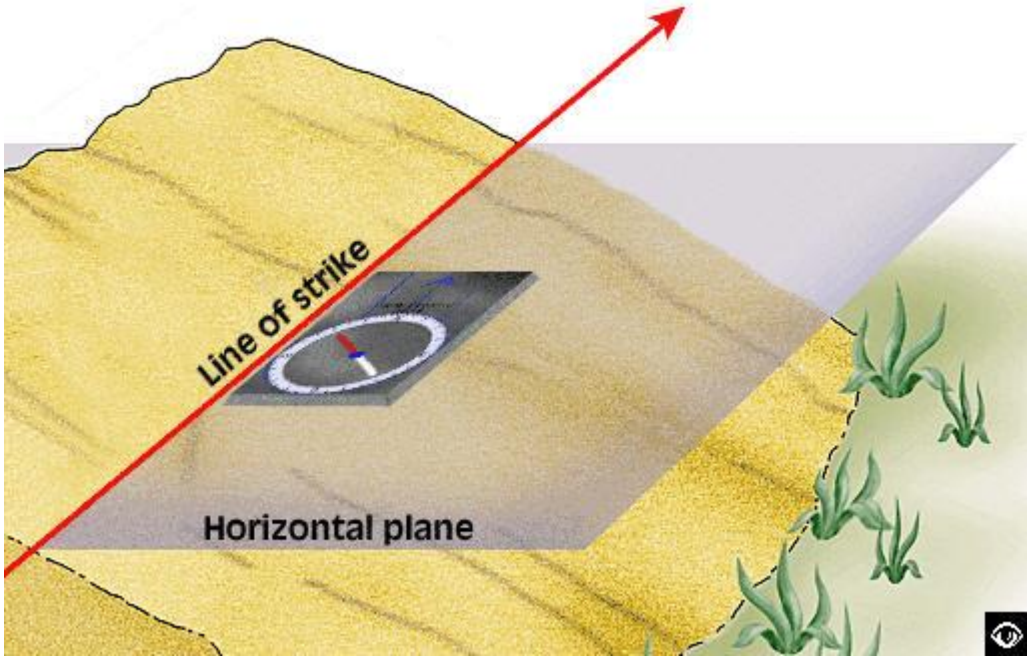

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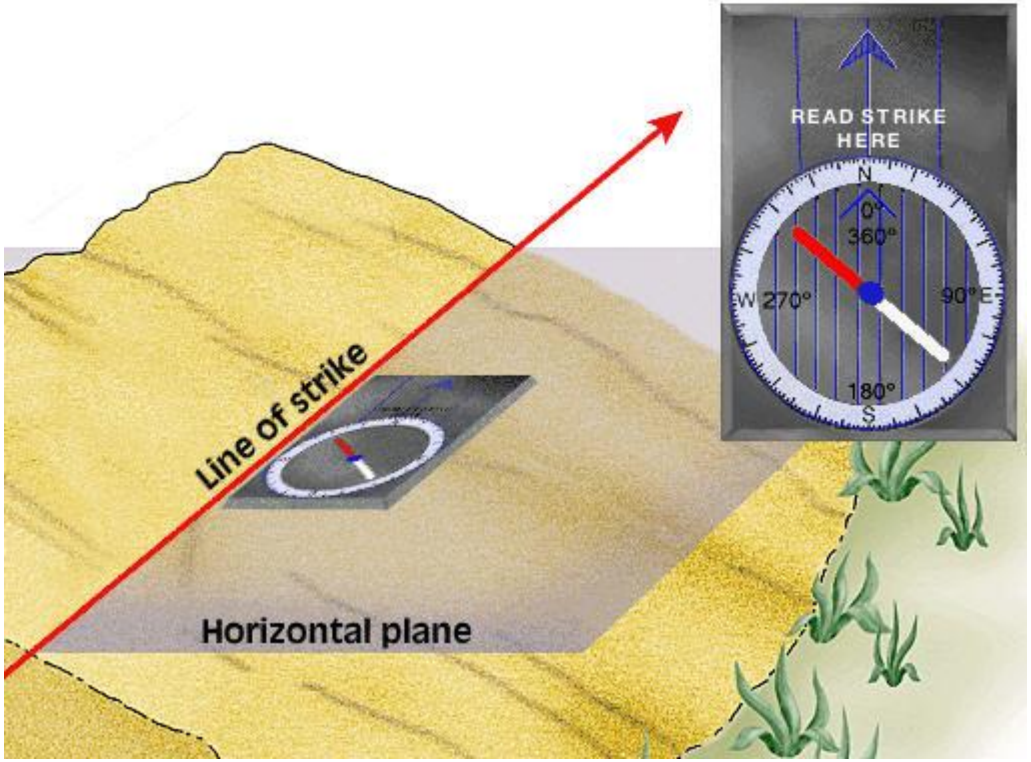
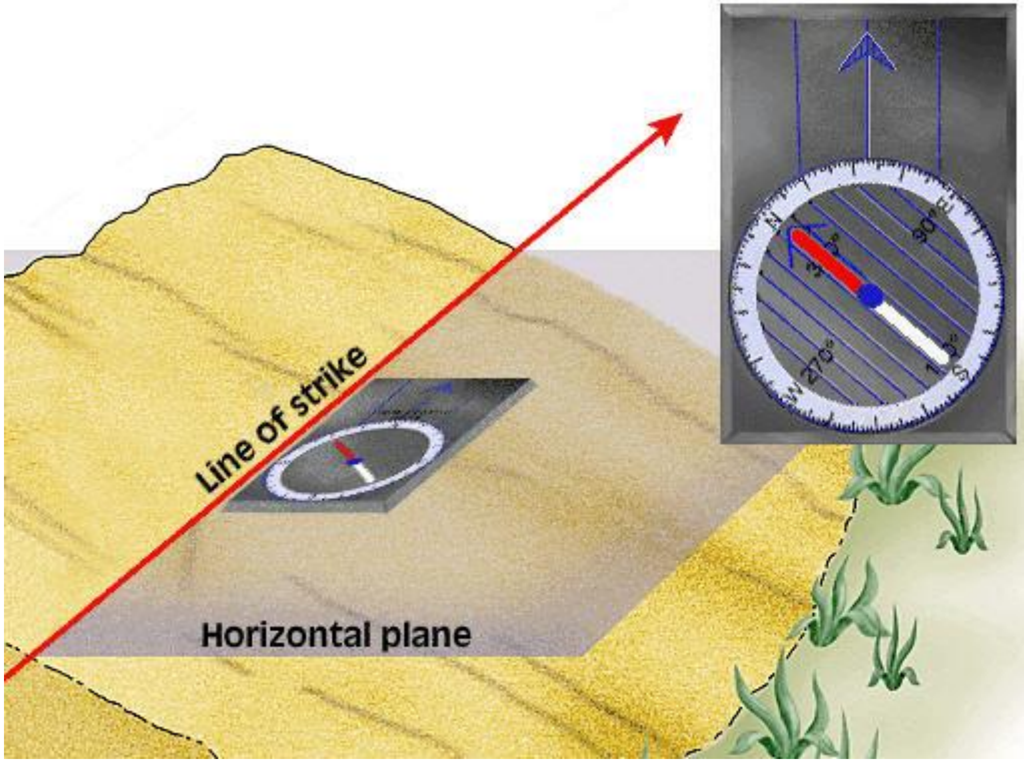


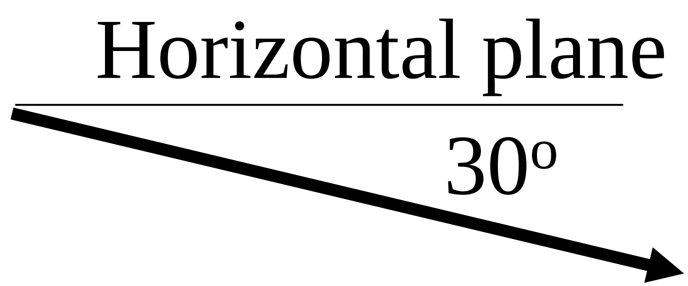
Line of strike
Horizontal plane
READ STRIKE HERE
N
0°
360°
W 270°
90° E
180°
S

810



Dip

- angle of inclination of the rock surface from the horizontal plane
  - the path of a ball rolling down the rock face
- dip is always perpendicular to the strike
- report angle and direction of dip
- dip of 30°E



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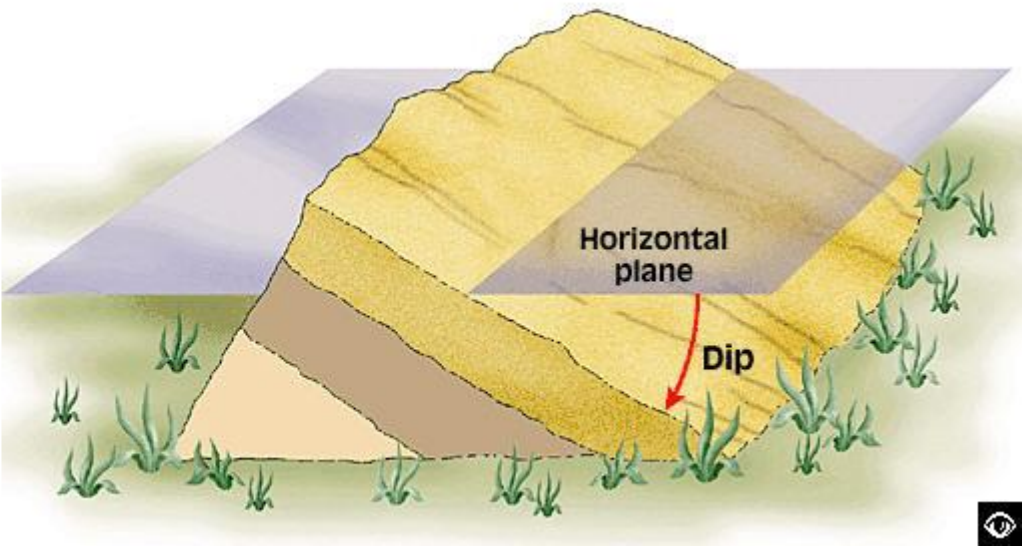
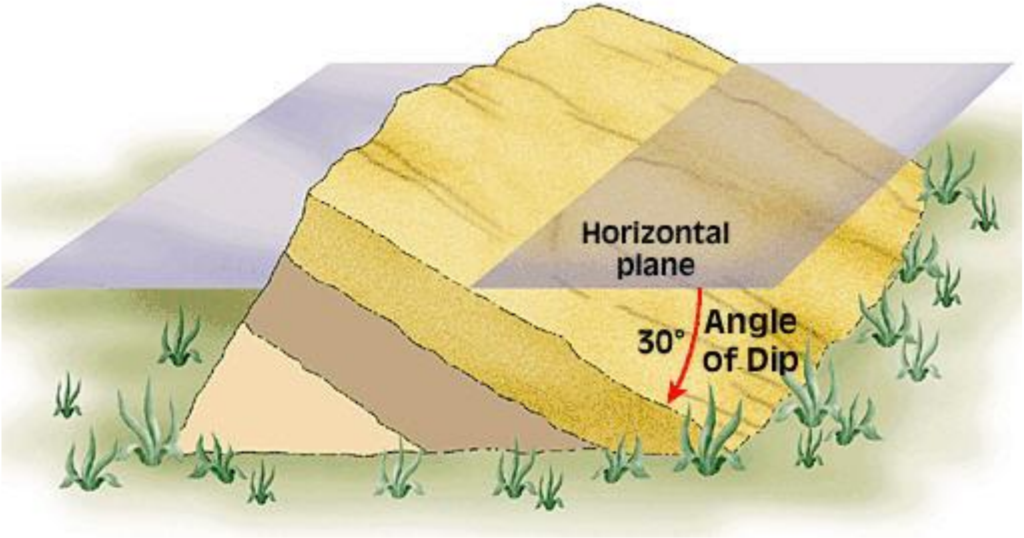
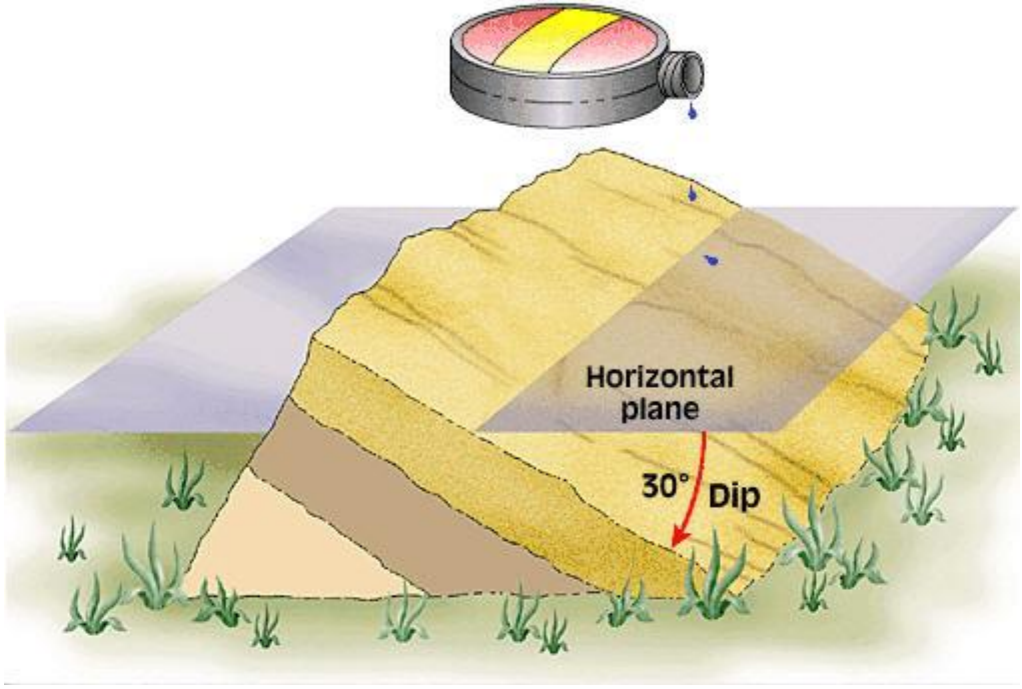



Horizontal plane
30°
Angle of Dip

813



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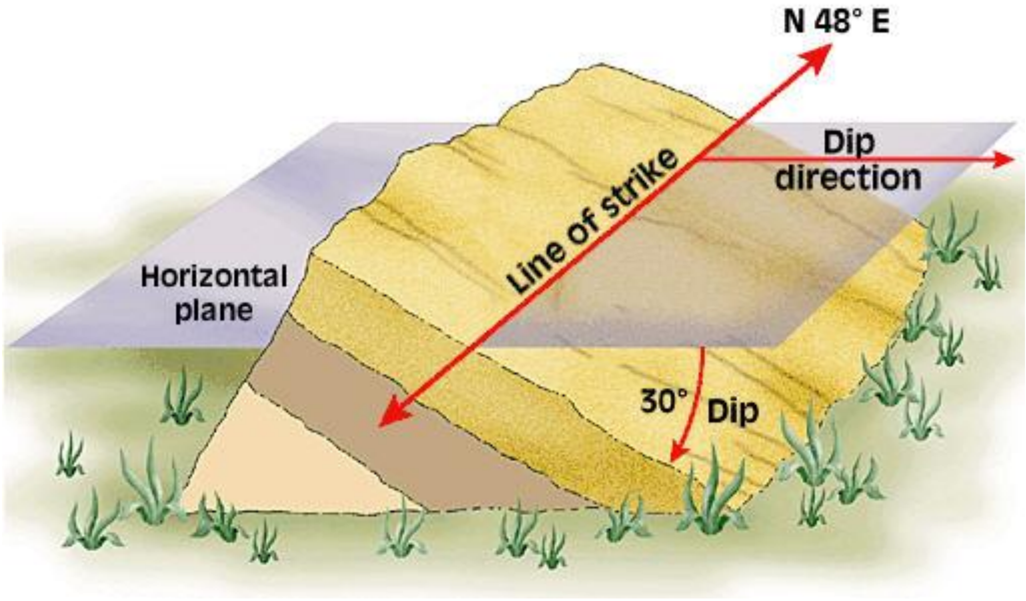
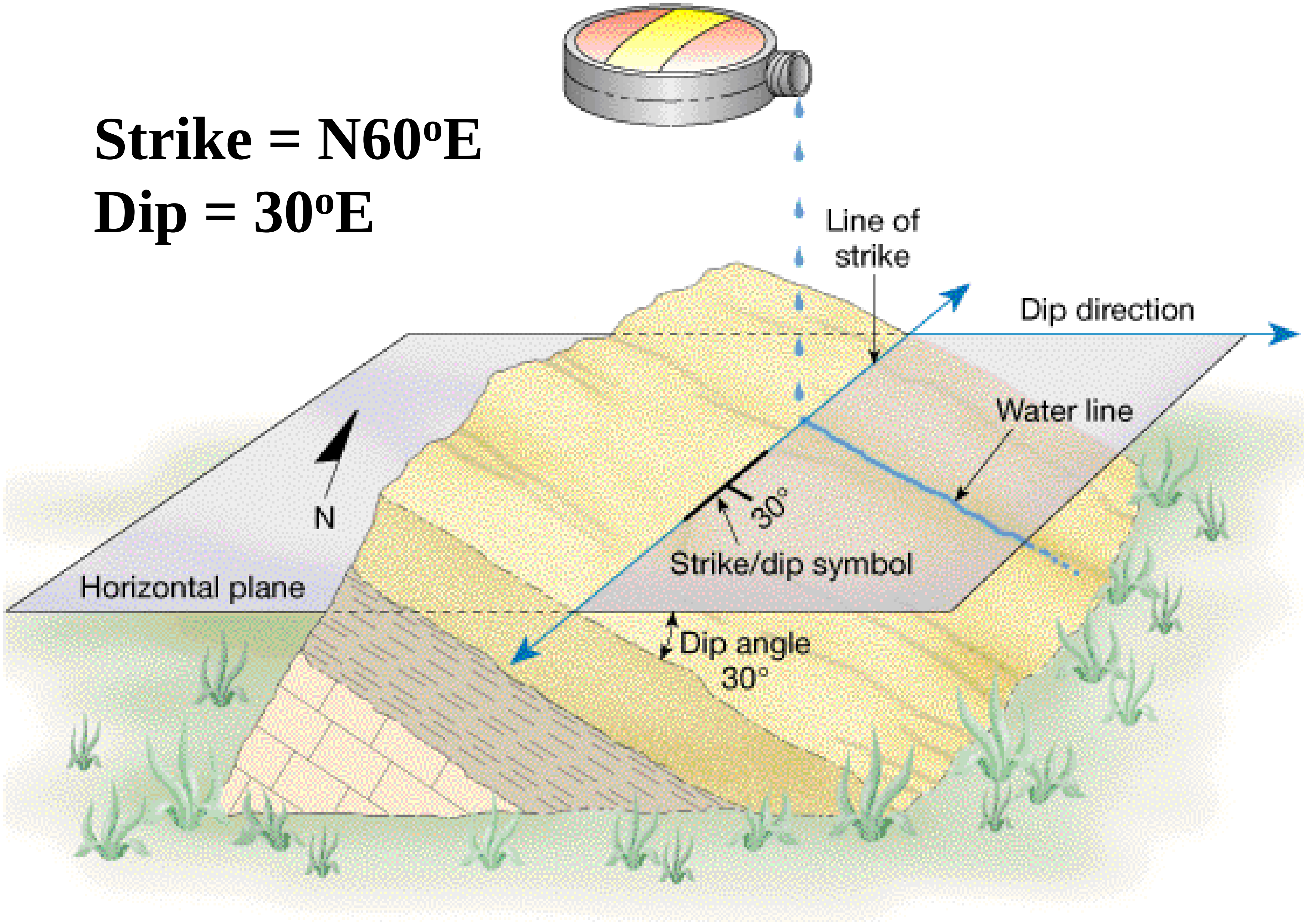


Strike = N60ºE

Dip = 30ºE



Geologic map

- plot strike and dip of each structure
- color code rock formations
- can use this map to infer the shape and orientation of structure below the ground

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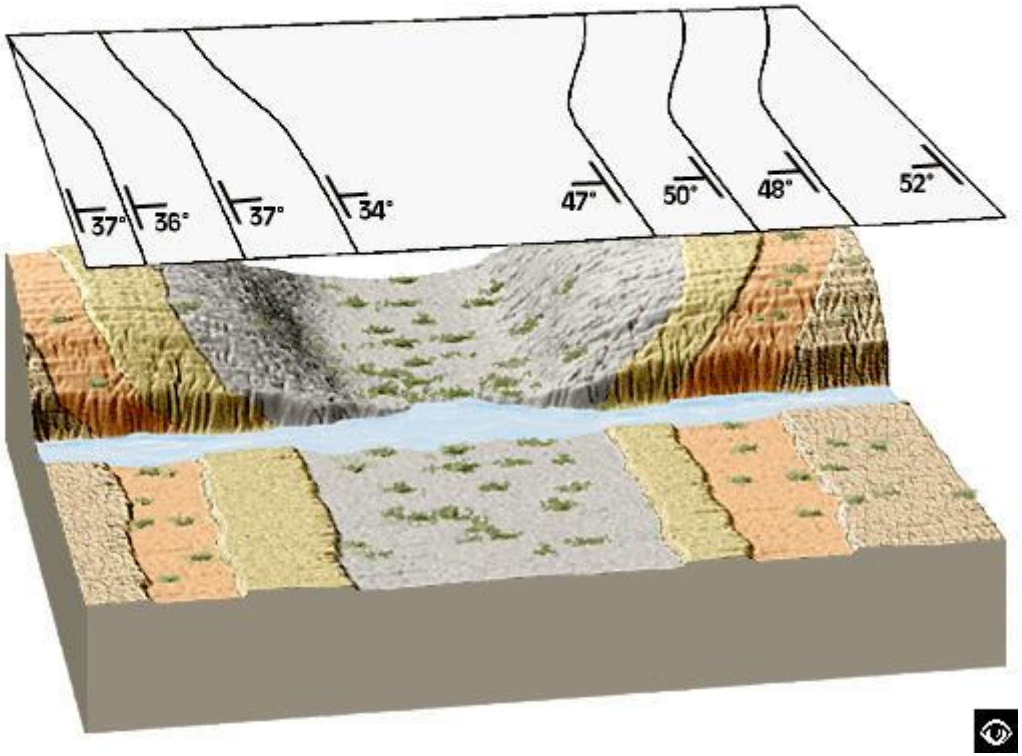

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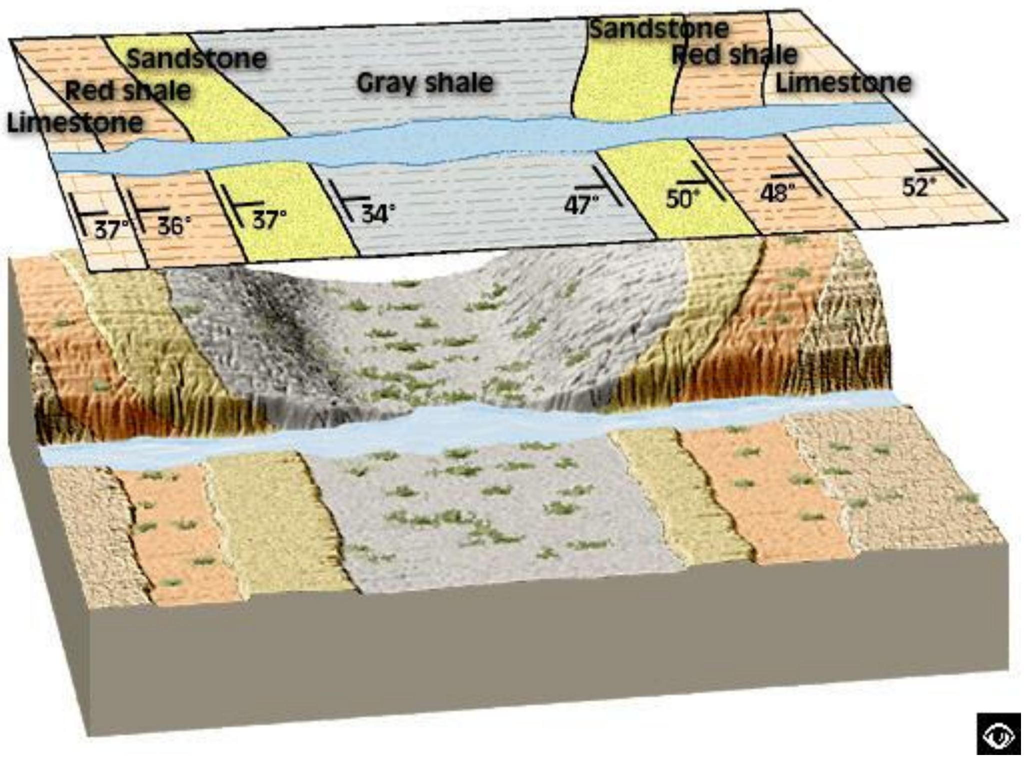
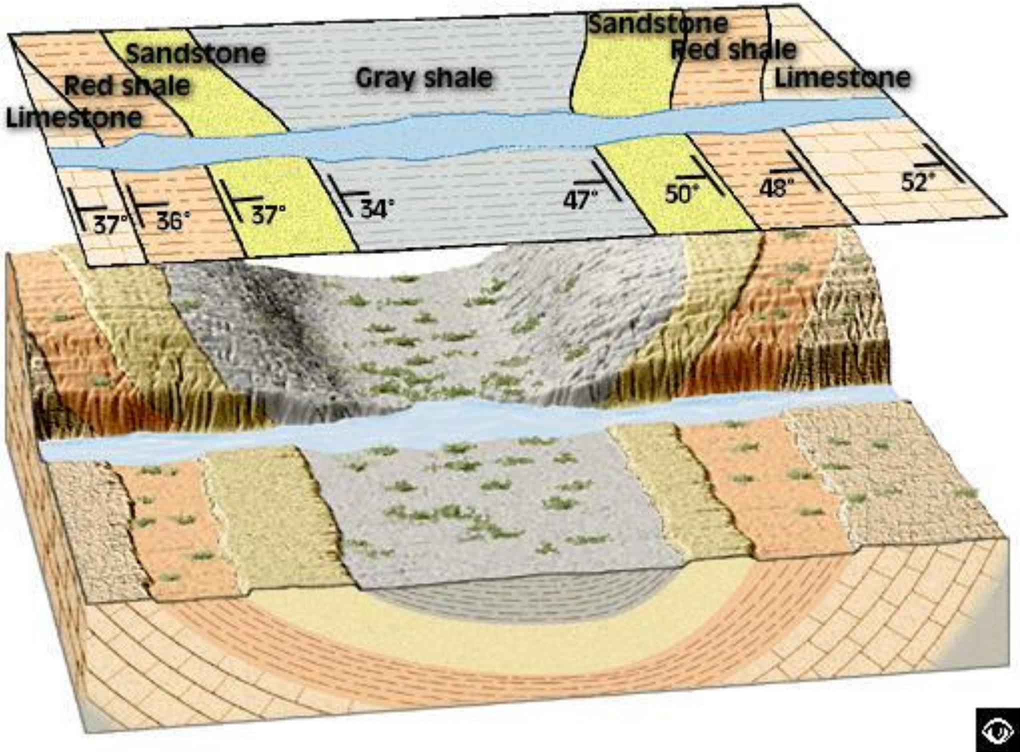

Sandstone
Red shale
Limestone
Gray shale
Sandstone
Red shale
Limestone
37°
36°
37°
34°
47°
50°
48°
52°

817

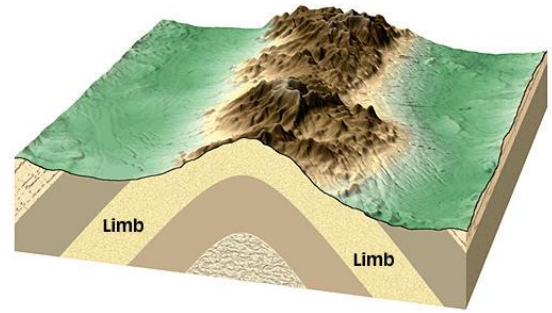


Sandstone
Red shale
Limestone
Gray shale
Sandstone
Red shale
Limestone
37°
36°
37°
34°
47°
50°
48°
52°

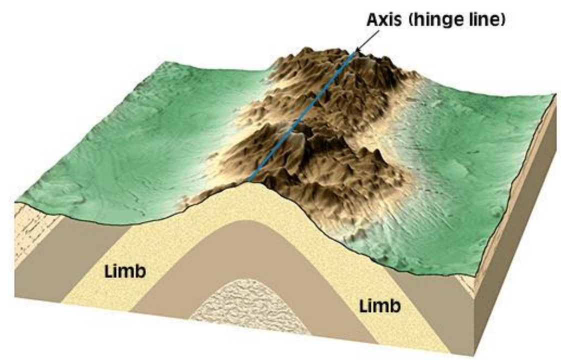
FOLDS

Parts of a Folded Rock

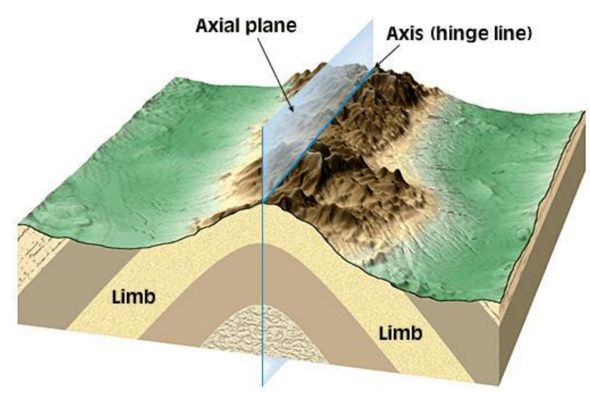
- limb - the 2 sides of the fold



- hinge line (axis) - a line drawn along the points of maximum curvature of each layer

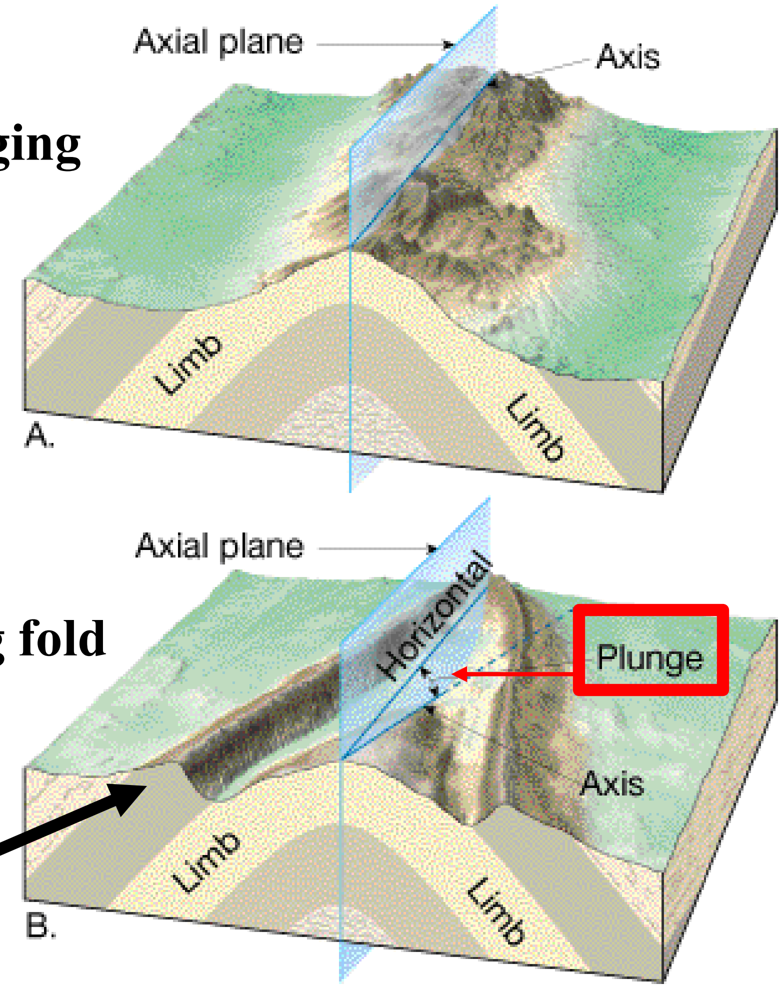


- axial plane - imaginary surface that divides the fold as symmetrically as possible



Parts of a Folded Rock (continued)

- <u>plunge</u> - the angle of incline of the axis
- <u>hogback</u> - steeply inclined angular ridges
  - formed when folded strata are resistant to weathering and form outcrop



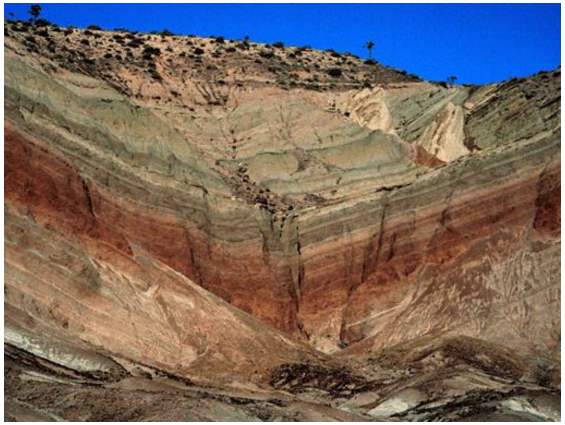
Fold types

- anticline/syncline
- monocline
- dome/basin

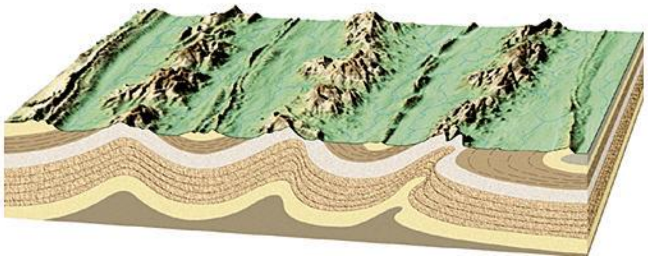
Anticline and Syncline

- anticline - arching of geologic layers
  - older rocks on the inside

- syncline - trough, downfolded layers
  - older rocks on the outside



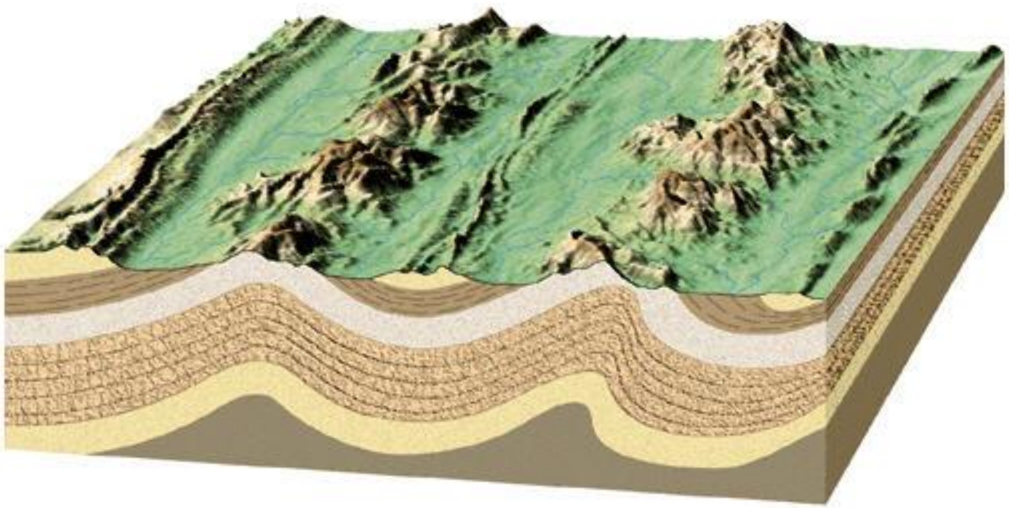
- produced by compressional forces
- occur together in sets



Features of anticlines and synclines

- symmetrical when both limbs are at same angle
- asymmetrical when the limbs are at different angle
- plunging when the hinge line dips into the ground
  - anticline outcrop points in the direction of plunge
  - syncline outcrop points opposite of the plunge direction
- these folds do not go on forever they dissipate at their ends

818



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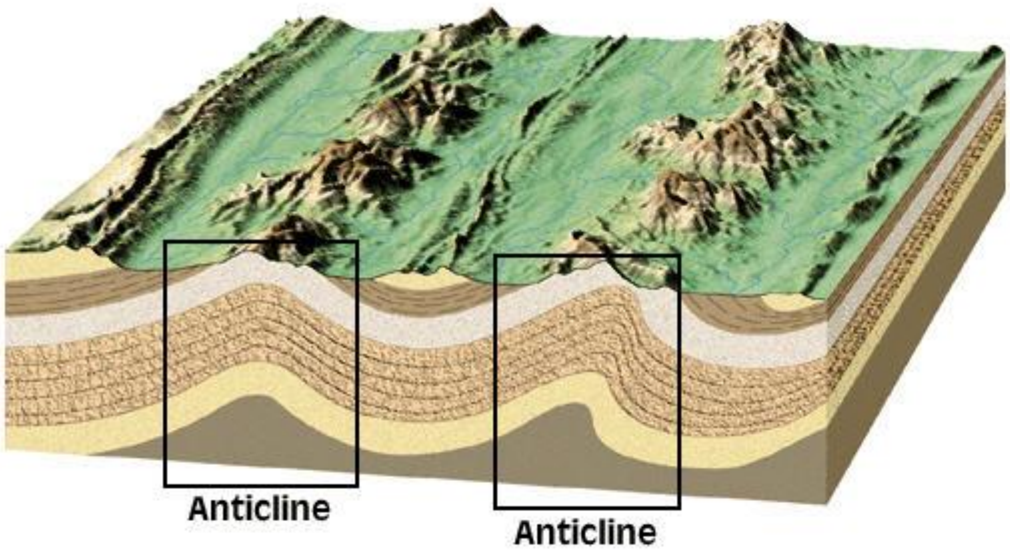

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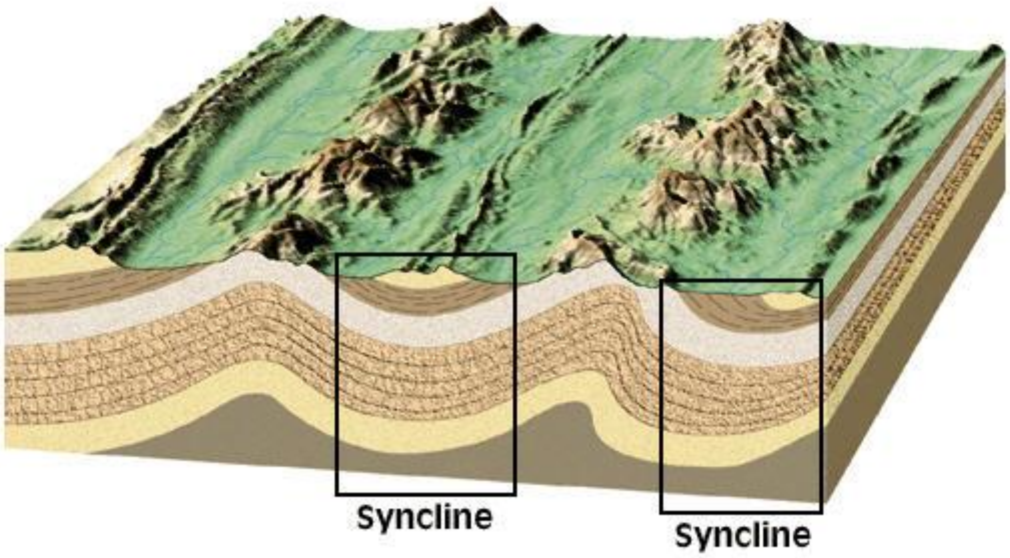

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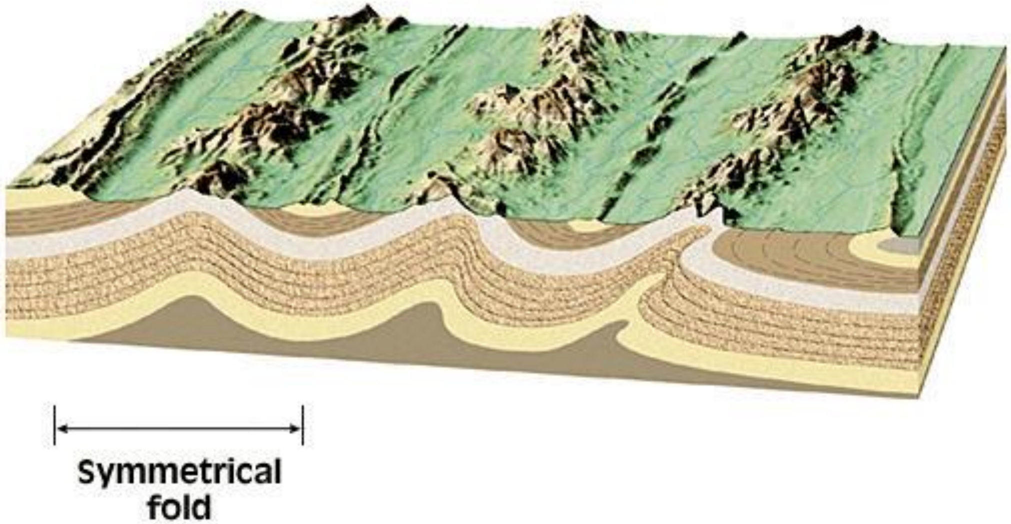

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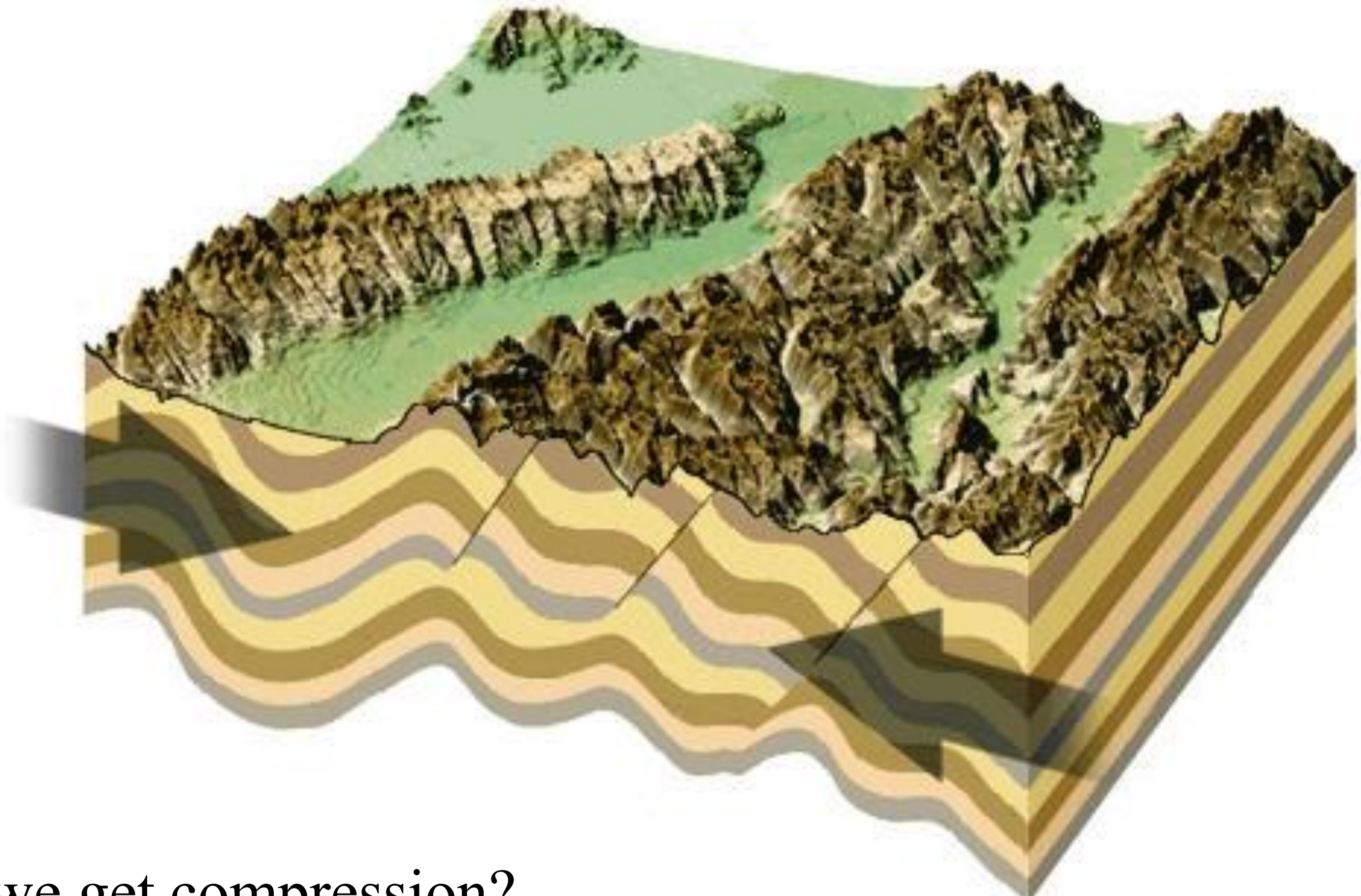
Compressional forces produce anticlines and synclines



Where do we get compression? –
Subduction zones where plates are colliding

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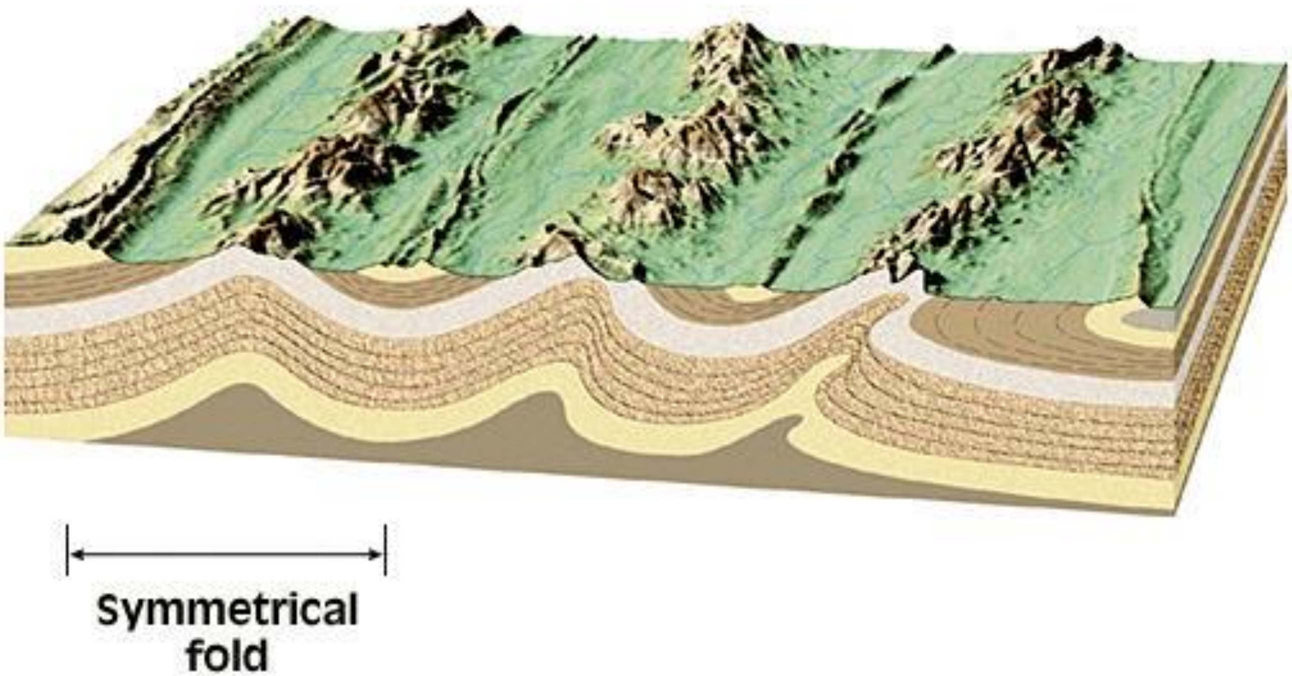

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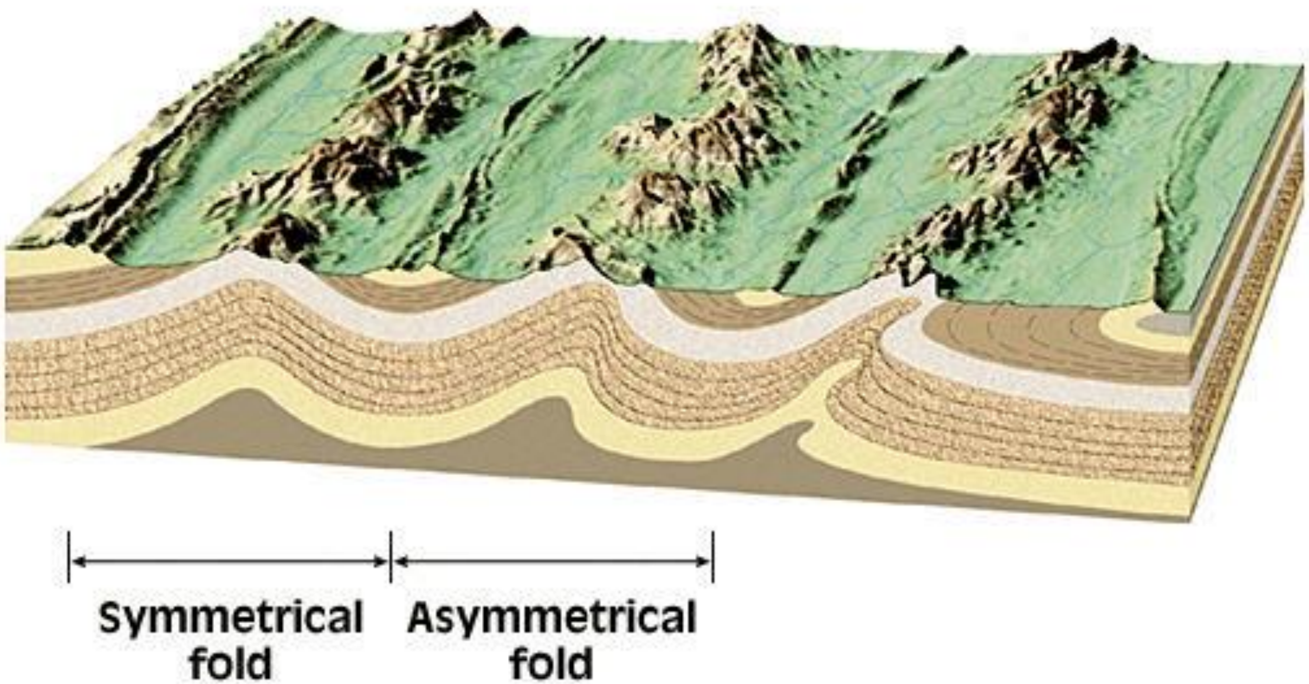
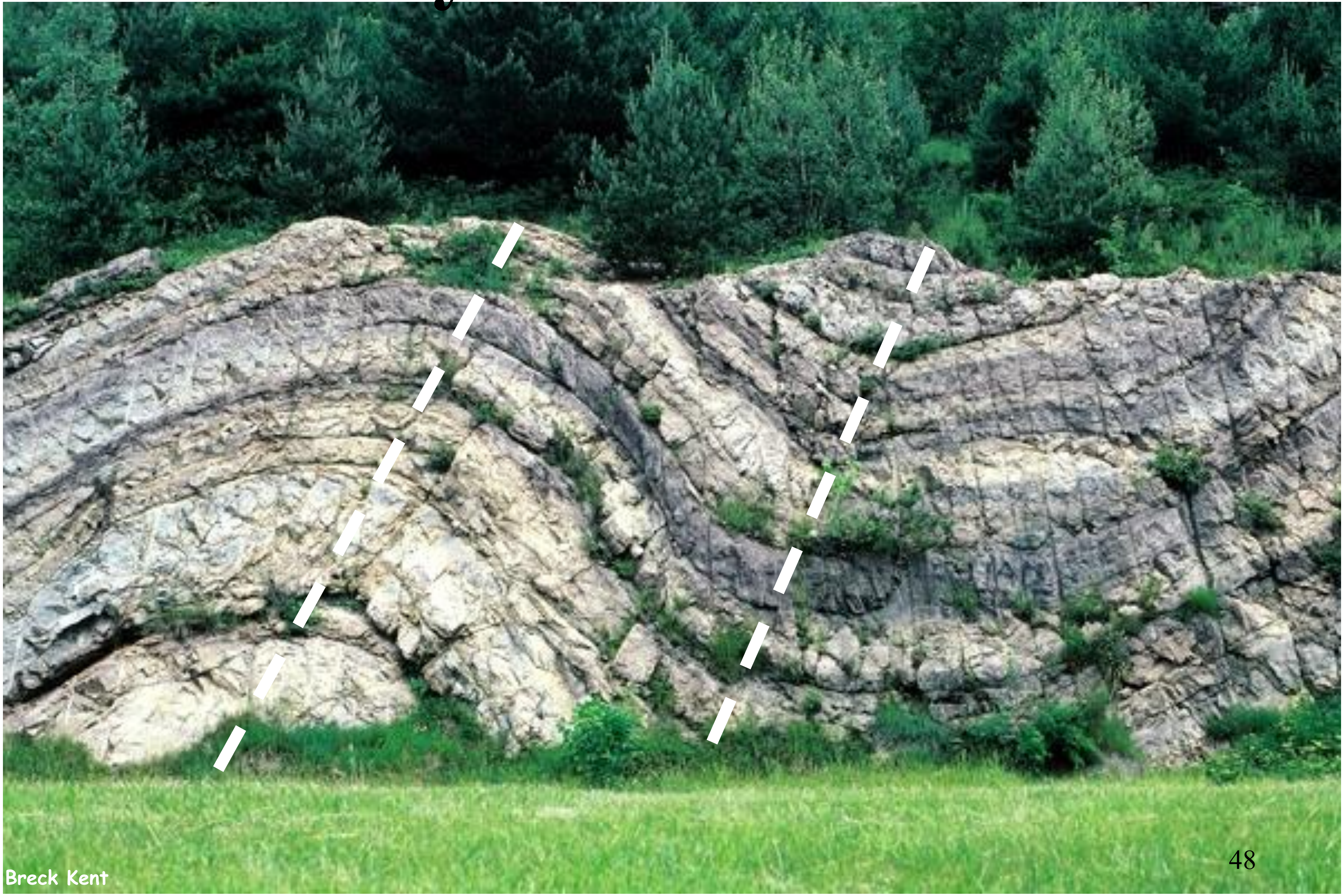
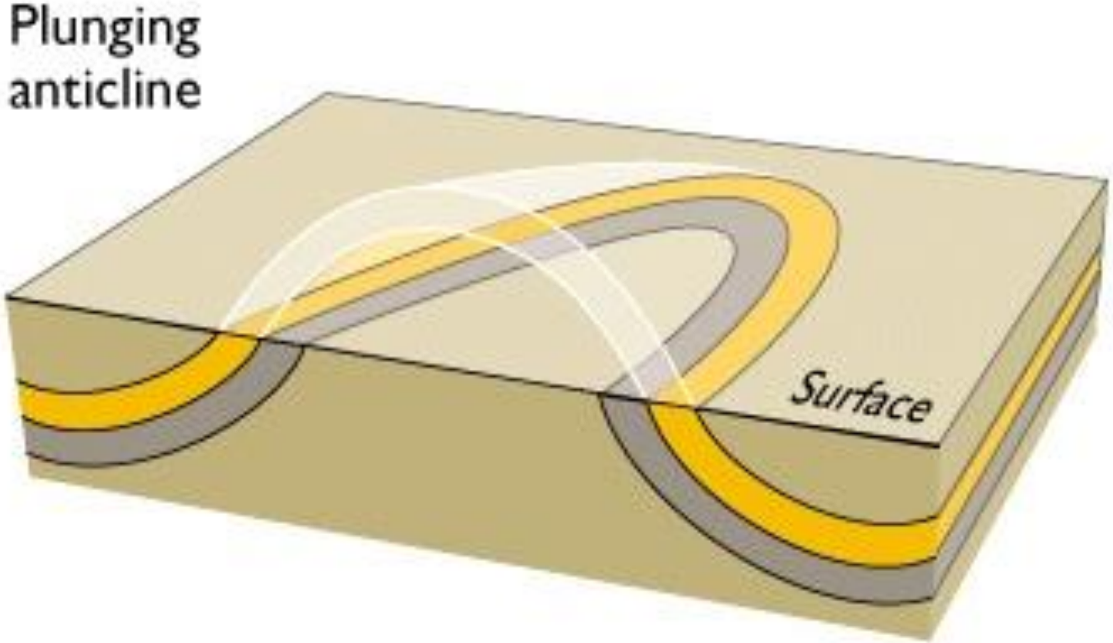
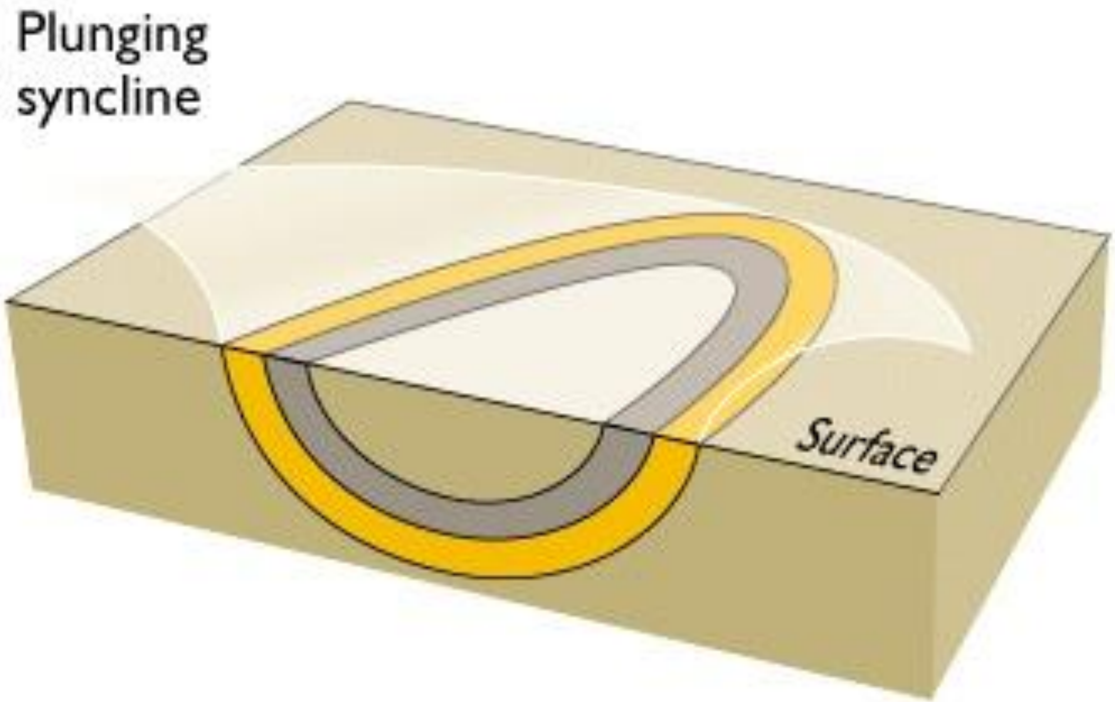


Asymmetric Folds

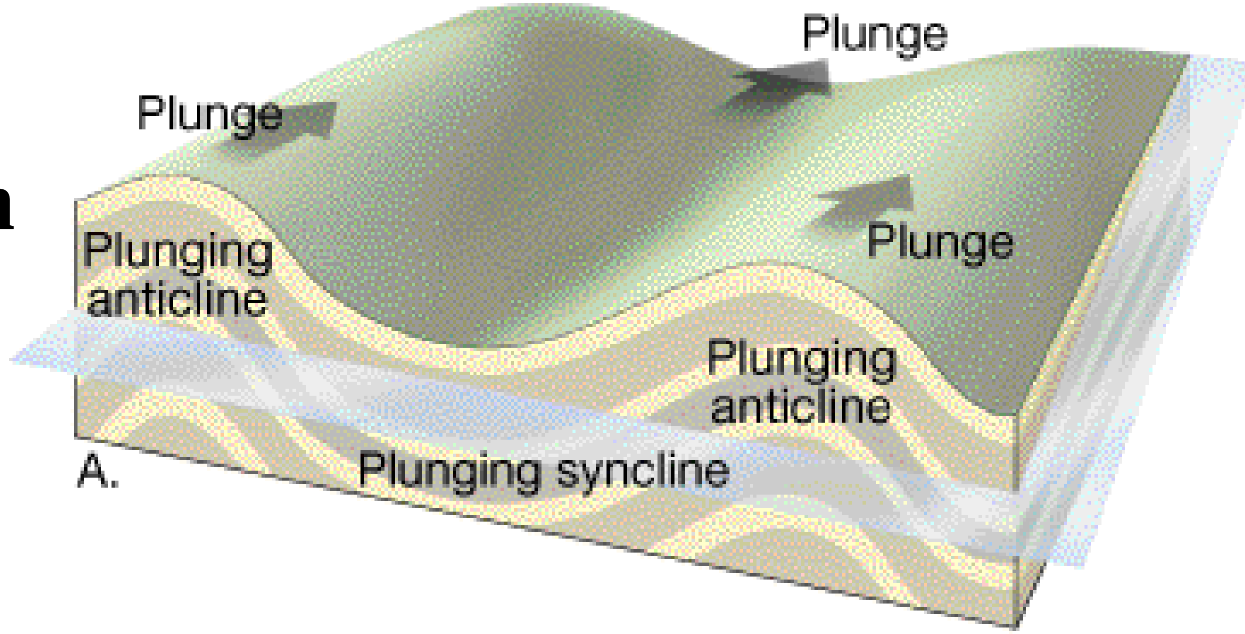




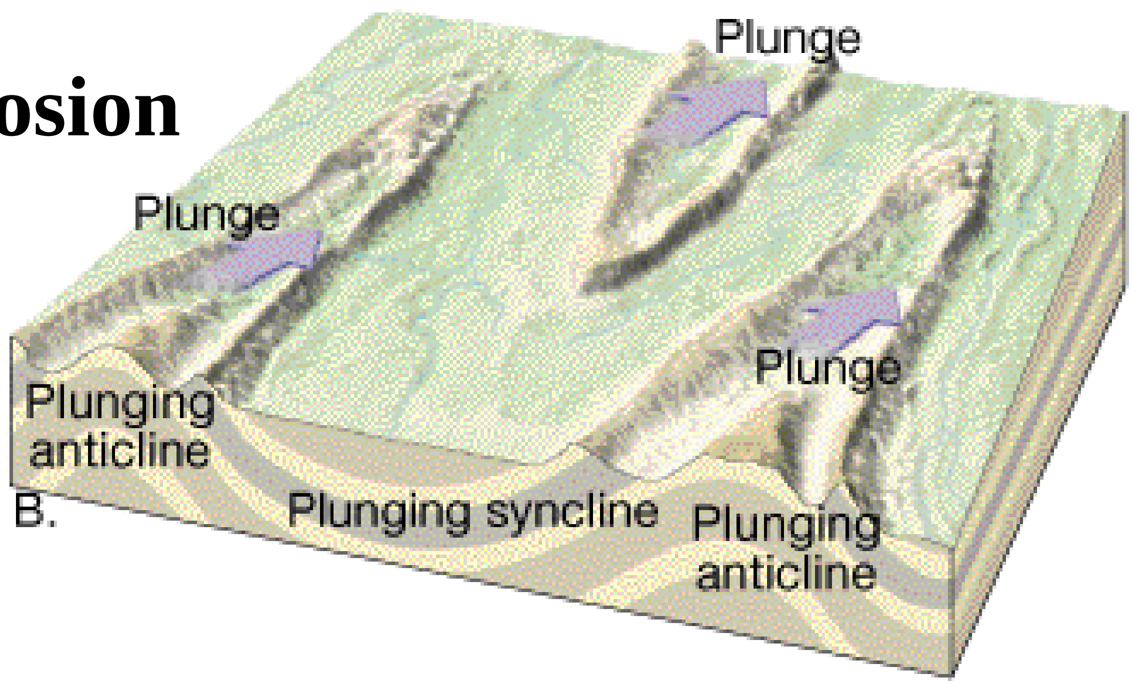


Map View of Plunging Folds

Before erosion



After erosion of to the plane shown above



Axial Trace of a Plunging Anticline

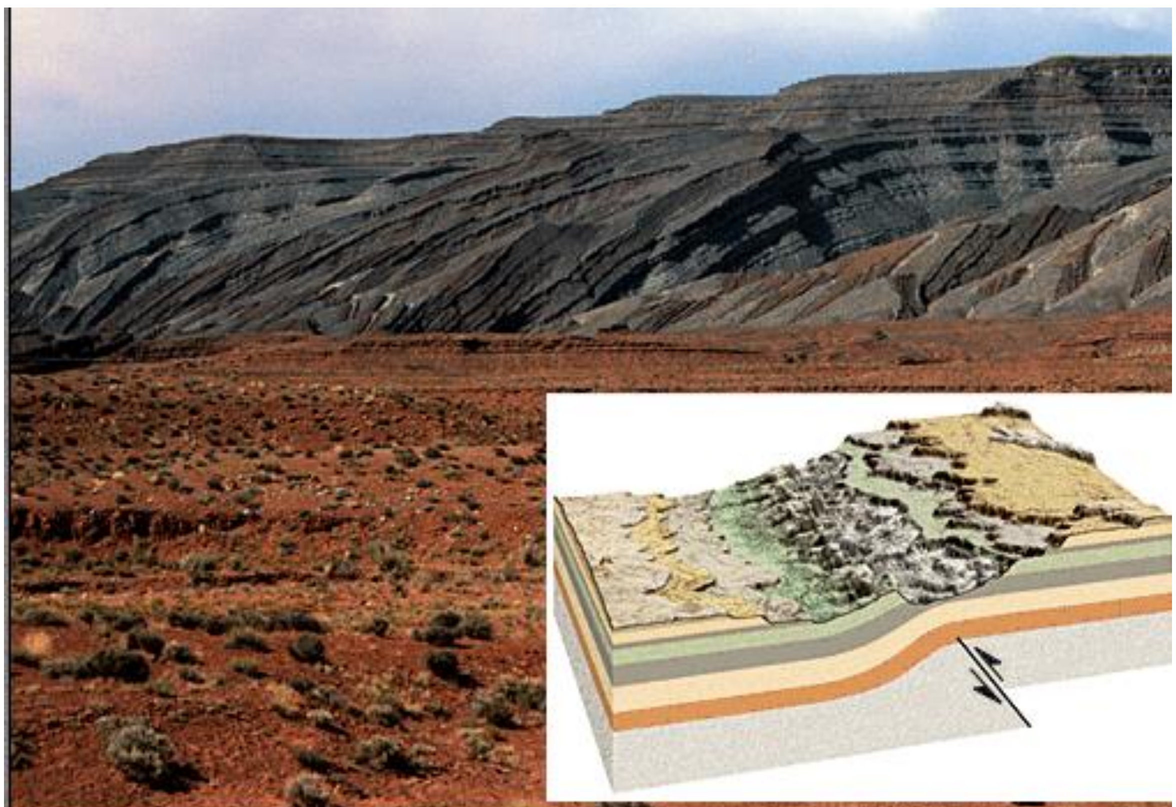
Landers Oil Field which occurs on the crest of an anticline

C.

Sheep Mountain Anticline, Wyoming, a plunging anticline.

Monocline

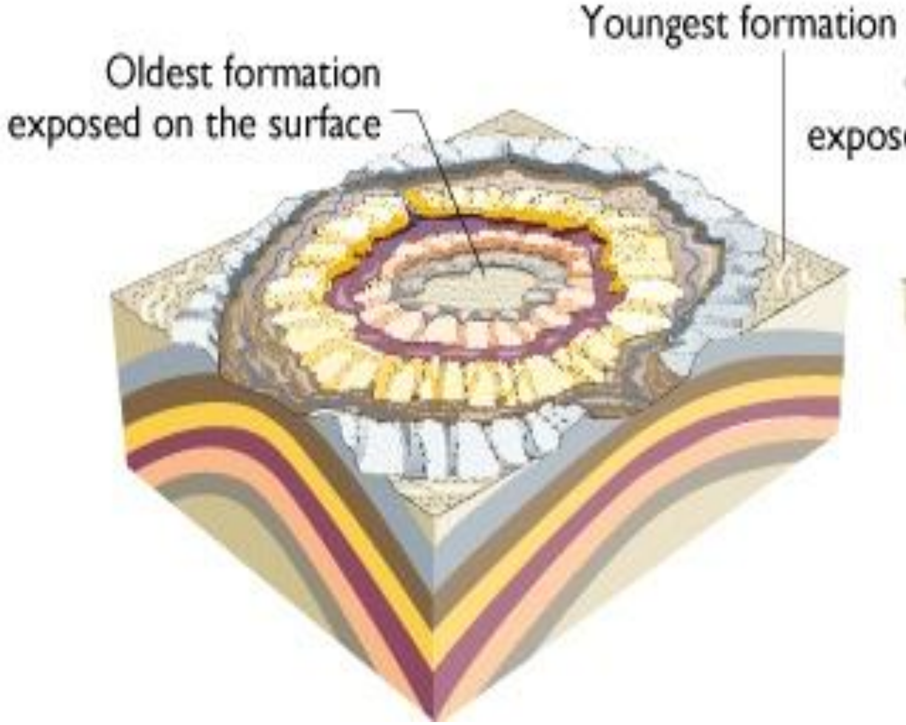
- A fold that has only one limb
- produced by vertical displacement along a fault rather than compression
- Overlying folded strata are folded over a vertical fault in the underlying basement rock



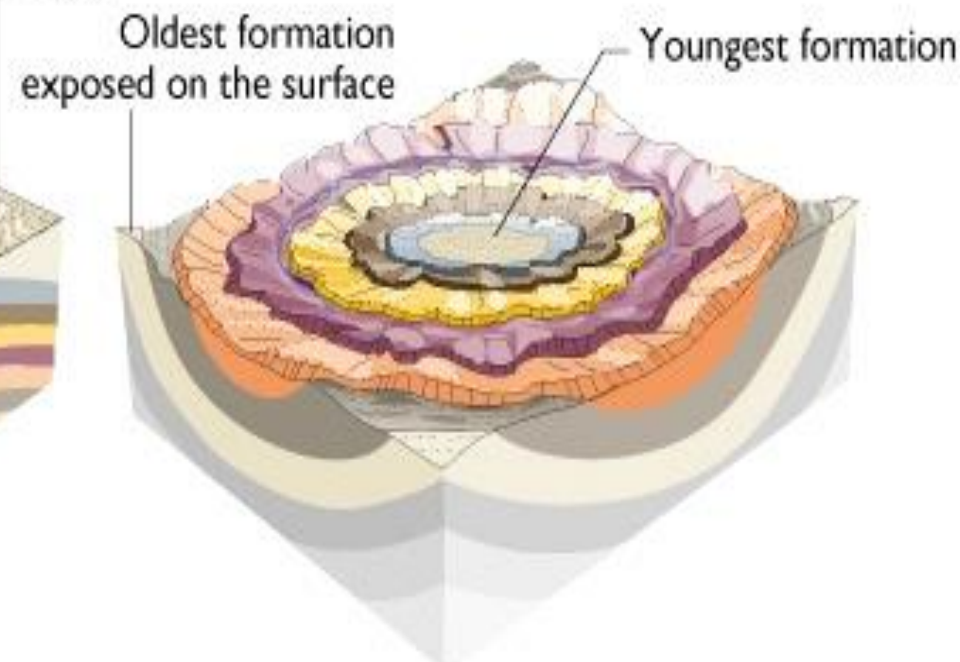
Dome and Basin

- dome - circular upwarping, oldest strata inside
- basin - circular downwarping, youngest strata inside

Dome

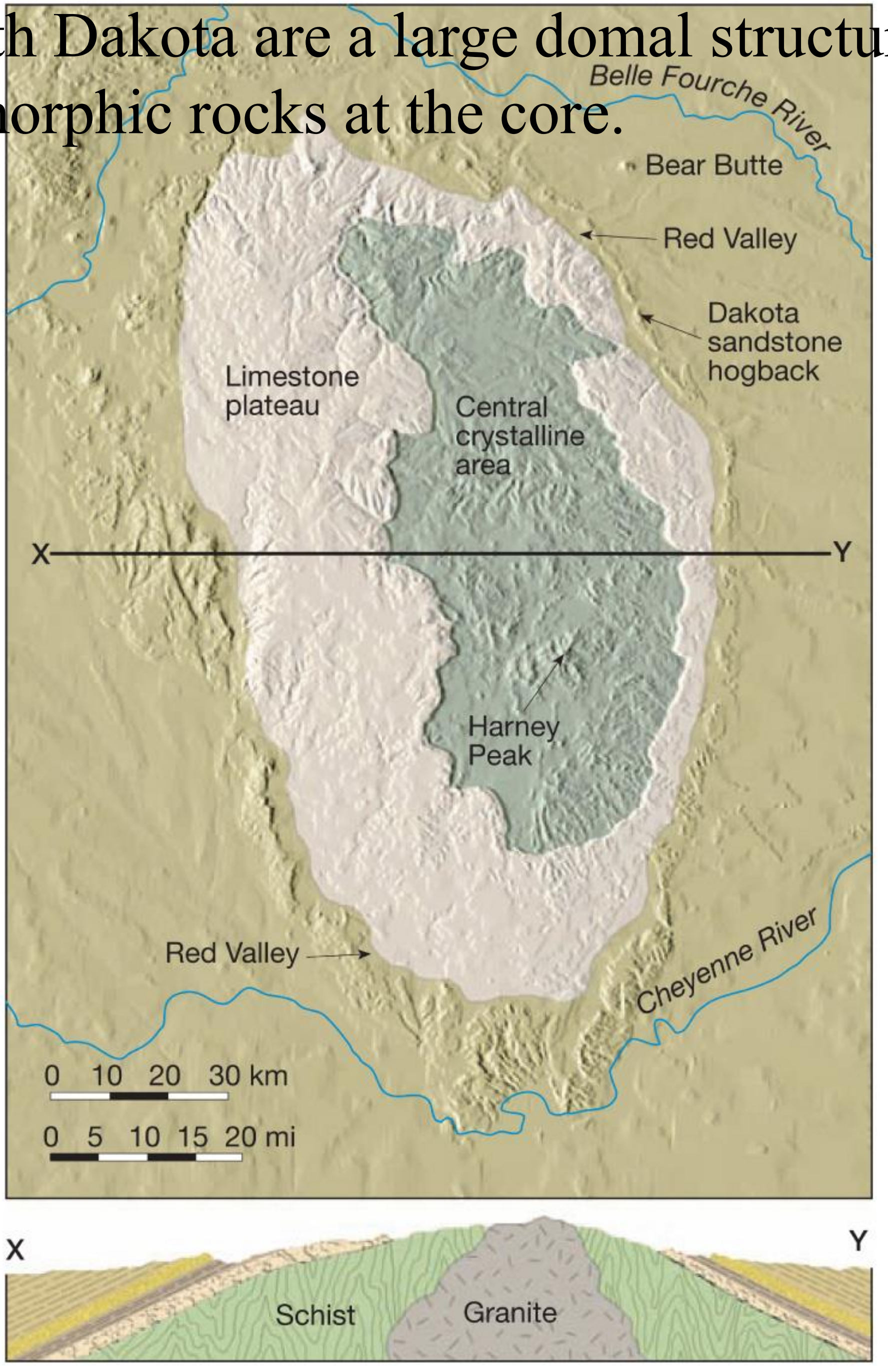


Basin

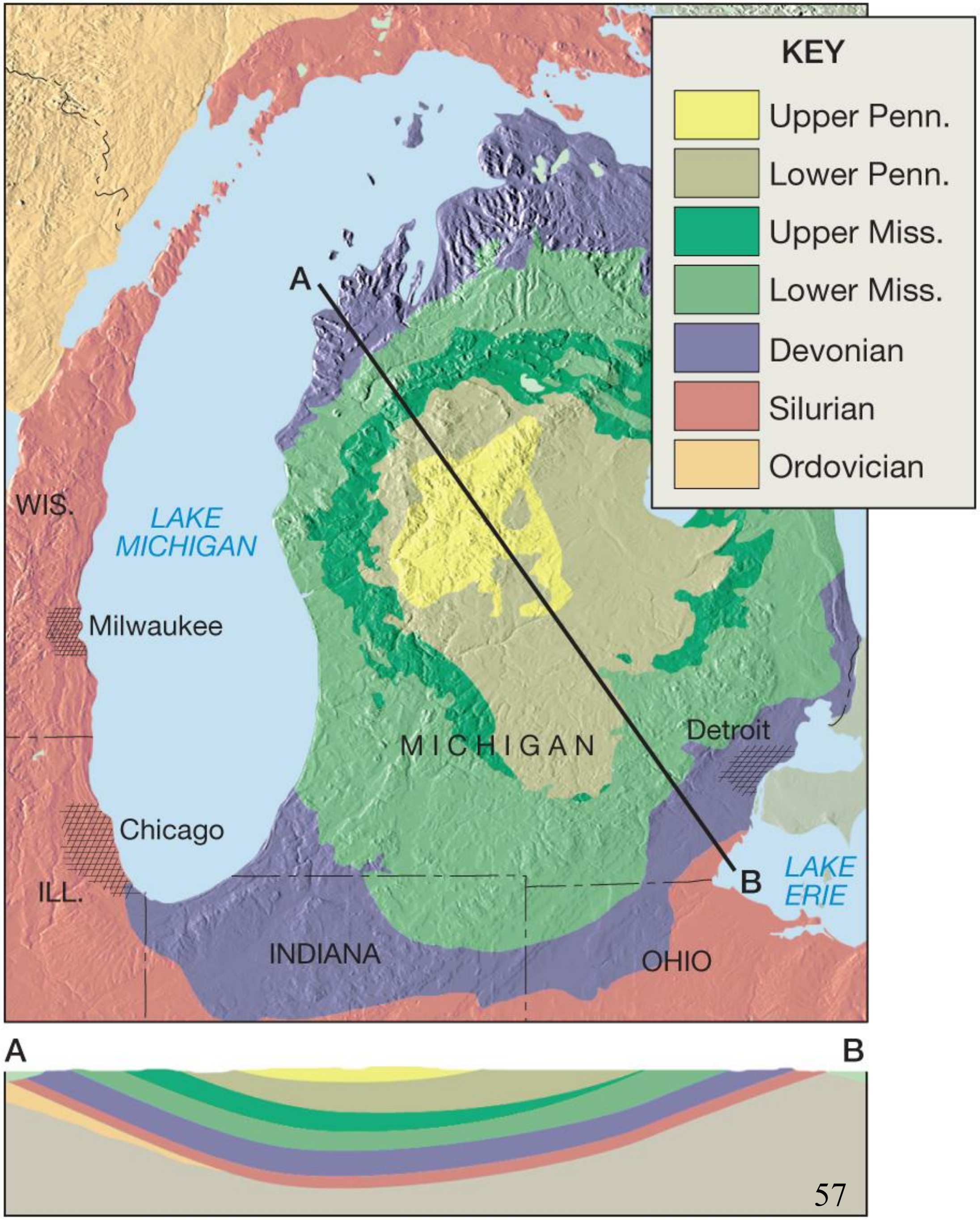


Sinclair Dome, Wyoming

Black Hills of South Dakota are a large domal structure with resistant igneous and metamorphic rocks at the core.



Michigan Basin



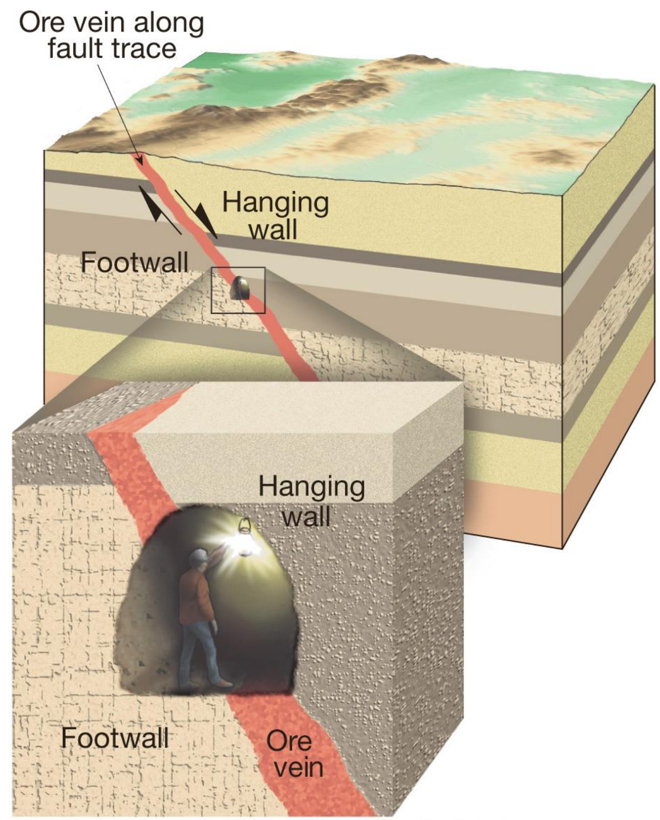
Faults

Faults

- Faults are fractures with appreciable displacement
- Three types of fault
  - Dip-slip
    - normal fault
    - reverse fault
  - Strike-slip fault

Dip-slip faults
(either a normal or a reverse fault)

- Dip-slip faults have movement parallel to the dip of the fault surface, so they have vertical displacement.
- hanging wall - rock surface above the fault
- foot wall - rock surface below the fault
- fault scarp - line of the fault on the surface, which is generally a long low-lying cliff

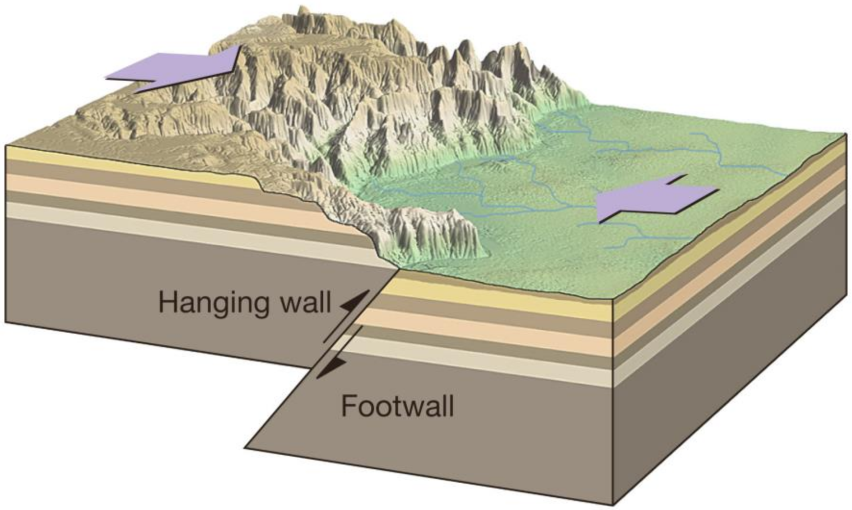


1964 Alaska earthquake

Reverse Fault

(A type of dip-slip fault)

- Hanging wall moves up relative to the footwall
  - older strata ends up over younger strata
- produced by compressional forces (pushing together)
  - results in crustal shortening
- can occur at subduction zones (convergent boundaries)

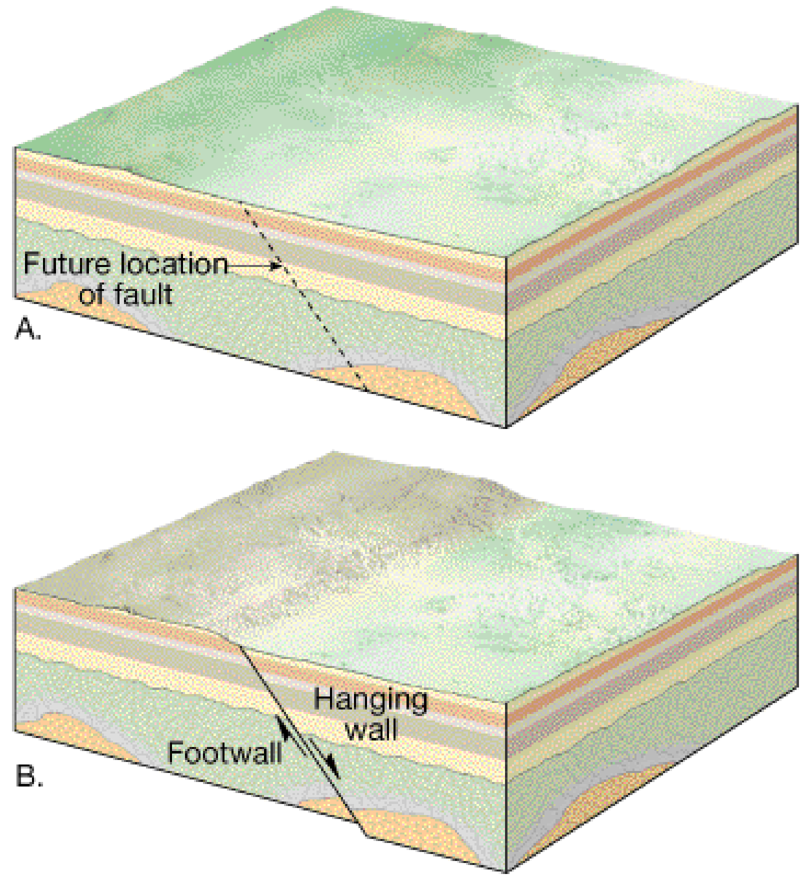


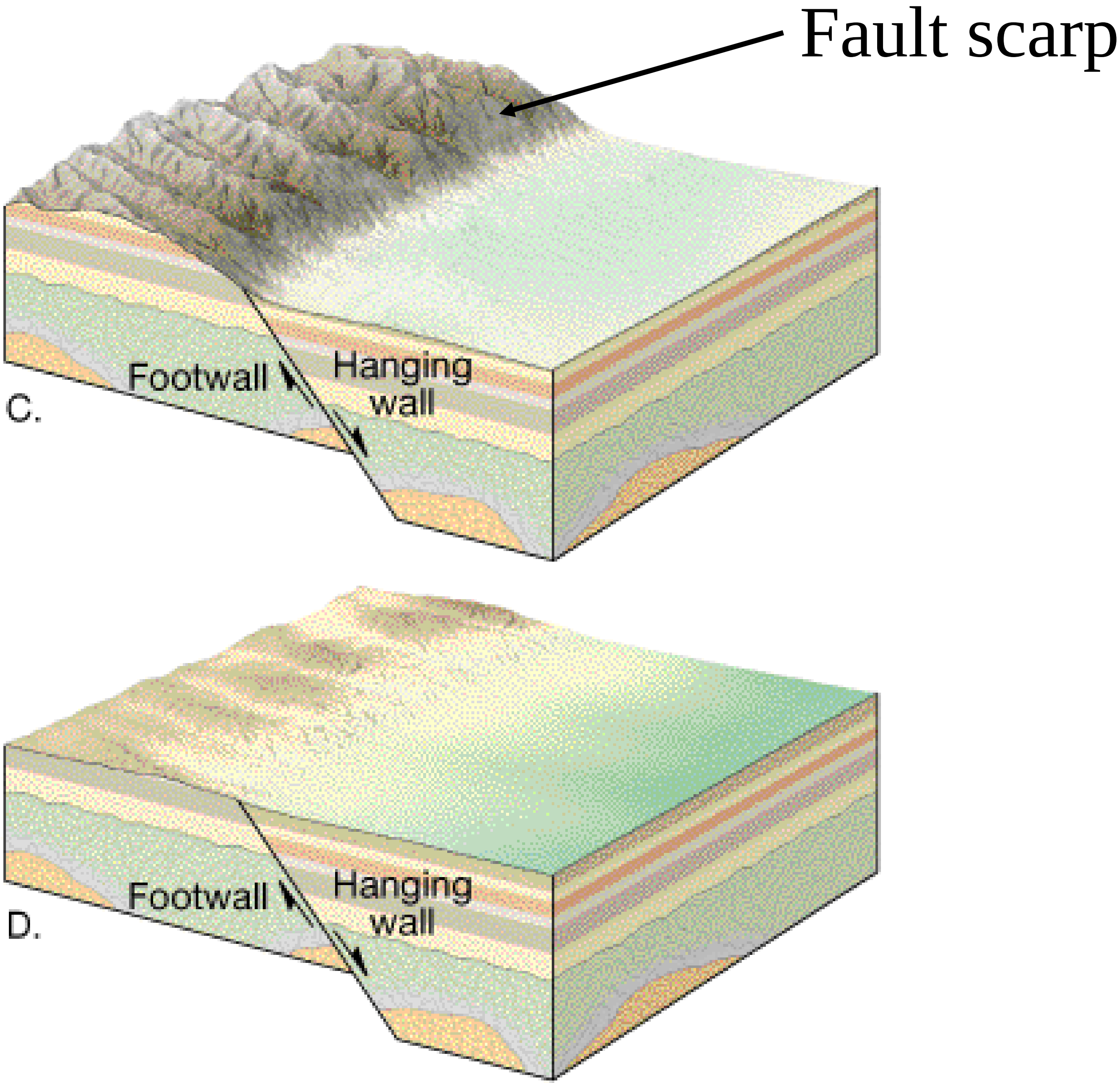
Ketobe Knob, Utah
https://structuralgeo.files.wordpress.com/2013/07/reverse-fault-zone-ketobe-knob-utah.jpeg

Normal fault

(a type of dip-slip fault)

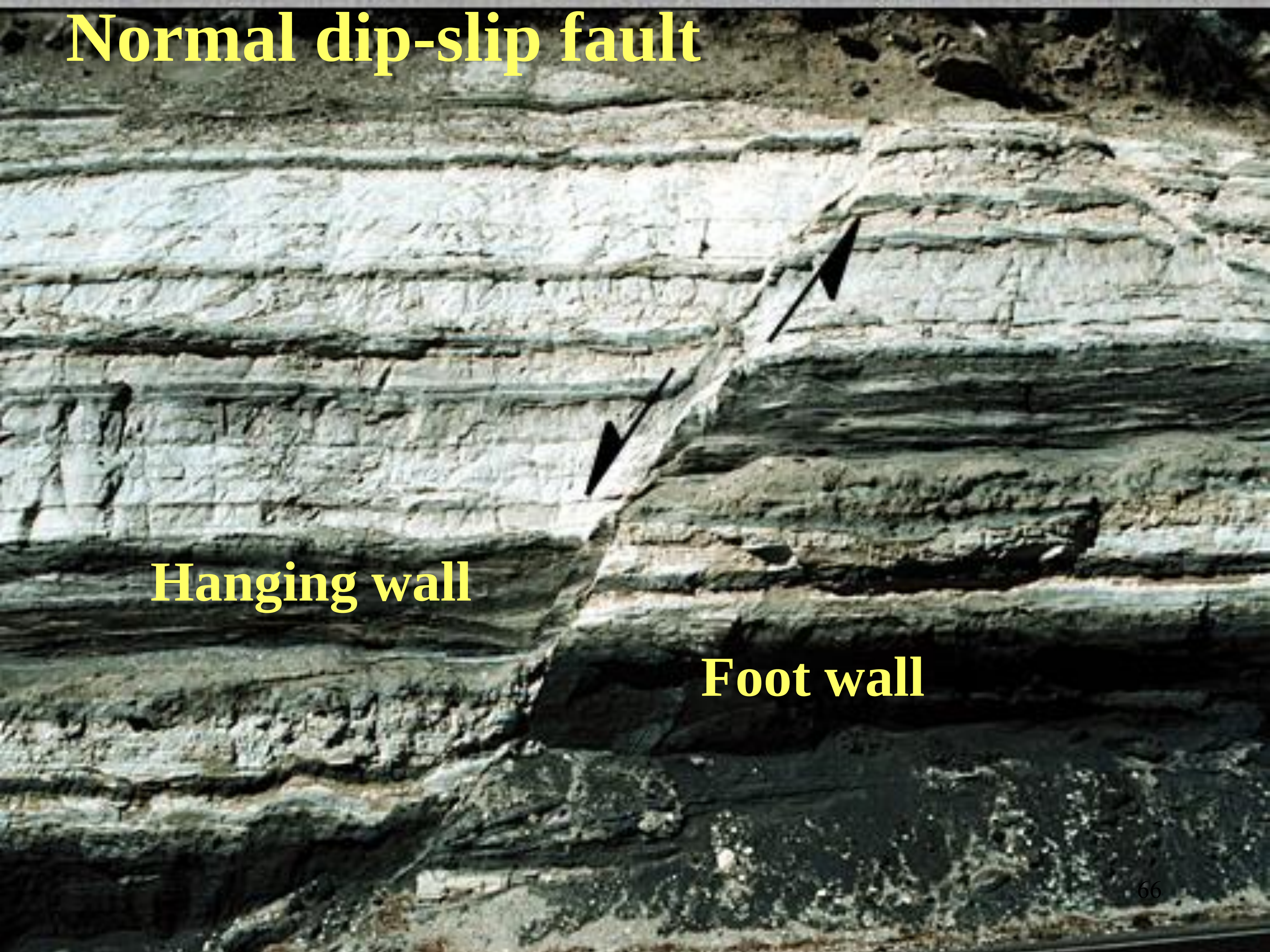
- In normal faults the hanging wall moves down relative to the footwall.
- produced by tensional forces (pulling apart)
  - results in lengthening and extension of the crust
- can occur at spreading centers





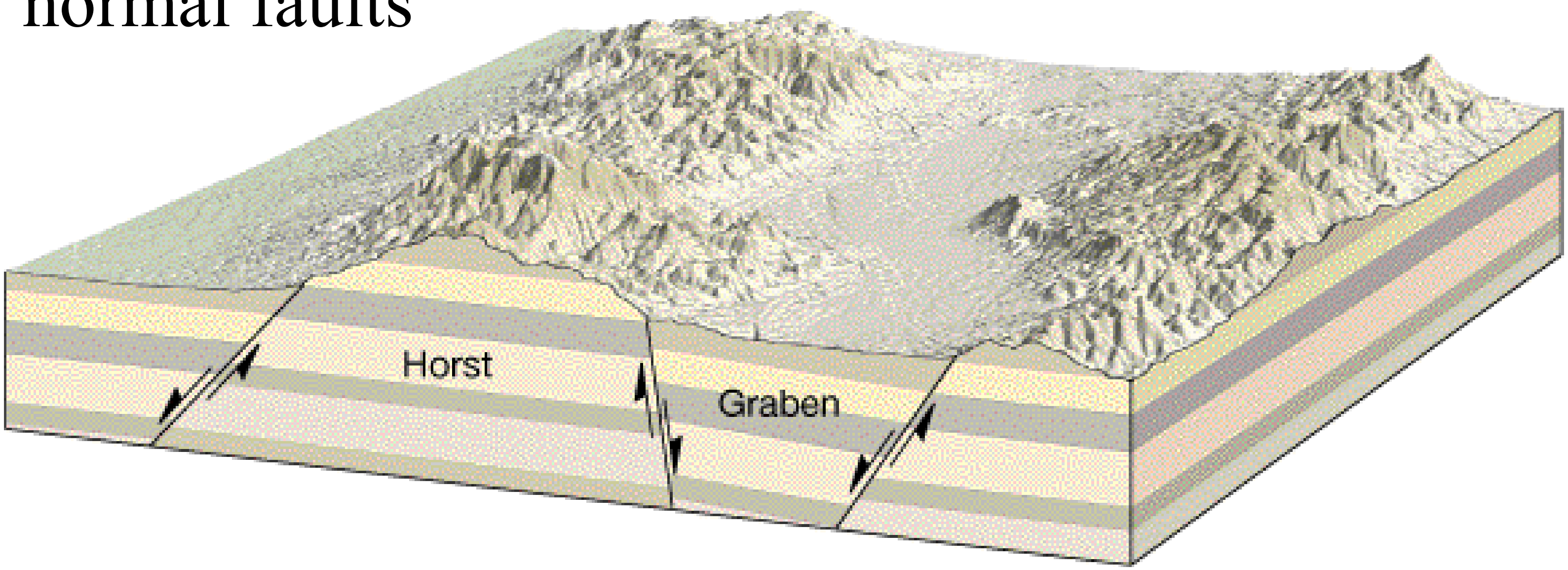
Normal fault

Normal dip-slip fault



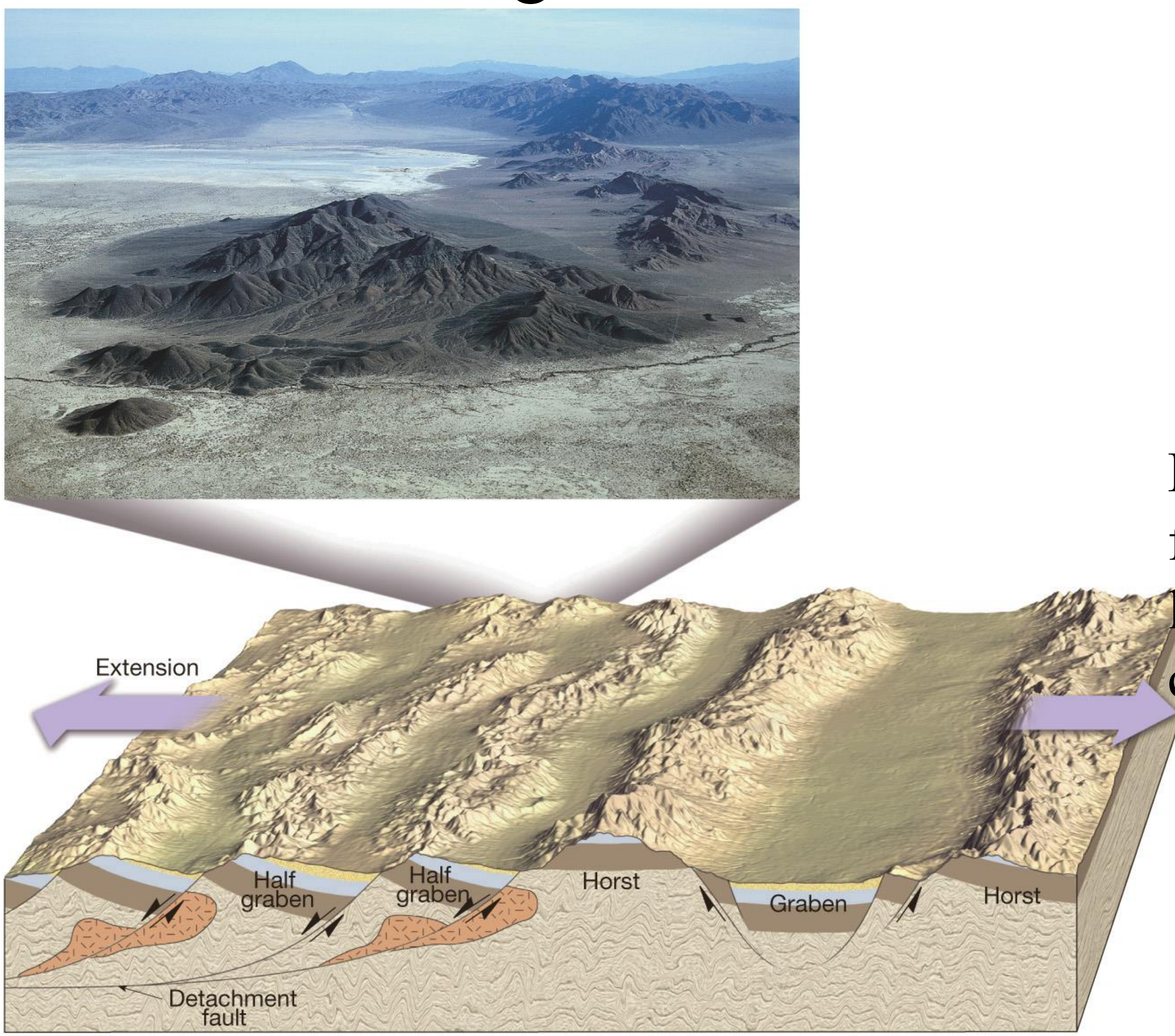
Features of normal faulted terrain

- horst – uplifted block bounded by two normal faults
- graben – down-dropped block bounded by two normal faults



- fault-block mountains are produced in normally faulted terrain.
  - Example - Basin and Range Province of the southwestern United States

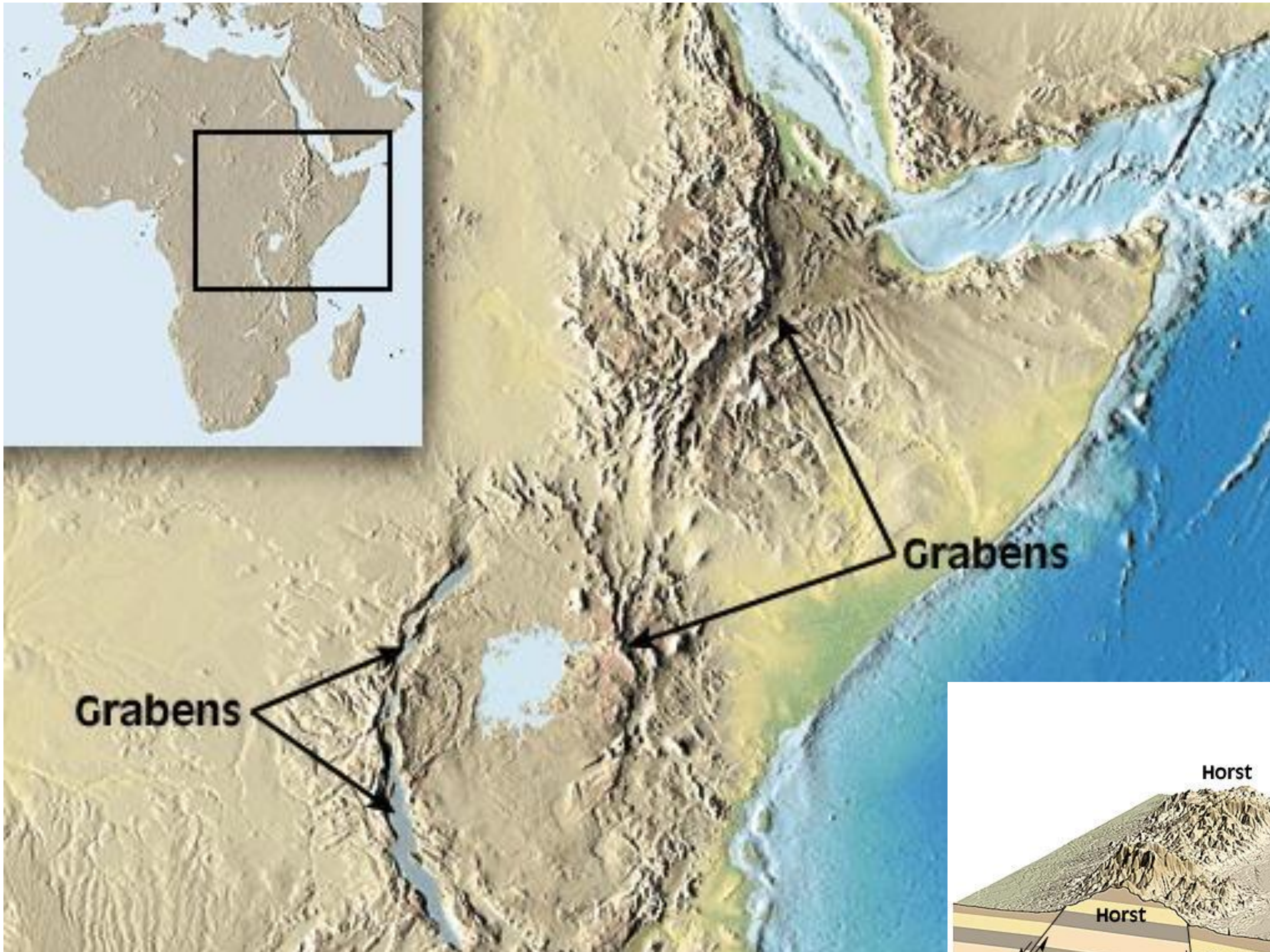
Normal faulted terrain: Fault block mountains of the Basin and Range Province of SW United States

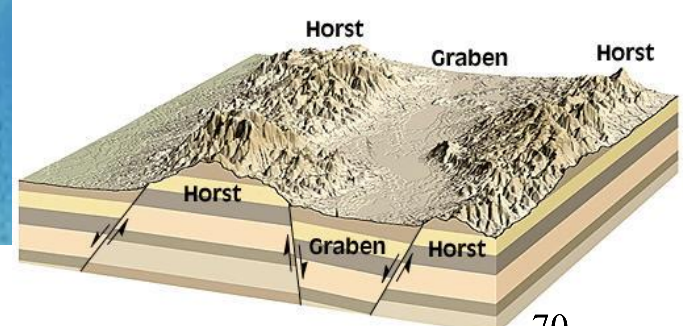


Extensional forces lengthen the crust


OR
ID
CA
NV
UT
WY
BASIN & RANGE
SIERRA NEVADA
WASATCH
AZ

Normal faulting occurs at spreading centers





- Clay model of the formation of normal faults at a spreading center. Movie

- (Clay demonstration by Ron Harris)

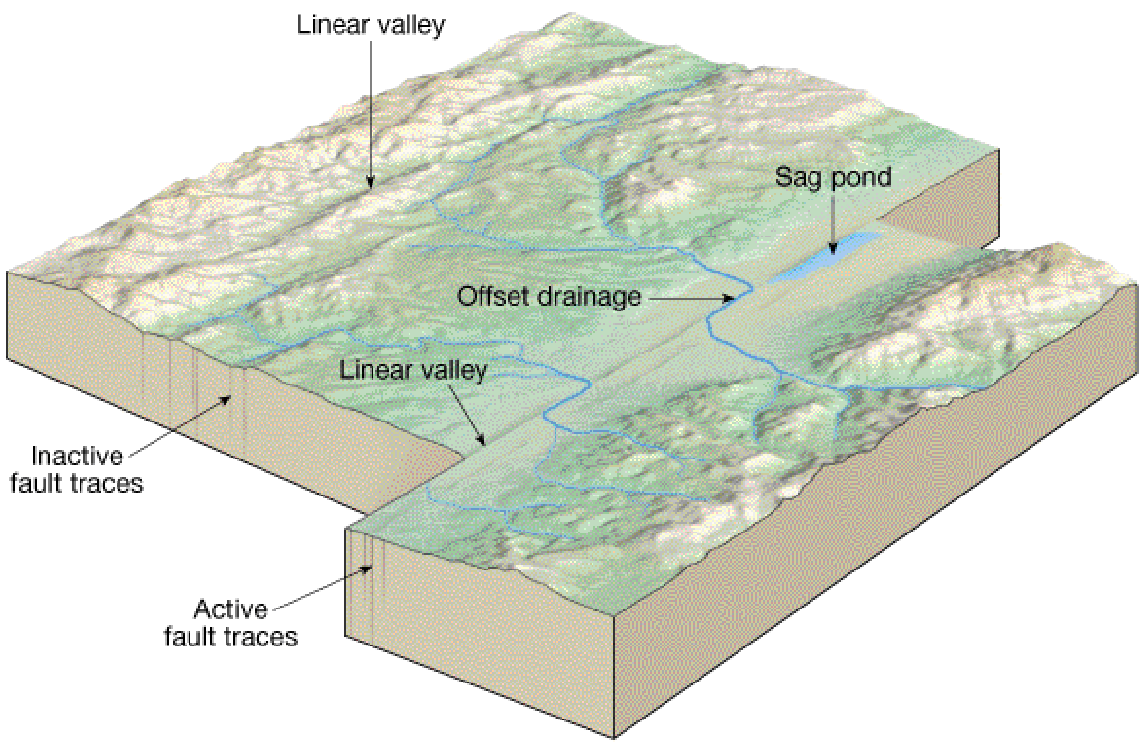
  http://geologyindy.byu.edu/faculty/rah/slides/Rock%20Canyon/Wasatch%20Fault/Wasatch%20Fault%20Home.htm

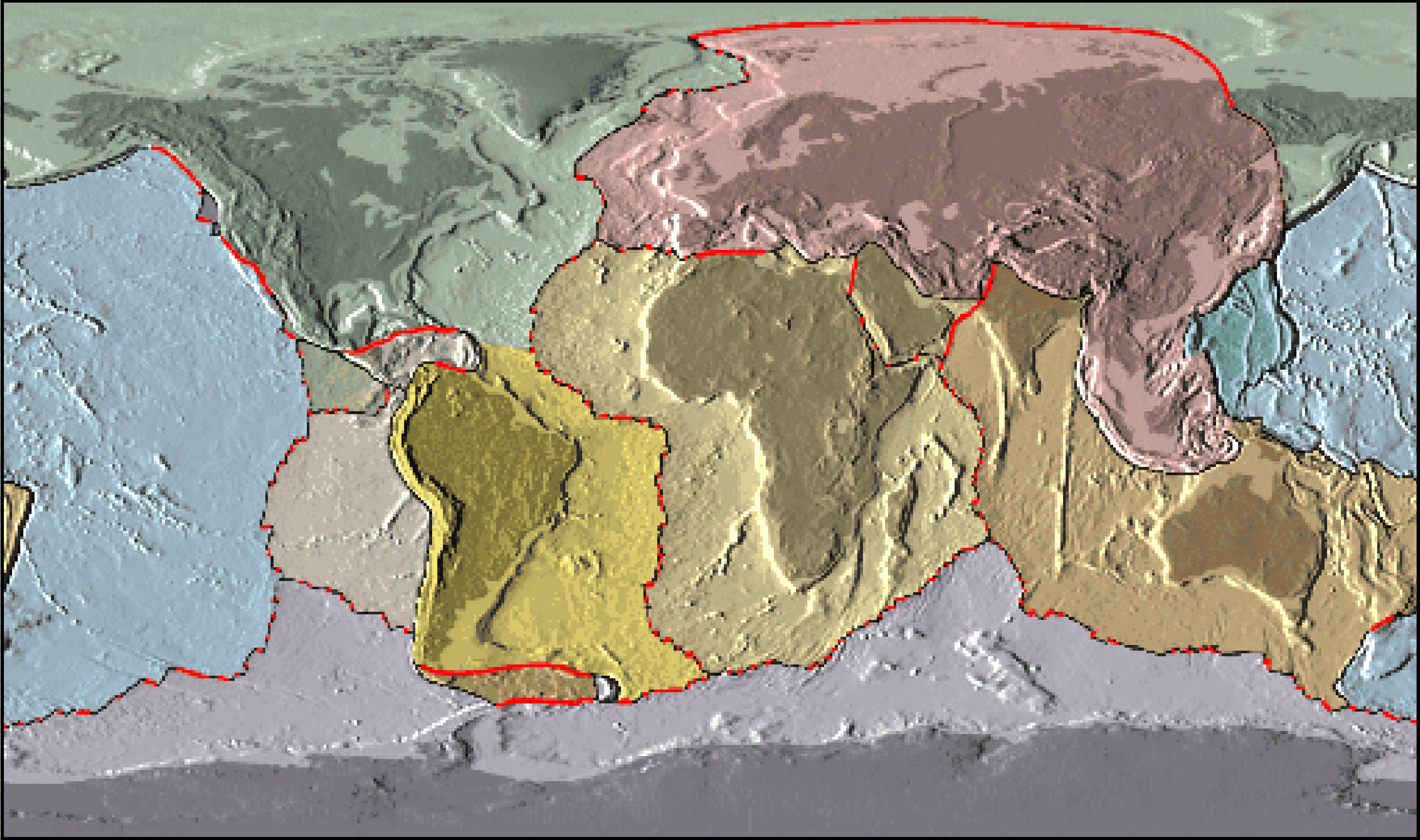
Strike-slip fault

(not a dip-slip fault, no vertical displacement)

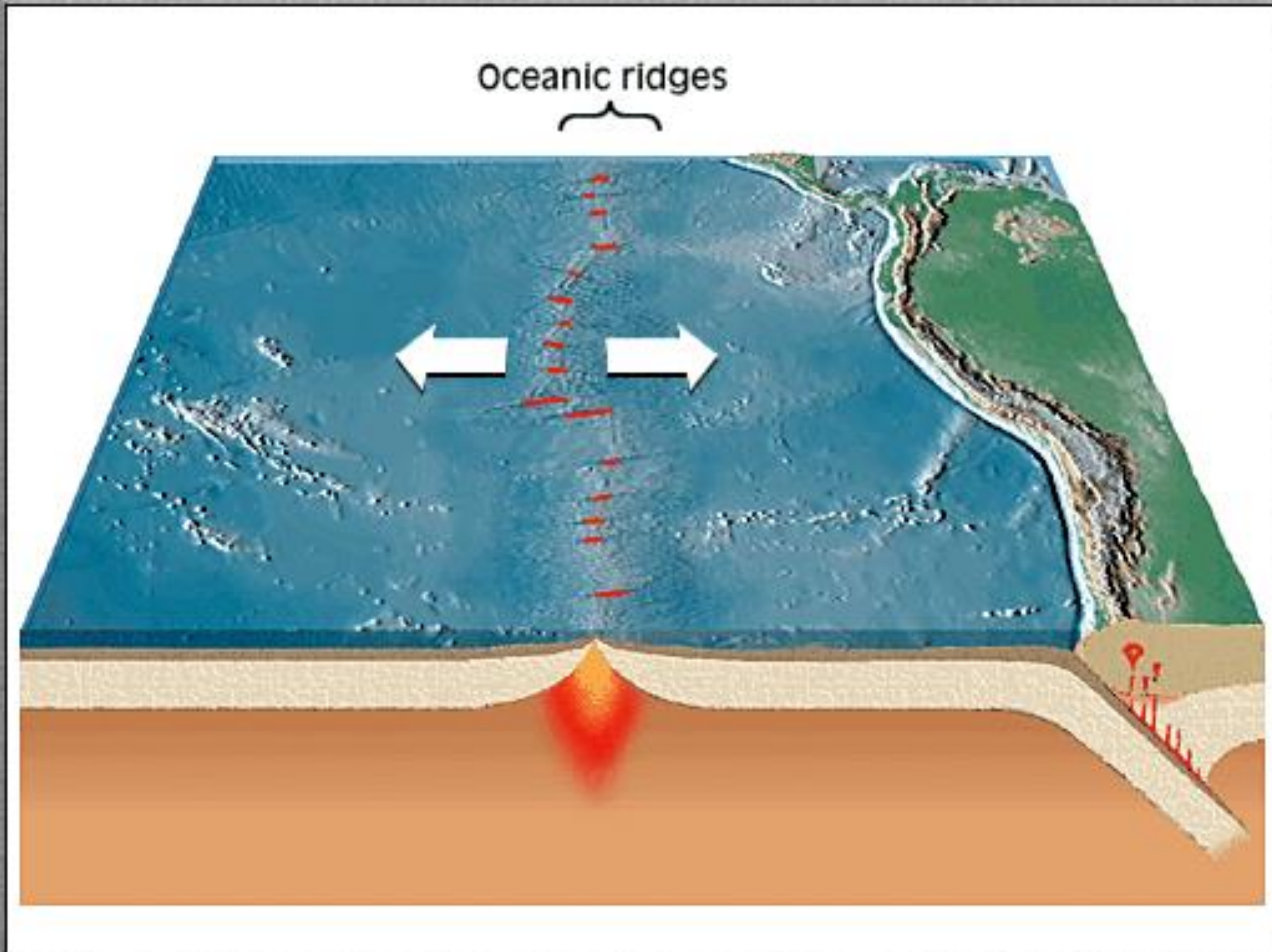
Strike-slip fault

- Fault movement is horizontal and parallel to strike
  - No vertical displacement,
  - fault gauge erodes to produce linear trough
- transform fault are strike slip faults
  - Example: San Francisco fault system (1906 earthquake)





Large strike-slip faults, called **transform faults**, accommodate displacement between plate boundaries.



Most transform faults cut the oceanic lithosphere and link spreading centers.


Alaska
Canada
Aleutian Thrust
Queen Charlotte fault
Juan de Fuca ridge
NORTH AMERICAN PLATE
Mendocino Fractur Zone
PACIFIC PLATE
San Francisco
California
Hayward fault
Calaveras fault
San Andreas fault
Garlock fault
Los Angeles
San Jacinto fault
Elsinore fault
Coyote Creek fault
Imperial fault
United States
Gulf of California
Mexico
Motagua fault
CARIBBEAN PLATE
Rivera fault
East Pacific Rise
Middle America Thrust
COCOS PLATE

San Andreas Fault System, transform faults

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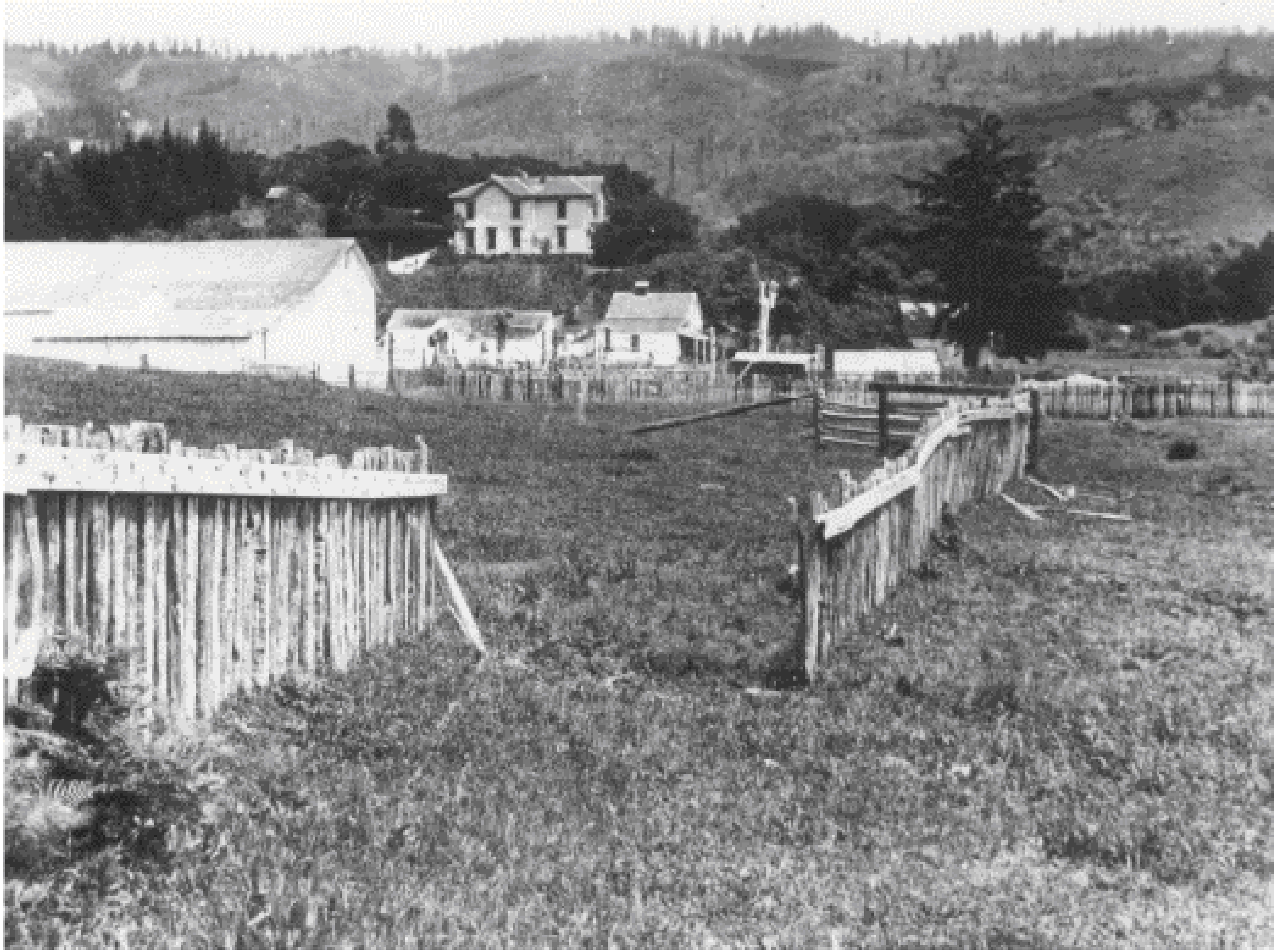


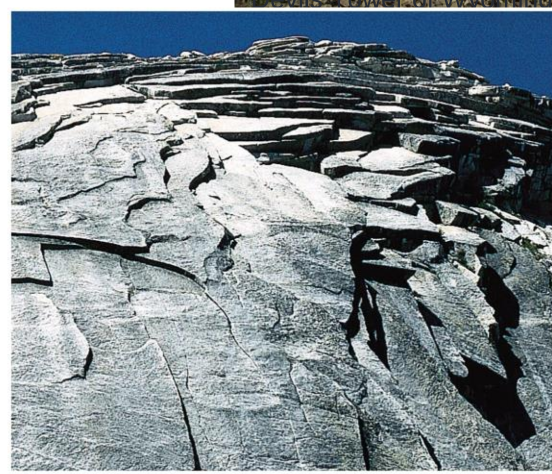
Joints

Joints- are fractures with no appreciable displacement

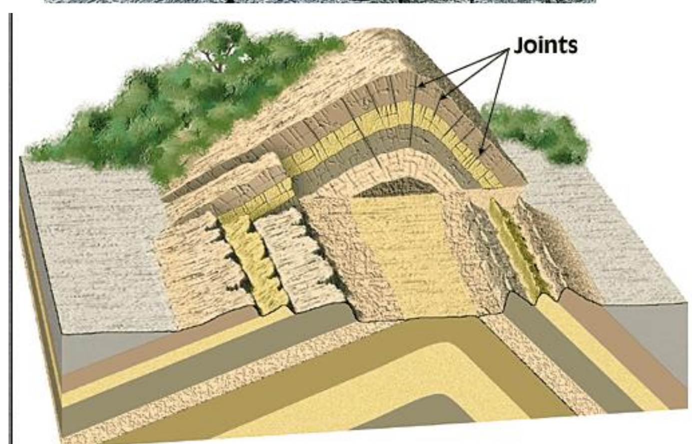
- Examples of joints
- columnar joints -
  - shrinkage fractures in cooling igneous rock creates elongate pillar-like structures

)11/08/31/columns-form-

- sheeting - from unloading of overlying rock
  - joints parallel to the ground surface
  - breaks rocks into “sheets”
  - Creates exfoliation domes



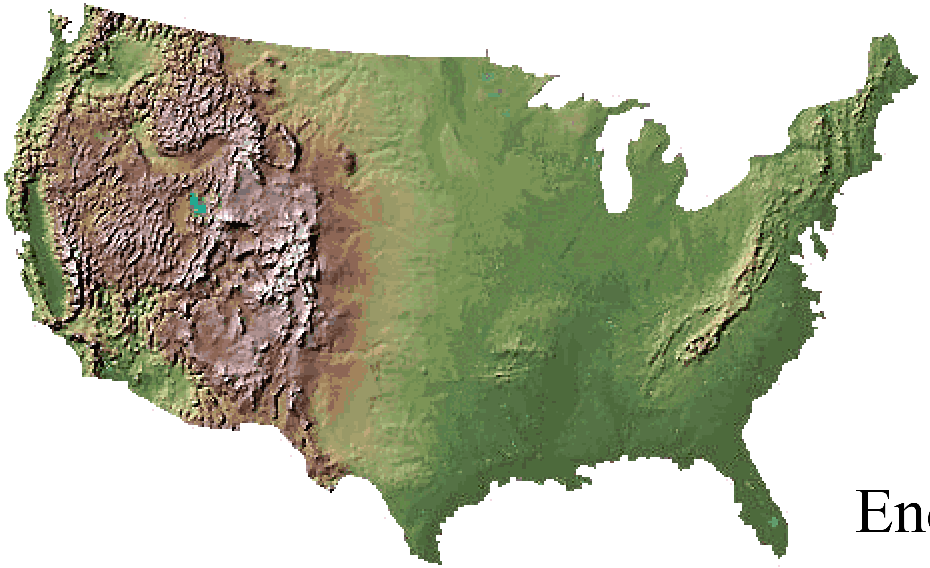
- brittle failure associated with folding



Importance of joints

- Enhanced chemical weathering
- can influence direction of streams
- hydrothermal solutions deposit ore minerals
- risk to construction projects
  - Teton Dam,Idaho, failure 1976
  - seepage along joints

Chemical weathering is enhanced along joints.



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