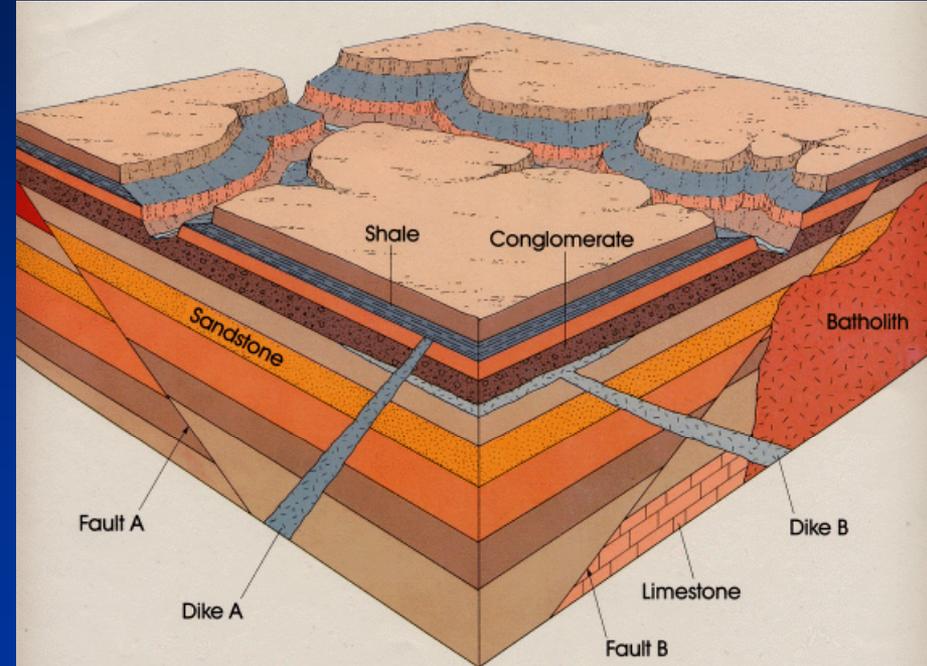


Structural Geology and Geology Maps Lab

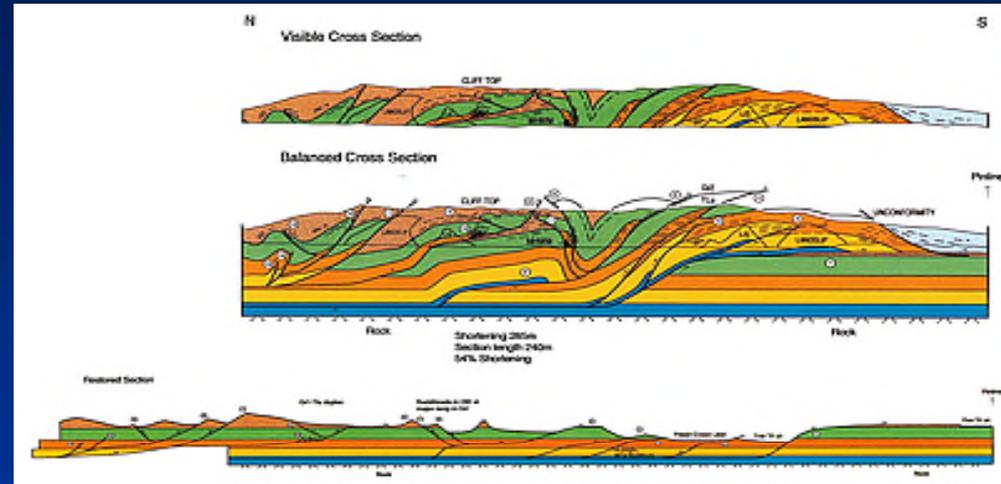


Geology 101 Lab
Ray Rector: Instructor



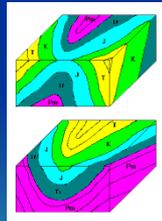
Structural Geology Lab

Pre-Lab Resources

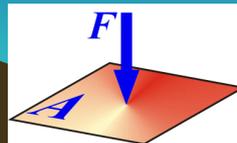


Pre-Lab Internet Links

1) Fundamentals of Structural Geology



2) Visualizing Bed Attitude



Structure Lab Learning Objectives

By the end of this lab, the student should be able to:

- 1) Explain the terminology and basic concepts of structural geology
- 2) Apply the general rules of structural geology to solving structure problems.
- 3) How to use field compass and inclinometer to determine strike and dip.
- 4) Identify the types of folds and faults, and correctly measure their attitude.
- 5) Correctly interpret and draw geologic block diagrams.
- 6) How to read a simplified geologic map.



General Geologic Terms of Structure

Outcrop: Exposure of bedrock at earth's surface



Formation: mappable body of rock with definite age, lithology, and external boundaries (contacts)

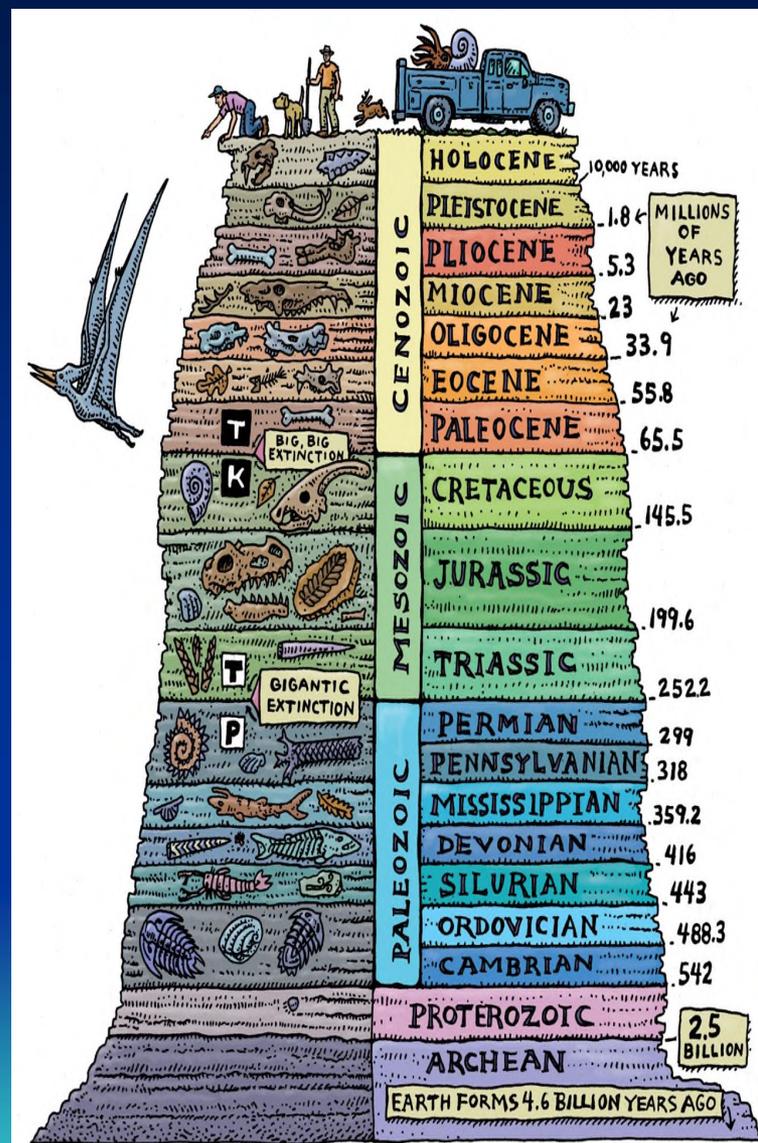


Contact: Boundary between adjacent rock bodies or structural elements



Rock Formations and Geologic Time

- 1) All geologic rock formations have a specific assigned age
- 2) All geologic rock formations have a specific range of lithology
- 3) Rock formations are listed in a temporally-ordered sequence in the “explanation” of a geologic map
- 4) Each rock formations has an assigned geologic period
- 5) Geologic period assignments of formations are further divided into lower (older), middle, and upper (younger)

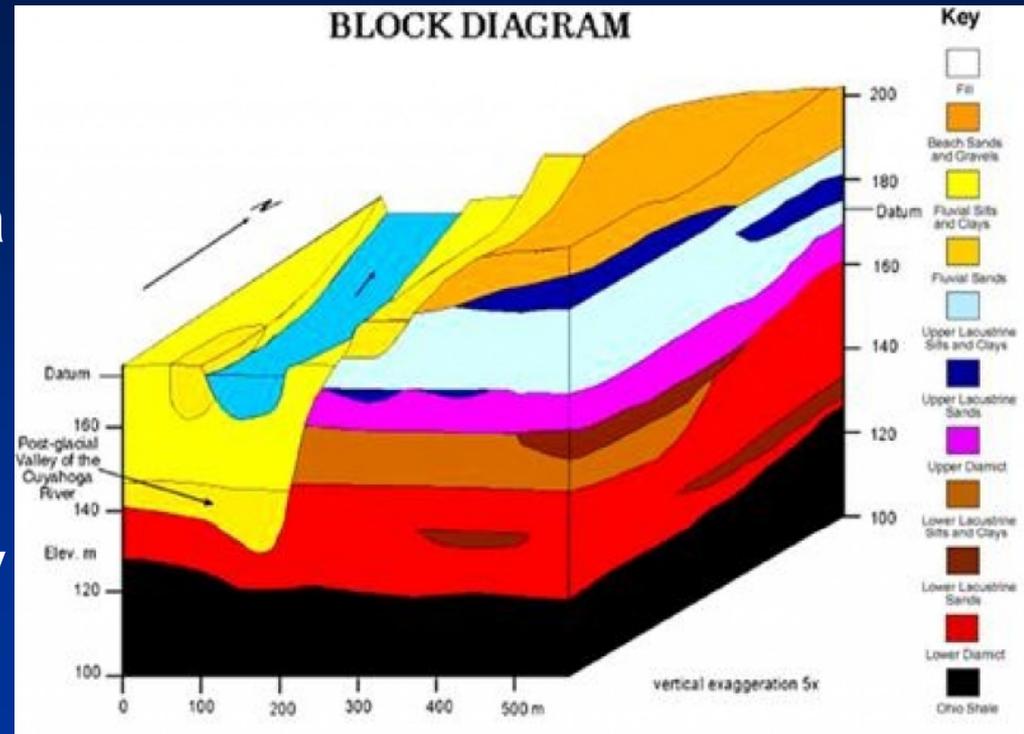


Rock Formations and Block Diagrams

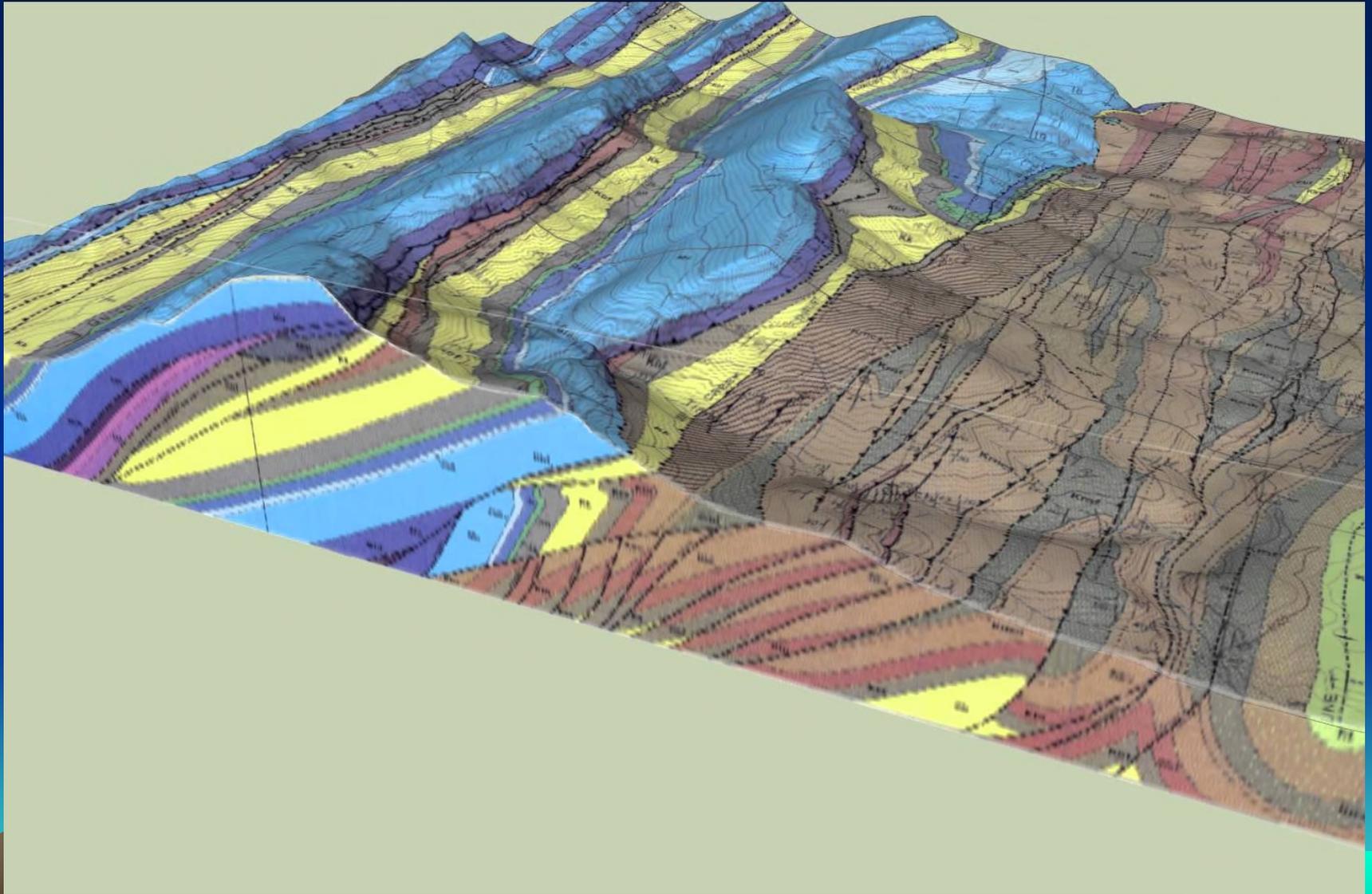
1) Geologic block diagrams combine a geologic map (top) with two cross-sections (sides) to create a three-dimensional block model of the crust.

2) Most block models are oriented in a particular way in respect to cardinal directions.

3) Block diagrams can be very helpful in analyzing various types of geologic structures, like stratigraphy, intrusions, folds and faults.



3-D Geologic Map Block Diagram



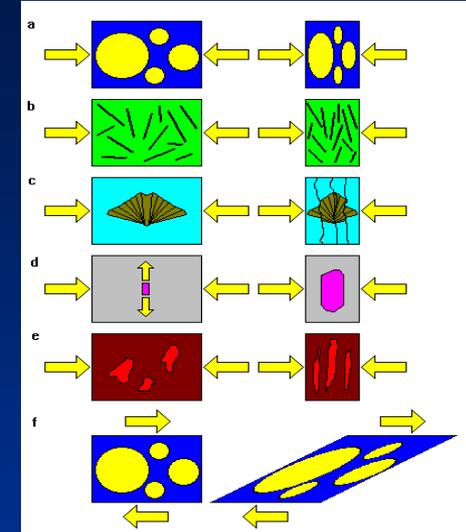
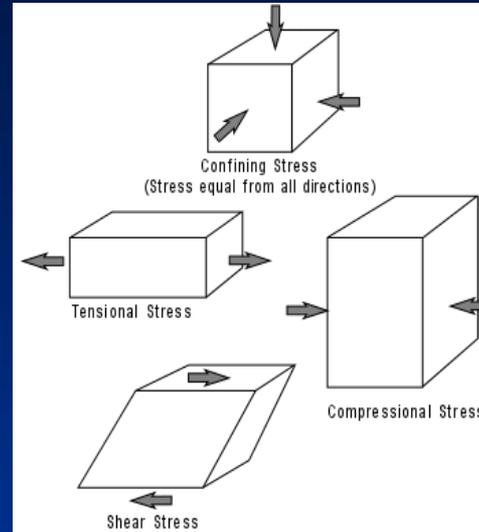
Origin and Nature of Rock Deformation

A. Stress Leads to Strain

- ✓ Stress is an applied force over an area
- ✓ Strain is the deformation of a solid body

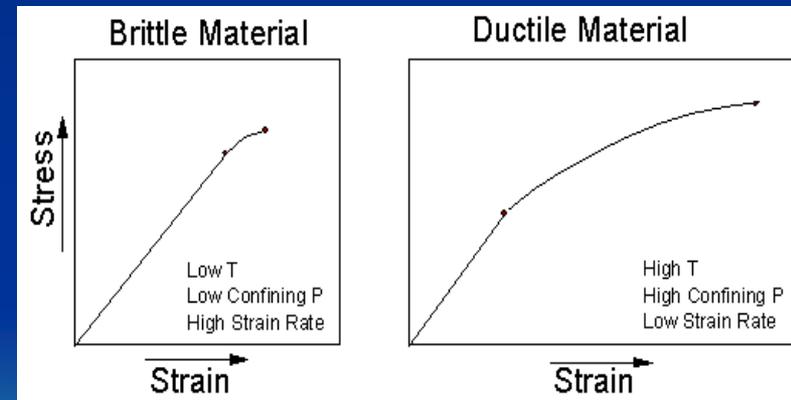
B. Different Types of Stress

- ✓ Tensional = pulling apart forces
- ✓ Compressional = pushing together forces
- ✓ Shear = grinding past each other force



C. Different Types of Strain

- ✓ Brittle = breaking into pieces
- ✓ Ductile = changing shape without breaking
- ✓ Elastic = deformed body returns to normal shape after stress released
- ✓ Plastic = deformed body remains deformed after stress released



Rocks strain in a predictable fashion, according to the amount and duration of strain under a given set of temperature-pressure conditions

Resultant Rock Strain from Specific Stresses

A. Undeformed Strata

- ✓ Original Horizontal layering

B. Compressional Stresses

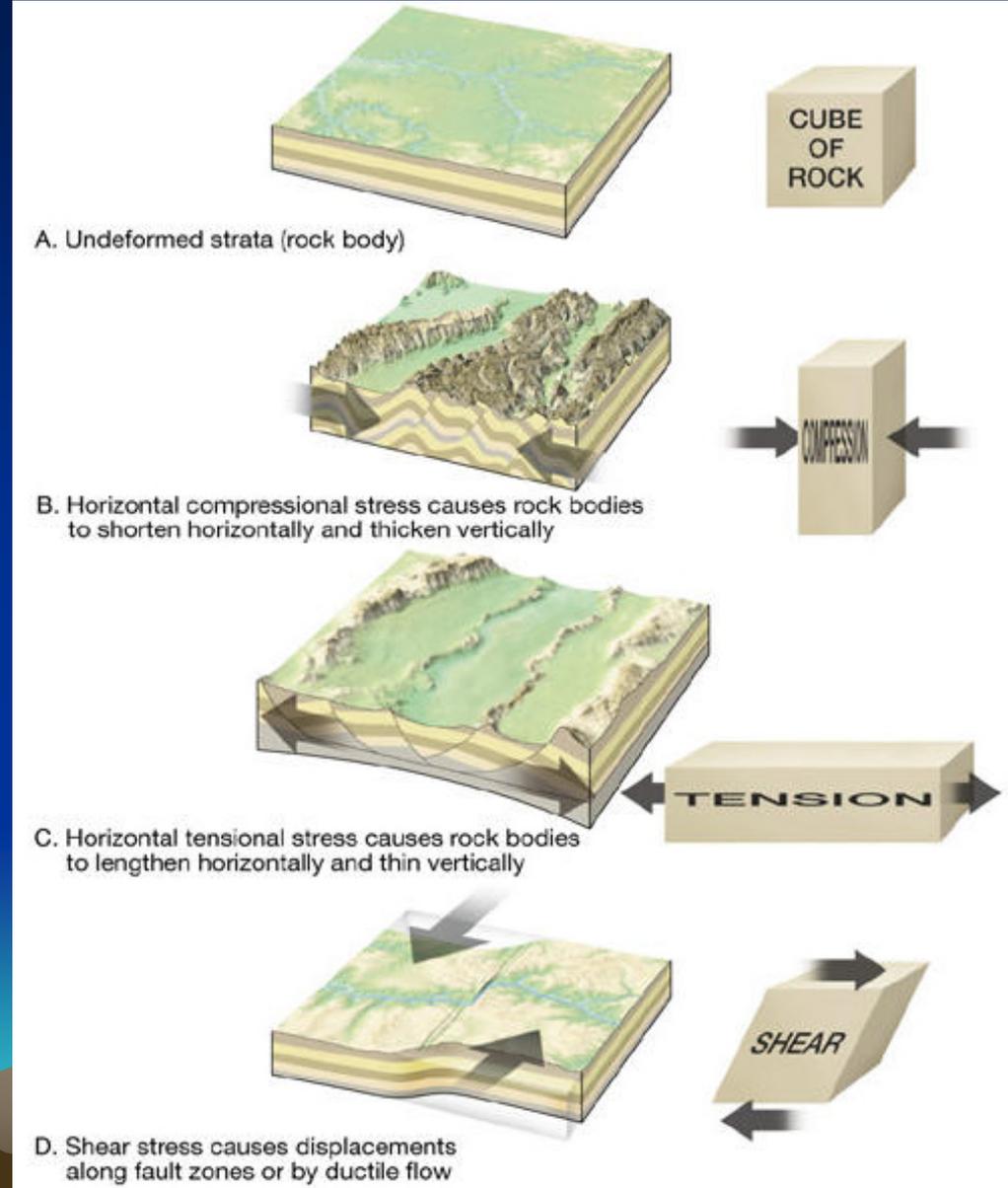
- ✓ Shorten horizontally
- ✓ Thicken vertically
- ✓ Folding and Reverse Faulting

C. Tensional Stresses

- ✓ Lengthen horizontally
- ✓ Thin vertically
- ✓ Tilting and Normal Faulting

D. Shear Stresses

- ✓ Lateral displacement
- ✓ Strike-slip Faulting



Resultant Rock Strain from Specific Stresses

A. Undeformed Strata

- ✓ Original Horizontal layering

B. Tensional Stresses

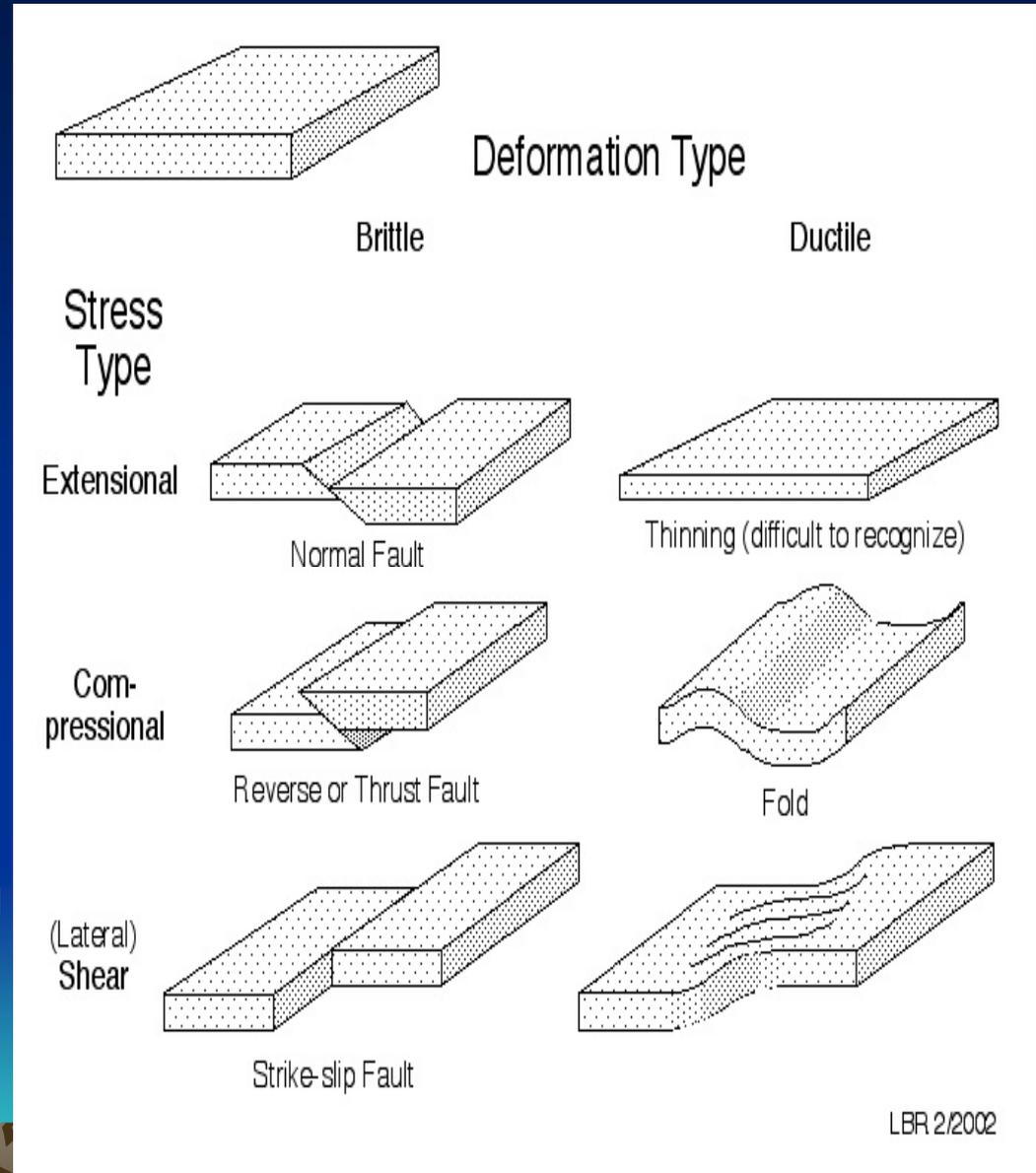
- ✓ Lengthen horizontally
- ✓ Thin vertically
- ✓ Tilting and Normal Faulting

C. Compressional Stresses

- ✓ Shorten horizontally
- ✓ Thicken vertically
- ✓ Folding and Reverse Faulting

D. Shear Stresses

- ✓ Lateral displacement
- ✓ Strike-slip Faulting



Geologic Structures



Rock Layering



Tilted Rock Layers



Folded Rock Layers



Faulted Rock Layers

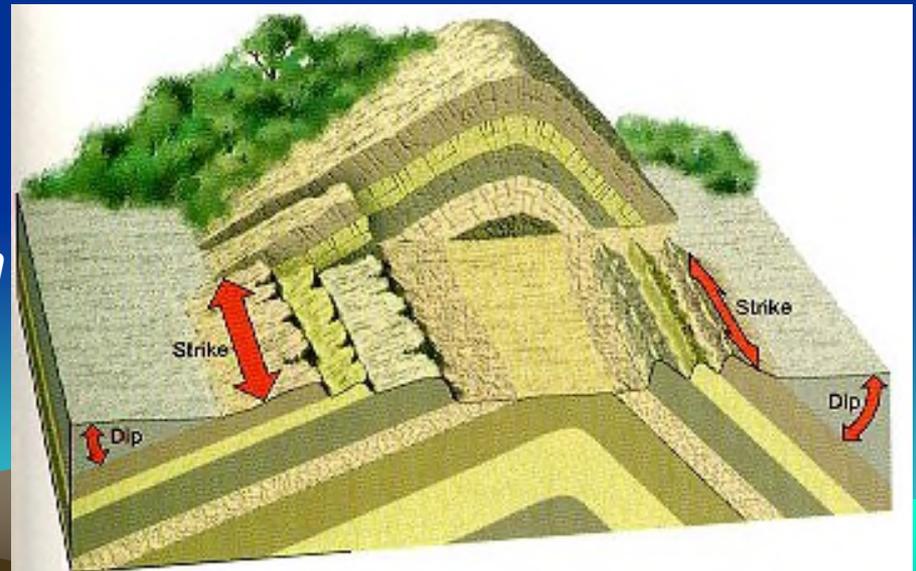
The Basic Rules of Structure

- 1) Strike of beds is always parallel to the direction of the contacts.
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 - 4) Youngest rocks exposed in the center of eroded synclines and basins.
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 - Syncline fold plunges toward *open* end of "U" pattern.
 - 8) Steeper the dip of the layer, the more narrow the width of its outcrop.
 - 9) Hanging wall is towards the fault dip direction; foot opposite to fault dip direction
 - 10) Hanging wall *moves up* relative to foot wall in reverse and thrust faults.
 - 11) Hanging wall *moves down* relative to foot wall in normal faults.
 - 12) Slickenside grooves oriented horizontal in fault scarp indicate strike-slip offset.
 - 13) Slickenside grooves oriented vertical in fault scarp indicate dip-slip offset.
- 

Spatial Orientation of Layers

Strike and Dip

- 1) The spatial orientation, or **attitude** of a planar rock layer or structural feature can be measured and recorded in the field.
- 2) Two spatial aspects are needed:
 - ✓ **Strike** = horizontal component
 - ✓ **Dip** = angle below the horizontal
- 3) The **Strike** is the line, or *trend* that represents the intersection of the planar feature with the horizontal.
- 4) **Strike** is measured with a compass.
- 5) **Dip** is the downward angle, or *inclination* of the feature from horizontal at a right angle to the strike.
- 6) **Dip** is measured with a clinometer.



Using a Compass/Inclinometer to Determine Spatial Orientation of Layers

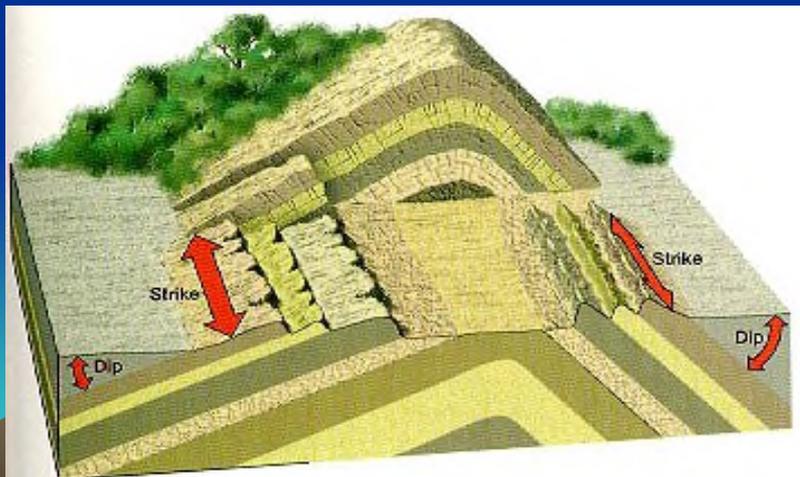
Strike and Dip



Measuring Strike Azimuth



Measuring Dip Angle



Strike Azimuth and Dip Angle



Completed Strike and Dip Measurement

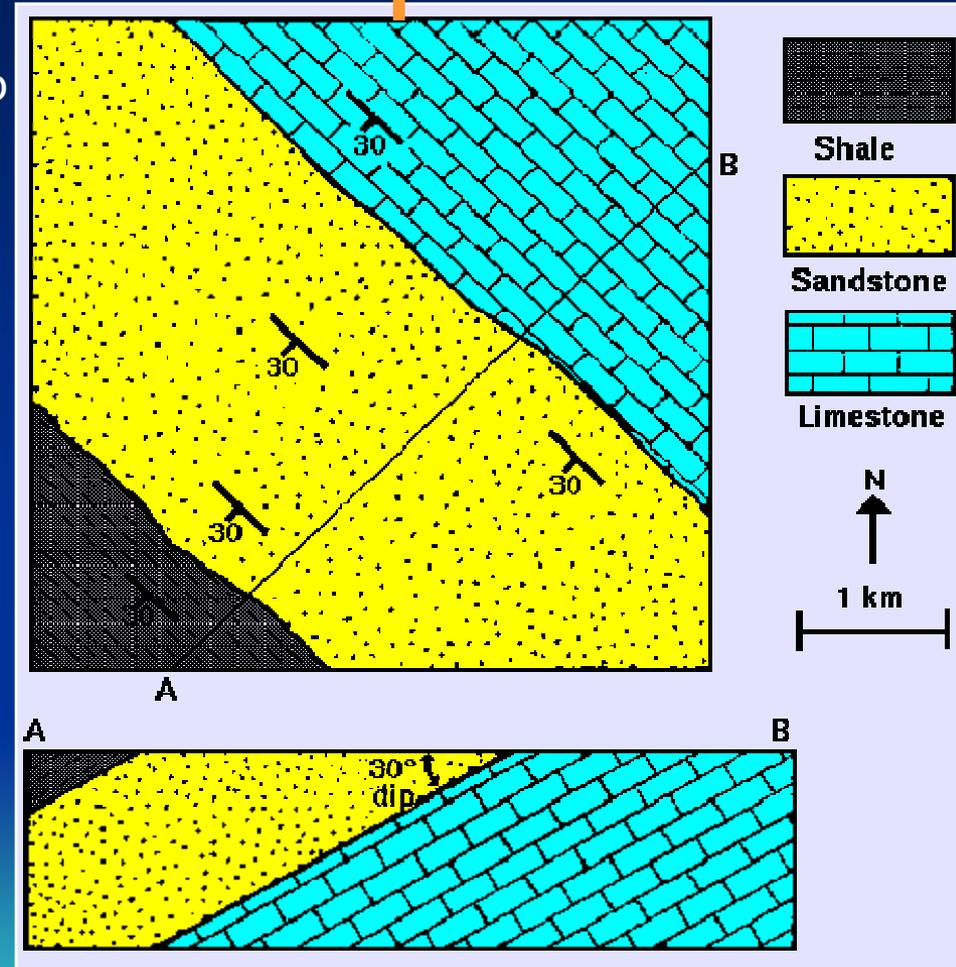
Spatial Orientation of Layers

Strike and Dip

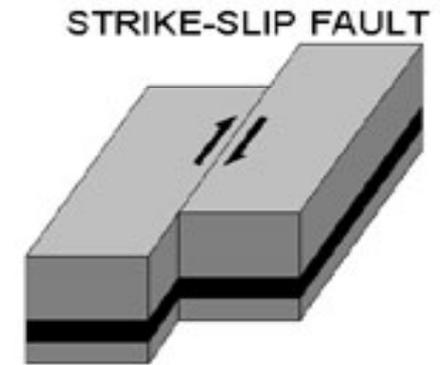
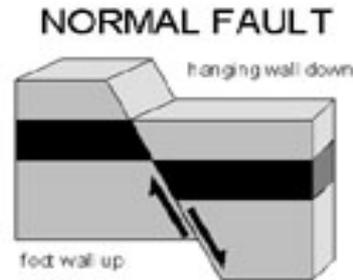
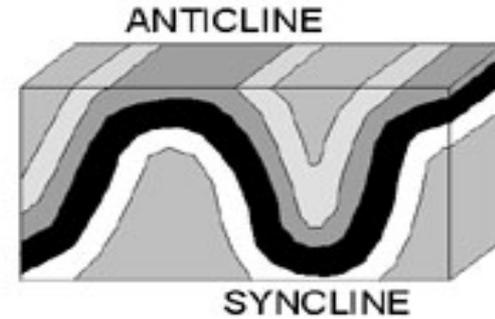
The **Strike** and **Dip** of a planar rock layer or feature is symbolized on a geology map by a



- ✓ The long bar is the strike trend
- ✓ The short bar points to the down dip direction with dip angle



Folds and Faults



General Geologic Terms of Folds

Folds: Buckled layers of rock formed by compressive stresses

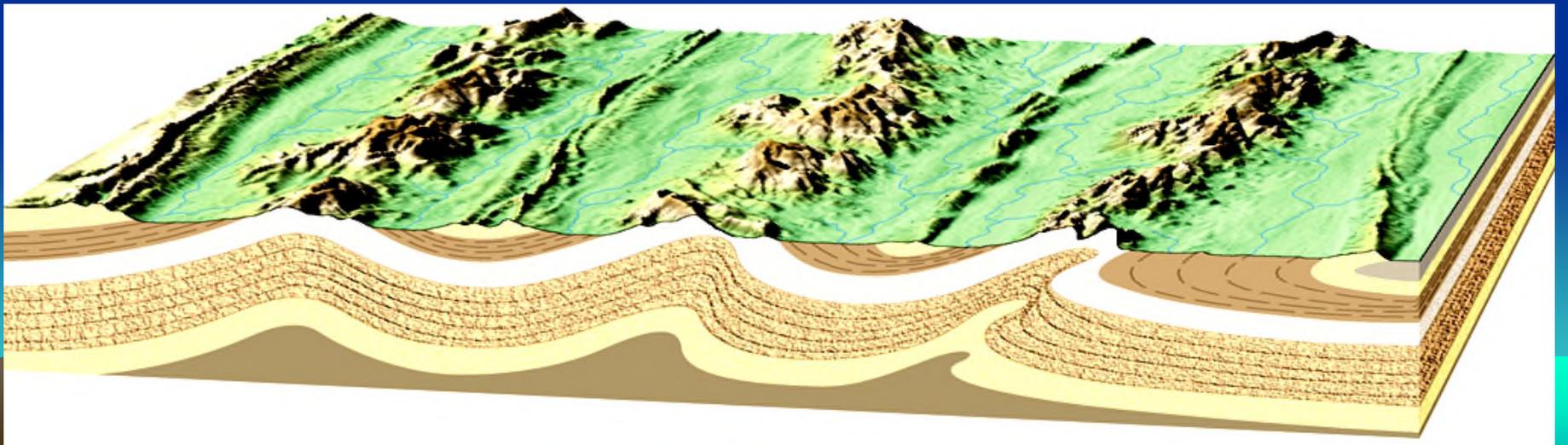
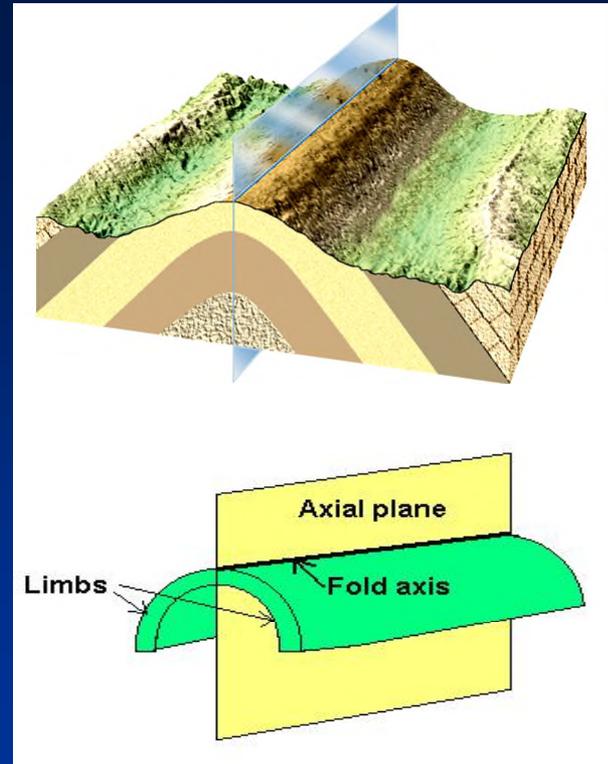


Anticline: Upwards-buckled fold with oldest rock at center and outward-dipping limbs

Syncline: Downwards-buckled fold with oldest rock at center and outward-dipping limbs



Fold Basics



Fold Basics

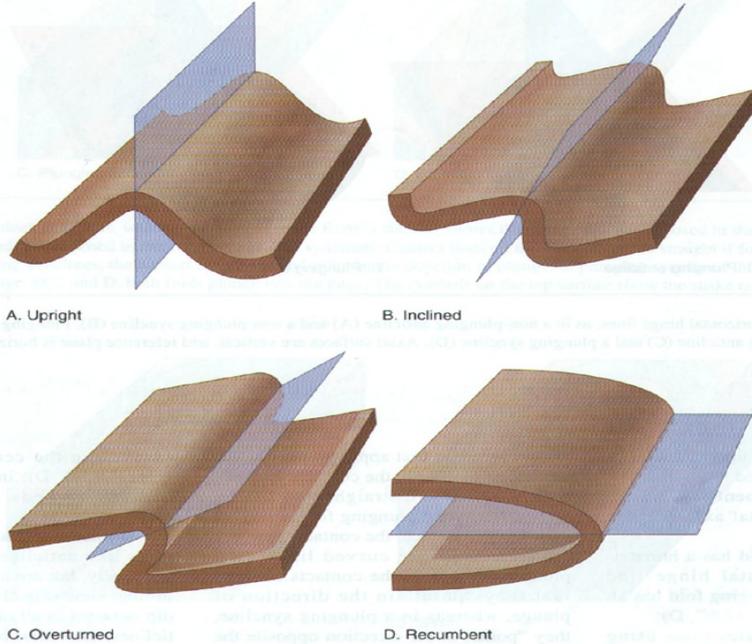
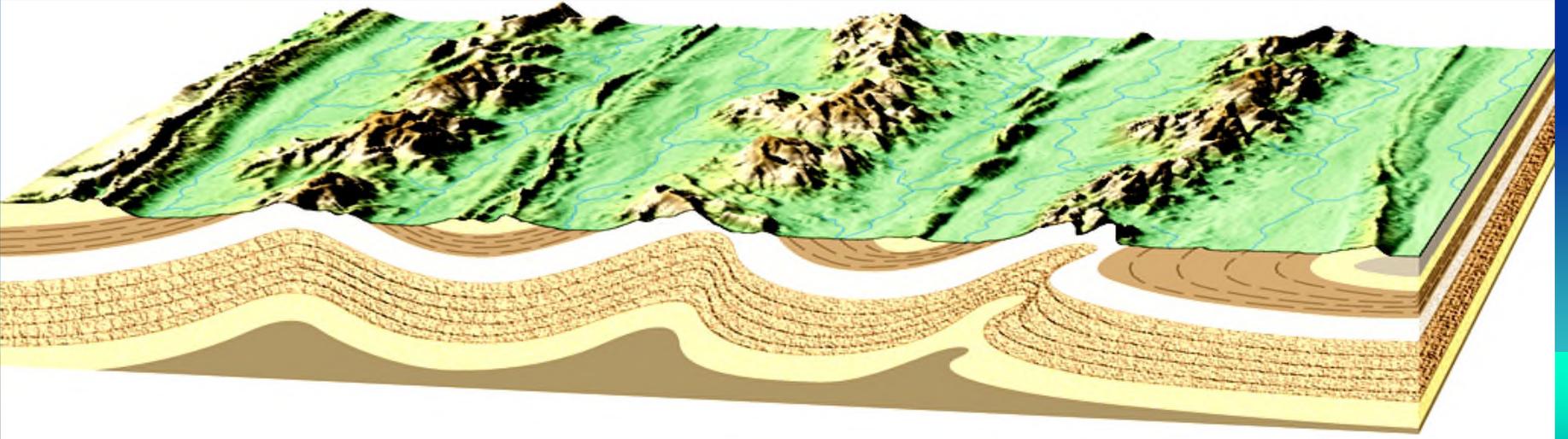
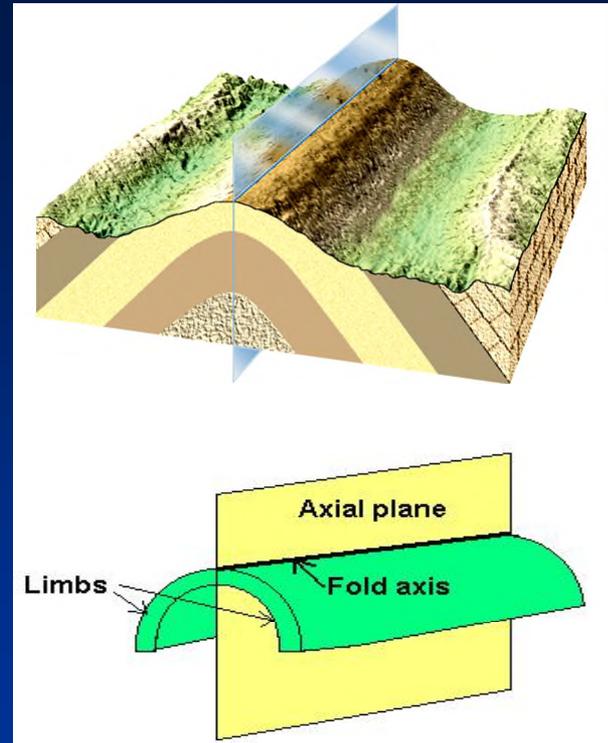
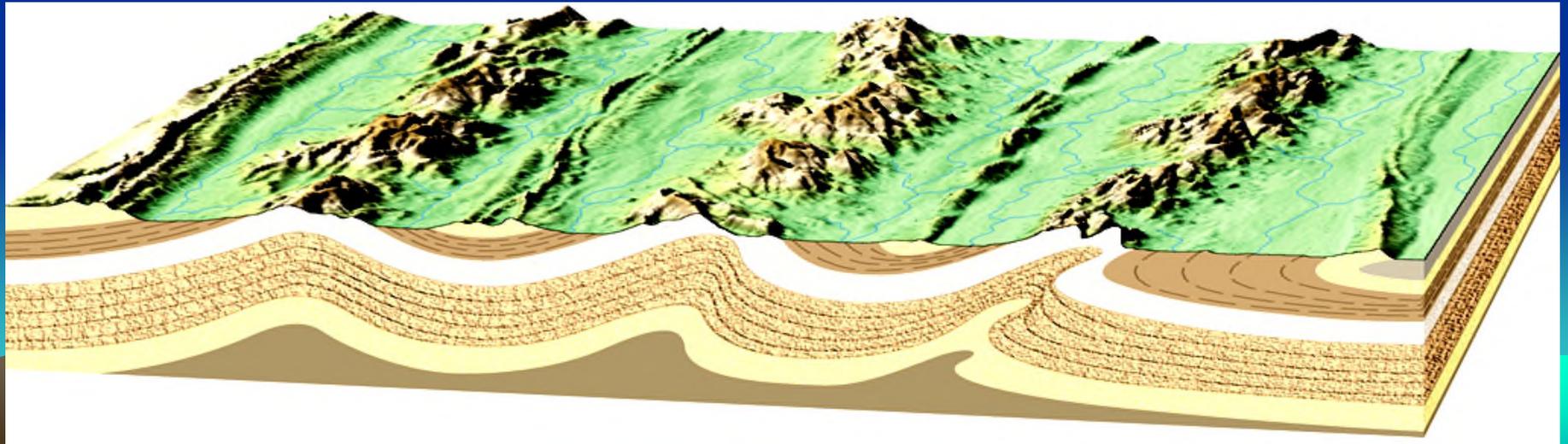


FIGURE 14.7
The axial surface of a fold can be: A. Vertical in **upright folds**; B. inclined in **inclined folds**; C. inclined so much that opposite limbs dip in the same direction in **overturned folds**; D. horizontal in **recumbent folds**, (Adapted from Jones, 2001: Laboratory Manual for Physical Geology, 3rd Edition)



Fold Basics



Rules of Folds

Anticlines

- 1) Oldest unit in center
- 2) Limbs dip outward

Synclines

- 1) Youngest unit in center
- 2) Limbs dip inward

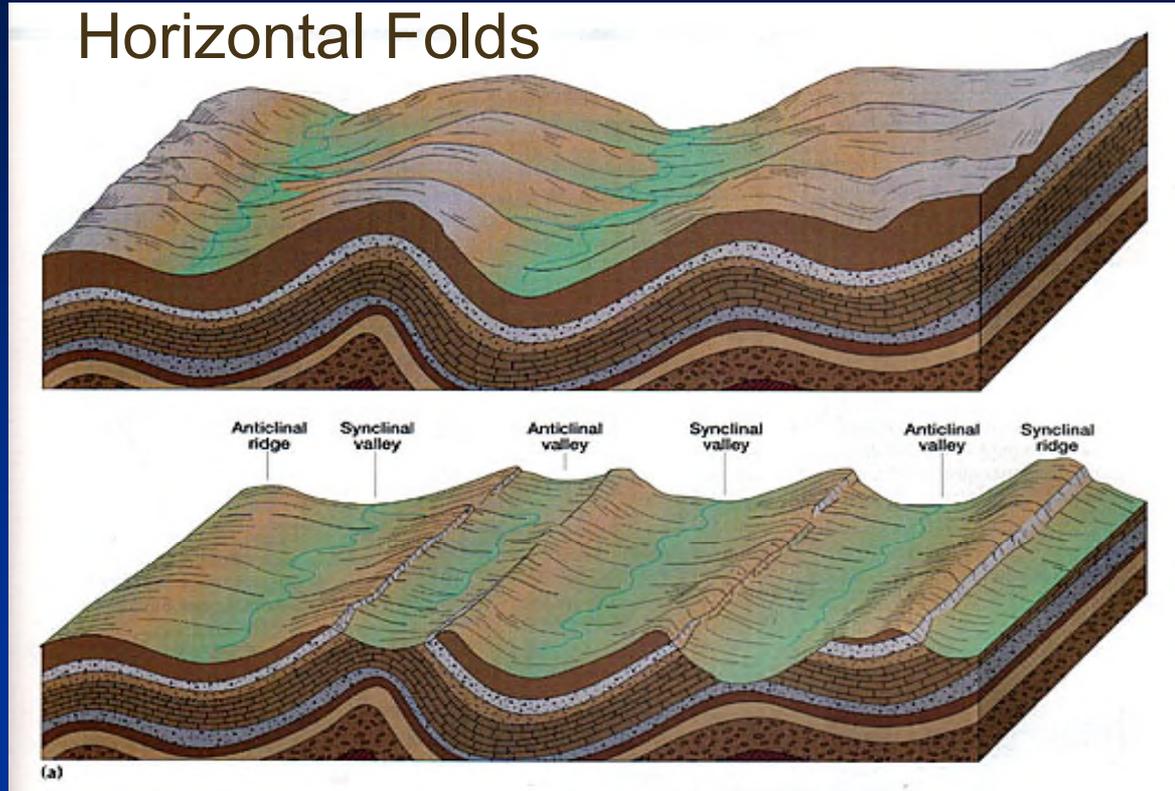
Horizontal Folds

- 1) Strikes of opposing fold limbs are all parallel
- 2) Folds form parallel striped pattern on geology map

Plunging Folds

- 1) Strikes of opposing fold limbs are not parallel
- 2) Folds form V-shaped pattern on geology map

Horizontal Folds

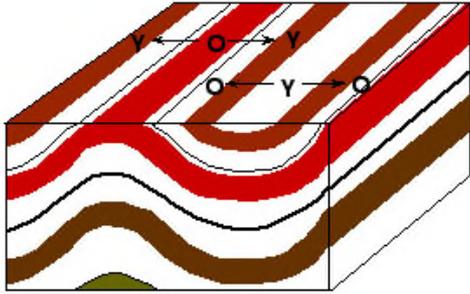


3) Anticlines plunge toward closed end of "V"-shaped bedding pattern

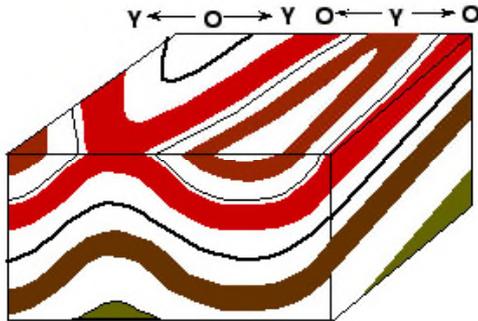
4) Synclines plunge toward open end of "V"-shaped bedding pattern

Plunging Folds

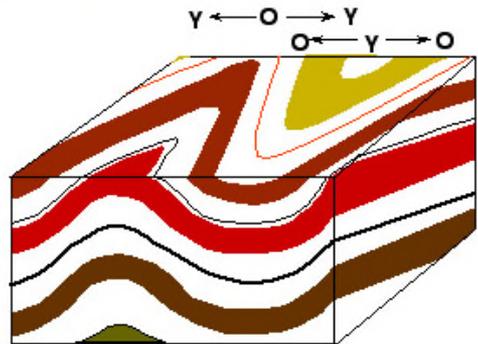
Plunging Folds



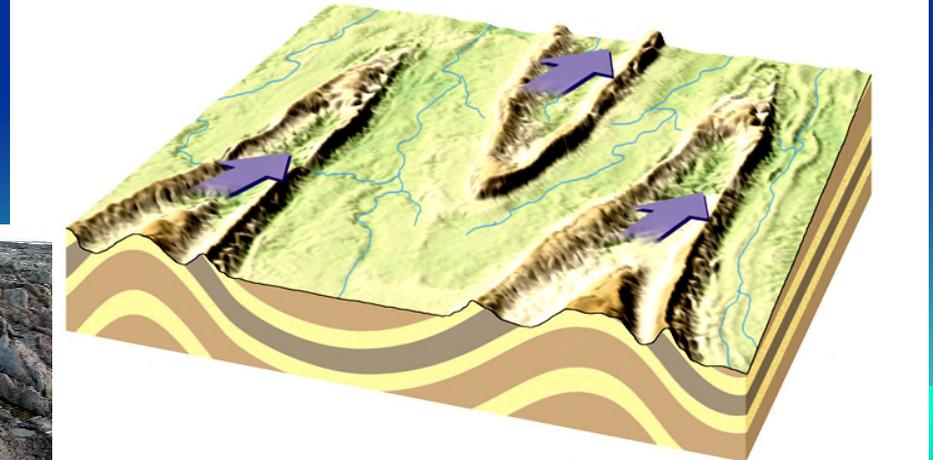
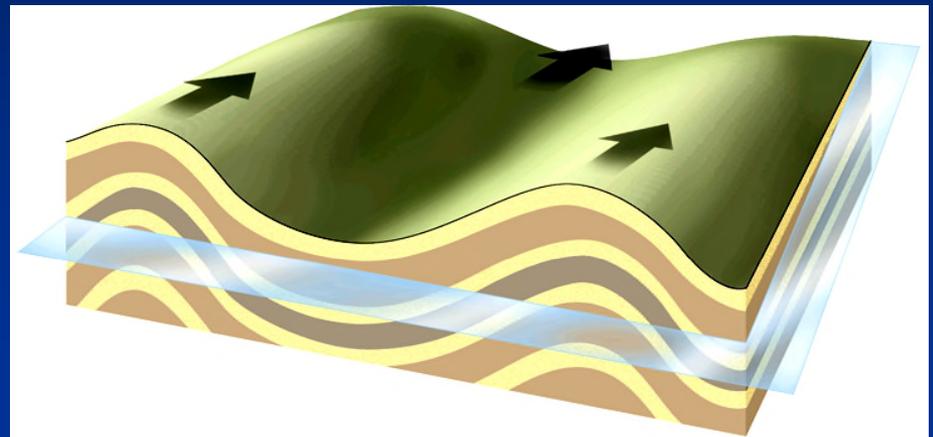
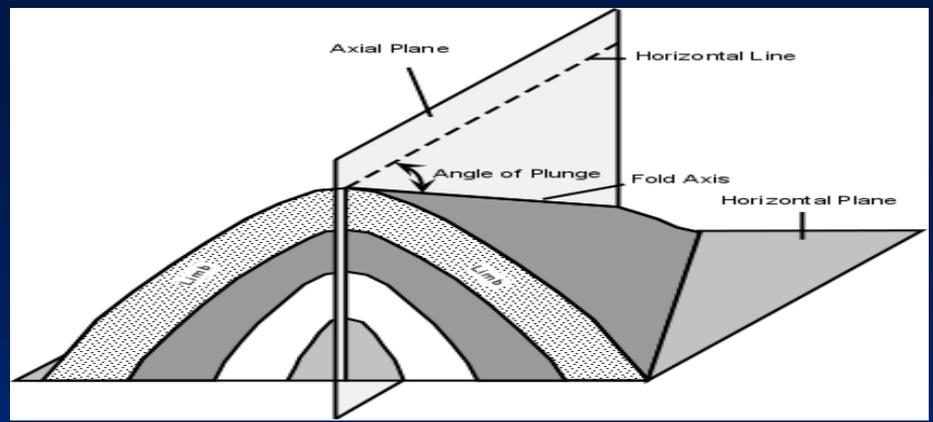
Anticline and Syncline in 3-dimensional view



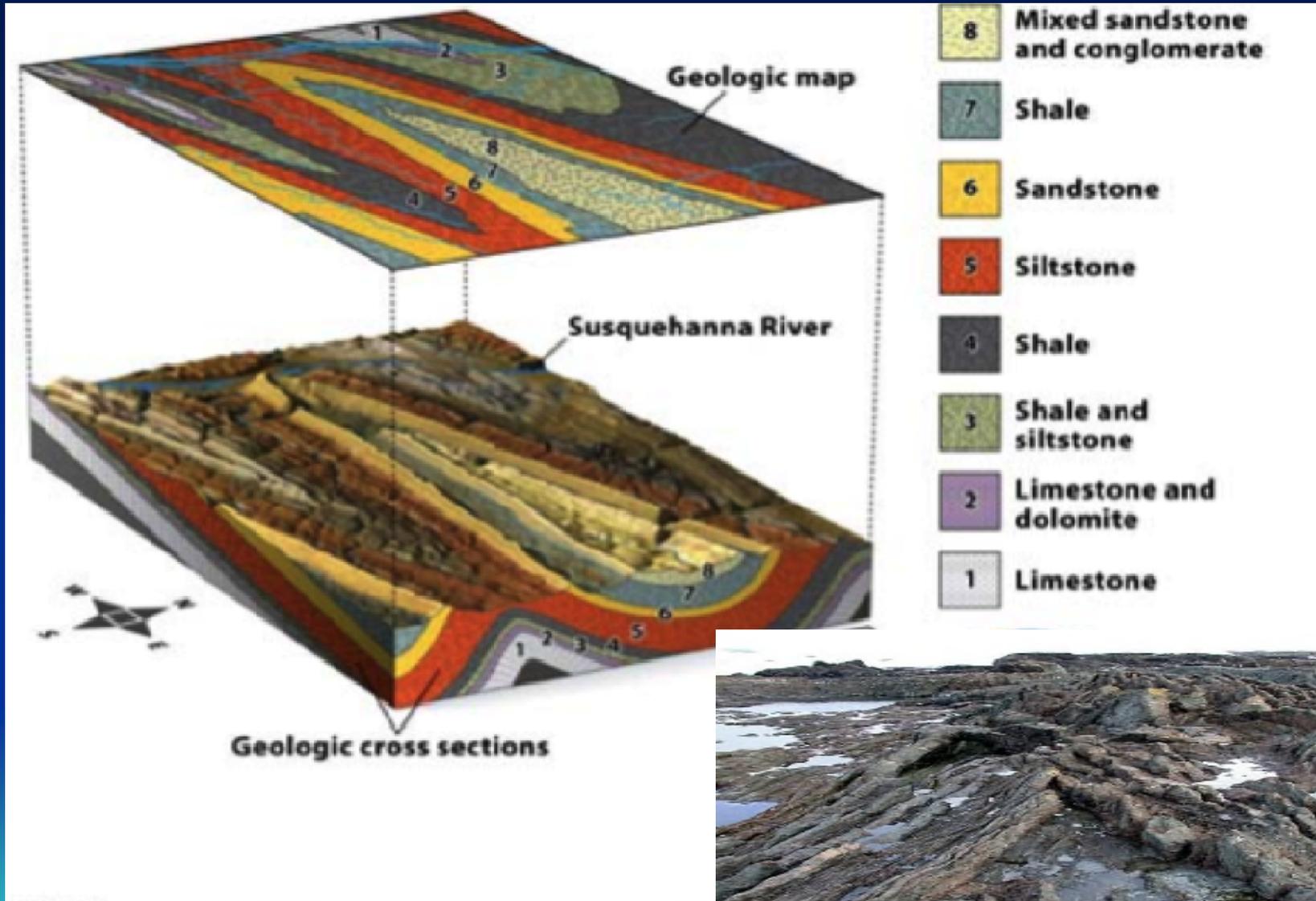
Anticline and Syncline plunging toward viewer



Anticline and Syncline plunging away from viewer

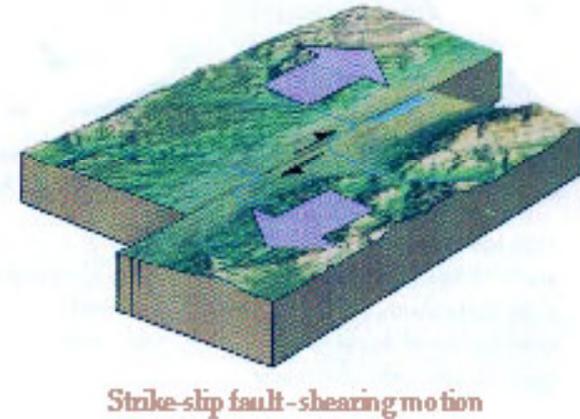
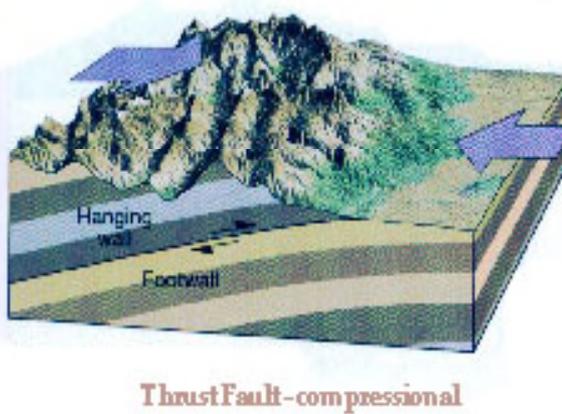
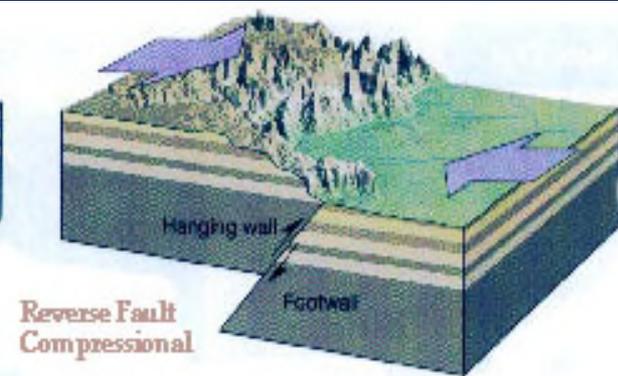
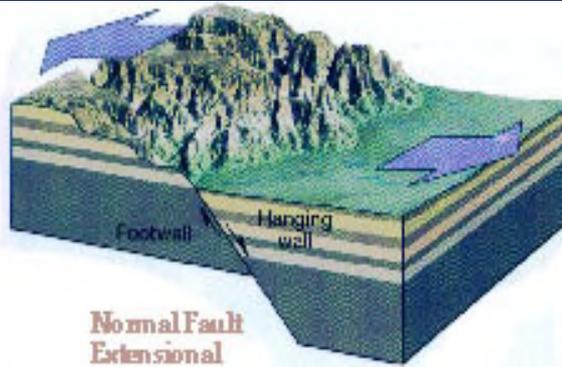
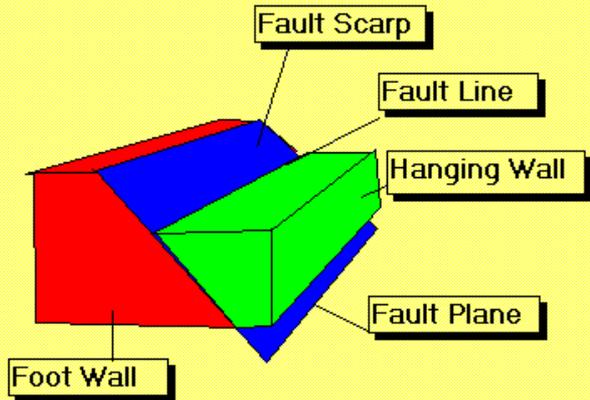


Plunging Folds

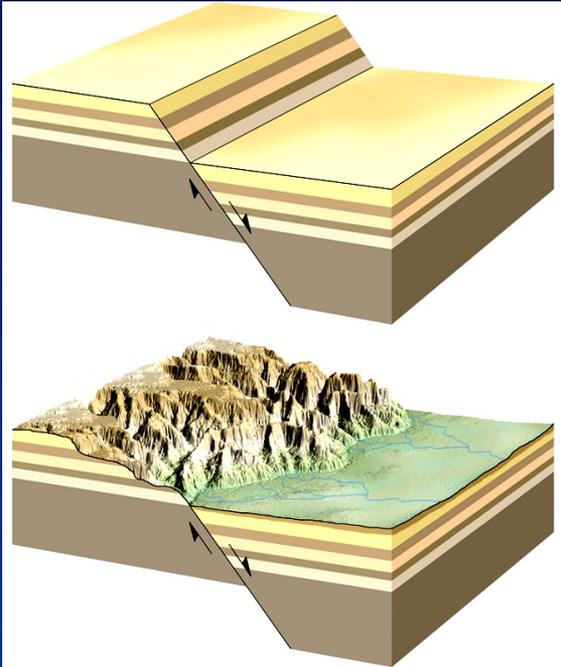


Fault Terminology

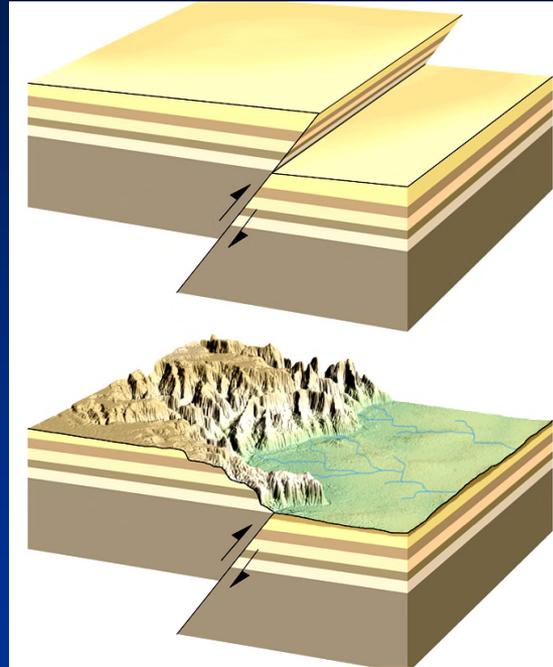
Features of Faults



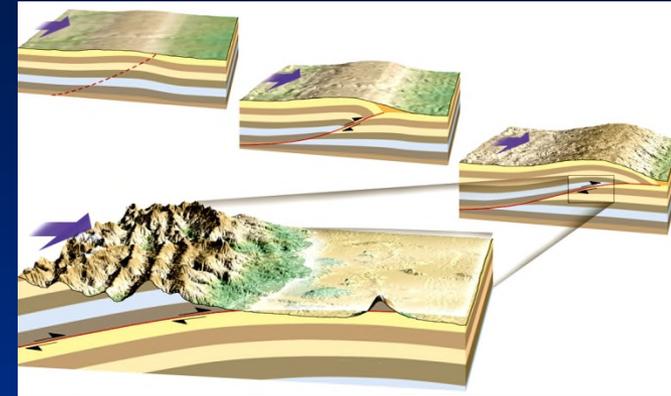
Types of Faults



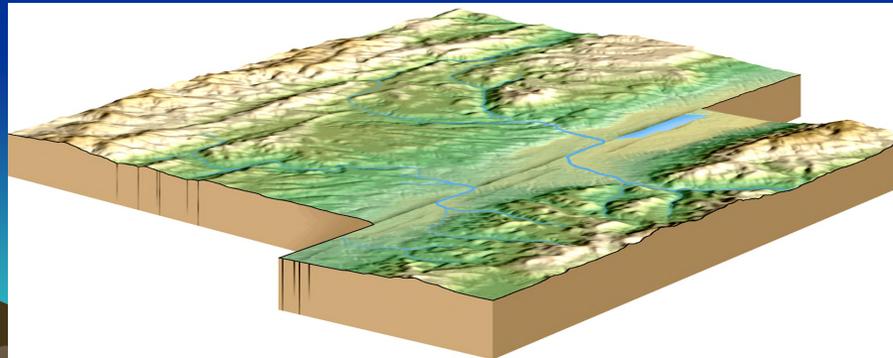
Normal Fault



Reverse Fault

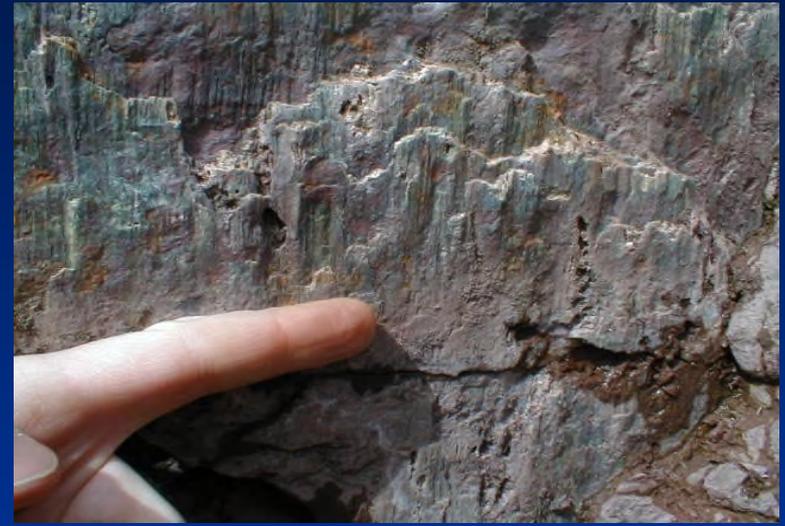
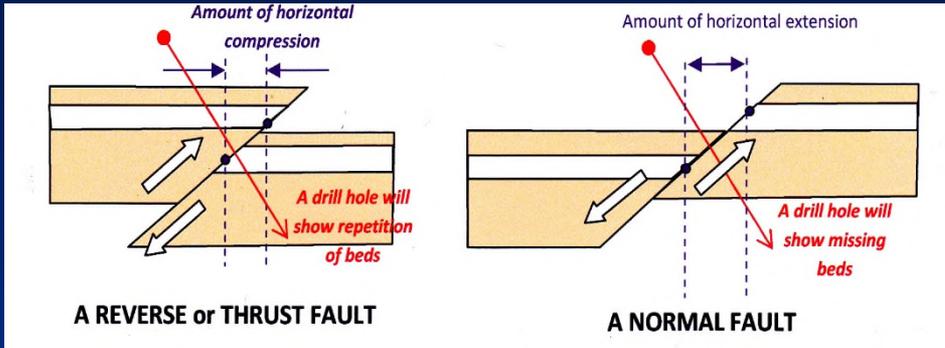


Thrust Fault

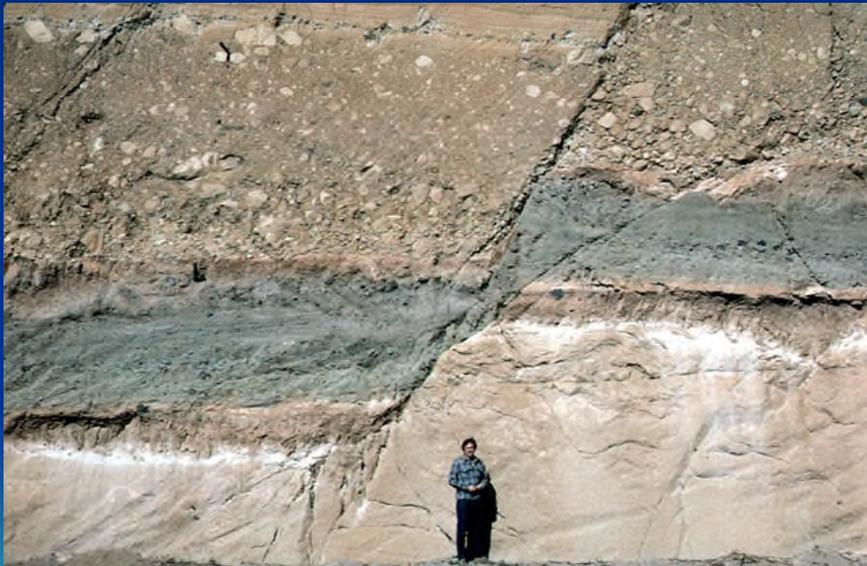


Strike-Slip Fault

Fault Offset and Slickensides



Dip-slip oriented slickensides



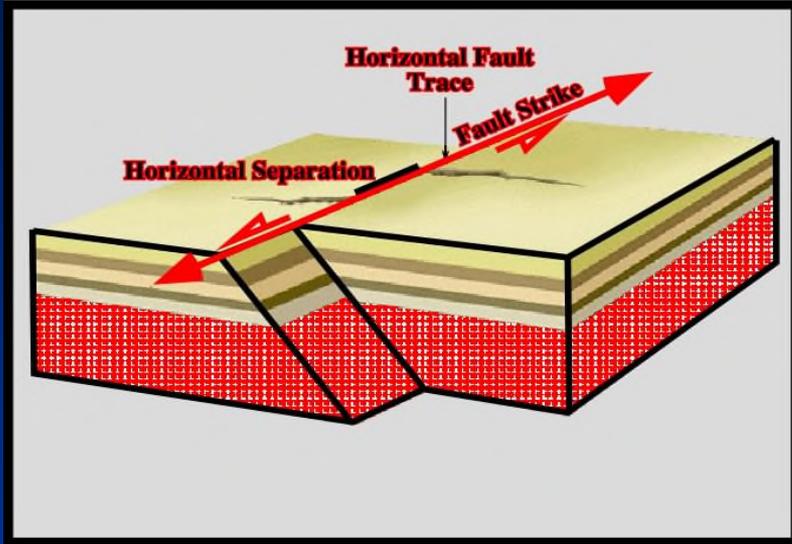
Normal-sense, dip-slip offset



Reverse-sense, dip-slip offset

Fault Slickensides

Strike Slip Movement



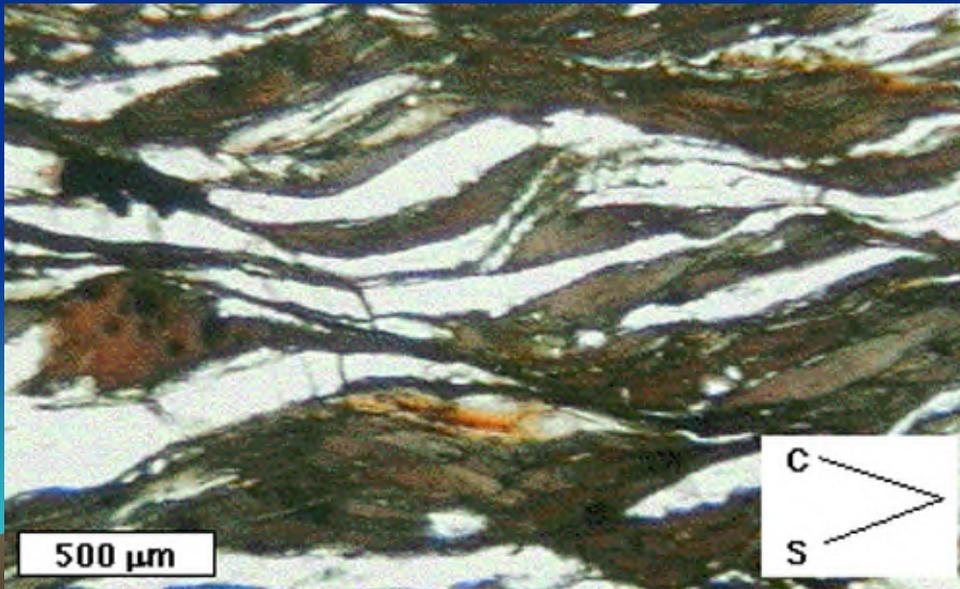
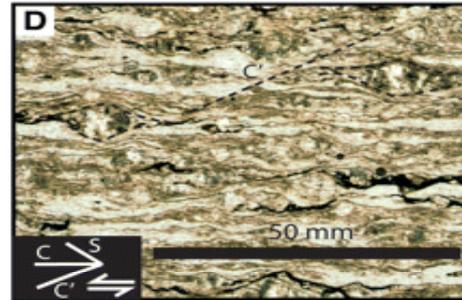
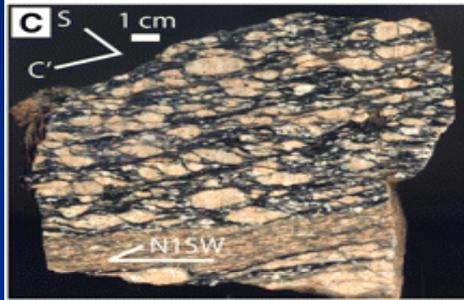
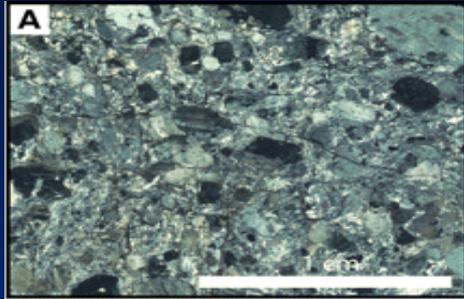
Strike-slip oriented slickensides



Right-lateral, strike-slip offset



Special Fault Rocks



Mylonite

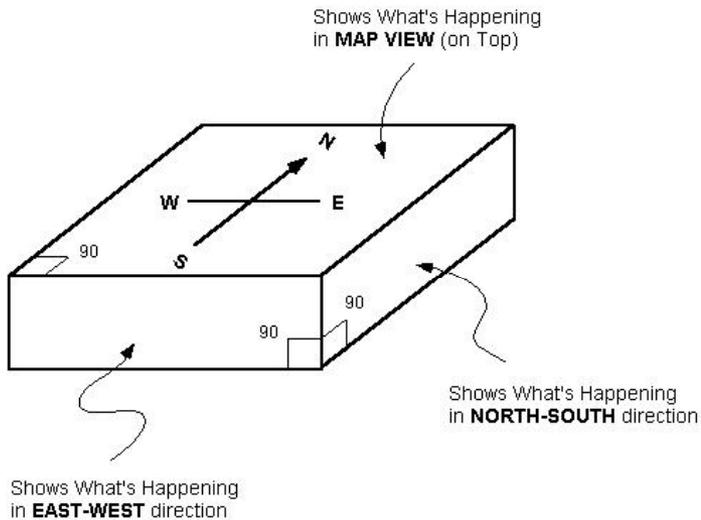
Brittle-ductile shear-like deformation along fault zone resulting in a special kind of foliation termed "S-C fabric".

The Basic Rules of Structure

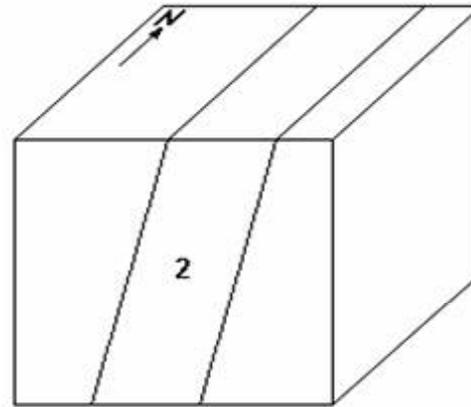
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 - 12) Slickenside grooves oriented horizontal in fault scarp indicate strike-slip offset.
 - 13) Slickenside grooves oriented vertical in fault scarp indicate dip-slip offset.
- 

Working with Block Diagrams

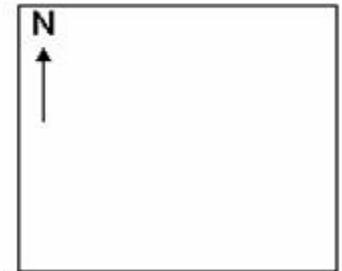
A GUIDE TO BLOCK DIAGRAMS



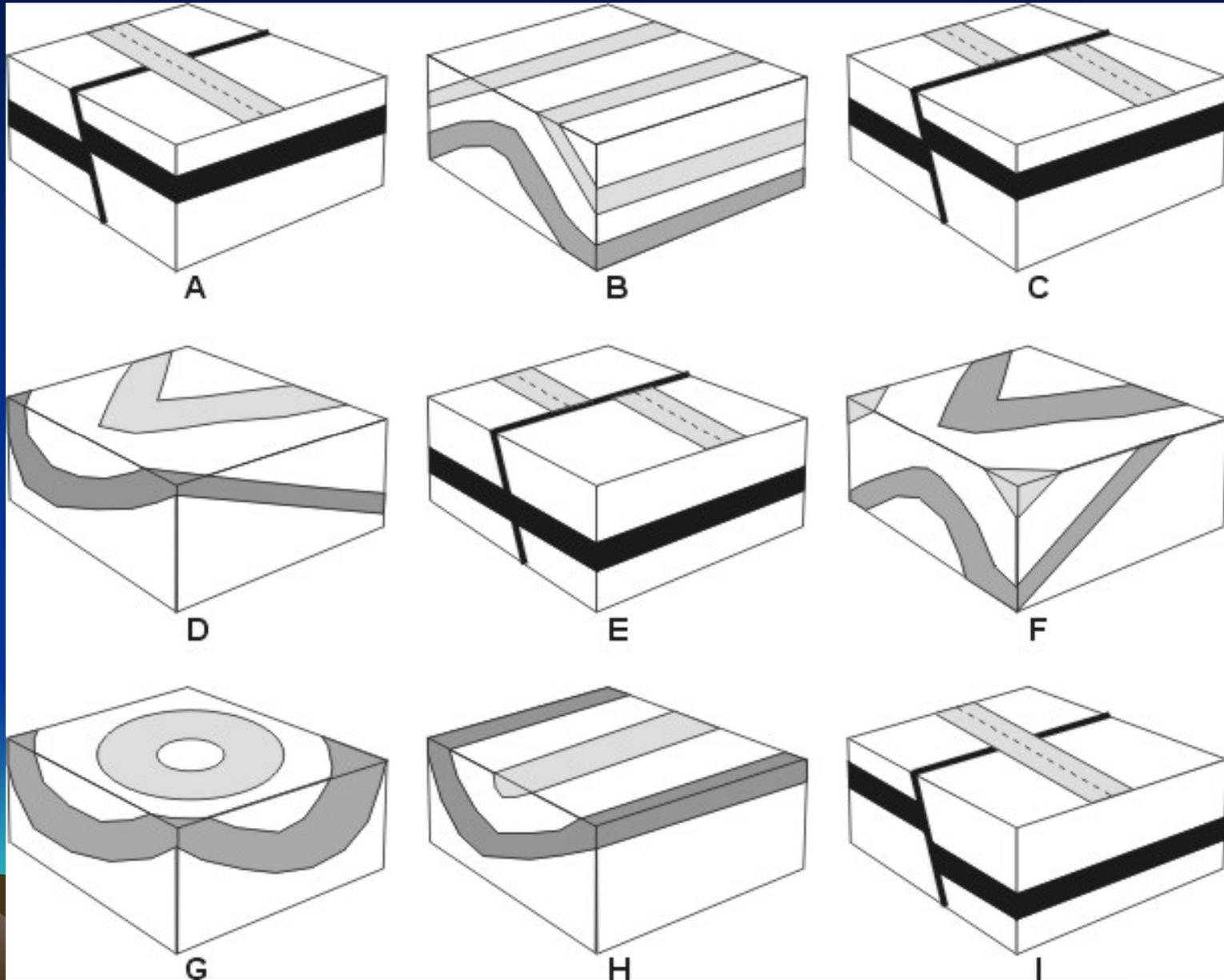
BLOCK DIAGRAM



MAP VIEW



Working with Block Diagrams



Working with Block Diagrams

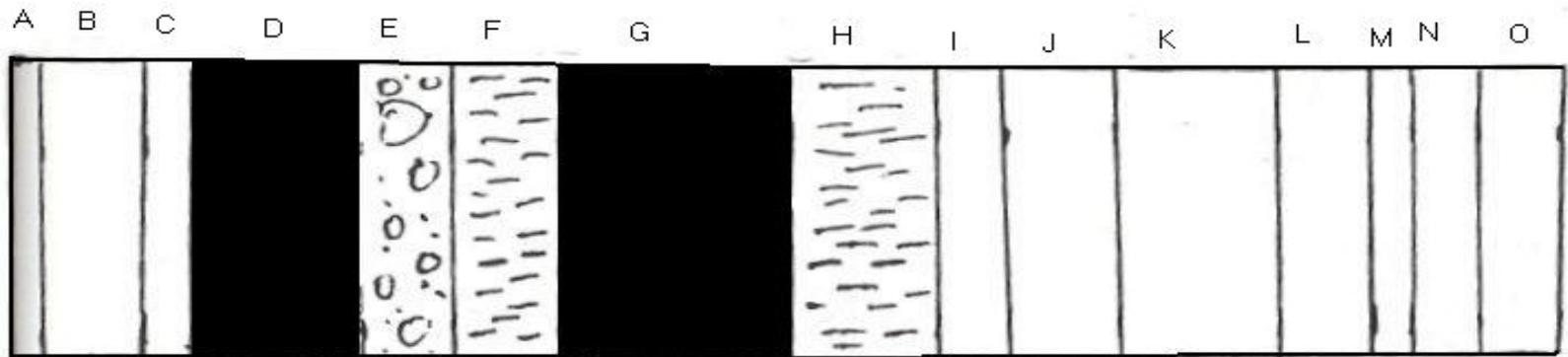
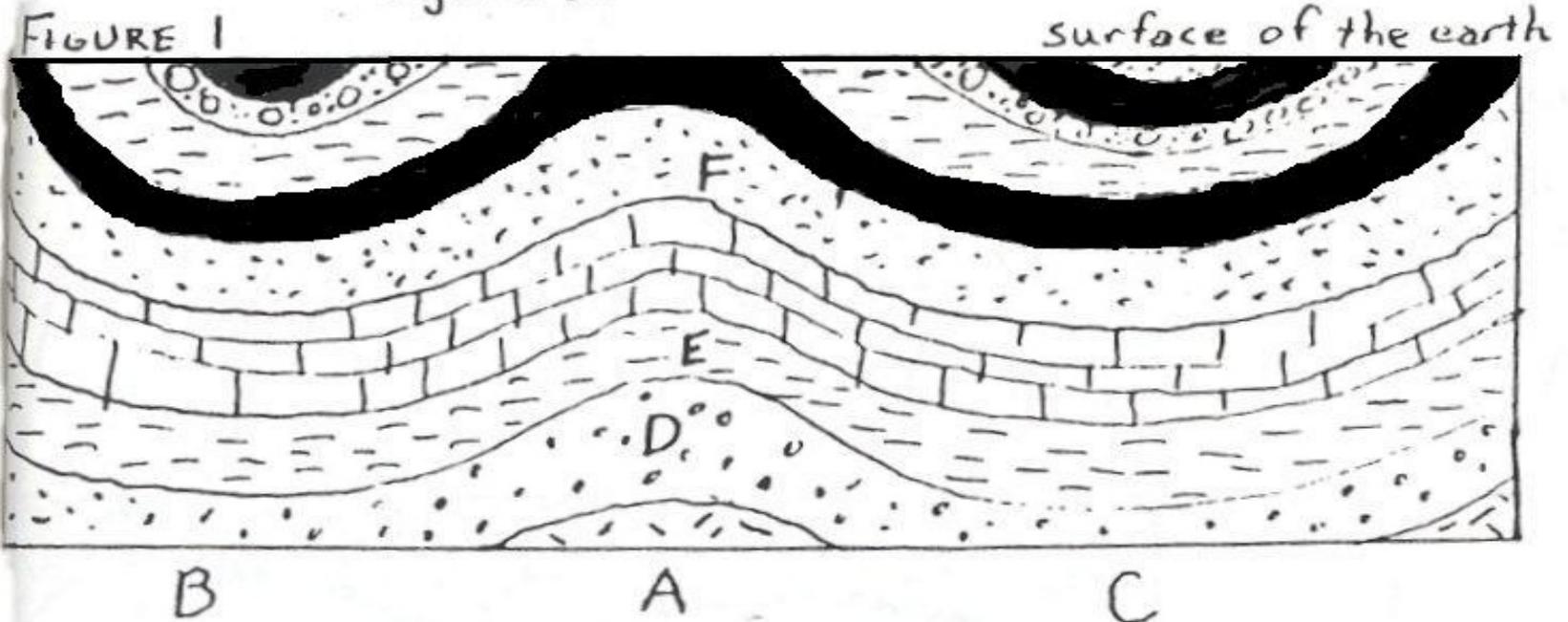
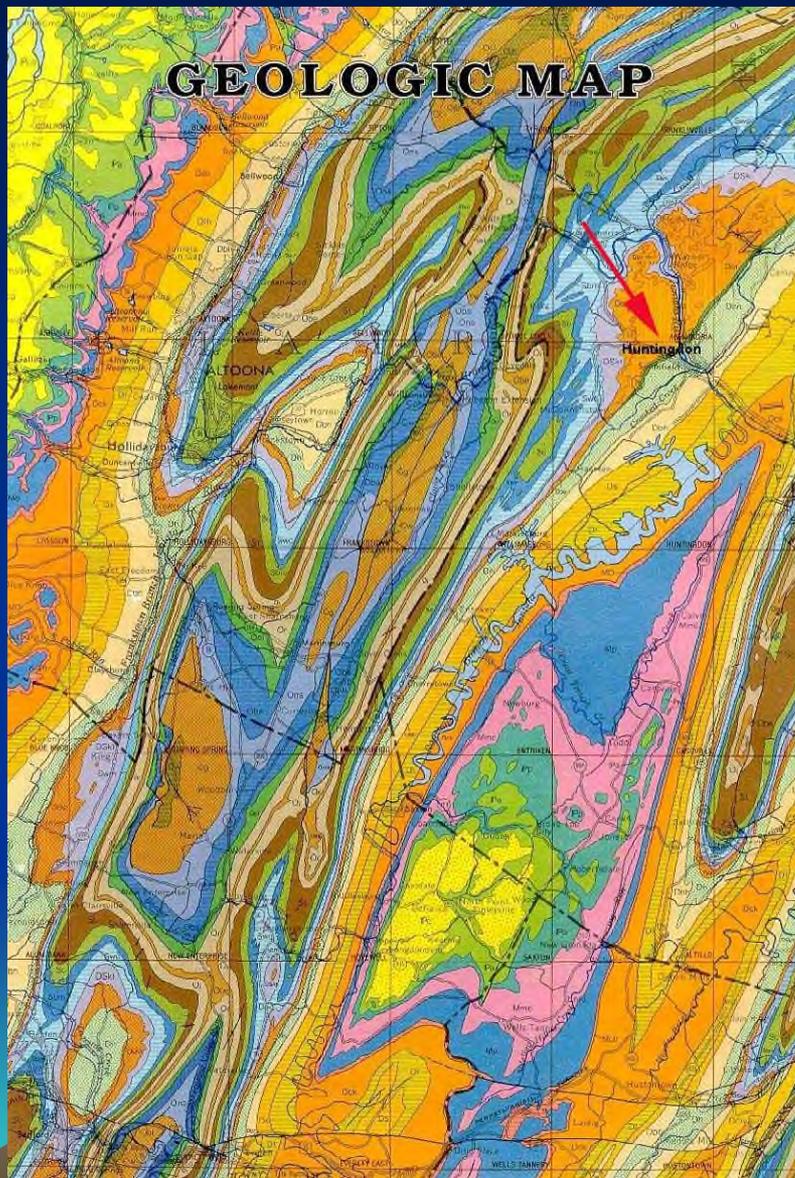


Figure 2



Geologic Maps = Science + Art



Union County Geology

The map below is a scan from the Geologic Map of Pennsylvania (1980) focusing on Union County. The location of Bucknell University is represented by the green circle located along the eastern portion of the map. Descriptions for the rock types have been modified from the original map to more accurately describe the geology of the Union County area (from mapping by Dr. Richard P. Nickelsen, Bucknell University).

EXPLANATION FOR THE ROCK TYPES IN THE LEWISBURG AREA

Dh Hamilton Group

Gray, brown and olive shale, siltstone; marine fossils; char. by coarsening upward cycles. Black carbonaceous shale with Tioga Bentonite at base.

Doo Onondaga and Old Port Formations

Gray calcareous shale; argillaceous limestone; marine fossils. Dark gray chert interbedded with calcareous shale and limestone; very fossiliferous.

Dskt Keyser and Tonoloway Formations

Gray coarse-grained limestone; highly fossiliferous. Gray, fine-grained platy limestone; poorly fossiliferous.

Swc Wills Creek Formation

Greenish gray shale, mudstone and minor limy beds; all rock types limy; unfossiliferous.

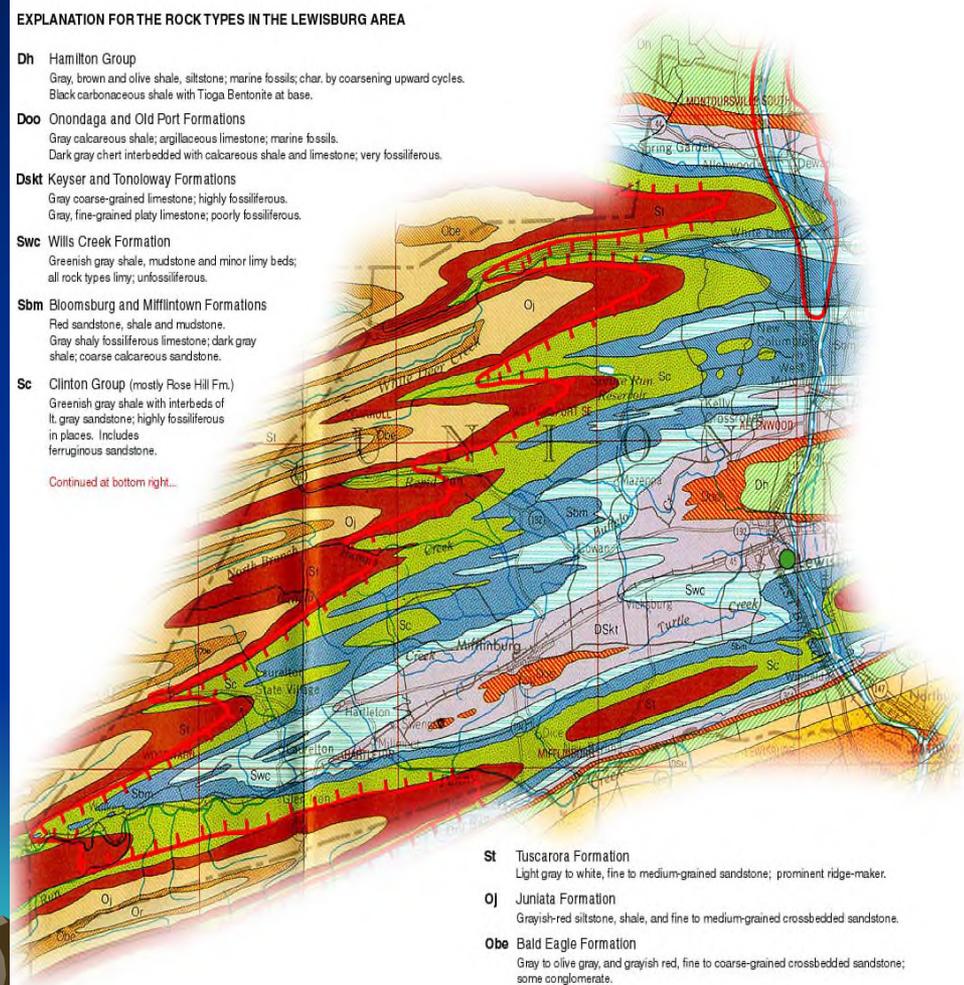
Sbm Bloomsburg and Millintown Formations

Red sandstone, shale and mudstone. Gray shaly fossiliferous limestone; dark gray shale; coarse calcareous sandstone.

Sc Clinton Group (mostly Rose Hill Fm.)

Greenish gray shale with interbeds of light gray sandstone; highly fossiliferous in places. Includes ferruginous sandstone.

Continued at bottom right...



St Tuscarora Formation

Light gray to white, fine to medium-grained sandstone; prominent ridge-maker.

Oj Juniata Formation

Grayish-red siltstone, shale, and fine to medium-grained crossbedded sandstone.

Obe Bald Eagle Formation

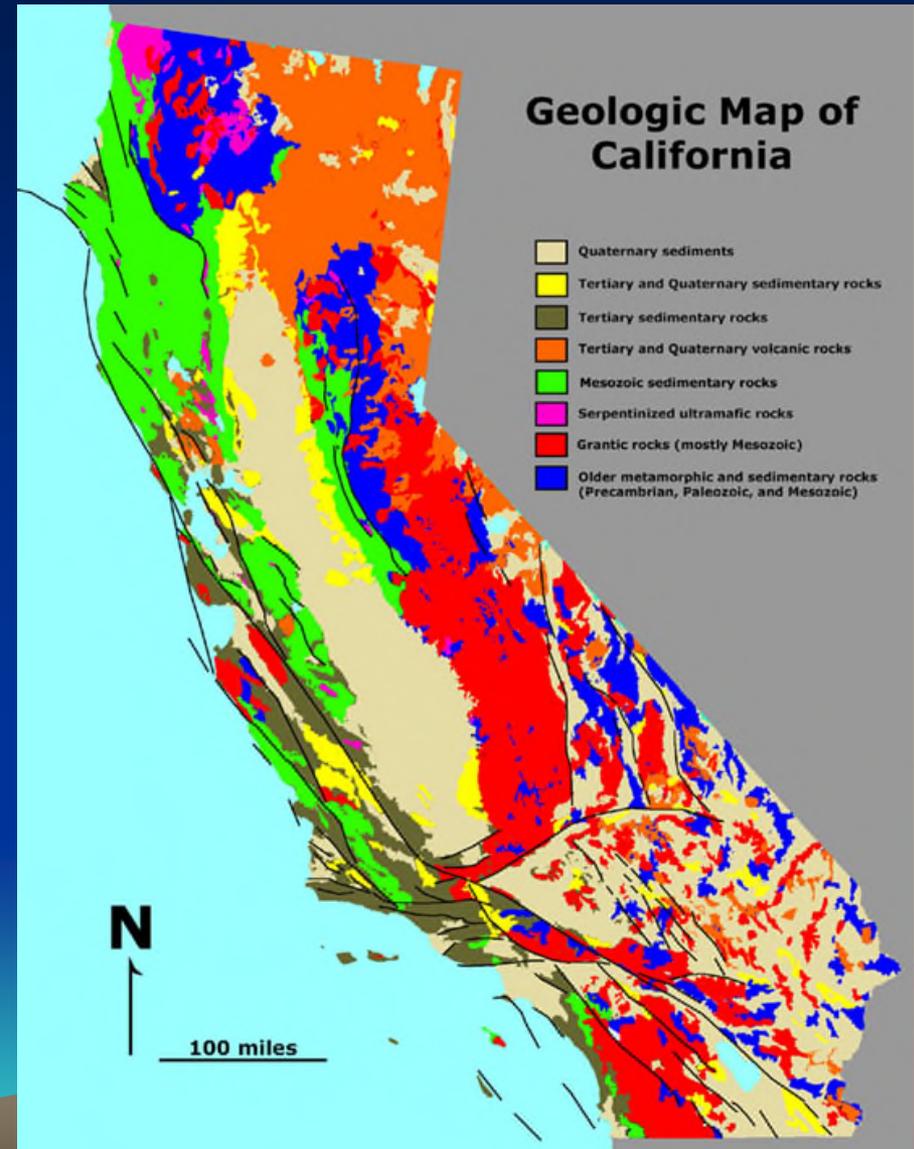
Gray to olive gray, and grayish red, fine to coarse-grained crossbedded sandstone; some conglomerate.

Usefulness of Geology Maps

1) Geology maps have many vital uses:

- ✓ Mineral Prospecting
- ✓ Engineering
- ✓ Earthquakes
- ✓ Historical geology
- ✓ Landform studies
- ✓ Soil development
- ✓ Biological studies

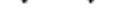
2) Geology maps are even useful when buying a home. Why?



Geology Map Key or Legend

1) The map key lists and explains the geologic rock formations and the structural symbols

- ✓ Rock Names
- ✓ Rock Types
- ✓ Rock Ages
- ✓ Contacts
- ✓ Strike and Dip
- ✓ Faults and Folds

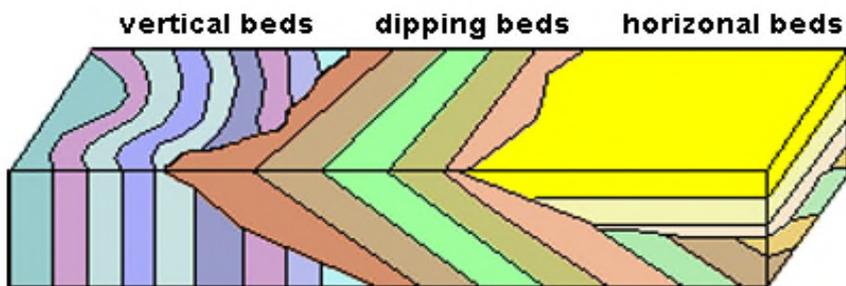
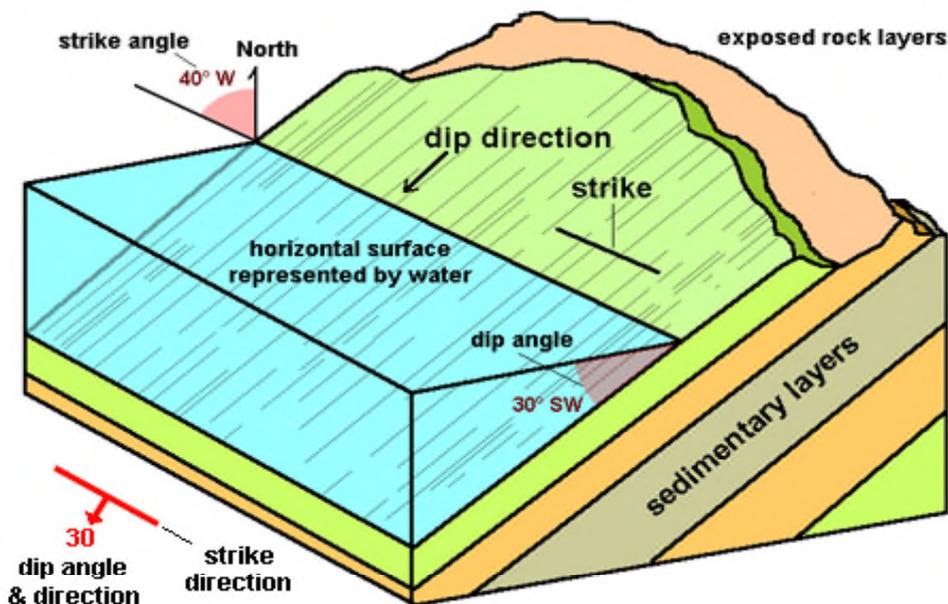
MAP KEY			
	af - Artificial Fill (Historic)		Contact
	all - Artificial Levee Fill (Historic)		Contact, approximately located
	Qhaf - Alluvial Fan Deposits (Holocene)		Contact, inferred
	Qhfp - Floodplain Deposits (Holocene)		Contact, concealed
	Qhfb - Flood Basin Deposits (Holocene)		Fault
	Qhbs - Salt Affected Flood Basin Deposits (Holocene)		Fault, approximately located
	Qhl - Natural Levee Deposits (Holocene)		Fault, inferred
	Qpaf - Alluvial Fan Deposits (Pleistocene)		Fault, uncertain
	Qpof - Older Alluvial Fan Deposits (Pleistocene)		Fault, concealed
	Tv - Unnamed volcanic rocks (Miocene)		Fault, concealed and uncertain
	Tor - Ojinda conglomerate (Miocene)		Oblique fault with thrust or reverse component
	Tbr - Briones sandstone (Miocene)		Oblique fault with thrust or reverse component, approximately located
	Tt - Tice shale (Miocene)		Oblique fault with thrust or reverse component, inferred
	Tcs - Claremont shale (Miocene)		Oblique fault with thrust or reverse component, uncertain
	Ts - Soberante sandstone (Miocene)		Strike and dip of bedding
	Tsh - Unnamed shale and sandstone (Miocene)		Strike and dip of overturned bedding
			Strike and dip of vertical bedding

2) Each rock unit has a unique letter symbol and is color-coded

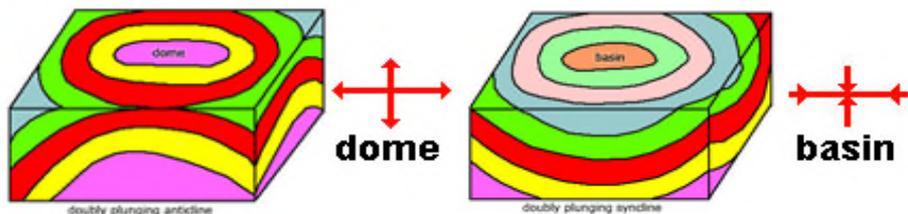
3) Map key is vital to understanding the accompanying geology map

Common Geologic Map Symbols

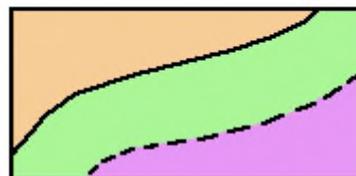
Describing orientation of geologic features with strike and dip



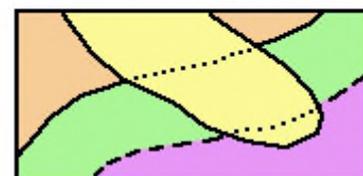
beds inclined straight up
 strata inclined at an angle
 flat-lying strata



Rock Unit Boundaries - contacts between rock units of different age and/or different composition

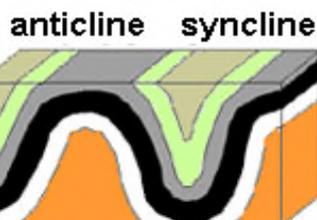


——— contact certain
 - - - - - contact inferred



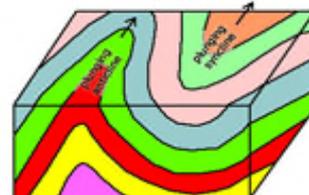
..... contacts inferred beneath sedimentary cover

FOLDS



anticline
 syncline

plunging folds



plunging anticline
 plunging syncline

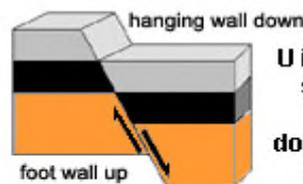
monocline



arrow points in fold dip direction

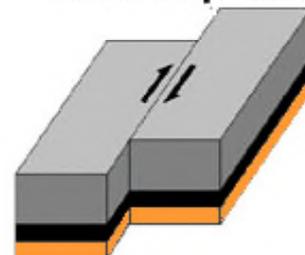
FAULTS

normal fault



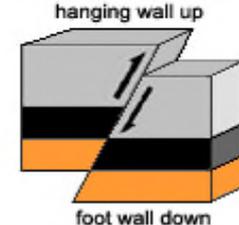
U is on the uplifted side (foot wall)
 D is on the down-dropped side (hanging wall)

strike-slip fault



half arrows show direction of fault motion

reverse fault



triangles on upper plate (hanging wall)

thrust fault



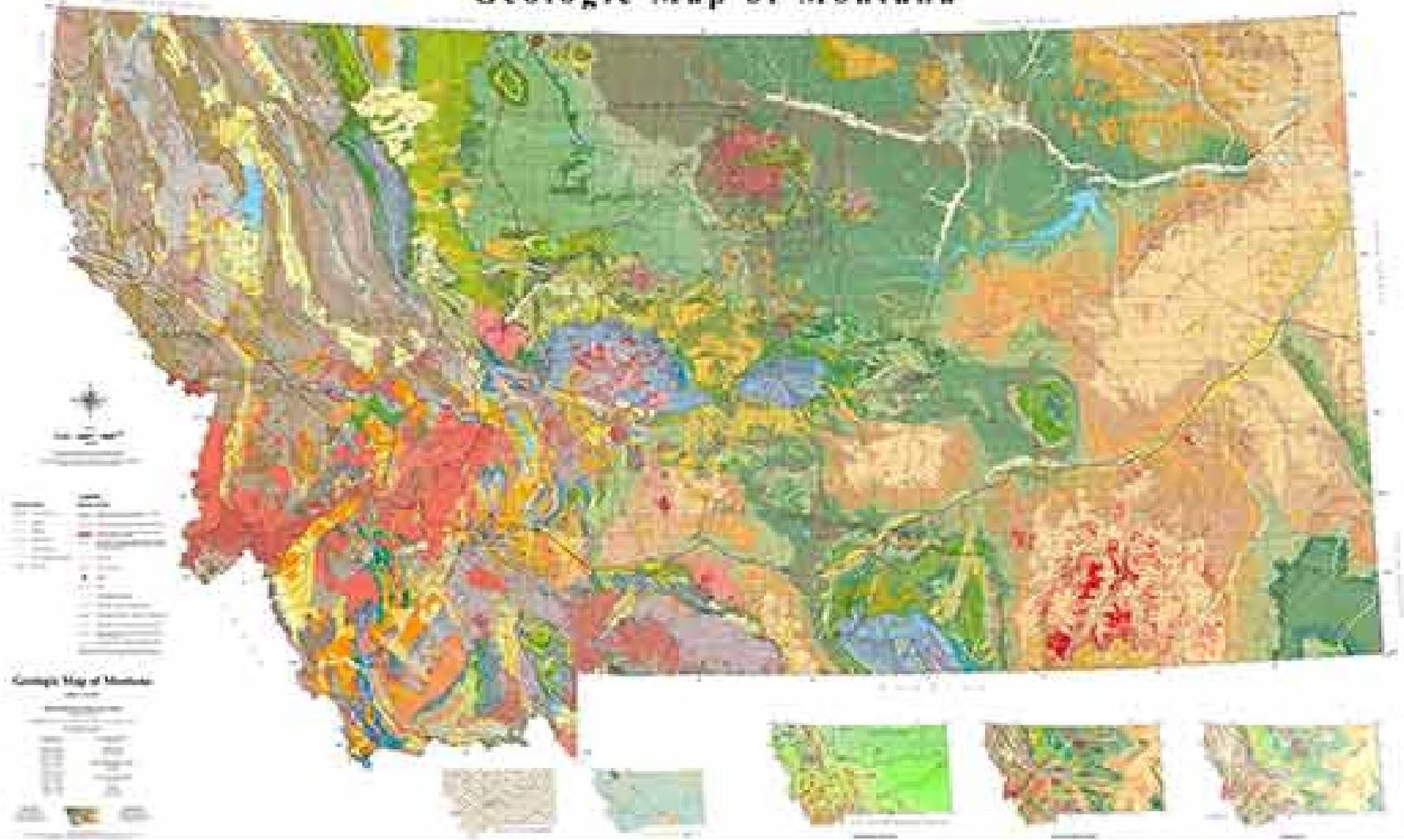
triangles on upper plate

The Basic Rules of Structure

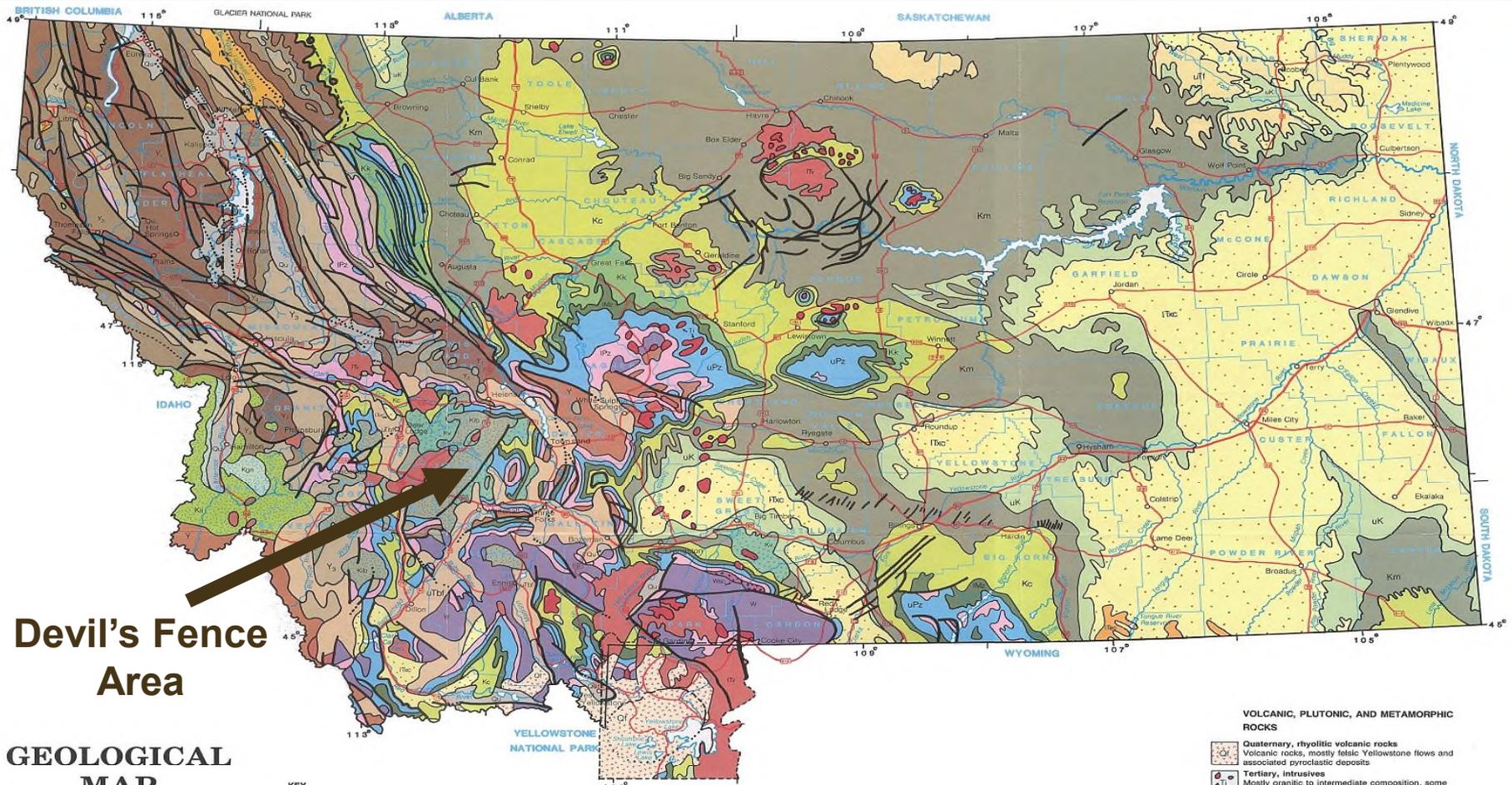
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- 

Geologic Map of Montana

Geologic Map of Montana

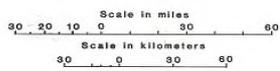


Geologic Map of Montana



Devil's Fence Area

GEOLOGICAL MAP of MONTANA and Yellowstone National Park



KEY

- Fault, sense of motion not indicated
- Contact

CONTINENTAL AND MARINE DEPOSITS

- Quaternary, extensive
Stream, glacial, and lake deposits
- Tertiary, Flaxville gravel
Gravel and sand with some silt, volcanic ash, and marl
- Tertiary, basin fill
Oligocene through Pliocene basin fill composed of a heterogeneous mixture of gravel, sand, silt, and clay deposited by streams and in lakes
- Eocene, continental deposits
Includes fine to coarse-grained clastic rocks
- Paleocene, continental deposits
Including stream-deposited sediments of coal-bearing Fort Union Fm. in the east, Willow Creek Fm. in the north central, and Beaverhead conglomerate in the southwest

- Upper Cretaceous, undifferentiated
Hell Creek sandstone and shale, St. Mary River mudstone, and volcaniclastic Livingston Gp. in south-central Montana
- Montana Group
Bearpaw shale, Judith River sandstone, siltstone, and shale, Cleggell shale, Eagle sandstone, and Telegraph Creek sandy shale. Includes Fox Hills sandstone and Pierre shale in the extreme east
- Colorado Group
Includes mainly shale of the Niobrara, Belle Fourche, Mowry, and Thermopsis Formations
- Kootenai Formation
Conglomerate, sandstone, shale, and mudstone
- Lower Mesozoic
Includes calcareous fossiliferous sandstone, shale, and limestone of the Ellis Group in the central and south central, and the Dinwoody and Thynnes Formations in the southwest as well as the Morrison shale, sandstone, and marl in the west

- Mississippian, Pennsylvanian, Permian
Includes Madison limestone, Big Snowy dolomite and limestone, and Quadrant sandstone
- Devonian and Cambrian
Consists of Three Forks shale, Jefferson limestone, Pilgrim and Meagher limestone, Park and Wolsky shale, and Flathead sandstone
- Upper Belt-Massoula and Plegan Groups
Chiefly red, maroon, and purple argillites and impure quartzite and limestone
- Middle Belt-Wallace, Sityeh, Helena Fms.
Heterogeneous Wallace Fm. including argillite, limestone, sandstone, shale, and quartzite; Sityeh and Helena limestones
- Lower Belt-Ravalli and Prichard Fms.
Ravalli Fm. includes siliceous and sandy quartzite, argillite, and shale; Prichard Fm. consists of banded shale with interbedded sandstone
- Undivided Belt Supergroup

VOLCANIC, PLUTONIC, AND METAMORPHIC ROCKS

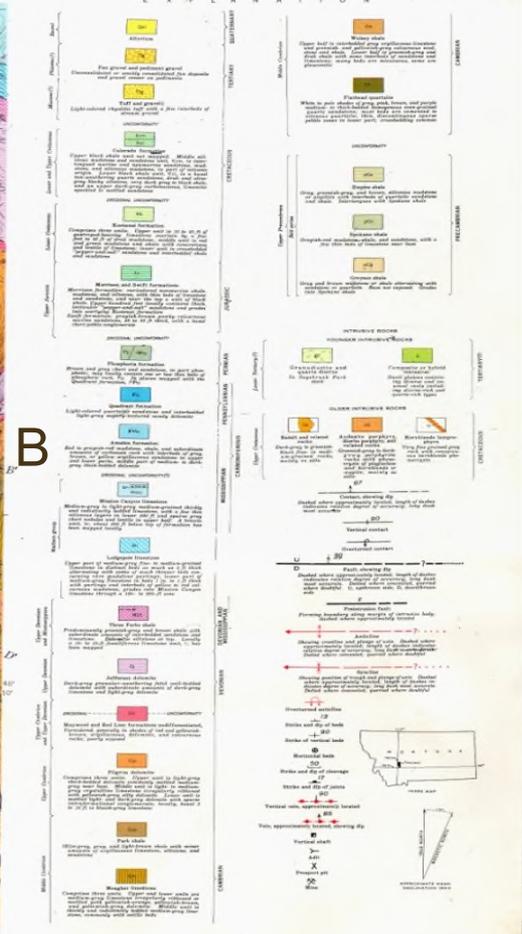
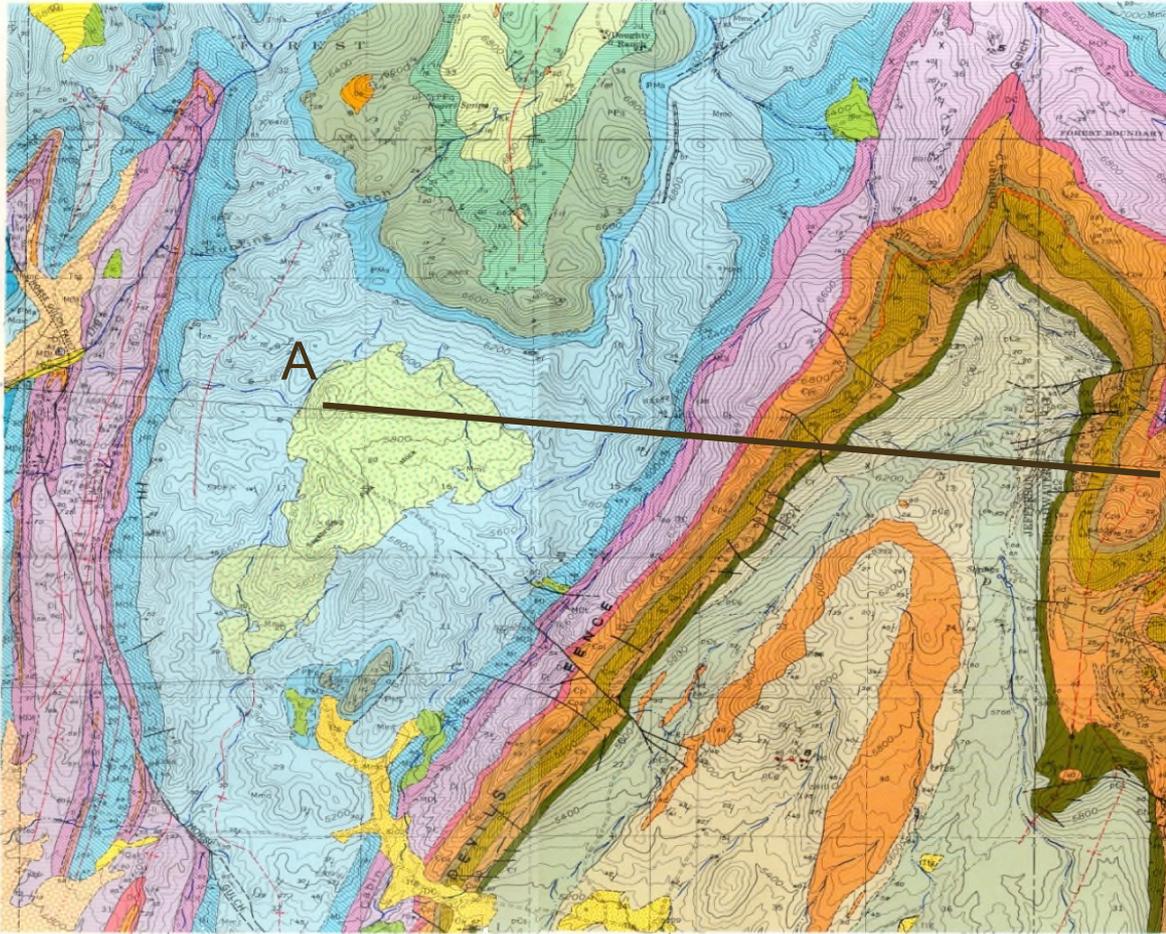
- Quaternary, rhyolitic volcanic rocks
Volcanic rocks, mostly felsic Yellowstone flows and associated pyroclastic deposits
- Tertiary, intrusives
Mostly granitic to intermediate composition, some alkaline especially in north-central Montana
- Lower Tertiary, volcanic rocks
Flows and associated pyroclastic deposits: latite, andesite, with some rhyolite and basalt and associated intrusive dikes and necks
- Younger Cretaceous, granitic rocks
Boulder Batholith and related rocks; predominantly quartz monzonite
- Cretaceous, volcanic rocks
Mafic to intermediate composition lava flows, ash flows, and other pyroclastic rocks with interbedded sedimentary rocks including Eikhorn Mountains volcanic rocks
- Older Cretaceous, volcanic rocks
Idaho Batholith and associated masses; monzonite and granodiorite
- Border Zone of Idaho Batholith
Metasedimentary rocks of Belt age intruded by granitic rocks
- Stillwater Complex
Layered mafic-ultramafic intrusive complex, includes anorthosite; associated with hornfels aureole
- Archean, undifferentiated
High-grade metamorphic rocks derived from igneous and sedimentary parent rocks. Lithologies include quartz-feldspathic gneiss, granulite, amphibolite, quartzite, and marble

Geologic Maps – Devil's Fence Quad

From: U.S.G.S. PROFESSIONAL PAPER 292 PLATE 2

GEOLOGIC MAP OF DEVIL'S FENCE QUADRANGLE, MONT.

MAP NO 5

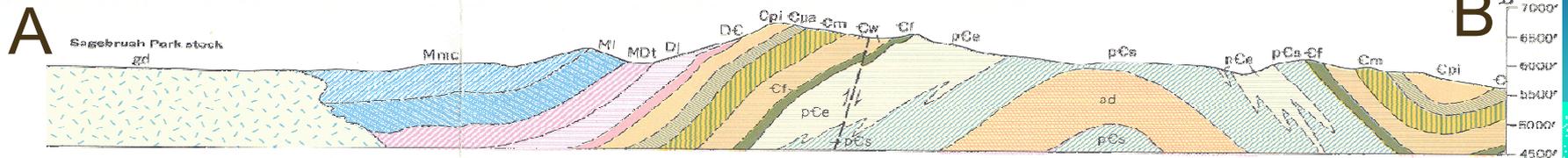


Geology by M. R. Klapper,
R. A. Weeks and C. T. Ruppel

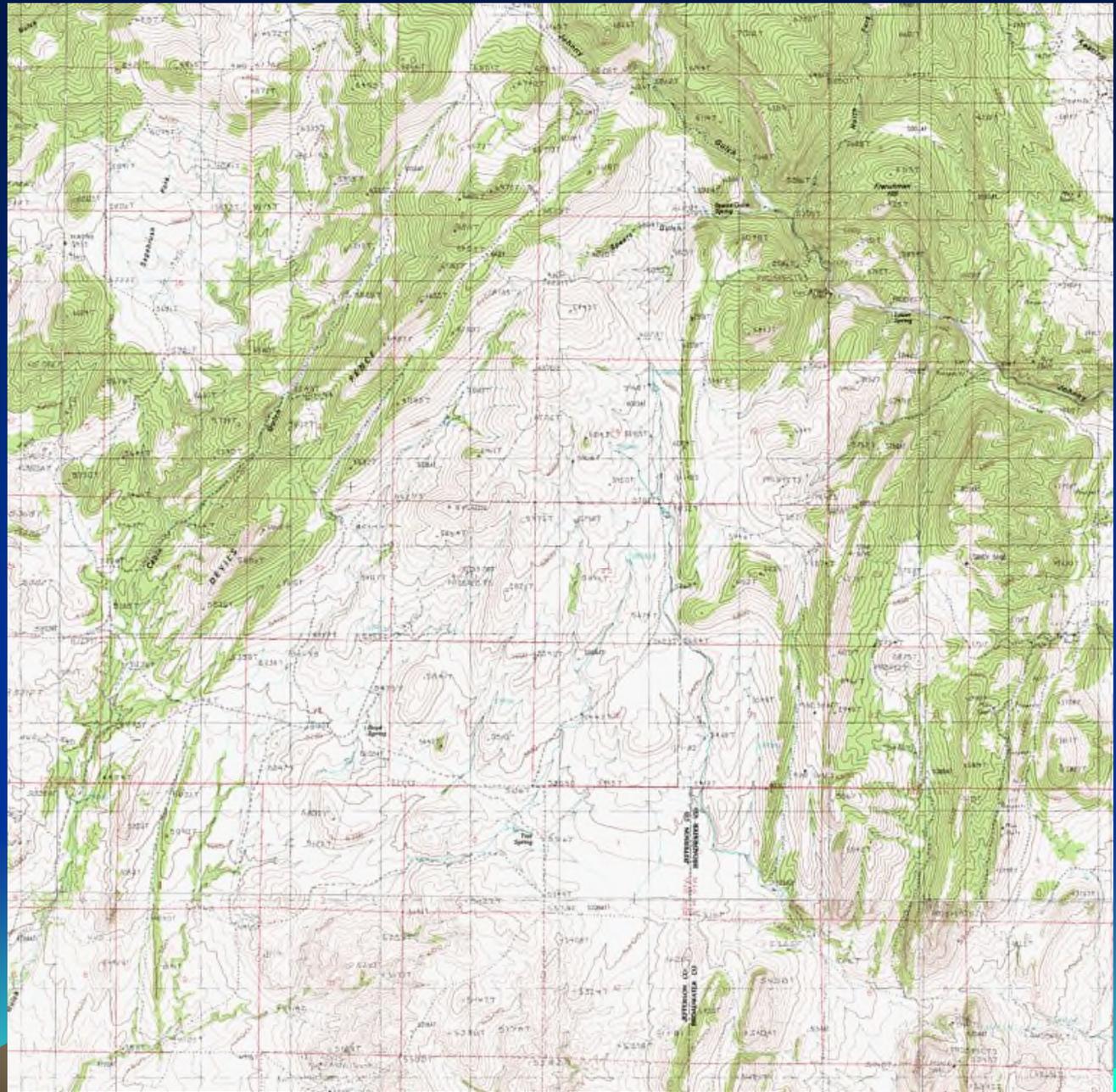
Scale 1:50,000

2 Miles Contour Interval 40 feet Datum is mean sea level

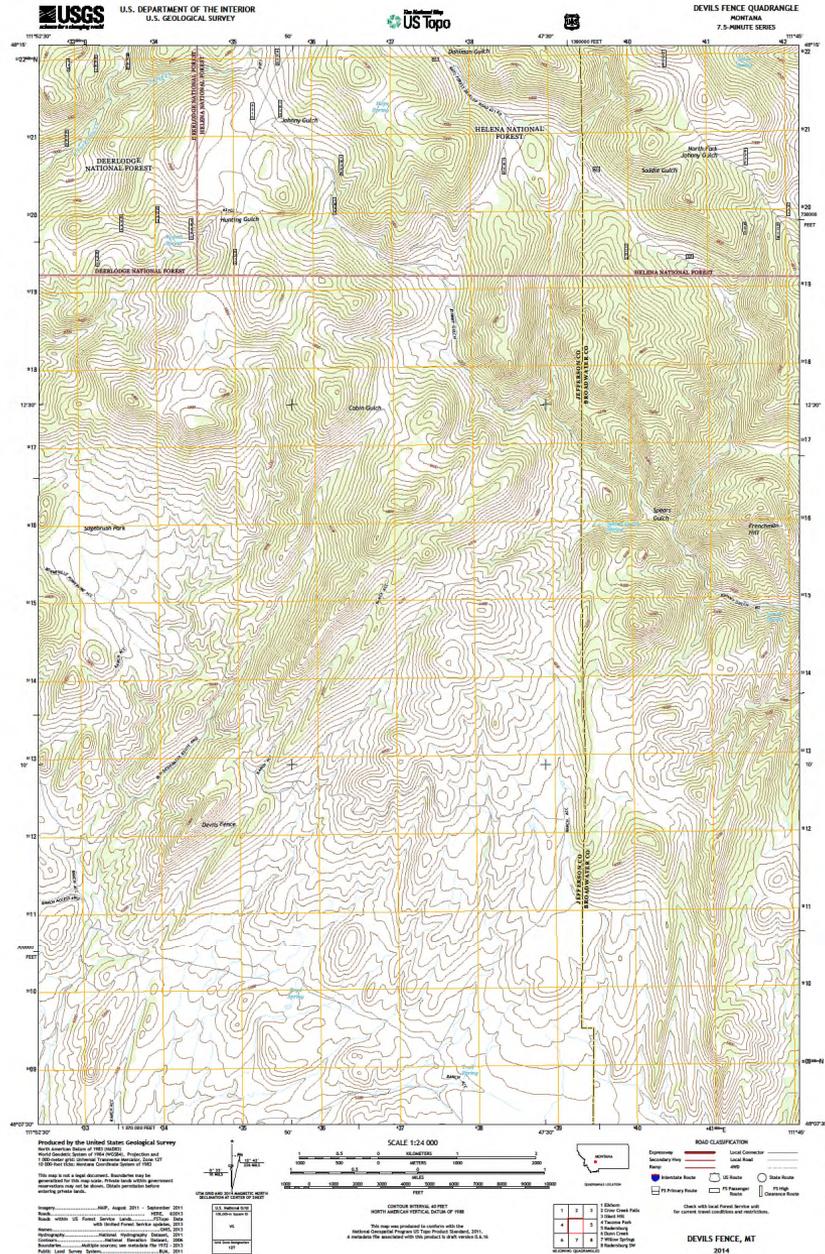
Base from U. S. Geological Survey from map of Devil's Fence quadrangle, Montana.



Devil's Fence Topo Quad



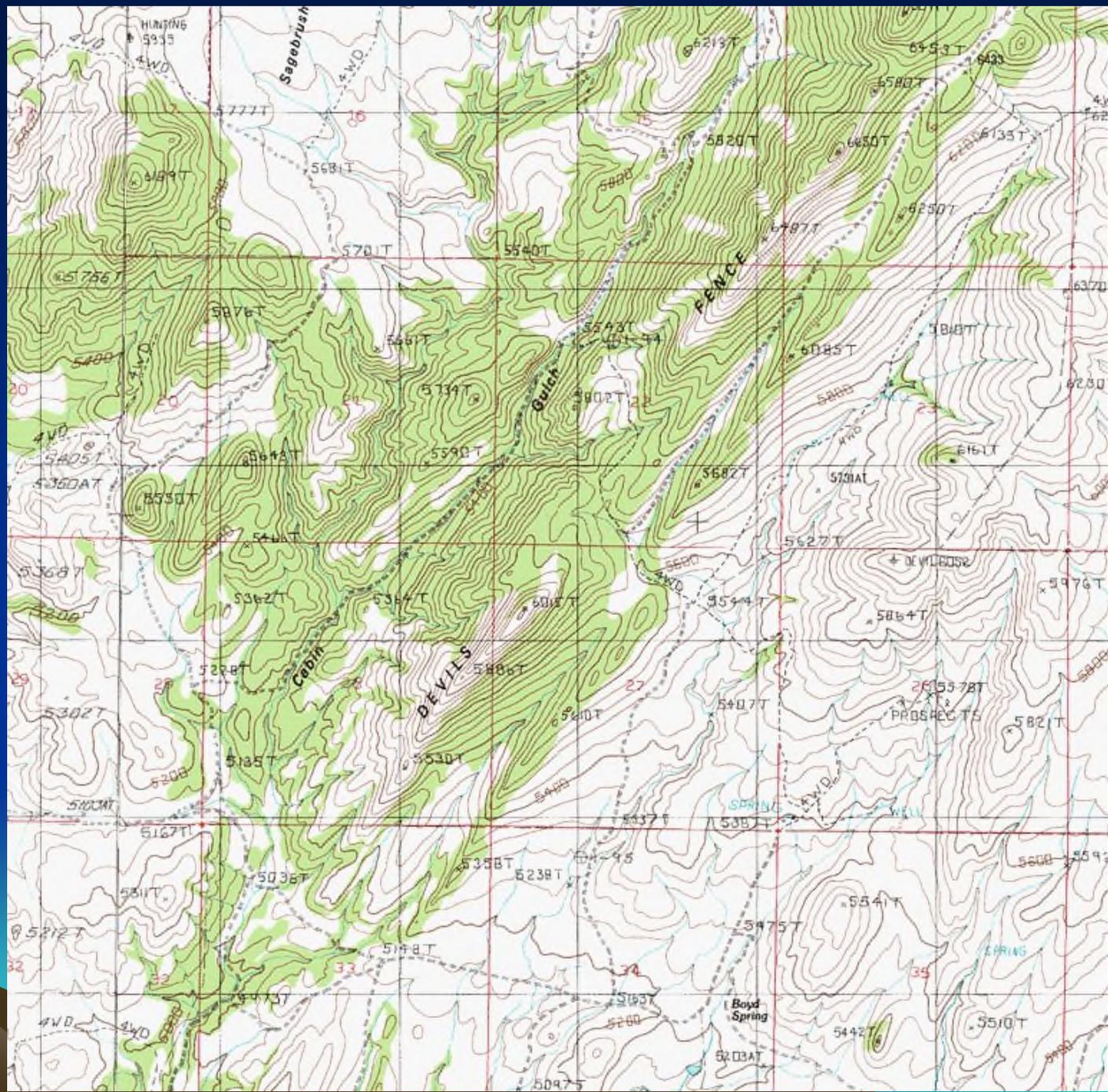
Topo Map of Devils Fence Quad, MT



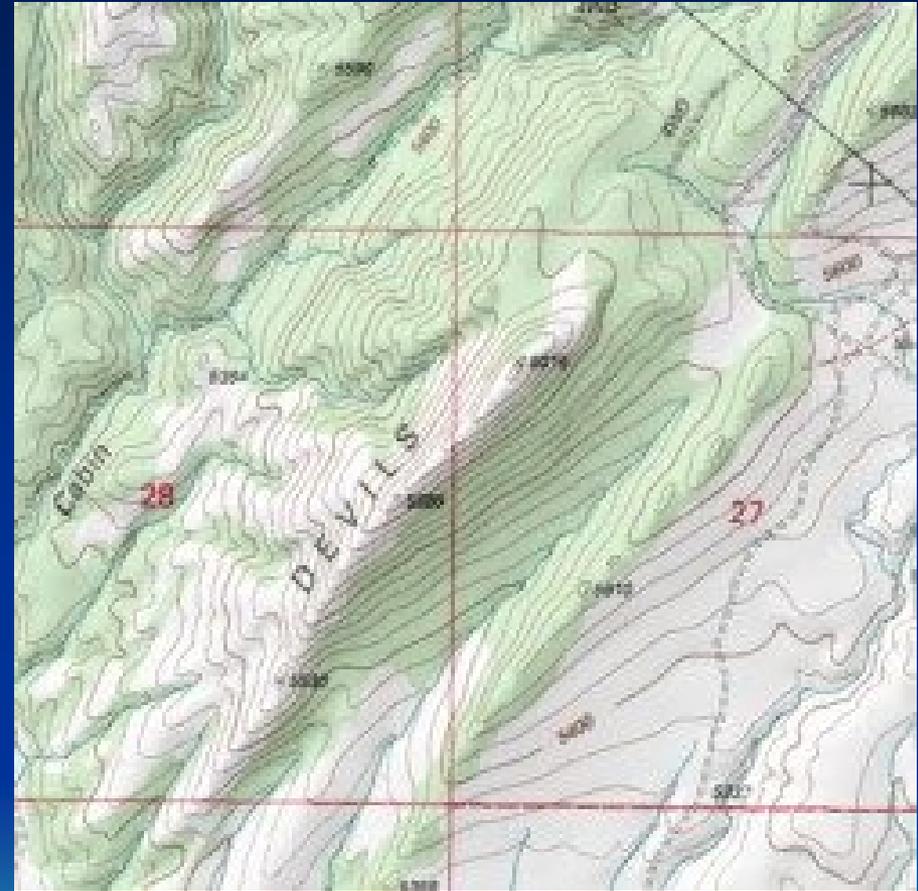
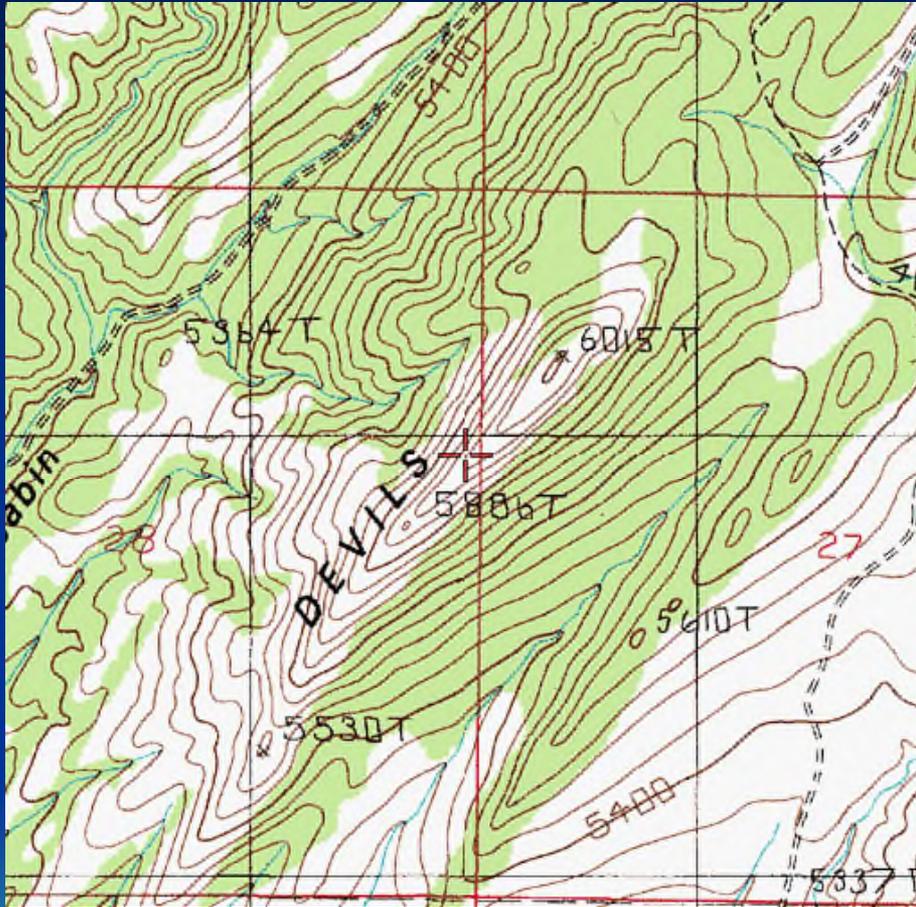
Devil's Fence Topographic Feature



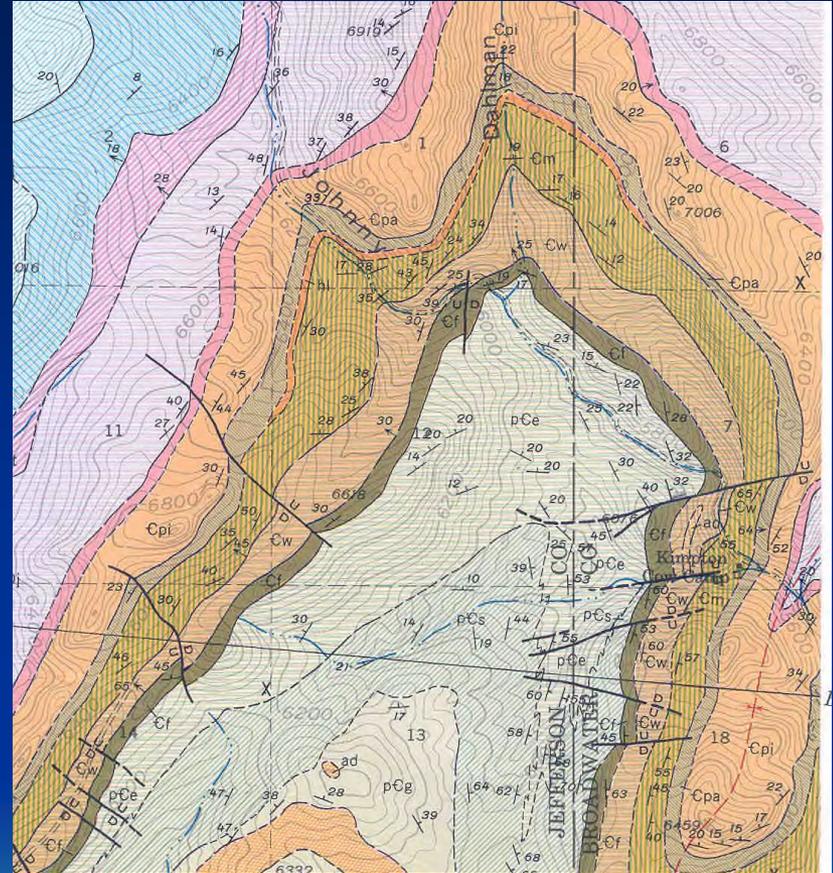
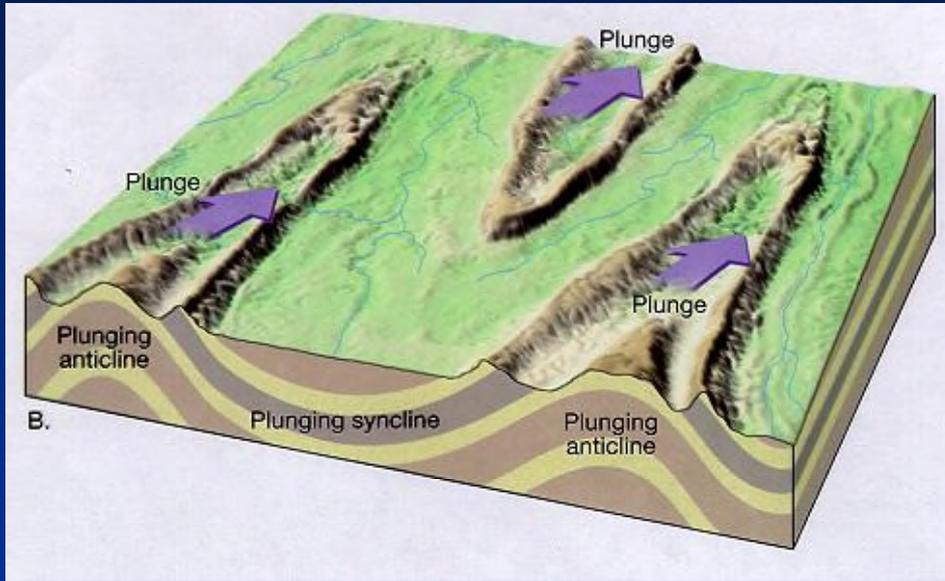
Devil's "Fence" Topo Feature



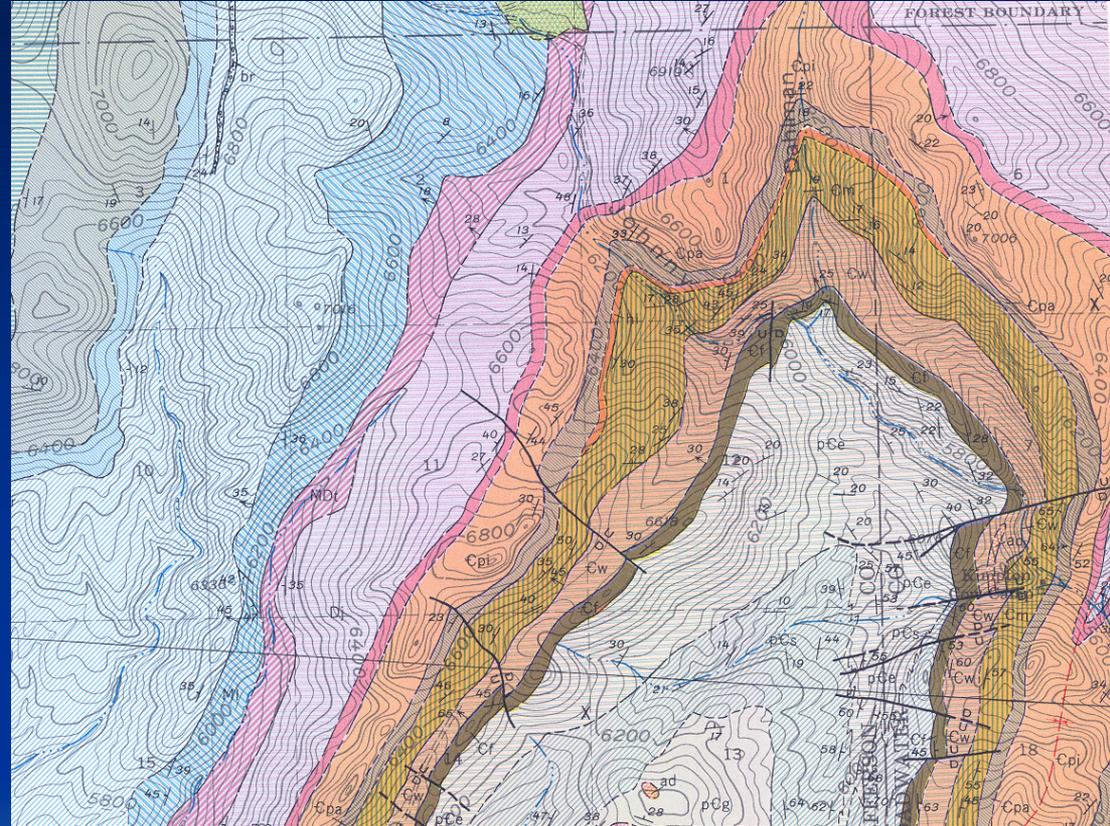
Devil's Fence Topography



Devil's Fence Folds



Devil's Fence Geology Map with Explanation



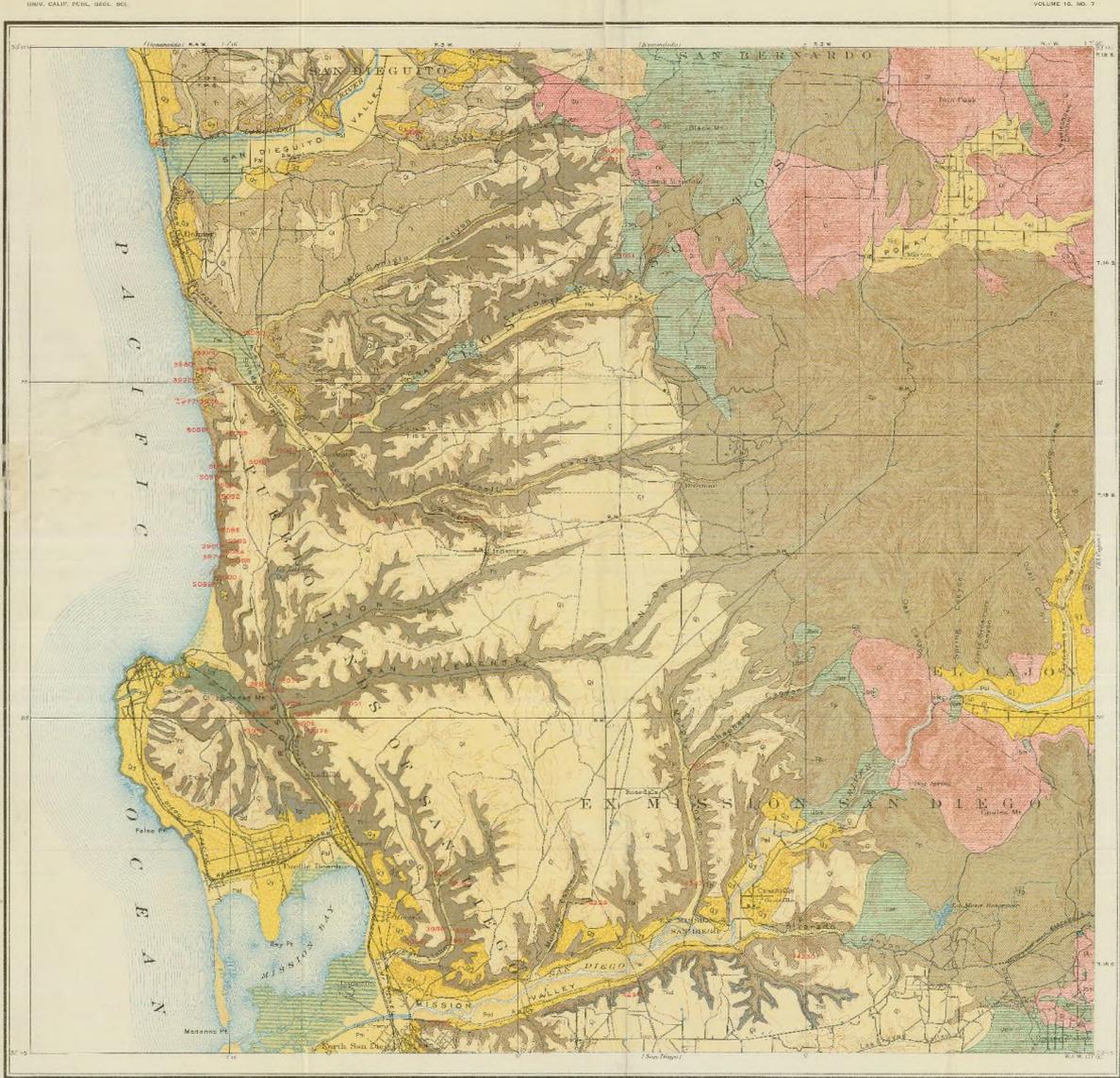
Geological Group	Formation	Symbol	Description
Upper Devonian and Marfatian	Jefferson dolomite	Dj	Dark-gray granular-weathering fetid well-bedded dolomite with subordinate amounts of dark-gray limestone and light-gray dolomite
	Three Forks shale	Fk	Predominantly greenish-gray and brown shale with subordinate amounts of interbedded sandstone and limestone. Dolomitic siltstone at top. Locally a 10- to 25-ft fossiliferous limestone unit, it has been mapped
Lower Devonian	Lodgepole limestone	Lp	Upper part of medium-gray fine- to medium-grained limestone in distinct beds as much as 2 ft thick alternating with zones of much thinner beds containing rare mudstone part; lower part of medium-gray limestone in beds 1 in. to 1 ft thick with partings and interbeds of yellow to red calcareous mudstone; grades into Mission Canyon limestone through a 150- to 200-ft zone
	Mission Canyon limestone	Mpc	Medium-gray to light-gray medium-grained thickly and indistinctly bedded limestone, with a few thin siliceous layers in lower 200 ft and sparse gray chert nodules and lentils in upper half. A breccia unit, br, about 200 ft below top of formation has been mapped locally
Carboniferous	Amsden formation	Am	Red to grayish-brown sandstone, shale, and subordinate amounts of carbonaceous rock with interbeds of gray, brown, or yellow argillaceous sandstone in upper and lower parts; middle part of medium- to dark-gray thick-bedded dolomite
	Quadrant formation	Pq	Light-colored quartzitic sandstone and interbedded light-gray argillaceous sandy dolomite
Pennsylvanian	Phosphoria formation	Pp	Brown and gray chert and sandstone, in part phosphatic, may locally contain one or two thin beds of limestone shale. Upper hundred feet locally contains thick, into pebbly Kootenai formation
	Morrison and Swift formations	M	Morrison formation, varicolored nonmarine shale, mudstone, and siltstone, with thin beds of limestone and sandstone, and near the top a unit of black lenticular "pepper-and-salt" sandstone and grades into pebbly Kootenai formation. Swift formation, grayish-brown punky calcareous marine sandstone, 20 to 25 ft thick, with a basal chert-pebble conglomerate
Jurassic	Kootenai formation	Kk	Comprises three units. Upper unit is 10 to 25 ft of postuplift-bearing limestone overlain by a few feet to 80 ft of drab mudstone, middle unit is red and lentils of limestone, lower unit is crossbedded "pepper-and-salt" sandstone and interbedded shale and mudstone
	Colorado formation	Kcm, Kcl	Upper Mack shale unit not mapped. Middle siliceous mudstone and sandstone unit, Kcm, is interstone, and siliceous sandstone, mudstone. Lower Mack shale unit, Kcl, is a basal fan-weathering quartz sandstone, drab and olive-gray blocky siltstone, very dark gray to black shale, and an upper dark-gray carbonaceous, limonitic speckled to mottled sandstone
Cretaceous	Park shale	Cop	Olive-gray, gray, and light-brown shale with minor amounts of argillaceous limestone, siltstone, and sandstone
	Meagher limestone	Cm	Comprises three units. Upper and lower units are medium-gray limestone irregularly ribbed or mottled with yellowish-orange, yellowish-brown, and yellowish-gray dolomite. Middle unit is thickly and indistinctly bedded medium-gray limestone, commonly with oolitic beds
Tertiary	Tuff and gravel	Tu	Light-colored rhyolitic tuff with a few interbeds of stream gravel
	Fan gravel and pediment gravel	Fg	Unconsolidated or weakly consolidated fan deposits and gravel veneer on pediments
Quaternary	Alluvium	Qal	Fan gravel and pediment gravel
	Unconformity	DC	Maywood and Red Lion formations undifferentiated, varicolored, generally in shades of red and yellowish-brown, argillaceous, dolomitic, and calcareous rocks, poorly exposed



The Basic Rules of Structure

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- 

Geology Map La Jolla Quad



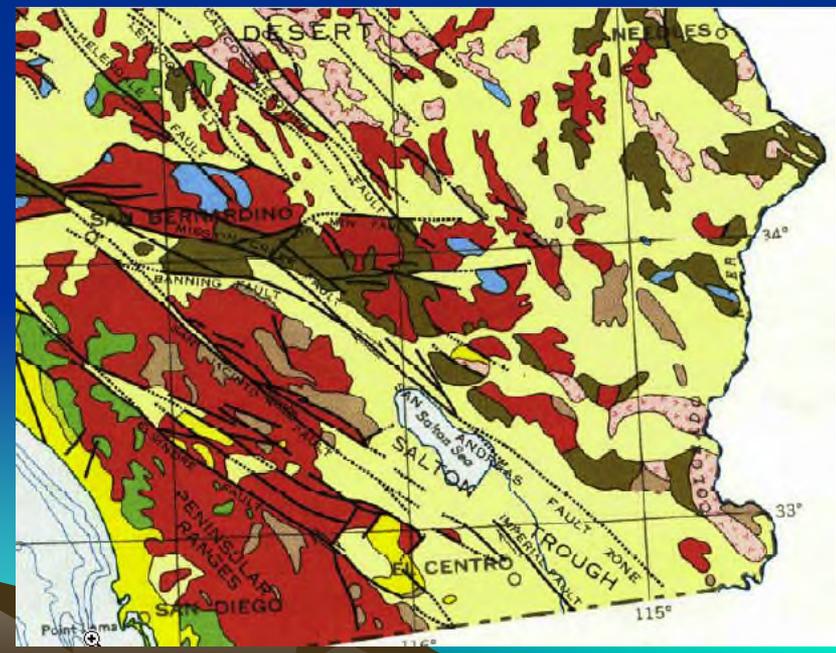
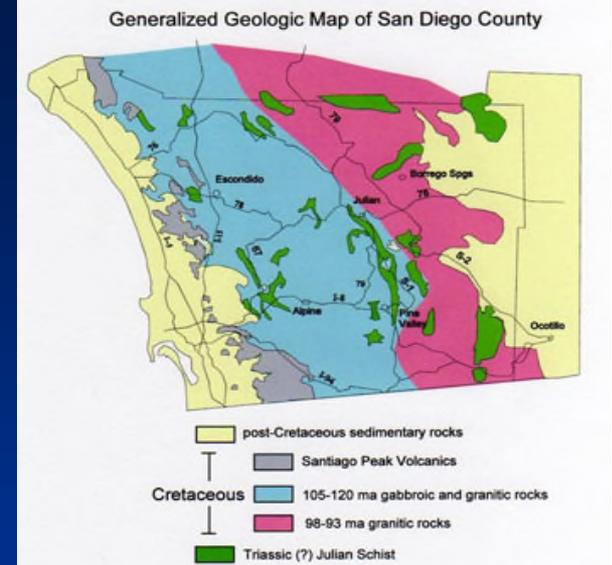
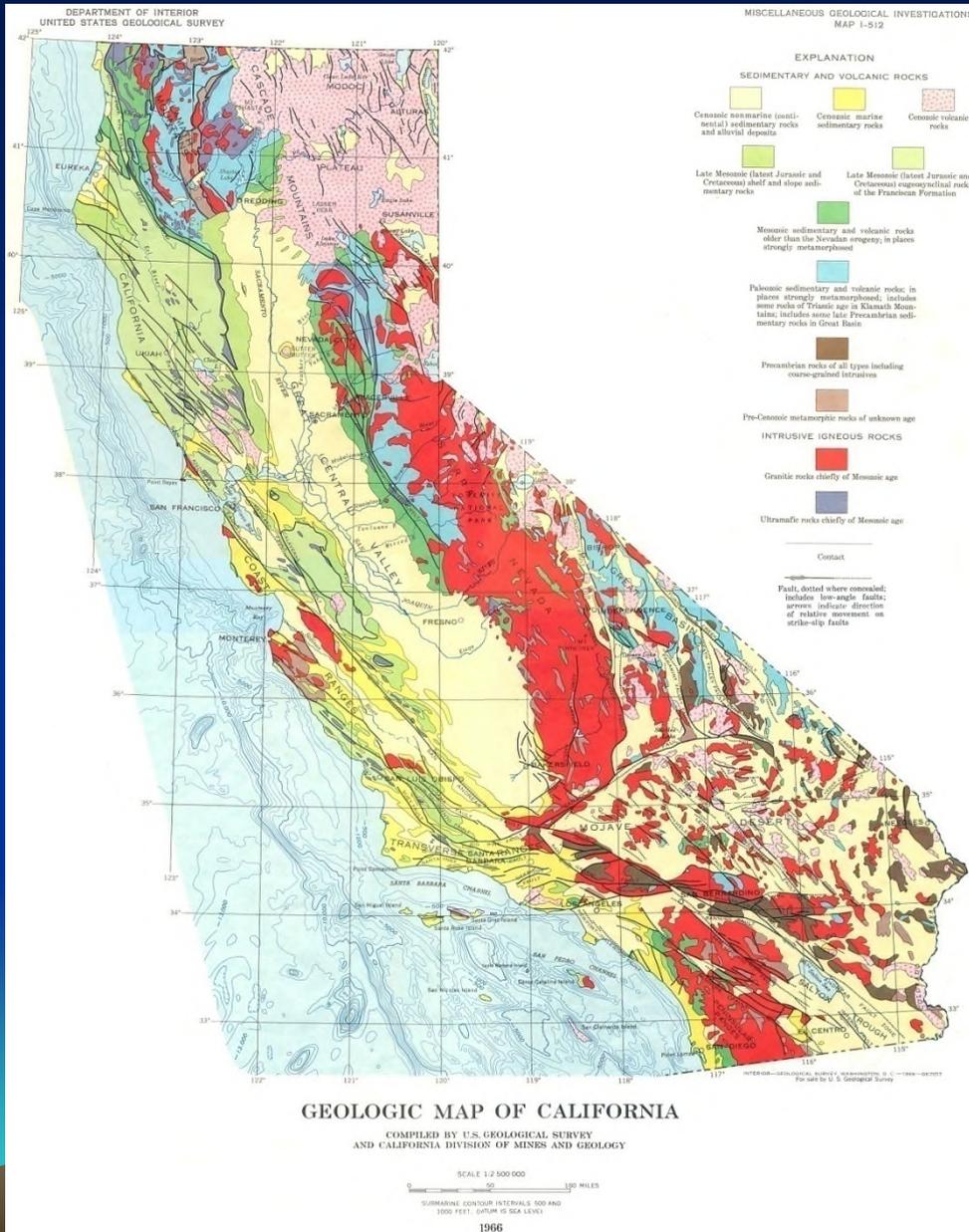
GEOLOGIC MAP OF LA JOLLA QUADRANGLE
BY MARCUS A. HANNA



[Note.—The numbers in red indicate the fossil collecting localities. These localities are described in the following paper (No. 9) in the present volume, HANNA, An Recent Invertebrate Fauna from the La Jolla Quadrangle, California.]

1911
CALIFORNIA

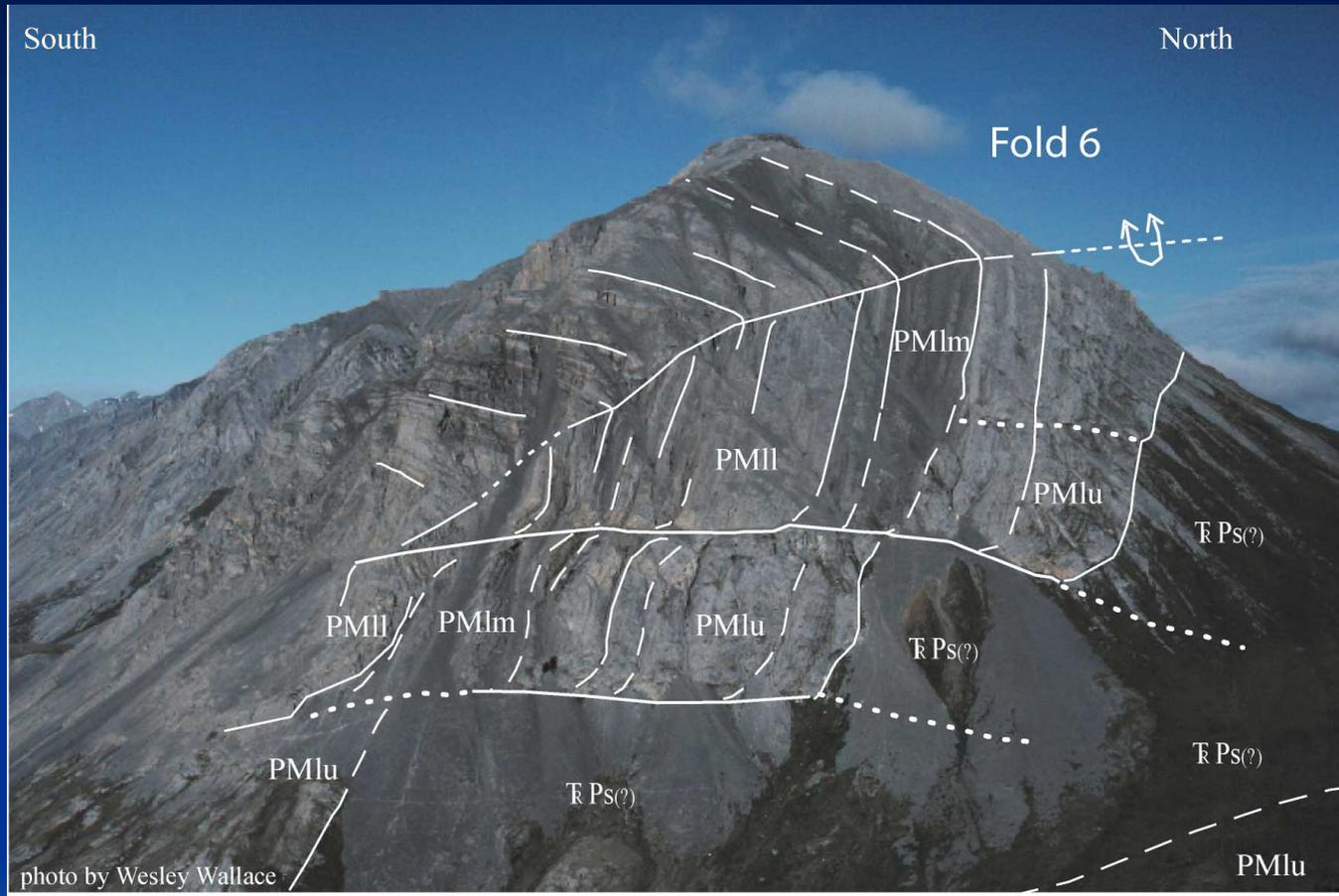
Geologic Maps of California



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Structure Web References



<http://www.nature.nps.gov/geology/usgsnps/gmap/gmap1.html#unique>

<http://www.globalchange.umich.edu/Ben/ES/earthstructure.htm>

<http://www.winona.edu/geology/MRW/maps.htm>

<http://www.nps.gov/archive/yell/slidefile/scenics/outsideynp/Page.htm>