# Structural Geology: Deformation of Rocks

Geology 200

Geology for Environmental Scientists

# Major Concepts

- Folds in rocks range from microscopic to hundreds of kilometers across.
- Faults are fractures along which displacement has occurred.
- Joints are fractures where there has been no displacement.
- Rocks deform when applied stress exceeds rock strength.  Deformation may be ductile flow or brittle fracture.

# Folds

- anticlines and synclines - plunge out eventually, don't go on forever
- domes and basins - very broad features within continental interiors
- complex folds - the result of very ductile behavior

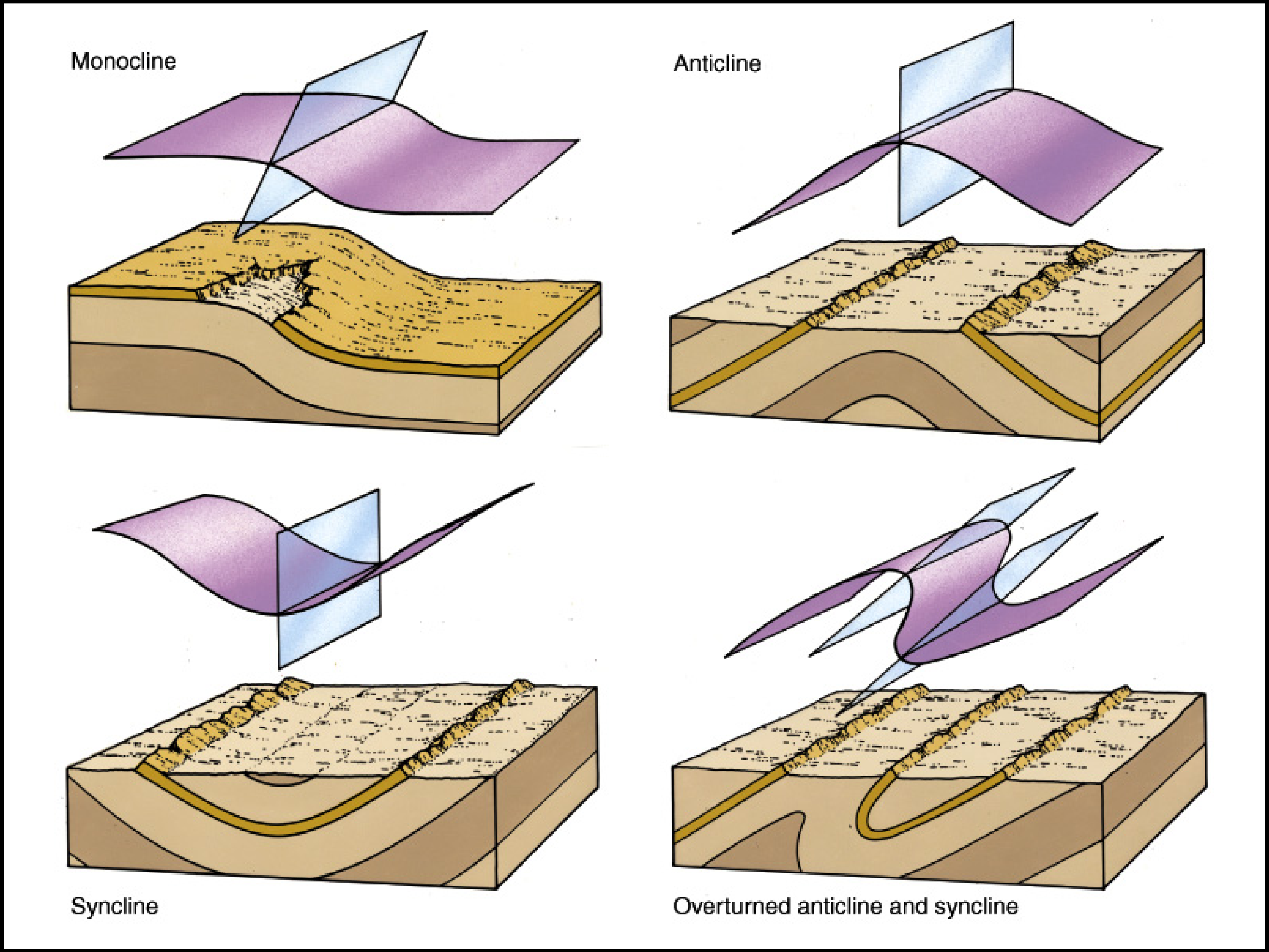


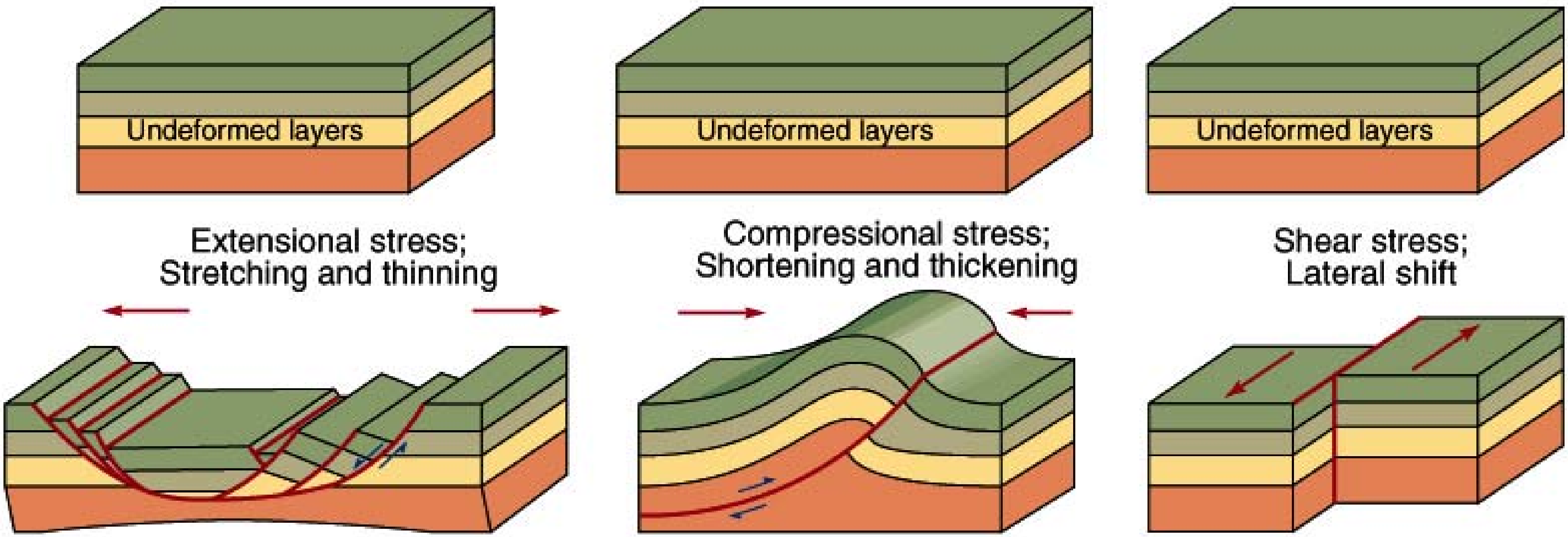

Fig. 7.11. Types of folds

Fig. 7.15a. A series of anticlines & synclines in southern California

# Anticline-syncline fold pair in SW Wales

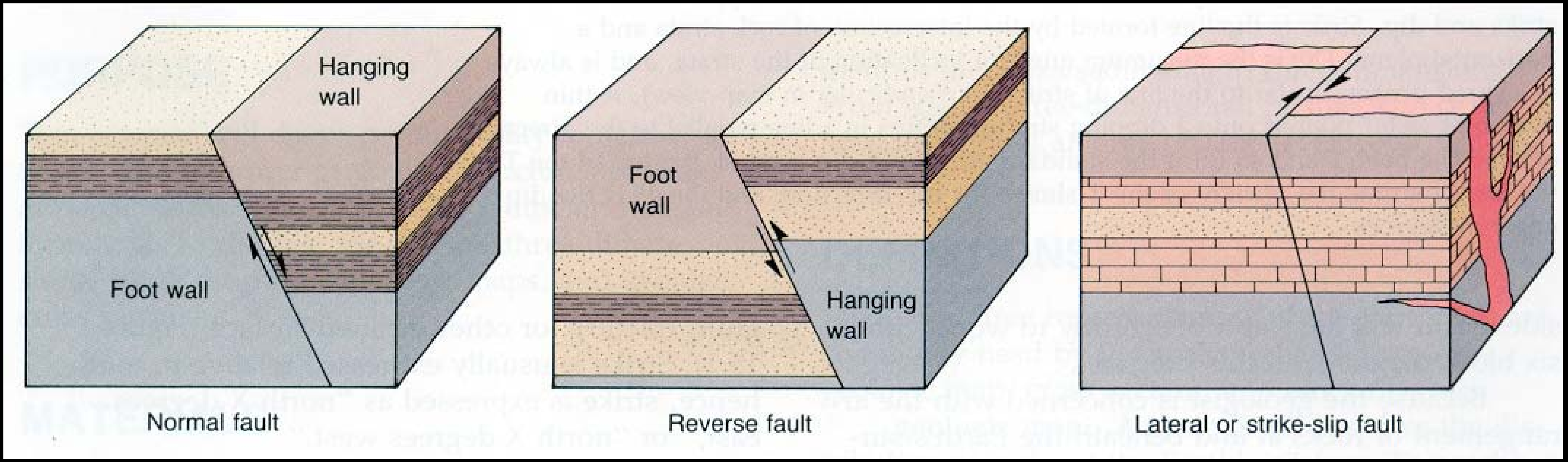
# Faults: 3 major categories

- normal faults - caused by extension or tension
- thrust faults and reverse faults - caused by compression
- strike-slip or tear faults - caused by lateral shear




Normal fault Thrust fault Strike-slip fault

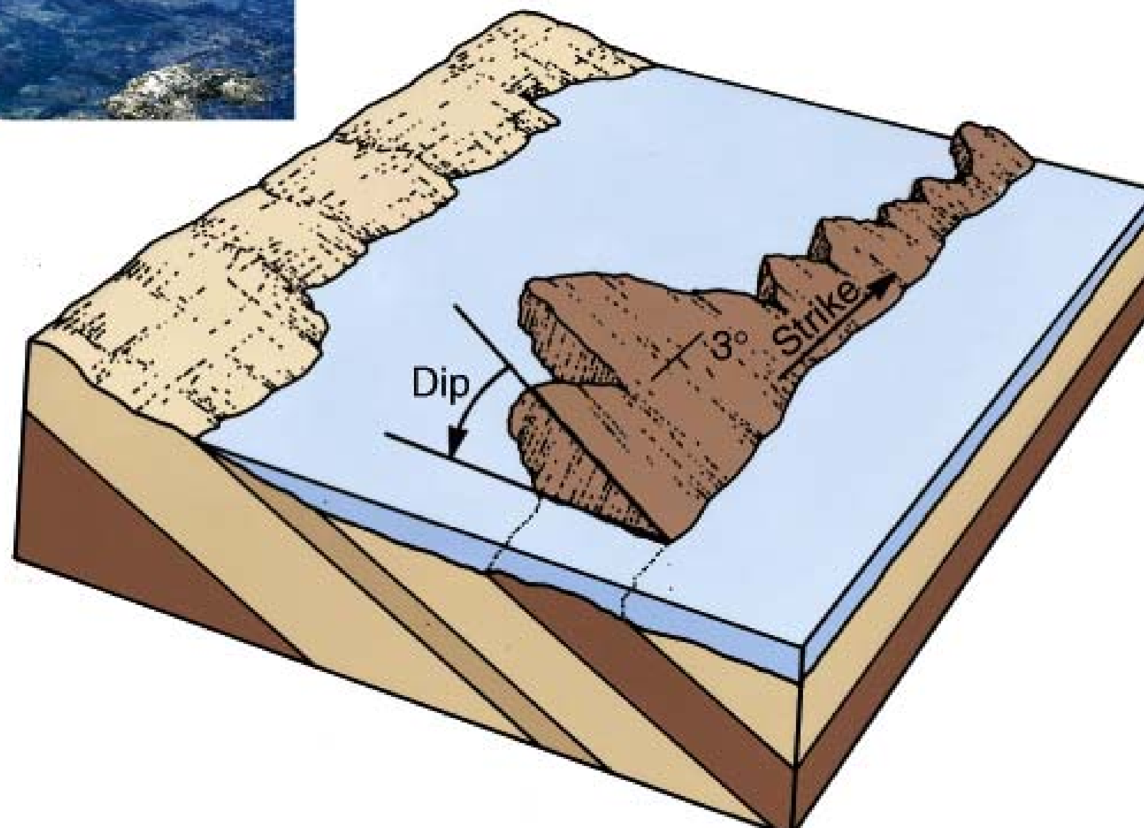
In both normal and reverse faults the hanging wall is above the footwall. Miners following mineral veins would walk down the footwall and hang their lanterns on the hanging wall.



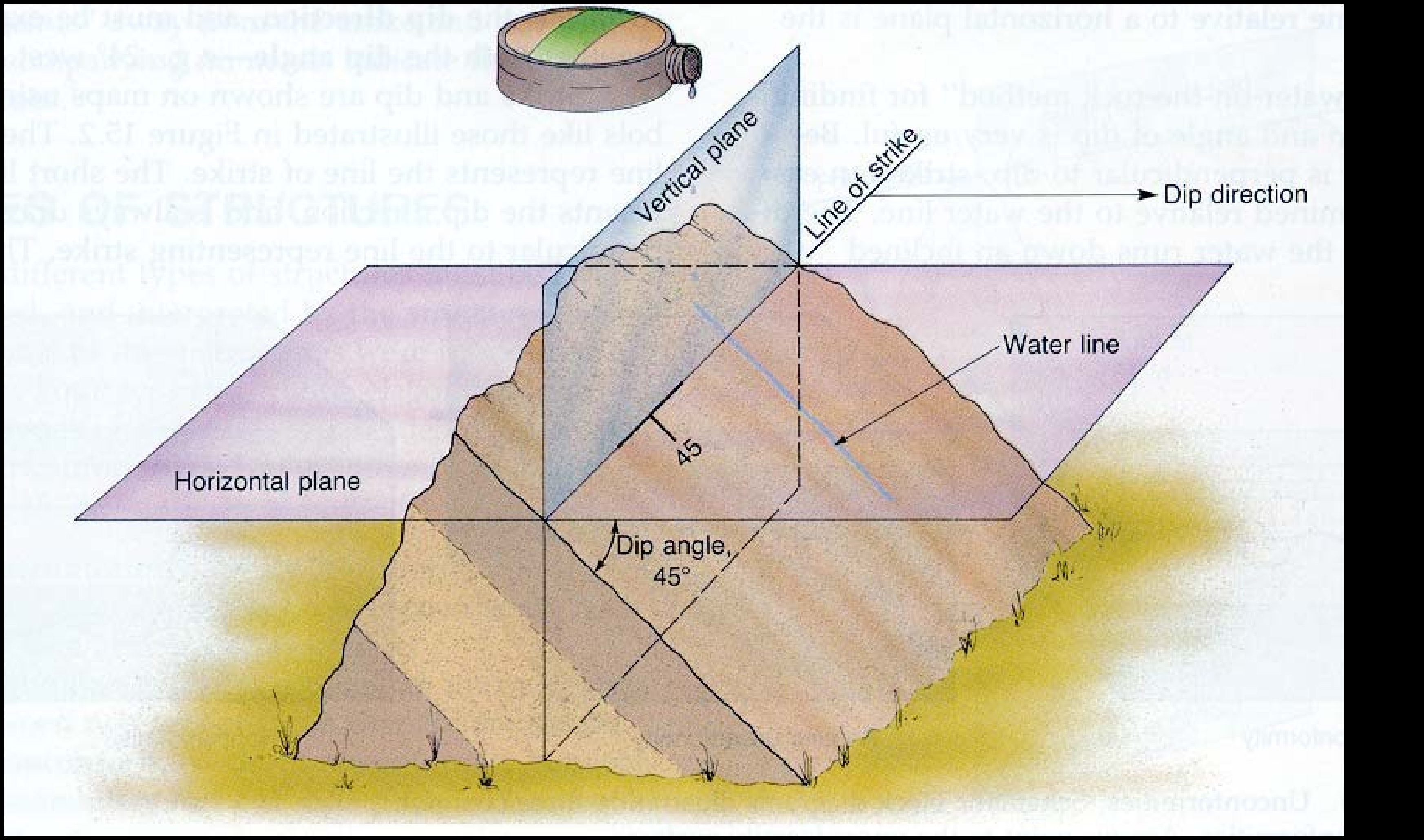
# Strike and Dip

- Describes the orientations of bedding planes, faults, or joints.
- Strike - compass bearing of a horizontal line on a plane
- Dip - the inclination of a plane from the horizontal. Dip direction is always at a right angle to the strike.
- See Fig. 7.5 in your book.

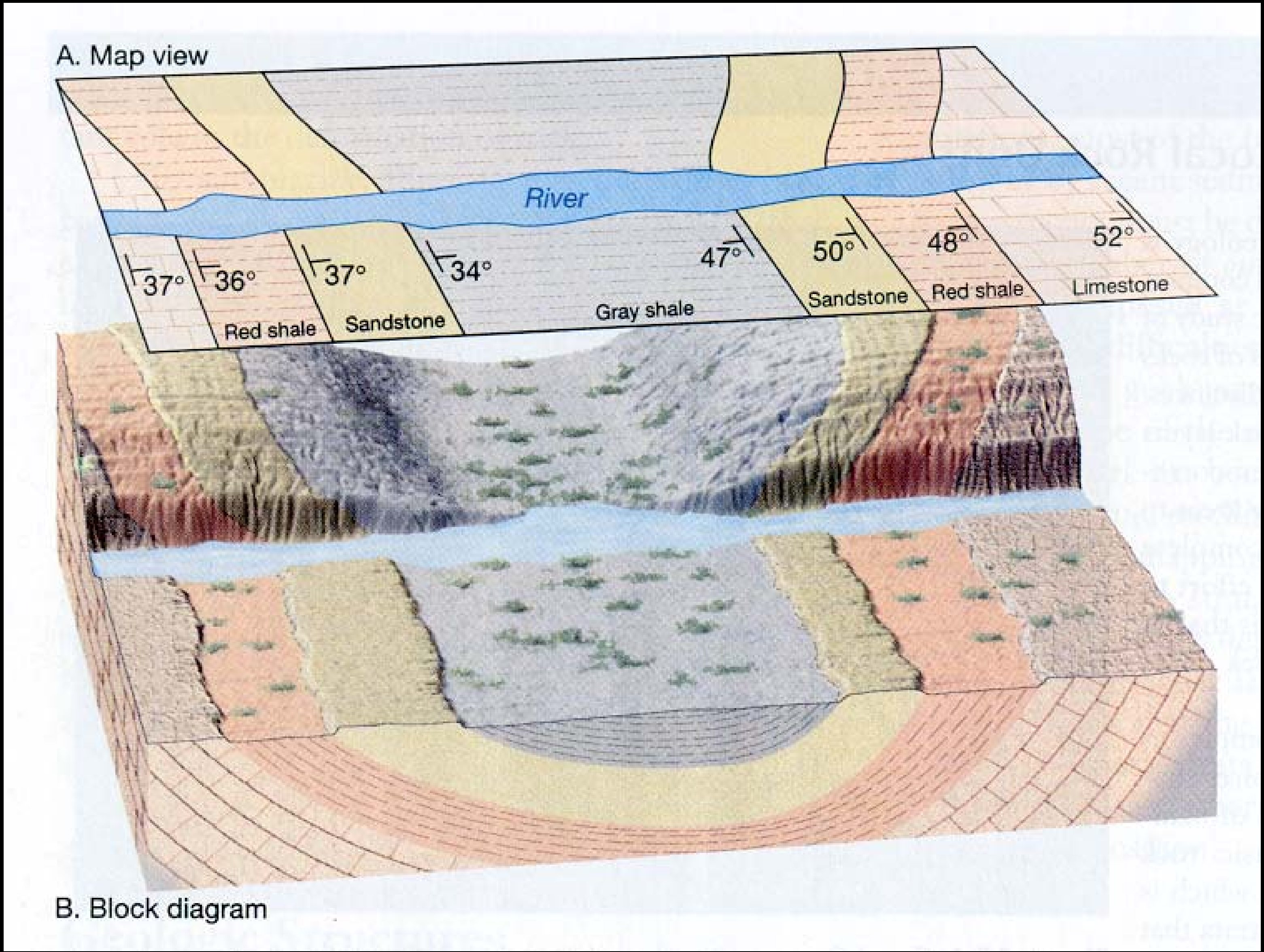
# Fig. 7.5.
# Strike & Dip



# A graphic representation of the concept of strike and dip of bedded rocks.



# Pattern of strikes and dips for a syncline.



# Fold Nomenclature

- anticlines - rocks older in the center
- synclines - rocks younger in the center
- limbs
- hinge and hinge plane or axial plane
- plunge

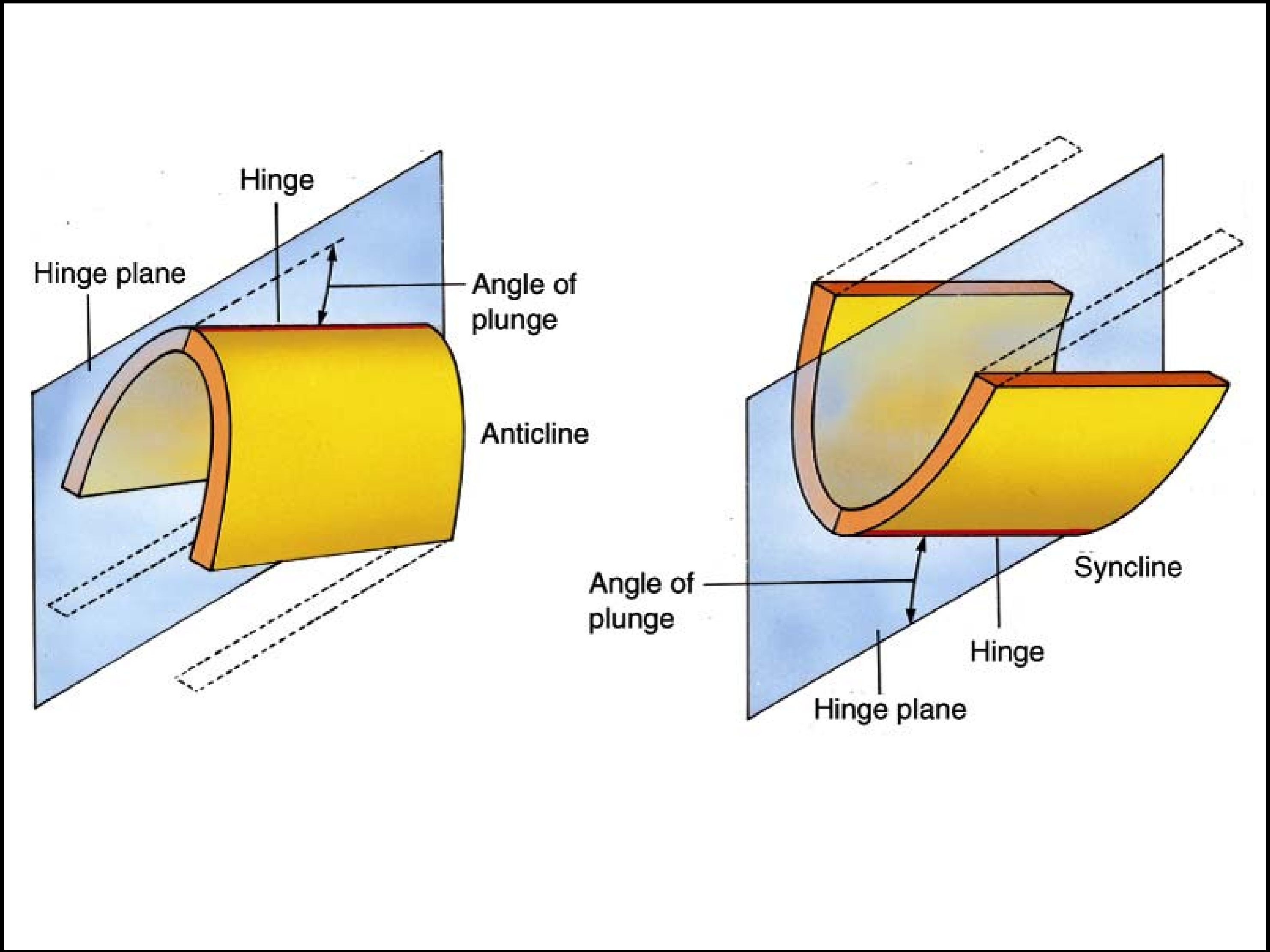
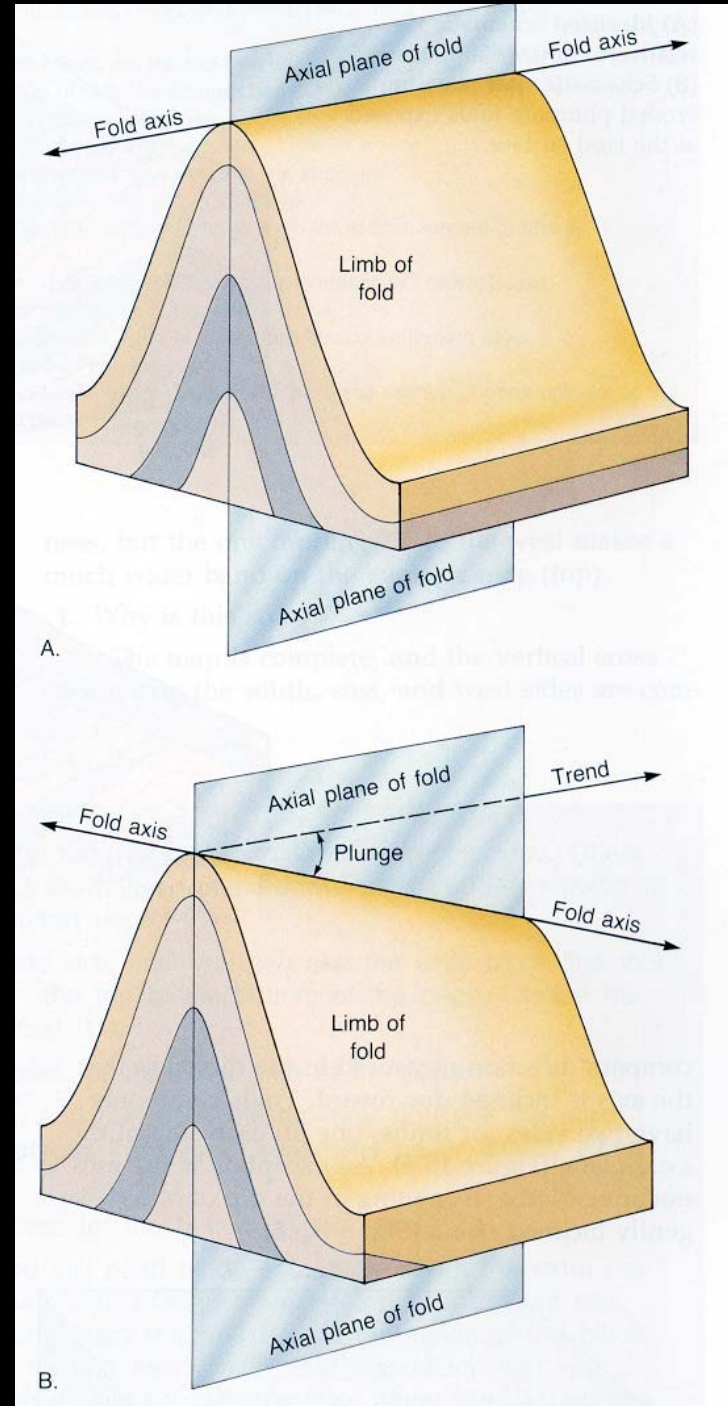
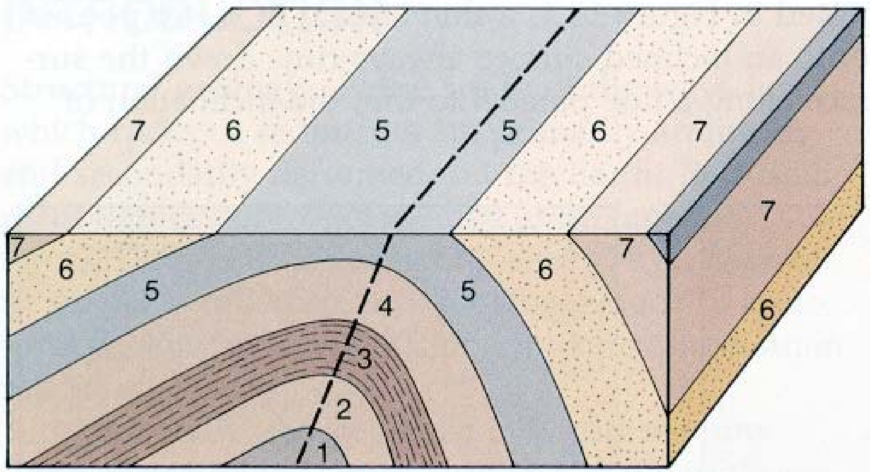


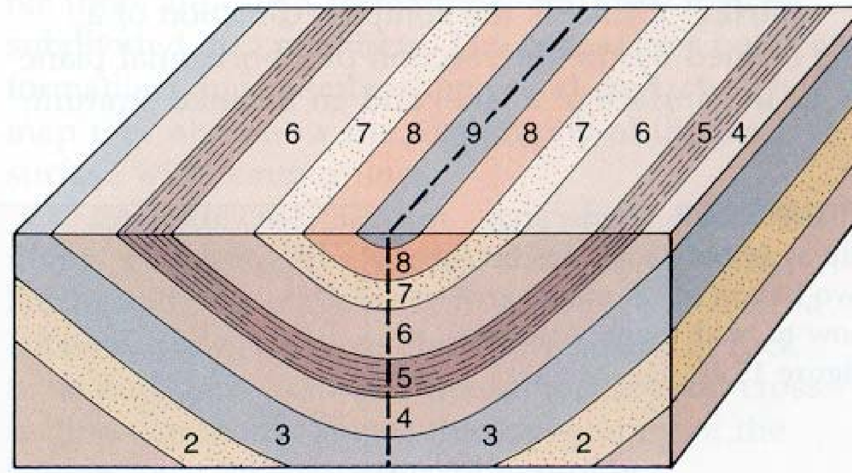

Fig. 7.12. Fold geometry

Examples of horizontal and plunging fold axes.



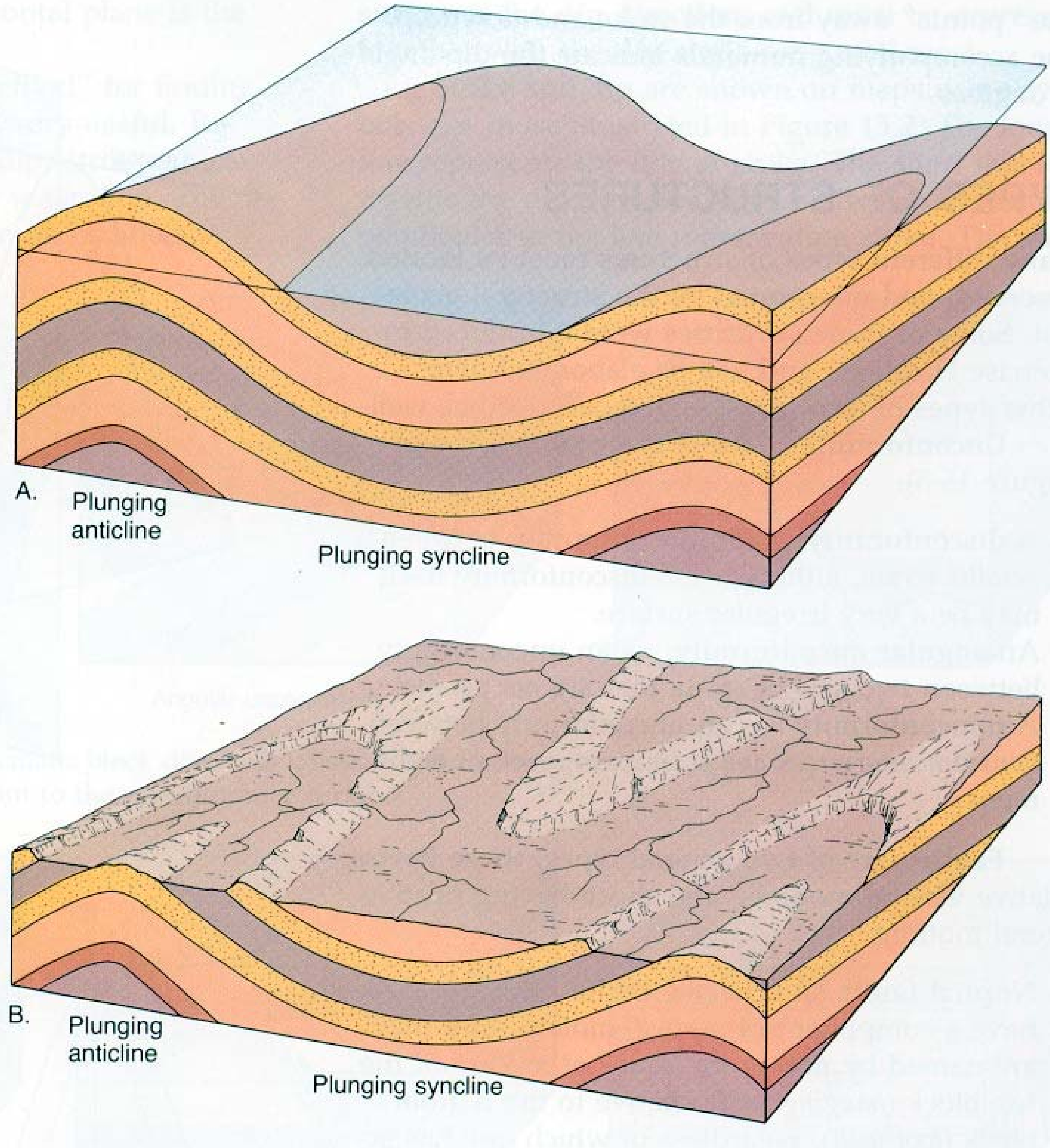


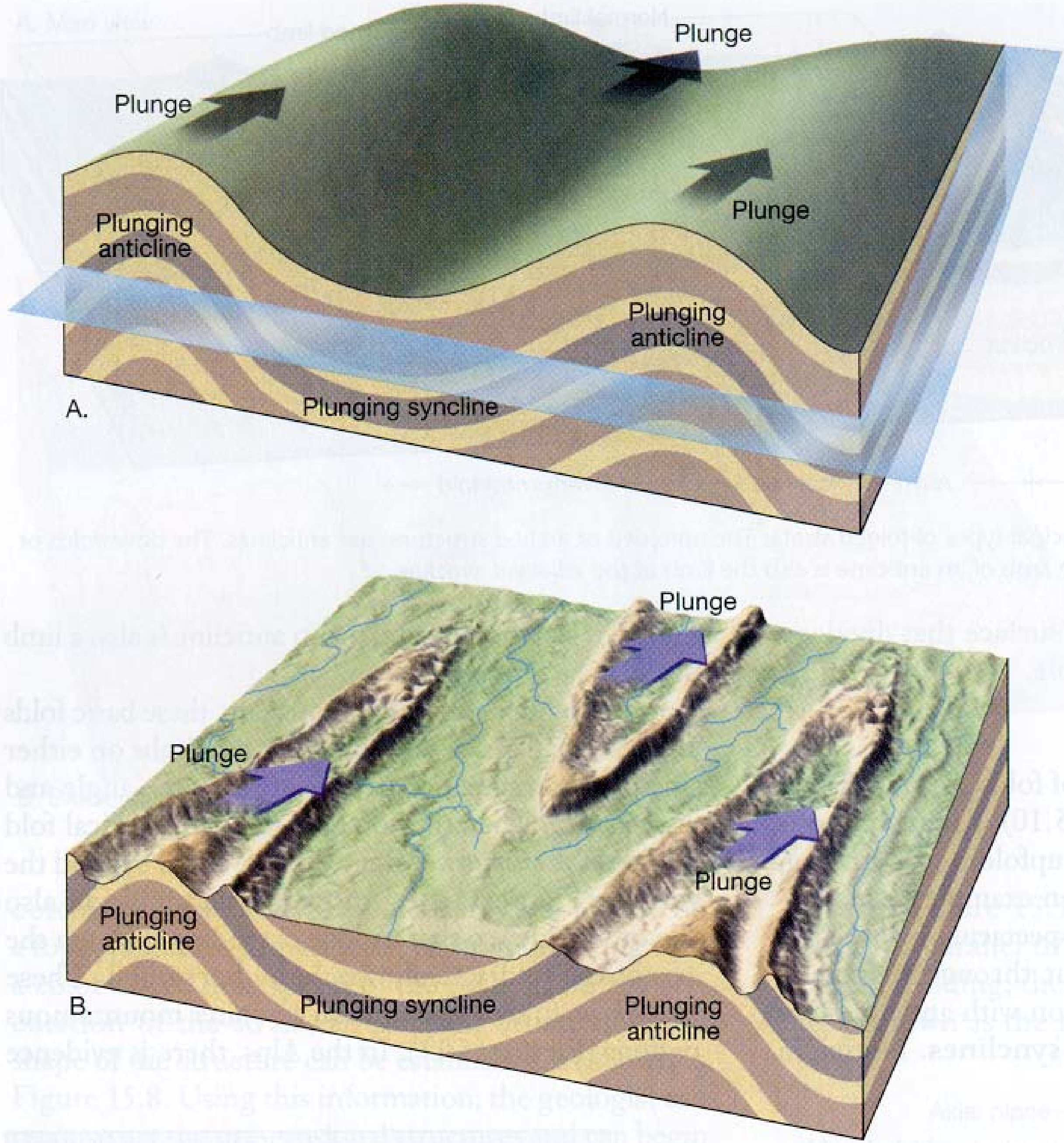

Anticline (asymmetrical)




Syncline (symmetrical)

Asymmetrical Fold at Geology Field Camp in SD


A.
Plunging
anticline
Plunging syncline
B.
Plunging
anticline
Plunging syncline


Plunge
Plunge
Plunge
Plunging anticline
Plunging anticline
A.
Plunging syncline
Plunge
Plunge
Plunge
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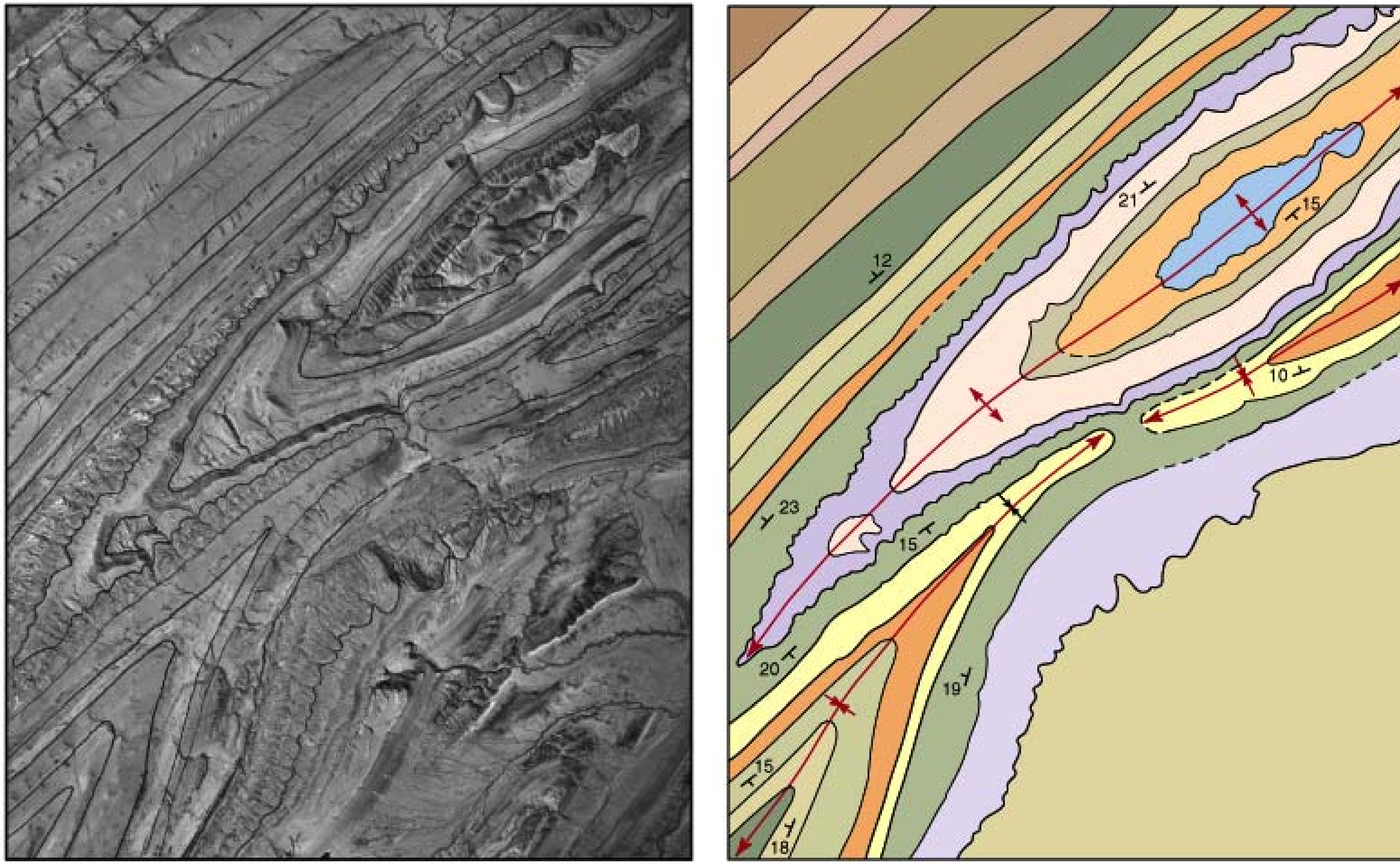
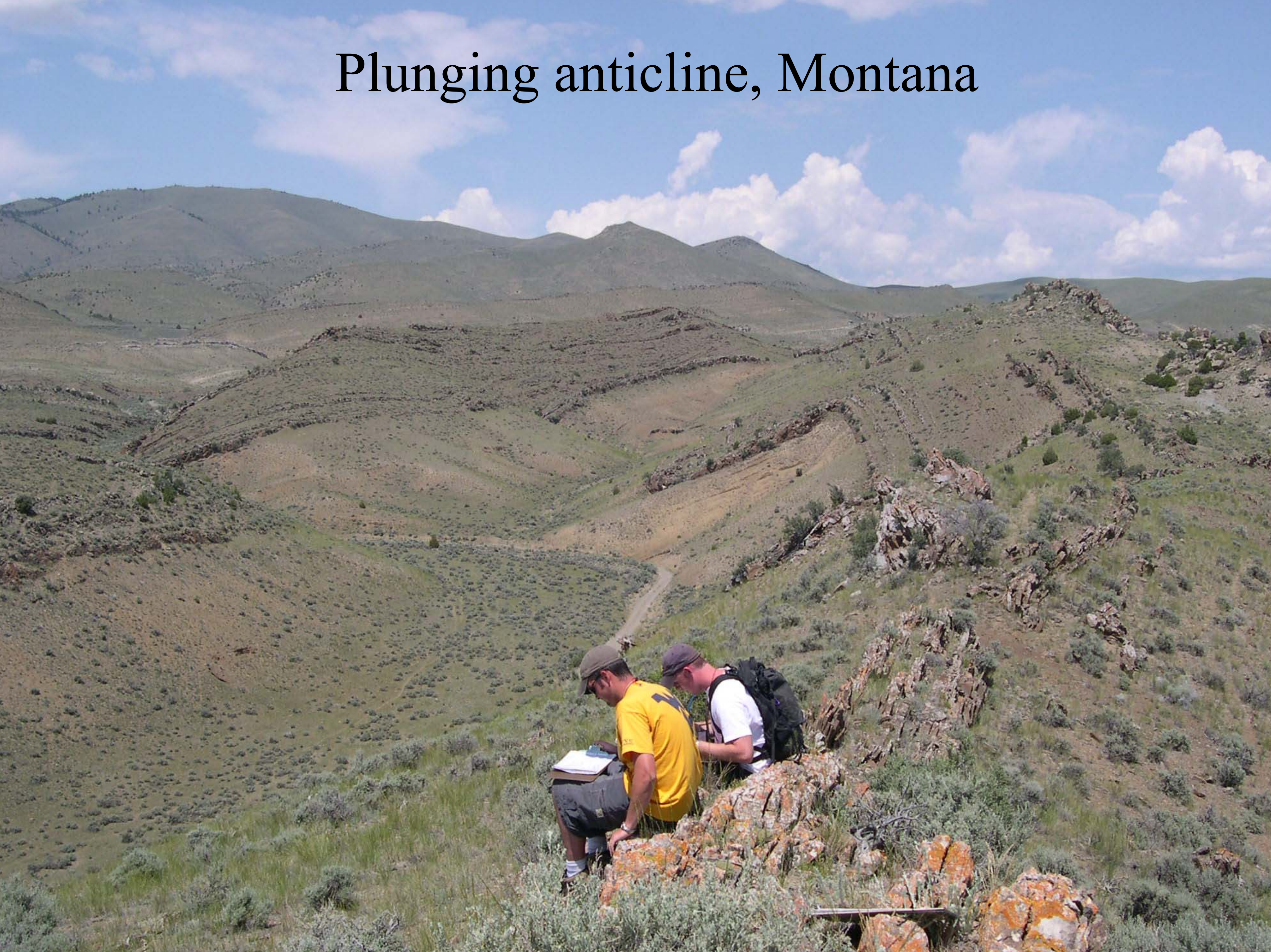
B.
Plunging syncline
Plunging anticline




Orogenic belt with complex folding

Fig. 7.15d.  A plunging anticline in southern Utah

# Plunging anticline, Montana



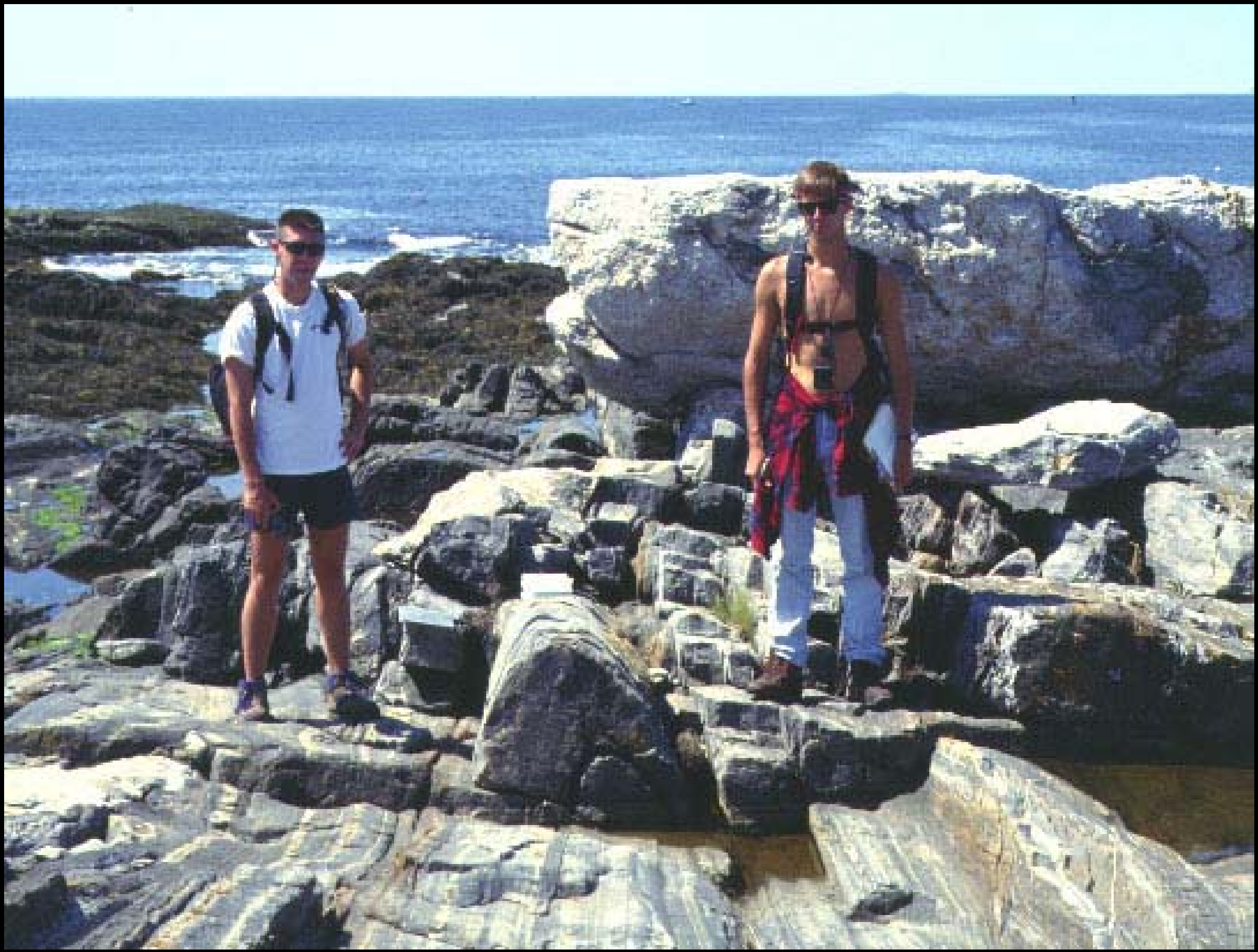
# Plunging anticline, Montana

# Anticline in the Keefer Sandstone of WV

# Open fold in the Tuscarora Sandstone, WVU Geology Field Camp

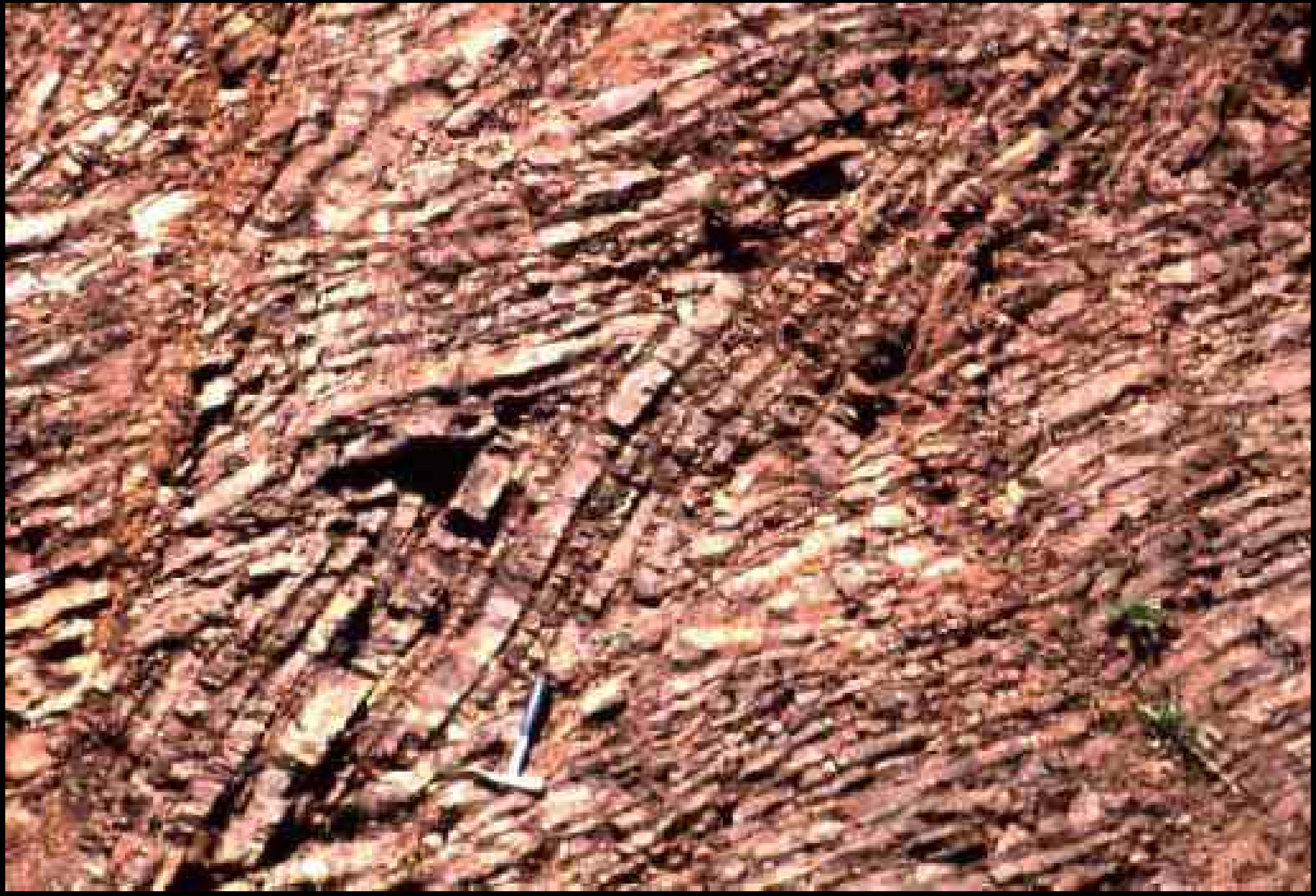
# Overturned folds: anticline-syncline pair in the core of an ancient mountain system, South Georgia Island

# Isoclinal folds along the coast of Maine



# Isoclinal folds along the coast of Maine

Chevron folds in brittle rocks. An example of angle parallel folding.

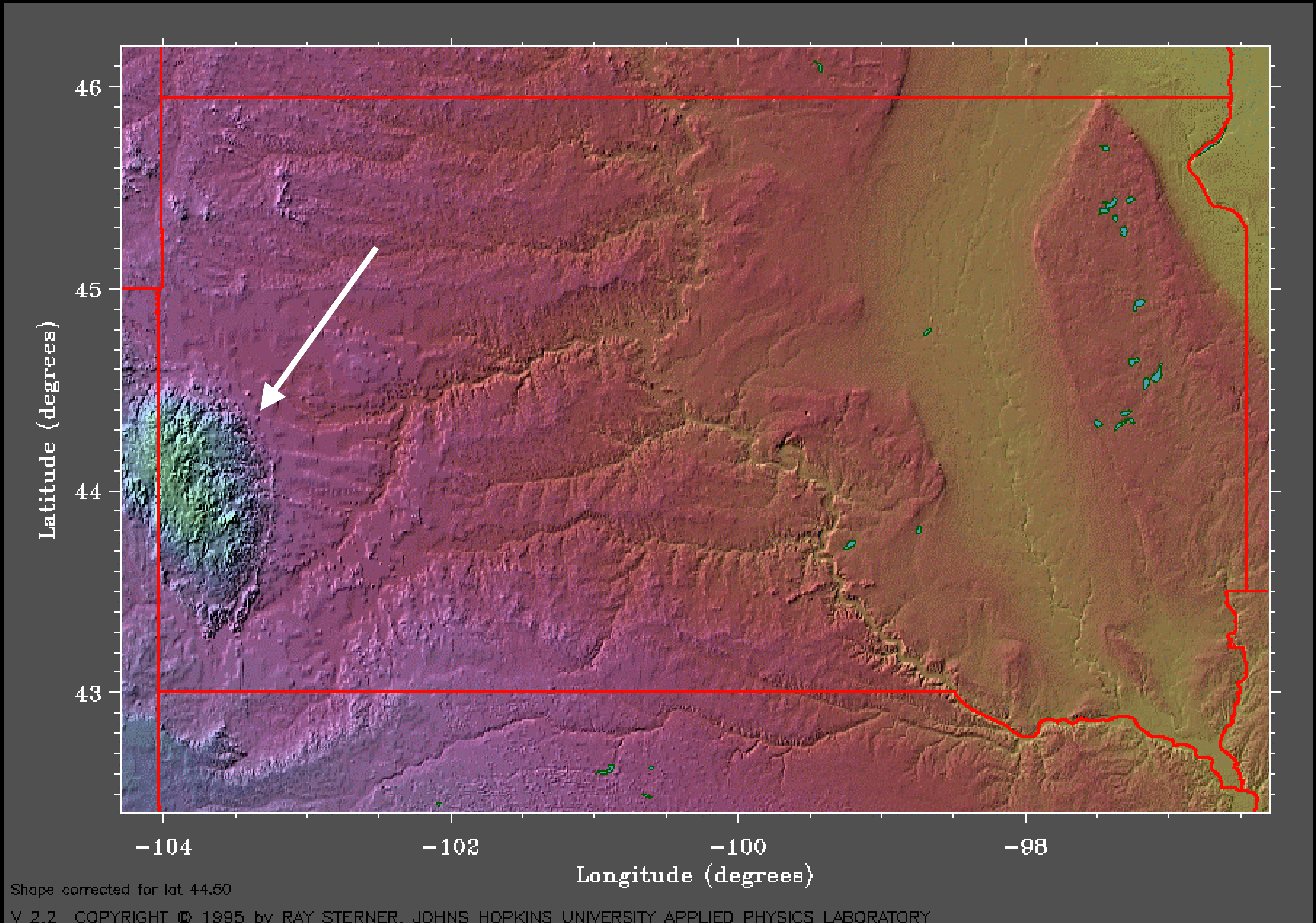


Angle parallel or kink folds in Italy

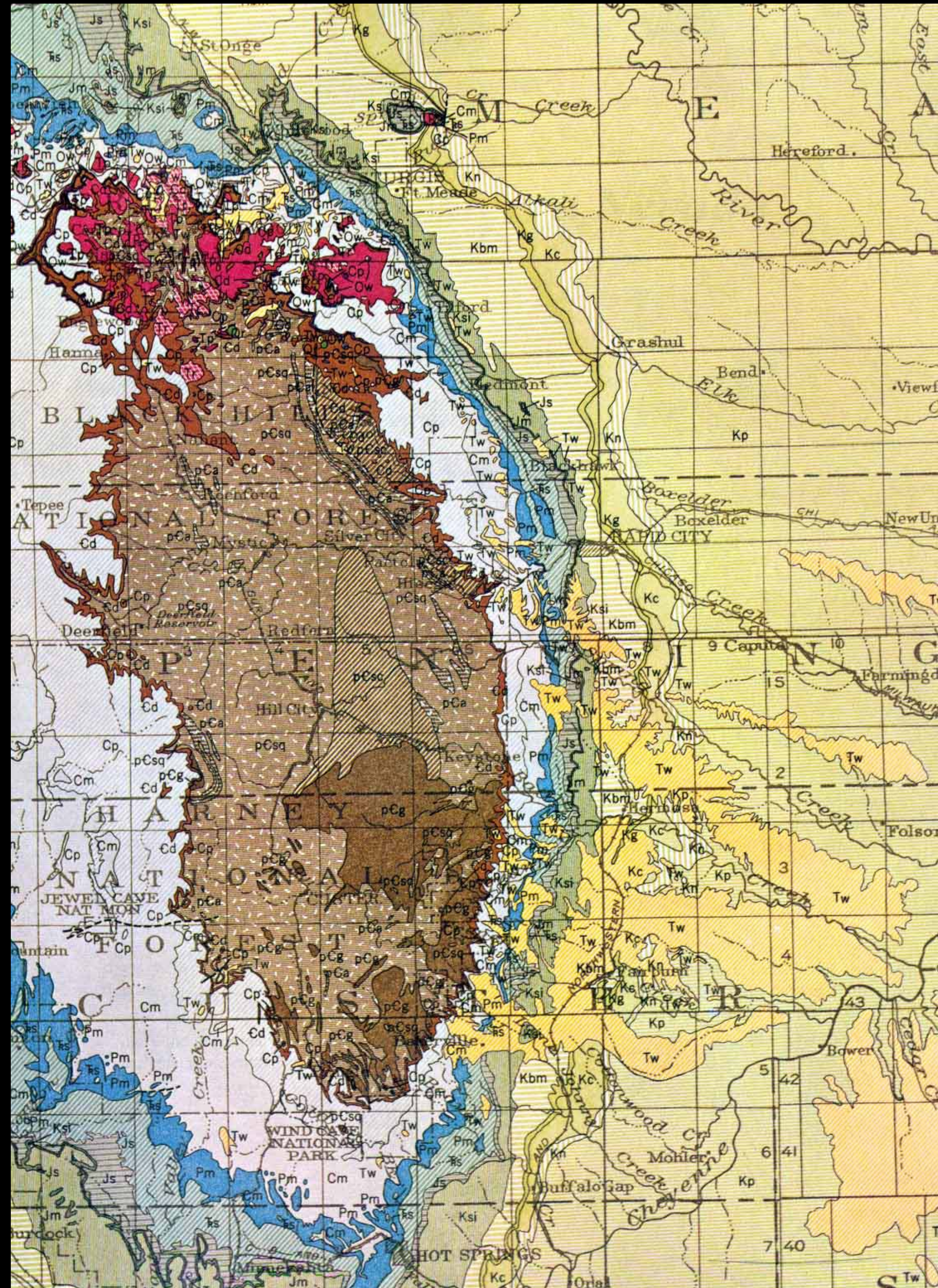
# Domes and Basins

- Very large features with gentle dips, usually only visible on geologic maps (too large to recognize on the ground).
- Restricted to continental interiors.
- Examples include the Michigan Basin, Illinois Basin, Cincinnati Arch, Nashville Dome, Black Hills, etc.

# The Black Hills of South Dakota are a structural dome.



# Geologic Map of the Black Hills of South Dakota



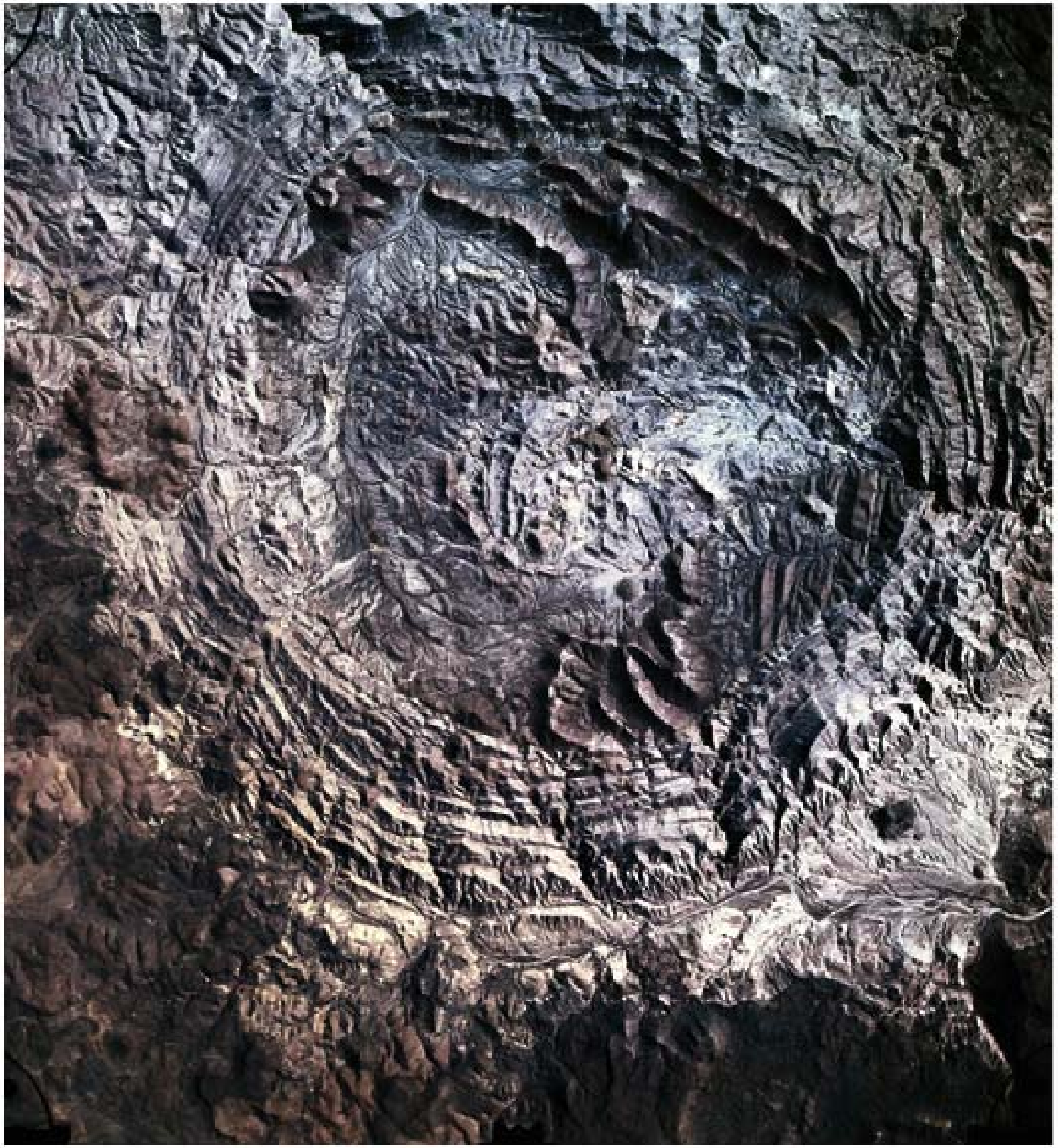


Fig. 7.15b. A small dome in Texas


Michigan Basin
47
46
45
44
43
42
Latitude (degrees)
−90
−88
−86
−84
Longitude (degrees)
Shape corrected for lat 44.50
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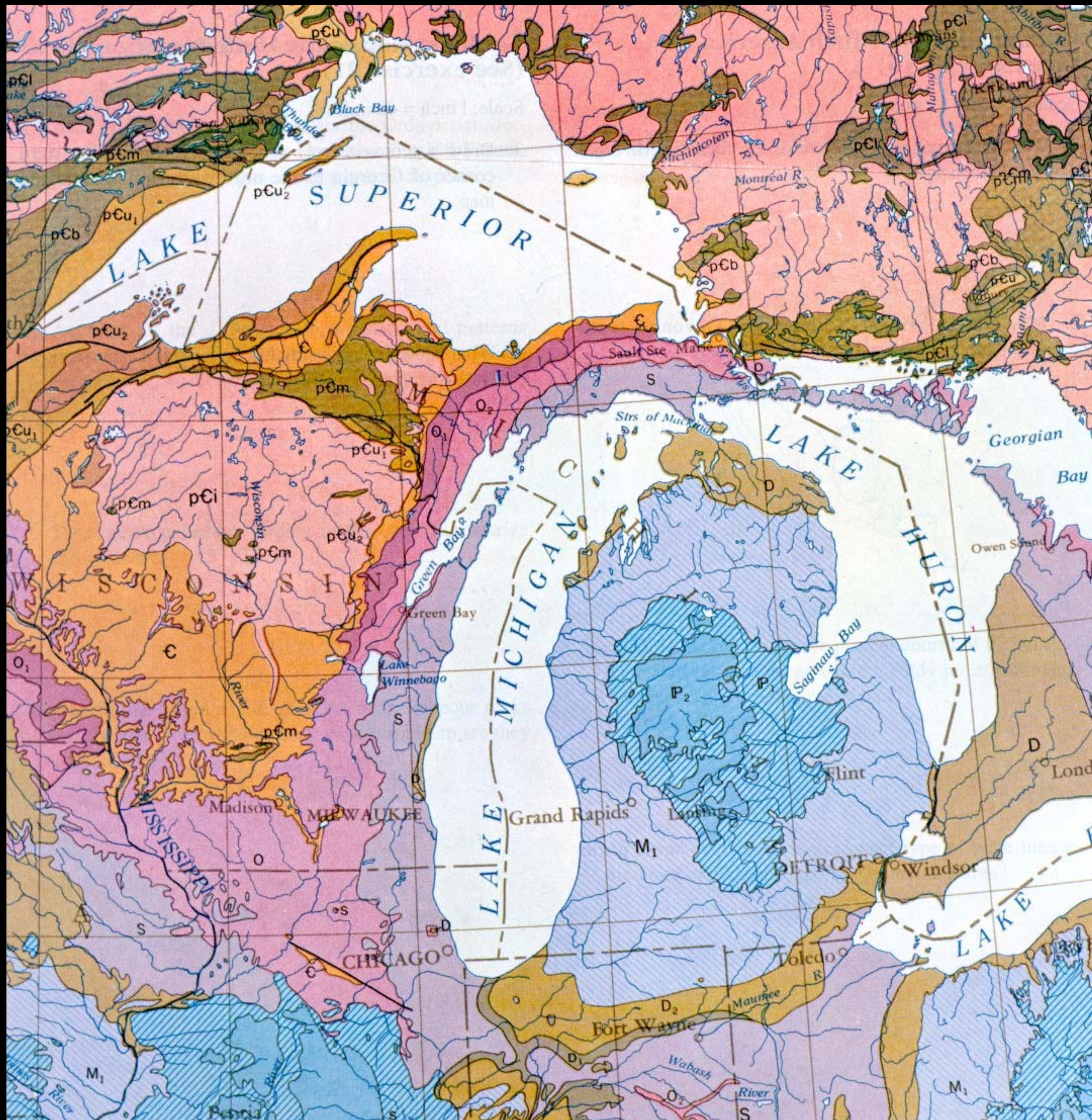
# Geologic Map of Michigan Basin



# Complex Folds

- Formed by intense deformation in mountain ranges.
- Usually the result of multiple episodes of folding.
- The folds themselves may be folded and they are often recumbent.
- Can be at any scale from outcrop to map scale.

# Complex folds in sandstone, Cornwall, UK

# Recumbent isoclinal folds in meta-sediments, Scotland

Complex folding in 1.2 Ga meta-sediments, Adirondack Mtns. of New York

Complex, disharmonic folds in ductile rocks.

# Ptygmatic folds of migmatite in metamorphic rocks, Spain

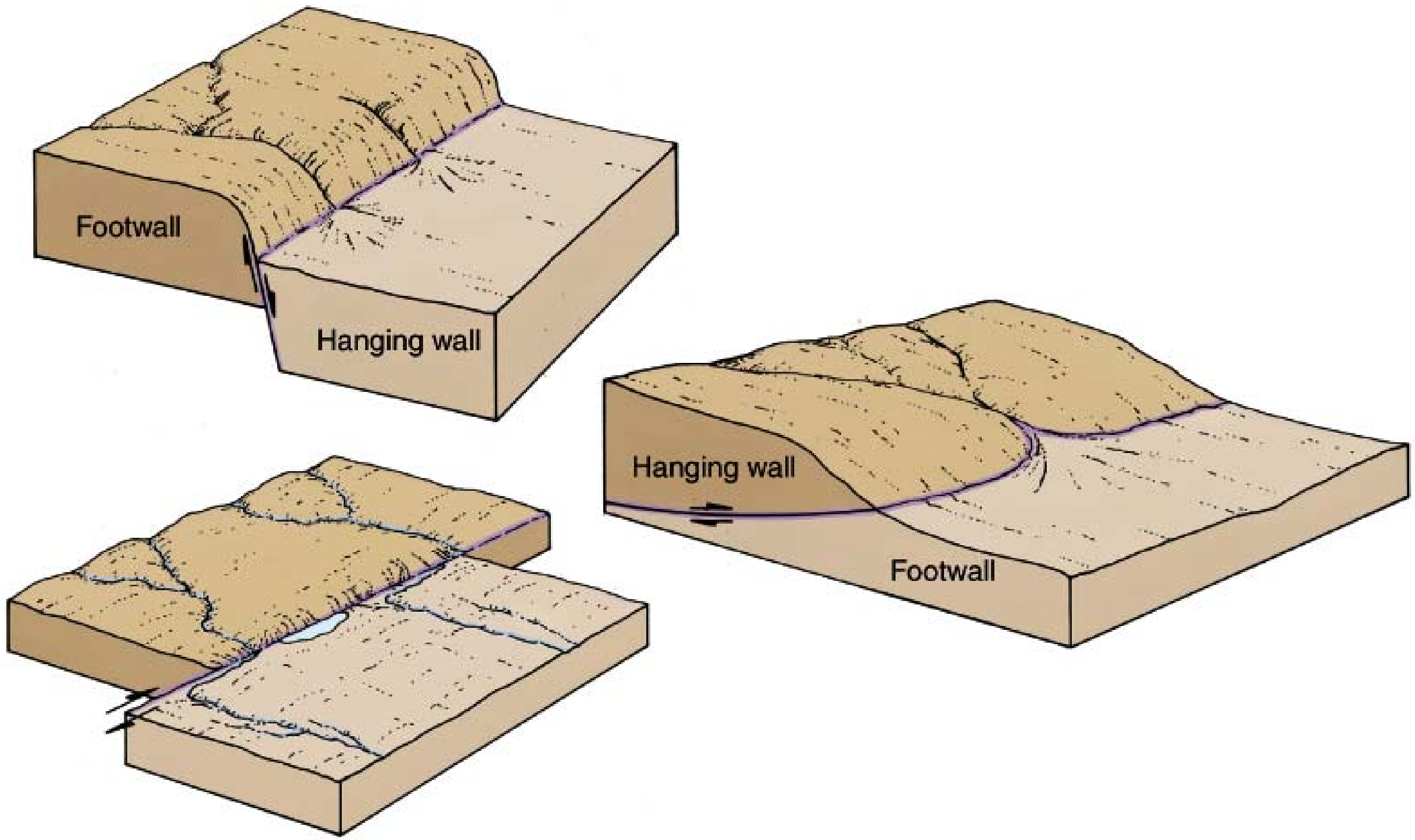



Fig. 7.7. Major types of faults

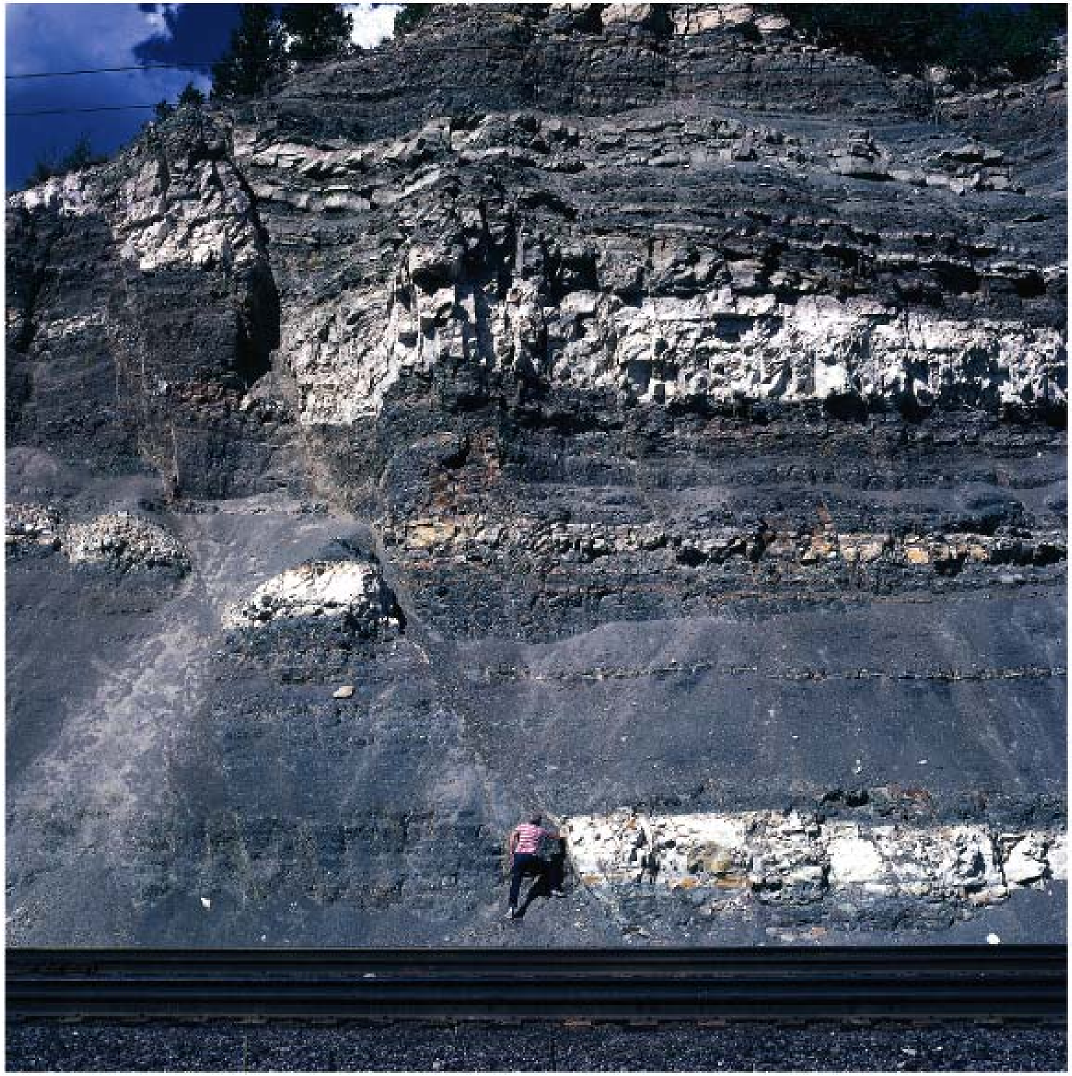


Fig. 7.8a.  Easily recognized displacement

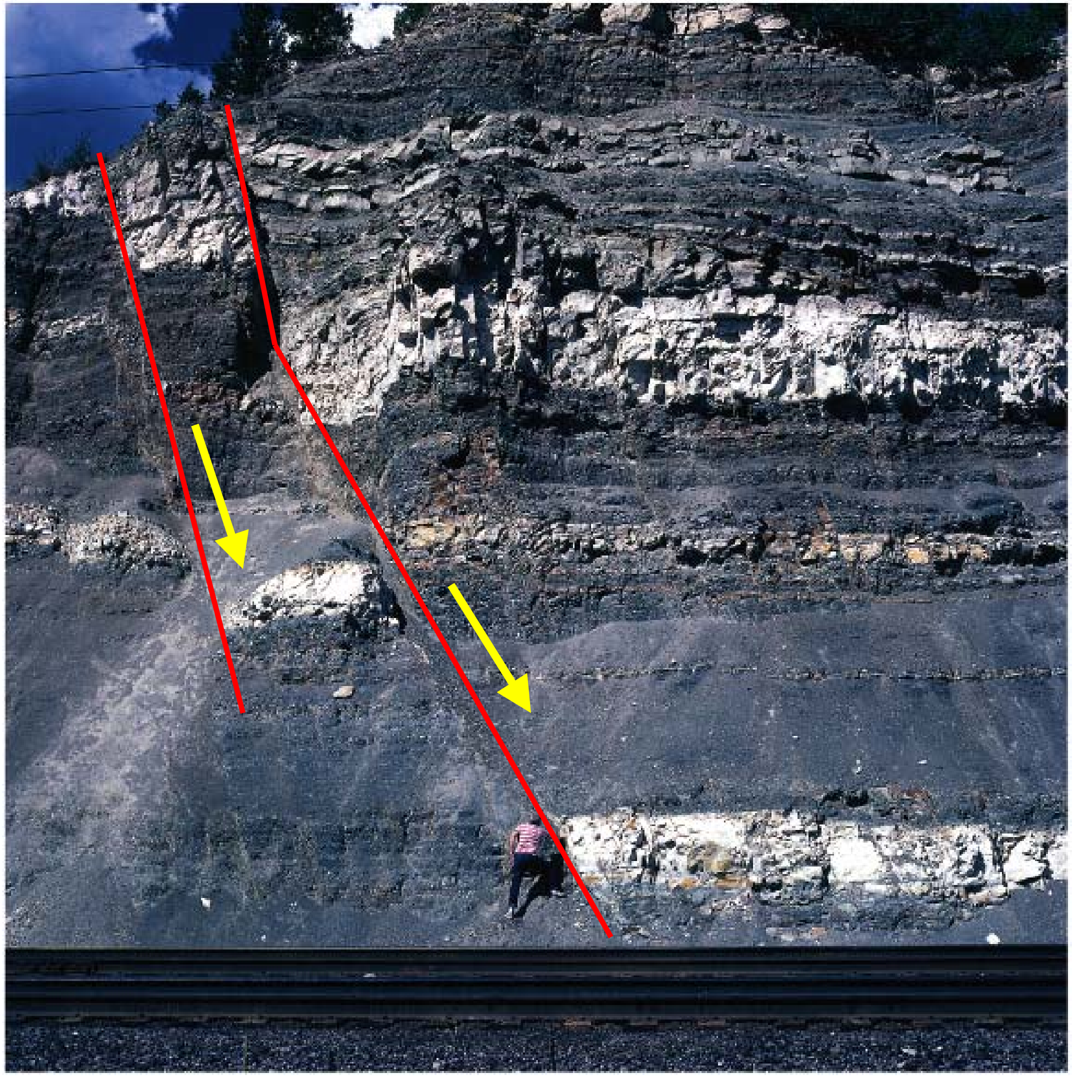


Fig. 7.8a.  Easily recognized displacement

# Normal faults

# Extension experiment in tectonic modeling lab exercise

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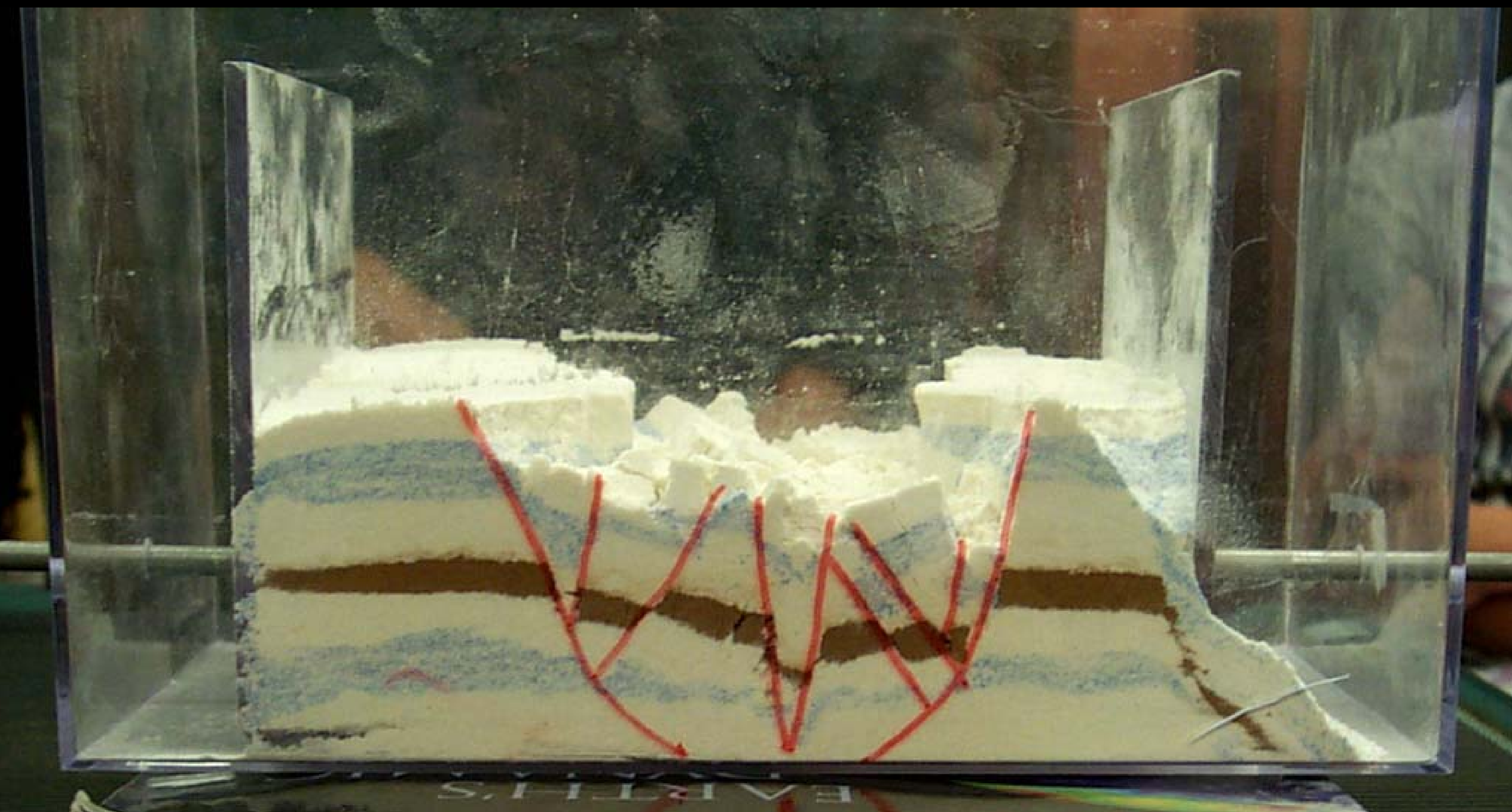
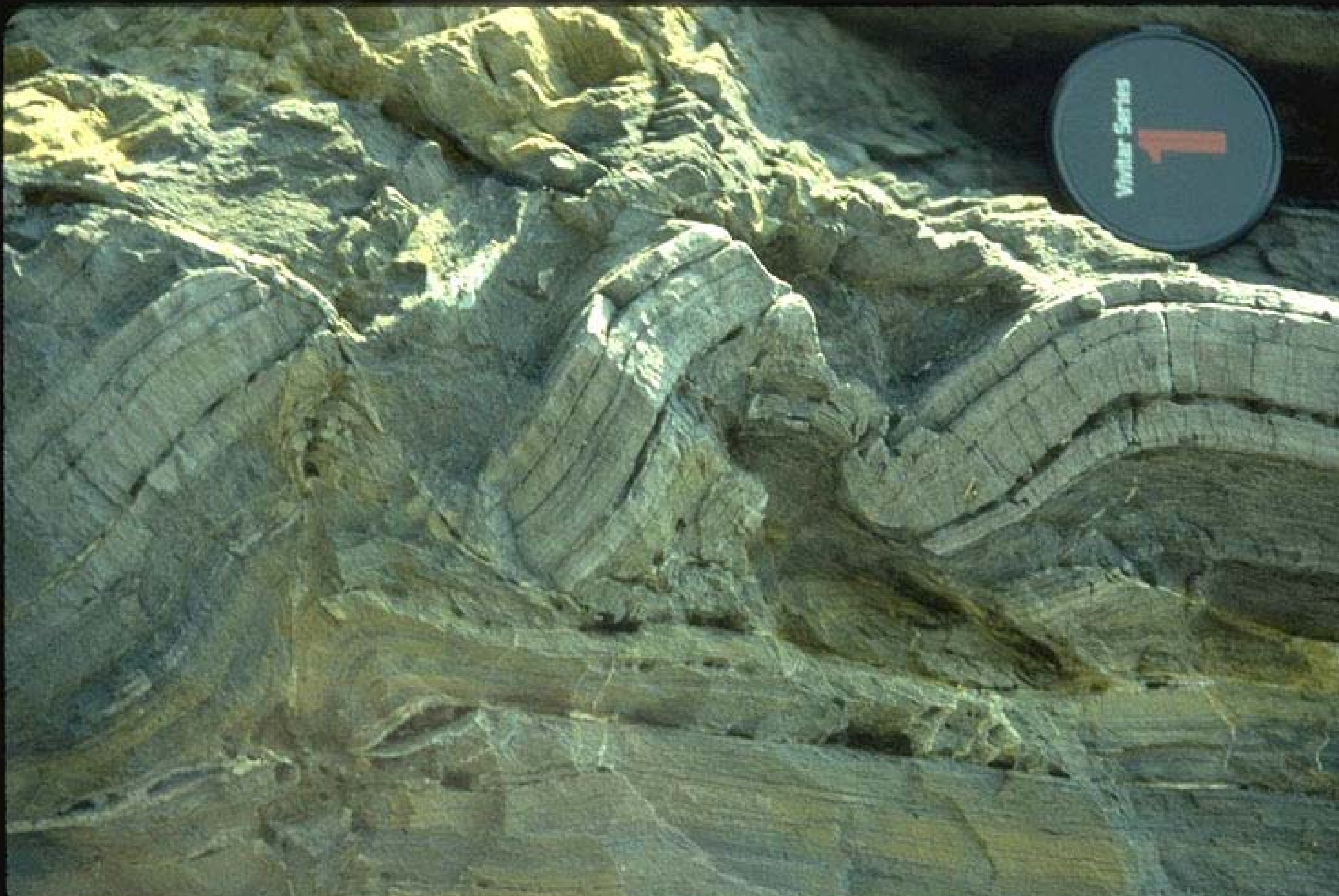


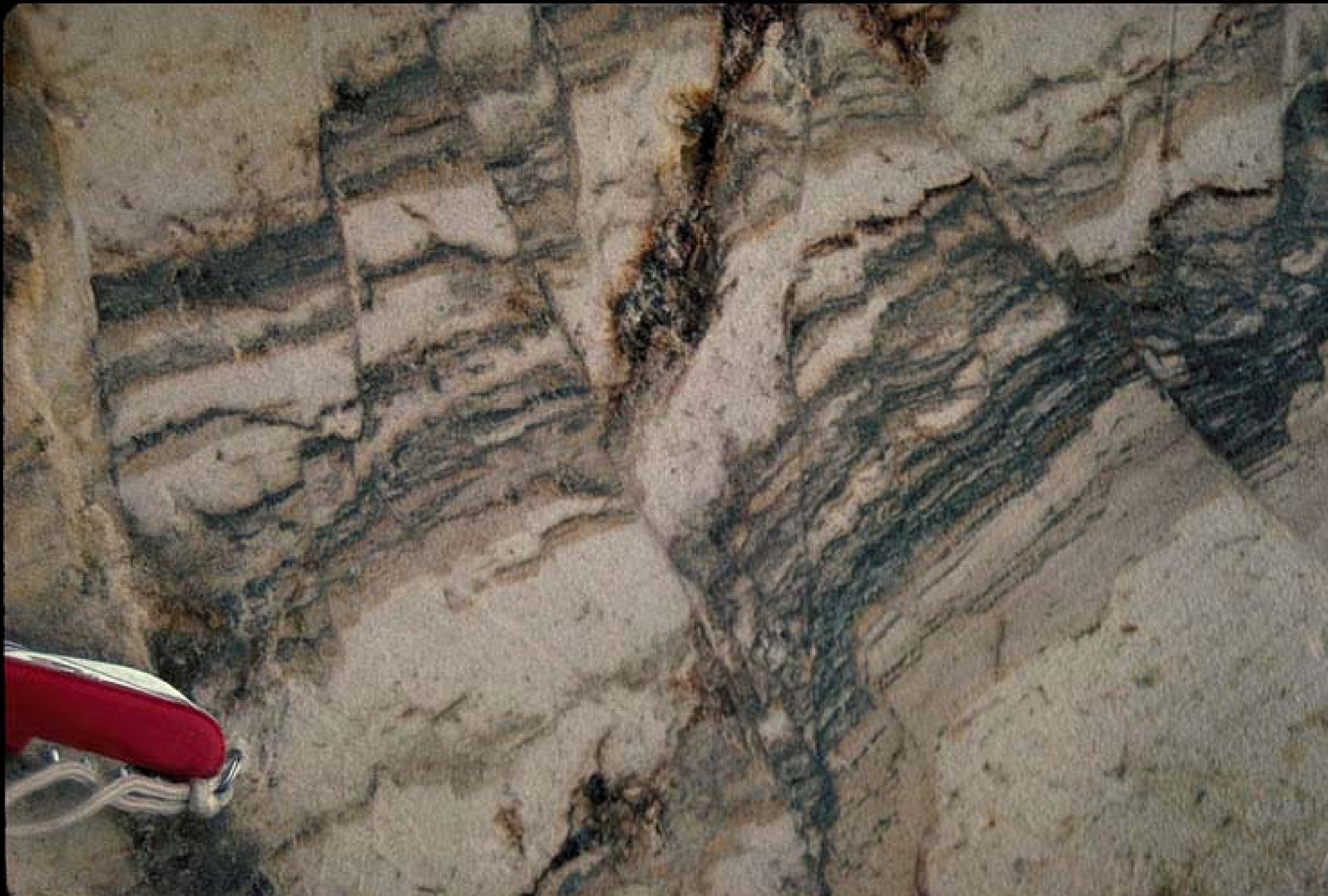
The Mid-Atlantic Ridge in Iceland. Note the fault scarps and tilted fault blocks caused by extension.

Fig. 7.8b. Normal faults produce grabens & horsts

Small scale listric normal faulting caused by gravity sliding. The faults becomes horizontal at depth. Can you recognize the fault planes?



Small scale faulting in soft sediments, both normal and reversed. Notice the horsts and grabens.

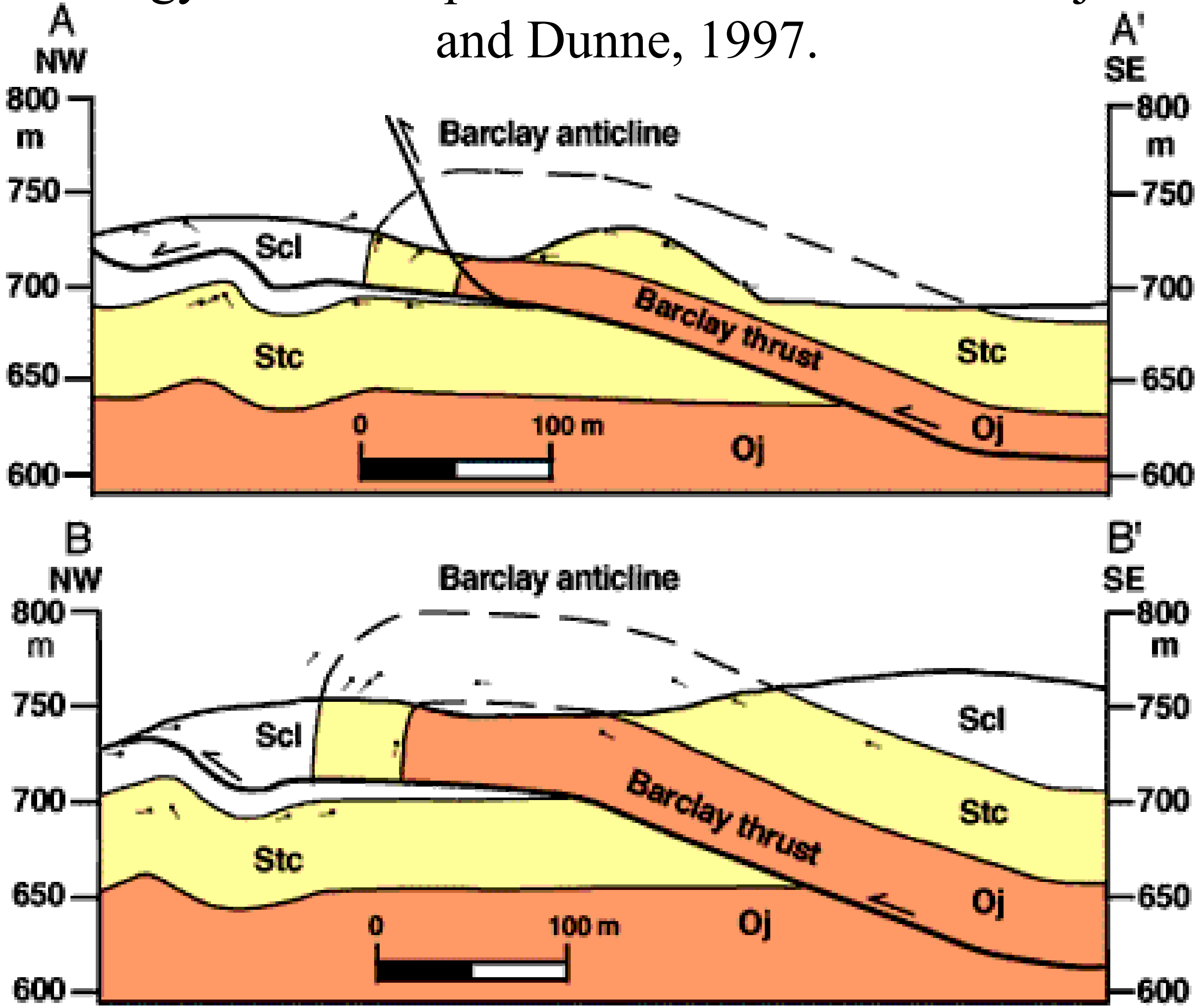


# Thrust faulting

# Types of Thrust Faults

- Fault bend folds - fault forms before the fold; deformation restricted to the hanging wall
- Fault propagation folds - fault forms along with the folding; deformation in both the hanging wall and foot wall

# Example of a fault-bend fold thrust fault at the WVU Geology Field Camp. Cross-sections from Thorbjornsen and Dunne, 1997.



# Fault propagation folds, backthrusts, and pop-up structure. Yukon River near Eagle, Alaska.

# Compression experiment in tectonic modeling lab exercise

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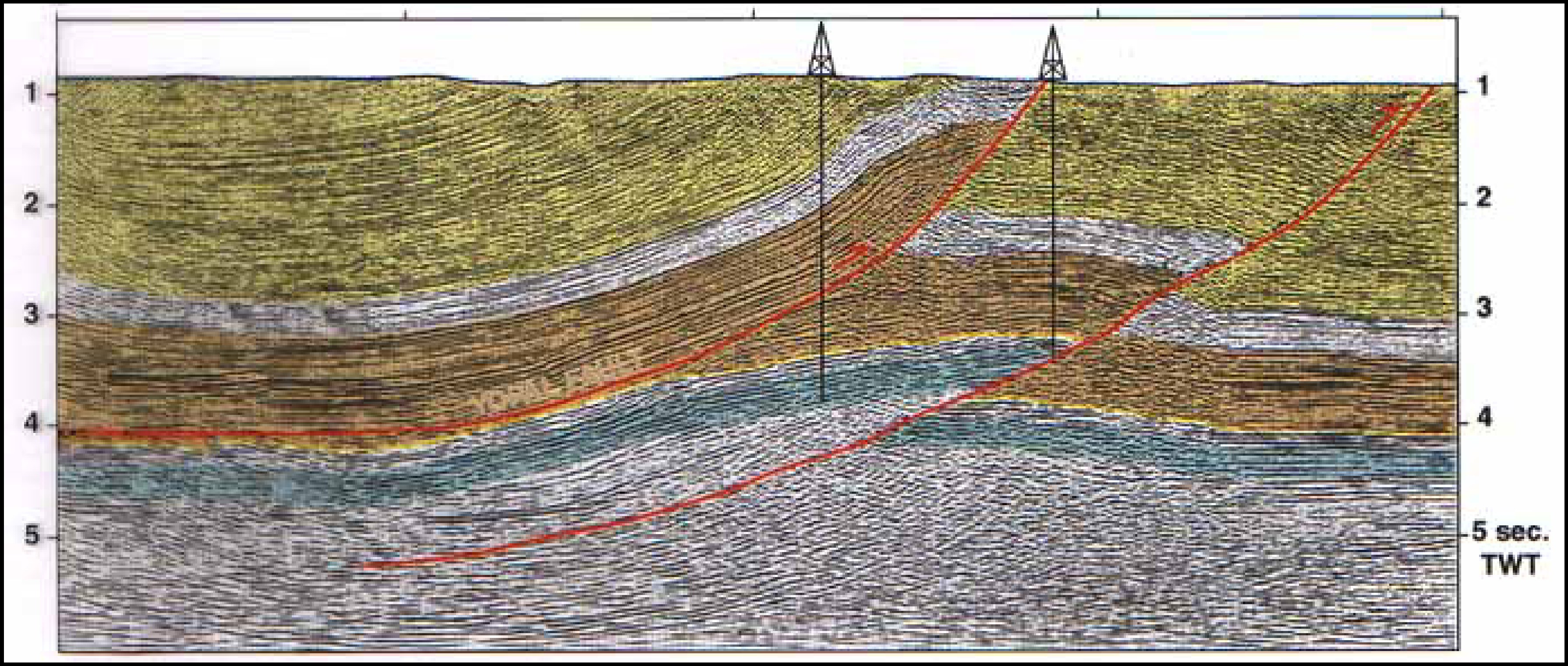
# Thrust faults seen on a seismic line across an oil field.



# Thrust faulting: a fault propagation fold.

Folded soil layer along a lake in Wisconsin caused by thrusting of ice on shore by high winds during spring thaw. Note the formation of the fault propagation fold and the anticline core exposed in the background by a tear fault.

A fault in the Grand Canyon. Precambrian rocks on the left, Paleozoic rocks on the right. What type of fault is this?

Fault scarp along the coast of Wales. What is the direction of motion? What type of fault is this?

# Fault scarp in the California desert. What is the direction of motion? What type of fault is this?

# Strike-slip fault, San Andreas Fault, California

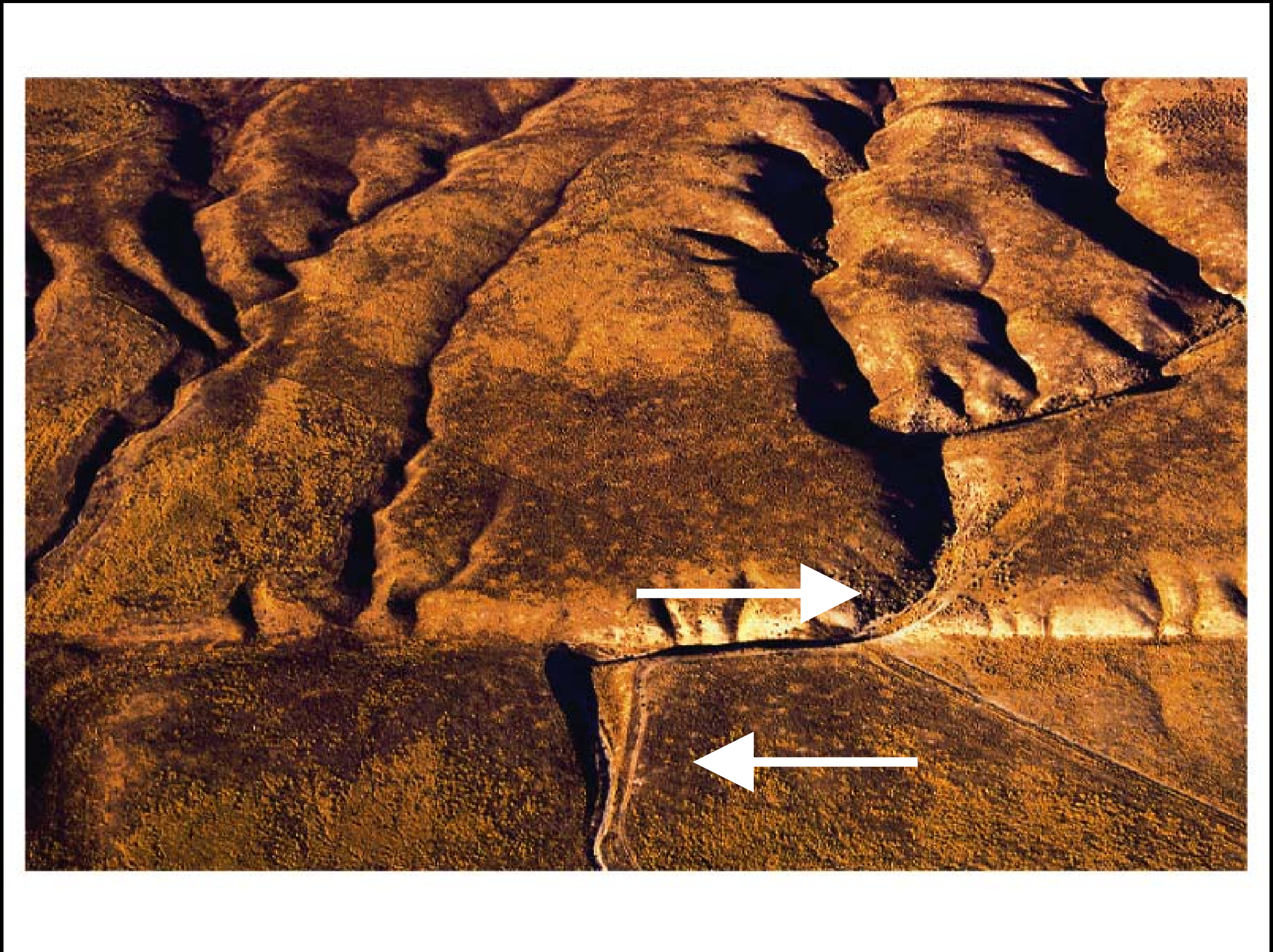
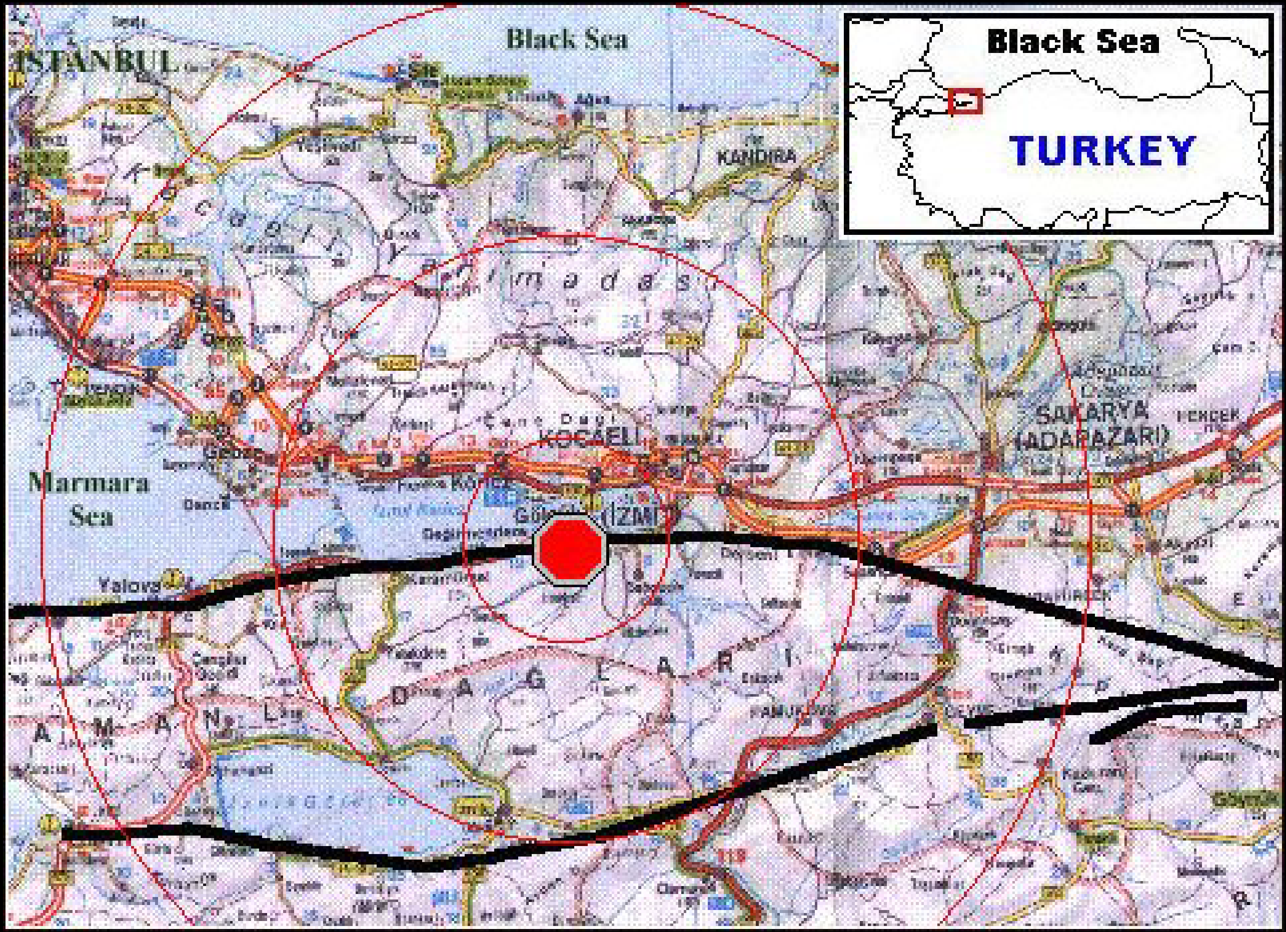


Fig. 7.8e. Strike-slip faults offset drainage, San Andreas Fault, California

August 17, 1999 earthquake in Turkey. 7.8 on the Richter scale.  The fault is a strike-slip fault between the Arabian and European plates.



# August 17, 1999 earthquake in Turkey -- rapid, brittle deformation

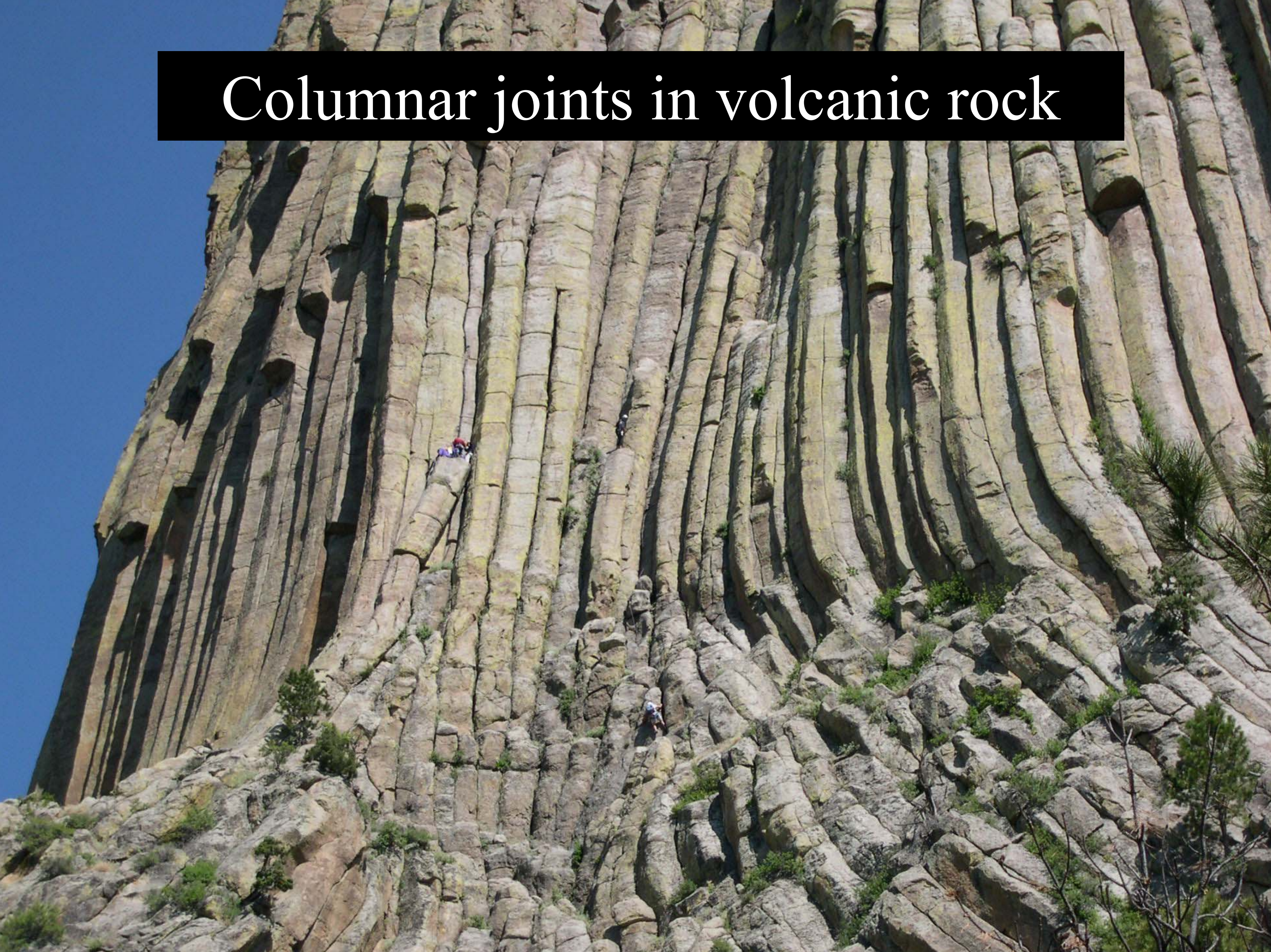
# August 17, 1999 earthquake in Turkey -- rapid, brittle deformation

# Joints

- Fractures in rocks with no appreciable displacement.  They are very common in all rocks.
- Such joints are often zones of weakness where later faults could develop.
- Fluids can travel along joints:  water, petroleum, pollution
- valuable metal ores may form along joints from hydrothermal solutions.

Devil’s Tower, Wyoming

# Columnar joints in volcanic rock



# Exfoliation: horizontal joints formed by sheeting as overburden pressure is released.

# Causes of Rock Deformation

- Stress - pressure placed on rocks
- Strain - deformation of the rock
- Strength - rock resistance to deformation
- Brittle deformation - the rocks break or fracture. Occurs at low temperatures and low pressures.
- Ductile deformation - the rocks bend or flow. Occurs at higher temperature and pressures.

Compression of a rock cylinder: left - uncompressed; center - confined pressure, ductile deformation; right - unconfined pressure, brittle deformation

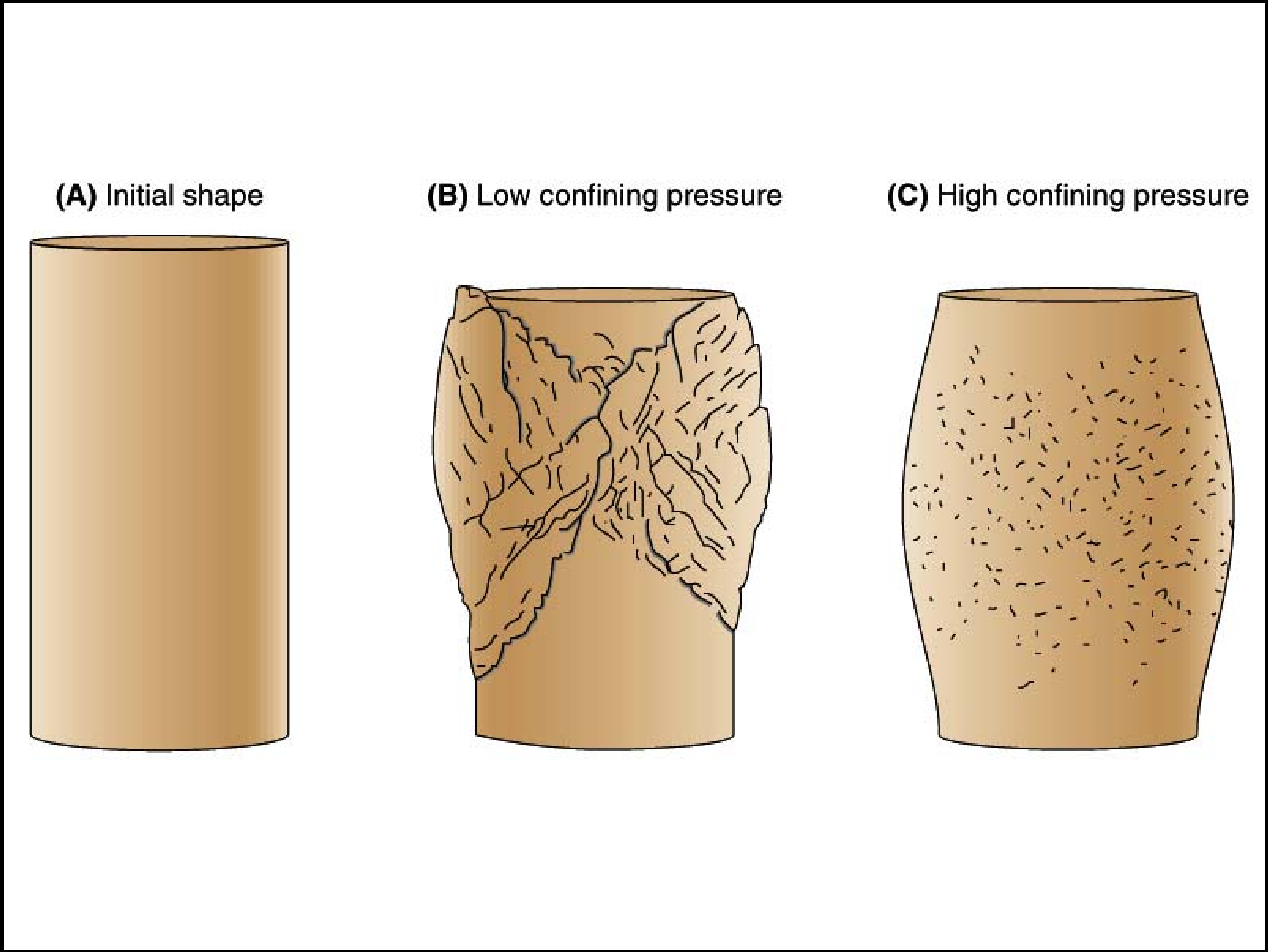



Figure 7.2 – Brittle vs. ductile behavior of rock

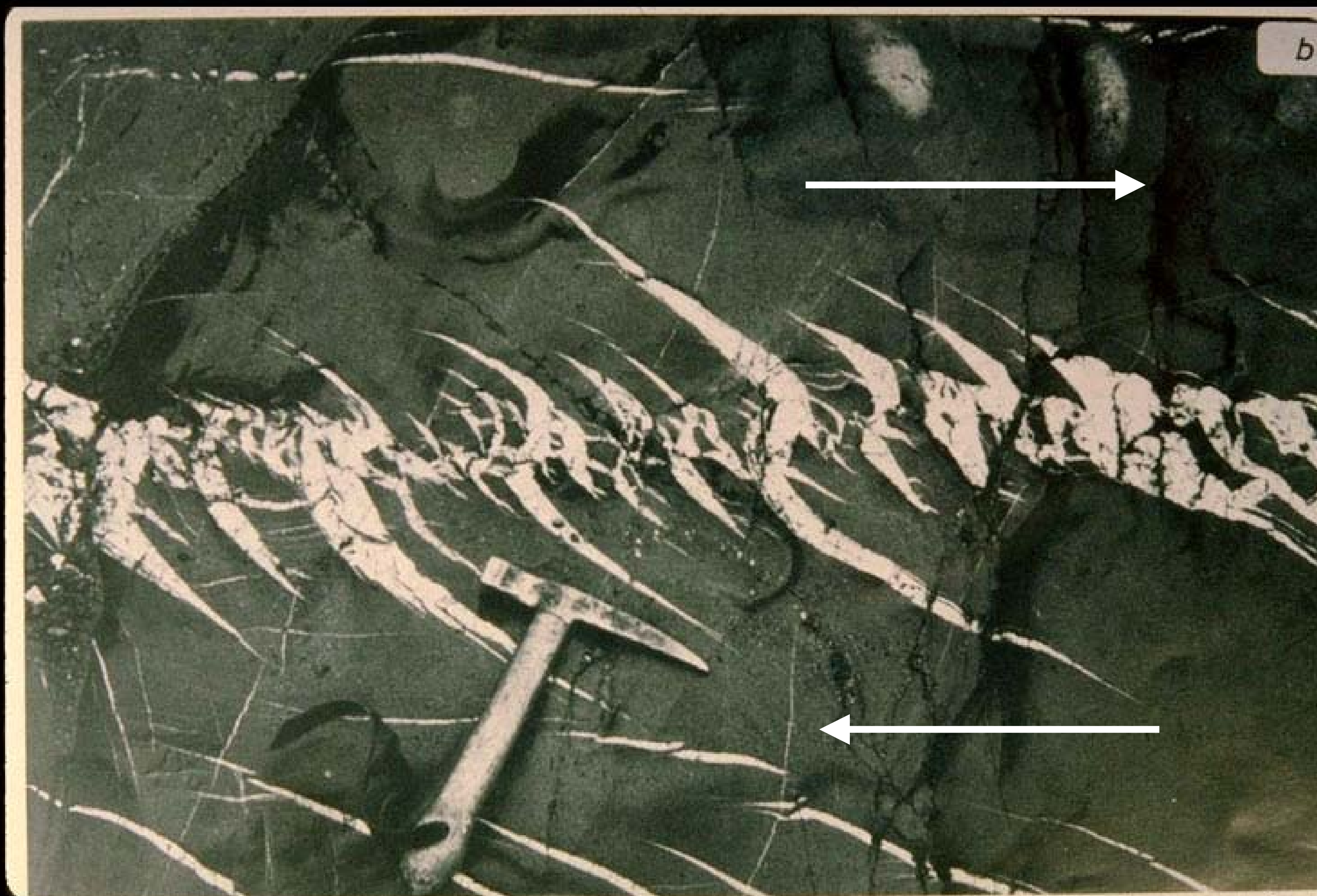
# Strain indicators

- fault offset
- tension gashes
- fractures
- ductile flow

Right-lateral displacement along strike-slip fault, Hayward, CA.  Curb underwent brittle rupture whereas asphalt failed by a series of en echelon tension gashes.

# Tension gashes in limestone filled with calcite. Motion is left lateral. Gashes are S-shaped.

En echelon sigmoidal veins in a brittle-ductile shear zone. Motion is right lateral. Gashes are Z-shaped.



Lithologic control on deformation. The dolostone shows brittle deformation whereas the surrounding limestone was ductilely deformed.

Effect of bed thickness on ductile flow. Thicker bed of limestone folded, whereas thin beds were squeezed out of the fold cores (curved nonparallel folding).

# Boudinage in a granitic sill intruded into schist. An example of ductile flow.