Overview of Structural Geology and Geologic Map Interpretation

I. **Rock Deformation and Structural Geology**- process of rocks becoming physically deformed as they are subjected to tectonic/crustal stress

A. **Plastic vs. elastic vs. brittle deformation of rocks**: rocks may respond to stress in the form of folding like paper (plastic deformation) or fracturing into blocks (brittle deformation) or may deform elastically (i.e. given volume of rock will return to its original size and shape after stress is removed)

1. **brittle deformation** of rocks is rather easy to recognize, analogous to hitting concrete with sledge hammer. Conditions of stress result in fracturing or rupturing of rocks.

2. **elastic**: stress is applied slowly under constant pressure, rocks return to original size and shape after stress is removed.

3. **plastic deformation**: a set of conditions must be met before rocks will deform plastically
   a. relative heat, constant pressure, and time

4. Generally: as stress is applied to rocks at low temp, and low press, rocks will first deform elastically (with ability to return to original size and shape once stress is removed), once the level of stress exceeds the elastic limit of a given type of rock (i.e. the point or strength of a rock, with stress beyond which rock will fail), it will then either deform plastically or brittally.

B. **Folding of Rock Strata**

1. Under components of horizontal stress: flat-lying layers of sedimentary/volcanic rocks may become bent into a series of folds (analogous to pushing and folding sheet of paper).

   a. folding process results in shortening and thickening the crust

2. **Fold Types**

   a. **Anticlines**-upfolded forms, results in older rocks becoming enclosed within younger strata

   b. **synclines**-downfolded forms, results in younger rocks becoming enclosed within older strata.

   c. **symmetrical folds** - both limbs of the fold dipping at same angle away from fold axis

   d. **asymmetrical folds** - both limbs of the fold not dipping at same angle away from fold axis
   e. **overturned folds** - one limb of fold has been tilted beyond vertical

f. **plunging folds**- axis of fold is tilted

g. **Domes**- more or less circular equivalent of anticline, oldest rocks exposed in center of dome

h. **Structural Basin**- more or less circular equivalent of syncline, youngest rocks exposed in center of dome (not to be confused with depositional basin)

3. **Outcrops Patterns Associated with Folded Rocks**

a. As rocks are folded, and subsequently subjected to erosion, regular patterns become evident in relation to type of rock that outcrops and age of the rock that outcrops in an area of folded strata. In essence, erosion exposes the interiors of the folds

b. **Non-plunging Folds**- axis of fold is horizontal, results in parallel bands of dipping strata about the fold axis

(1) anticlines- oldest strata exposed along fold axis

(2) synclines- youngest strata exposed along fold axis

c. **Plunging Folds**-axis of fold is tilted, results in alternating V-shaped bands of dipping strata oriented about the fold axis.

(1) anticlines- oldest strata exposed in the center of the V, V points in direction of plunge of fold axis

(2) syncline- youngest strata exposed in the center of the V, V points in opposite direction of plunge of fold axis.

d. **Doubly Plunging Folds**- fold axis is plunging in two opposite directions, results in a flattened oval pattern, or a double V-shaped pattern <<<>>>>.

(1) anticlines- oldest strata exposed in center of flattened oval

(2) synclines-youngest strata exposed in center of flattened oval.

C. **Faulting and Related Structures**

1. **Faults** - fractures within the earth's crust along which movement or offset of crustal blocks has occurred.

a. **Dip-slip faults**- movement is vertical down the plane of the fault, movement along the inclination or dip of fault plane hence "dip-slip".

b. **Normal Faults**-faults in which crustal block above the fault plane (hanging wall) move down relative to crustal block below the fault plane (foot wall)

c. **Reverse Faults**- faults in which crustal block above the fault plane (hanging wall) moves up relative to crustal block below the fault plane (foot wall).

   (1) **Thrust Fault**- reverse fault with very low angle, or very gently inclined (<30^o) fault plane.

      (a) associated with strong, horizontally oriented, compressional stresses.

d. **Strike-slip faults**- movement along fault is horizontal along the fault (similar to notion of transform faults in plate tectonics), i.e. offset is parallel to the trend or strike of the fault plane.

   (1) **Strike** - the trend or compass direction of the line formed between the intersection of a horizontal plane with any inclined plane.

e. **Oblique-slip faults**- faults which have both vertical and horizontal components of movement.

2. Stress Regimes and Style of Faulting

a. Reverse/Thrust Faults- often associated with compression or squeezing of crustal blocks, rupture results when stress>strength of rocks. E.g. in association with convergent tectonic zones.

b. Normal Faults- associated with "pulling apart" or tensional forces exerted on crustal blocks. E.g. in association with rift zones or spreading centers in plate tectonics.

   (1) Grabens- crustal block bounded by two inward-dipping normal faults, crustal block downdrops to form a graben.

   (2) Horst- relatively uplifted crustal block flanked by two adjacent grabens.

3. **Joints**-in contrast to faults- fractures along which no appreciable movement has taken place.

a. joints - accommodate stress during tensional and shear stresses associated with crustal movements.

b. joints often occur in very low-stress regimes, with broad, gentle warping of earth's crust.

c. joints often serve as sights of enhanced weathering processes, may result in streams and rivers following their trends.

II. Continental Tectonic Landform Units

A. Craton- low-relief core of continent

1. **Cratonic Shields**: complexly deformed and metamorphosed crystalline basement rocks, generally of Precambrian age

    a. E.g. Canadian Shield = Precambrian granitic core of North America

    b. **Stable Platform**: sedimentary cover overlying Cratonic Shields

        (1) "Stable" = relatively undeformed/broad upwarping

B. **Folded Mountain Belts** (aka "complex mountains")

1. Mountain relief a result of erosion and dissection of portions of the earth's crust that has been folded and thickened.

    a. Product of tectonic convergence

2. Fold belts are also commonly associated with faulting, metamorphism, and igneous intrusion; although folding is the most conspicuous deformation style.

    a. E.g. Alps, Himalaya's, Appalachian Mountains

C. **Fault-Block Mountains**

1. Associated with erosion and dissection of portions of the earth's crust that has been displaced and tilted along high-angle normal faults (in association with tensional stresses)

2. E.g. Basin and Range Province of Nevada, Utah, Eastern CA, SE Oregon, AZ.

    a. Often associated with precursory volcanic activity.

D. **Continental Rift Zones**

1. Zones of continental extension and pull-apart (rifting) of crust

    a. Sites of intense extensional faulting and pursuant volcanism

    b. represents early stage of oceanic spreading center development

        (1) "Pangaea" breakup initiated by continental rifting, with subsequent evolution of seafloor spreading centers

2. **"Triple Point Junctions"**: rift geometry is such that triple fracture systems radiates outward from central locus of stretching
   a. E.g. Red Sea-East Africa-Afar Triangle Triple Point

3. **Aulacogens**: failed arms of rift systems
   a. Rift process initiated, however one or more rifts in triple-point junction fail to successfully undergo continued extension
      (1) E.g. Gulf Coast-Mississippi Valley Rift/Aulacogen System

E. **Upwarped Mountains**
   1. produced in association with broad arching or upwarping of the crust or of vertical uplift along high angle reverse faults.
      a. e.g. Black Hills of S.D. and Adirondack Mtns. of NY e.g. of broad arching or uplift

   2. Rocky Mtns of CO, NM result of vertical uplift, leave front range in which mantle of sed. rocks are tilted upward along high angle faults.
      a. results in hogbacks or flat-irons of front range

F. **Volcanic Mountains**
   1. Volcanic Arc Complexes
      a. Linear volcanic mountain chain formed on over-riding plate of subduction complex
         (1) e.g. Andes, Cascades

   2. "Intraplate" Volcanic Complexes
      a. Hawaii Hot Spot
      b. Yellowstone Hot Spot
      c. Extensional-volcanism of SW U.S.

   3. "Leaky Transform" volcanic systems
      a. volcanism associated with transform faulting
         (1) e.g. New Zealand

III. **GEOMORPHOLOGY OF FOLDED TERRAIN**: BEDROCK ATTITUDE AND LANDFORMS

A. Controlling Factors
   1. Rate of Crustal Deformation
      a. Influenced by Tectonic Process
      b. Measured deformation rates: avg. 5-20 mm/yr
   2. Three-dimensional Geometry of Rock Structure
      a. Influenced by Stress-Strain Relationships
   3. Differential Erosion of Rock
      a. Influenced by climate, rock type and structural weakness
         (1) e.g. Sandstone = resistant, Shale = nonresistant

4. Balance Between Deformation and Erosion
   a. If rate erosion < rate deformation....
      (1) Topographic Form = Structural Form
         (a) e.g. Anticlinal Ridges: topographic and structural highs
         (b) Synclinal Valleys: topographic and structural lows

   b. If rate erosion > rate deformation....
      (1) Structural Form Modified by Erosion
         (a) Topographic and Structural Relationships Dependent on 3 controlling factors above

B. **Differential Erosion, Rock Structure and Topographic Expression**

1. **Differential Erosion**: variable rates of rock weathering associated with resistance of rock to weathering

   a. Non-resistant Rocks: easily etched and eroded in landscape
      (1) e.g. Shale, Limestone (humid climates): commonly underlies valleys/lowlands
   b. Resistant Rocks: resistant to weathering and erosion
      (1) e.g. Conglomerate, Sandstone, Limestone (in arid climates): commonly ridge formers, standing resistant to erosion
      (2) Others: Quartzite, chert, lava flows, sills, dikes

   c. Stream/Erosion Patterns: conform to rock resistance to erosion

2. **Topographic Expression: Flat-rock and Homogeneous Terrain**
   a. Characterized by uniform resistance to erosion
   b. Dendritic Drainage Patterns Commonly Developed
      (1) Uniform Distribution of Erosional Topography

   c. Landscape Dissection: vertical down-cutting
      (1) **Cliff and Bench Topography:** Grand Canyon like topography
         (a) sharp cliffs punctuated by flat topographic benches
            i) Benches formed by resistant rock
            ii) Common in arid climates
            iii) Flat-rock country
            iv) Parallel slope retreat over time
               a) Resistant benches "undermined" by erosion of less resistant rock, with subsequent collapse and slope retreat.

         (b) Humid Climate: "cliff and benches" subdued with rounded hillslopes, thick weathering profile, vegetation, creep

      (2) **Butte and Mesa Topography:** common to Cliff and Bench Terrain

         (a) Butte: rounded flat-topped erosional remnants
         (b) Mesa: elongated, table-like, flat-topped erosional remanents
            i) Product of differential erosion, parallel slope retreat,

and resistant cap rock.

3. **Topographic Expression of Tilted Strata**

a. Homoclinal Structure: Homo = same, Cline = inclination; homoclinal structure = uniformly tilted beds

(1) Differential Erosion Processes: Strike and dip of homocline provide preferred directions of weakness, and hence preferred directions of stream orientation

(a) Selective Headward Erosion: cuts "strike valleys" along non-resistant rock layers

(b) Resistant Strata: "strike ridges" standing above valleys

(c) Net Result: Topography of parallel ridges (resistant strata) and valleys (non-resistant strata)

(2) Homoclinal Ridges: erosionally-resistant "strike ridges" in tilted rock terrain

(a) Asymmetric Cross-Sectional Ridge Profile

i) Scarp Face: more steeply inclined "bed" face

ii) Dip Slope: topographic slope formed along dip-plane or bedding plane of resistant unit

(scarp faces > steepness than dip slopes)

b. Cuestas: homoclinal ridges formed in gently tilted homoclinal sections

(1) $<25\text{-}30^{o}$ dip

c. Hogbacks: homoclinal ridges formed in more steeply tilted homoclinal sections

(1) $>30\text{-}40^{o}$ dip

d. Homoclinal Stream Shifting: as initial streams begin cutting rock on newly formed homoclinal surface, down-cut the more easily eroded layers (e.g. shale) along strike.

(1) Vertical Limit of Downcutting: underlying resistant bed

(2) Dip-slope forces streams to "shift" laterally down dip laterally carving the more easily eroded strata

e. Erosional Retreat of Homoclinal Ridge

(1) Scarp-face Retreat: because scarp faces are more high angle than dip slopes, the scarp face is more energetically eroded over time

(a) Scarp face retreats laterally in down-dip direction

(2) Homoclinal Shifting: homoclinal valleys migrate laterally in down-dip direction, and vertically along dip slope

(3) V-shaped Notches
(a) Where streams incise homoclinal ridges perpendicular to strike, via headward erosion, V-shaped notches are cut through the scarp face

(b) Law of V's: In the case of a v-shaped notch, the apex of the "V" points down dip in the direction of dip.

(4) Determining Angle of Dip in Homoclinal Topography
(a) Examine contour pattern along dip slope

(b) Dip = topographic slope of dip slope
i) Dip = Slope = rise/run = vertical relief/horizontal distance

ii) Tan (theta) = V/H; where theta = dip angle
a) "Inv" Tan (V/H) on calculator = dip angle

4. **Topographic Expression of Folded Strata**: Processes and forms of eroded structural folds

a. Anticlinal Ridge: structural anticline mirrored in surface form of a ridge or hill

(1) "Unbreached" anticline: resistant folded layers undissected along axial plane of fold

(2) "Breached" anticline: folded layers along axial plane of fold are incised by erosion and down-cutting streams

b. Anticlinal Valley: Breached anticline- structural anticline eroded in form of topographic valley along axis of fold

(1) result of easily eroded lithologies along axial plane of fold

(2) Topographic Inversion- sense of structural relief opposite of that of topographic relief

(a) e.g. Anticlinal Valleys, Synclinal Ridges

c. Synclinal Valley: sense of structural relief = sense of topographic relief

d. Synclinal Ridge: topographic ridge formed along axis of syncline

(1) Result of erosionally resistant strata along axial plane of fold, with easily eroded strata on flanks

e. Non-plunging Fold Patterns

(1) Parallel sets of hogbacks oriented symmetrical about fold axis
(a) Anticlines: oldest strata exposed along axis
(b) Synclines: youngest strata exposed along axis

(2) Scarp face and dip slope relations apply as above

f. Plunging Folds and "Zig-Zag" Mountains

(1) Plunging Folds result in alternating V or Zig-Zag shaped topography
(a) Plunging Anticlines
i) Homoclinal ridges converge to apex in direction of plunge
ii) "V" of pattern points down plunge

(b) Plunging Synclines

i) Homoclinal ridges diverge in direction of plunge, converge in "up plunge" direction
ii) "V" of pattern points up plunge

g. Monoclinal Structure: structures in which strata dip in one direction, but displays local steepening and flattening of dip along "monoclinal flexures".

5. **Stream Development and Geologic Structures**

a. Consequent: stream patterns formed synchronously as beds are tilted, and drainage flows in direction of dip
(1) Stream courses are "consequence" of initial slope of surface

b. Subsequent: stream pattern developed in accordance to erosional resistance of folded or tilted strata.
(1) Form "subsequent" to structural deformation

c. Antecedent: streams maintain stream course (pattern) that was established prior to structural deformation (unaltered by deformation patterns)

(1) e.g. Susquehana River cutting through Valley and Ridge near Harrisburg
(a) Entrenched meander pattern cutting through Valley and Ridge

IV. **GEOMORPHOLOGY OF FRACTURED TERRAIN:** JOINTING, FAULTING AND LANDFORMS

A. Jointing

1. Fractures along which no movement has occurred
    a. Brittle rock deformation
        (1) crustal (tectonic) stress
            (a) Tensional stress (pull apart)
            (b) Compressional stress (squeezing)
            (c) Shear stress (sliding motion)

        (2) shrinkage/cooling phenomena (volcanics)

        (3) Occurs in all rock types
            (a) Degree of fracturing function of:
                i) rock type
                    a) Sandstone: brittle, readily fractured, heavily influenced by joint patterns

                    b) Shale: less brittle, undergoes more "plastic" or pliable deformation, does not readily display joint patterns

                    c) Crystalline igneous and metamorphic rock: brittle and readily displays joint deformation

                ii) strength (resistance to breaking)
                iii) degree of stress

            (b) Geometry of fracturing function of:
                i) stress orientation
                    a) Tensional Stress: fractures form perpendicular to direction of maximum tension

                    b) Shear/compressional stress: fractures form within 30-45 degrees of maximum compression direction
                    i) Conjugate joint sets

                ii) Secondary jointing
                    a) secondary by-product of rock folding

B. Topographic Expression of Joints (Paths of Least Resistance)

1. Joints: represent fractures and zones of weakness easily exploited by the weathering and erosion process (physical and chemical)
    a. Avenues of increased permeability and chemical weathering
    b. Differential erosion phenomena

2. Joints provide sites of weakness and erosion: strongly influence stream erosion patterns

   a. Rectangular Drainage Patterns
   b. Angular Drainage Patterns

3. Joints Identified from maps and air photos
   a. "joint" lineaments: linear, geometric patterns observable in map analysis
      (1) Identifiable by:
         (a) geometric drainage patterns
         (b) vegetative growth patterns
         (c) Linear "topographic grain"

C. Faulting

1. Erosional Phenomena
   a. Faults represent relatively narrow, linear zones of crustal deformation
      (1) Zones of lithologic weakness

      (2) Avenues of enhanced physical and chemical weathering
         (a) Differential weathering phenomena

2. Scarps: word derived from "escarpment" which represents a sharp inclination in topographic grade

   a. Fault Scarps: escarpments along fault zone that result from direct offset of land surface by fault movement
      (1) Linear form in plan view

      (2) May erosionally degrade with time
         (a) Further tectonic deformation will rejuvenate scarp

   b. Fault Line Scarps: escarpments along fault zone that result from differential erosion of rocks of contrasting resistance juxtaposed by displacement
      (1) Less resistant rock: rapid erosion
      (2) More resistant rock: comprises scarp-face

   c. Composite Fault Scarp: combination of processes of direct land displacement and differential erosion

3. Fault Displacement and Fault-Scarp Geomorphology
   a. Structural Morphology and Processes
      (1) Land Displacement
         (a) Fault offset creates scarp, linear front to uplifted mountains

i) Land displacement: instantaneous rupture of ground surface, offset of rock and/or unconsolidated surface materials

a) accompanied by earthquake/seismic activity

b) Single event scarps range from inches to feet to 50 Ft of vertical offset of land surface

(2) Fault Splays: displacement along interwoven network of fault strands

(3) Fault Slices: en echelon offset along sets of parallel faults
(a) aka "step faulting"

(4) Fault Segmentation and Differential Stress
(a) Faults of any significant length, rarely undergo uniform offset along entire lengths

i) Differential stress distribution along fault zone results in differential displacement at various geographic locations and times.

ii) Fault may become segmented into definable linear domains which may become active and inactive according to stress-strain relationships

(5) Earthquakes: fault rupture and offset is most common cause of earthquakes and seismic activity; related to brittle deformation and "elastic rebound" of rock material immediately following rupture

(a) Slope failure: quake-related seismic activity (ground shaking) may trigger slope failure and mass wasting activity (slumping, earthflow, liquefaction)

(b) Tsunami: "seismic sea waves" formed from the passage of seismic waves through ocean water

b. Fault Scarp Landforms

(1) Triangular Facets: headward erosion results in V-shaped valleys cut through the fault scarp

(a) Rock remanents left between erosional valleys form triangular-shaped faces (or "facets") of rock exposed along the fault scarp

(b) Erosion over time will result in degrading the fault scarp and facets (youth-mature-old age progression)

i) Renewed uplift/offset on fault will result in rejuvenating the fault-scarp geomorphic topography

(2) Scarp-notches-"Wineglass" structure

(a) Streams transecting the displaced fault zone impacted by relatively instant changes in local base level and development of displacement-related knickpoints

i) Streams draining from upthrown block, down scarp, erode "hanging valleys", create water falls, and erode to form a Y-shaped cross-sectional profile

(3) Drainage Disruption

(a) Land displacement associated with faulting may cause local damming of drainage systems, resulting in ponding and establishment of local base level

(b) Fault-sag ponding: fault zones commonly form low-lying zones via differential erosion, may form sites of elongated ponds, and linear series of ponds along length of fault zone

(4) Spring Development

(a) Linear, aligned springs commonly form along fault zone

(b) Spring formation result of:

i) Creation of zone of high permeability fault breccia through which groundwater may reach the surface

ii) Juxtaposition of high permeability and low permeability rocks along fault zone, forcing groundwater to surface as spring

(5) Surface Uplift/Marine Terracing

(a) Erosion Surfaces

i) Wave-cut terraces and stream terraces may become displaced by fault offset

ii) Uplift of land surface results in elevating the erosional surface above active level of erosion

4. Scarp Erosion: Fault-Line Scarp Geomorphology

a. Differential Erosion: fault-line scarps form from differential erosion of less resistant rock along fault zone

b. Fault Scarp Degradation with Time

(1) Free Faces: steep initially formed fault scarps of 45-90 degrees

inclination

(2) Progressive erosional degradation via erosion-mass wasting processes
  (a) debris fall
  (b) slope wash

(3) Time-dependent degradational process
  (a) Scarp height diminishes with time
  (b) Scarp slope lessens with time

(4) Can be quantitatively defined via detailed topographic profiling across fault scarps
  (a) Semi-log regression establishes time-decay relationships
    i) function of initial scarp slope, time, vegetation, climate, material

c. Stages of Fault-line Scarp Erosion

(1) Stage 1: Initial Offset- Height of fault scarp = height of fault-line scarp, erosionally degradation of scarp little to non-existent

(2) Stage 2: Scarp-front retreat via headward erosion, retreat of fault-line scarp away from fault and line of rupture (Fault scarp does not equal fault-line scarp)

(3) Stage 3: Obsequent Fault-line Scarp: uplifted block eroded below grade of downthrown block, fault-line scarp dips in direction opposite that of original fault plane

(4) Stage 4: total degradation and erosional flattening of scarp, no to little relief along fault zone

(5) Stage 5: Resequent Fault-line Scarp: rejuvenated uplift along fault, fault-scarp rejuvenated, however rocks offset along fault are from lower stratigraphic position

5. Block Fault Topography: essentially fault-bounded mountains and lowlands of the Basin and Range Province
  a. Fault-Block Mountains: fault bounded uplift along mountain fronts, alternating with fault-bounded down-dropping of structural basins
    (1) Up to thousands of feet of fault displacement

      (a) e.g. Teton Range, WY; Sierra Nevada, Calif., Sandia Mountains of NM.

    (2) Fault Segmentation: Segmented Mountain Fronts

      (a) Uplift along fault-bounded mountain front not an exact or constant process, scarp-front evolution proceeds as differential tectonic deformation as stresses are distributed sporadically along mountain front according to stress-strain conditions

b. Horst and Grabens
   (1) Horsts: Uplifted fault blocks

   (2) Grabens: Down-dropped fault blocks
      (a) Half-grabens: asymmetric faulting on one side of graben

      (b) Tilted Fault-block Mountains: asymmetric faulting on one side of mountain block

c. Strike-slip Faults: primary sense of displacement is horizontal, along strike of fault plane (e.g. San Andreas Transform Zone)

   (1) Recognition
      (a) Offset Streams
      (b) Sag Ponds
      (c) Mismatched topography/bedrock with intervening lineament

   (2) Transpression and Transtension

      (a) Oblique strike slip motion with components of tension and compression accompanying strike slip motion

         i) Transpressional mountains: uplifted blocks and slivers within strike-slip fault zone (e.g. Transverse Ranges of Southern Calif.)

         ii) Transtensional Basins: down-dropped blocks and slivers within strike-slip fault zone (e.g. San Gabriel Basin of Southern Calif... associated with oil and gas entrapment)

d. Thrust Faults: low-angle reverse faults, < 30 degrees dip

   (1) Commonly occurring as low-angle thrust sheets, faults may be flat to undulating to gently dipping

      (a) Displacements along thrust sheets may be up to 10's to 100' of miles

         i) Result of highly detached, low friction fault zone

         ii) Extreme compressive tectonic force

         iii) Divided into:
            a) Upper Thrust Sheet: above fault
            b) Lower Thrust Sheet: below fault (floor)

(b) May be accompanied by secondary drag folding and general fold deformation

(c) e.g. Northern Rocky thrust sheets of Montana

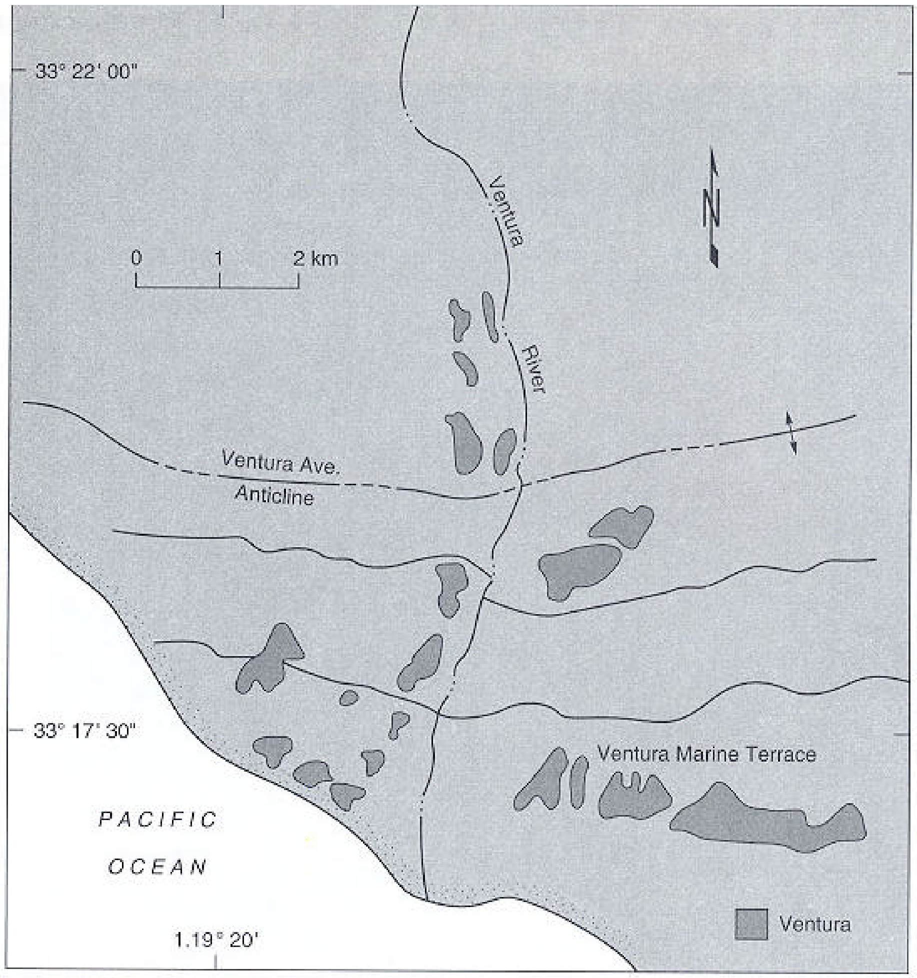
(2) Klippes: erosional remnants of Upper Thrust Sheet, stranded and surrounded by rocks of lower thrust sheet

(a) base of klippe marks location of thrust fault

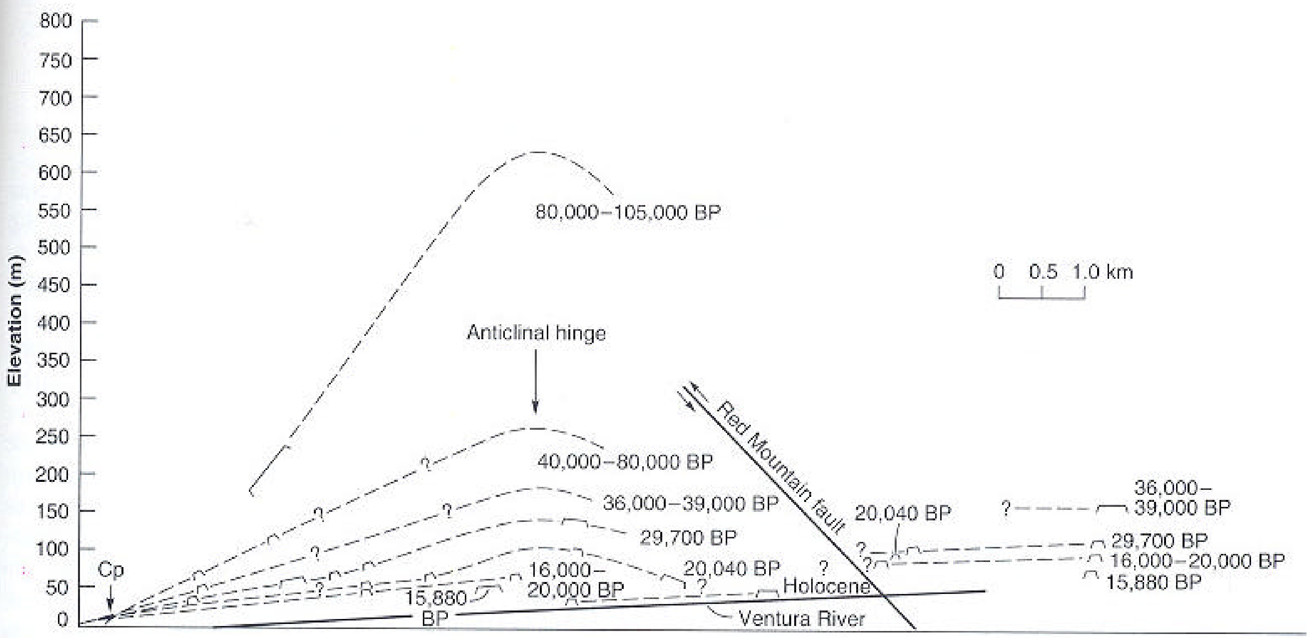
(b) e.g. Chief Mountain, Montana

(3) Fensters: erosional windows cut through Upper Thrust Sheet, showing rocks of lower thrust sheet surrounded by rocks of upper thrust sheet.

FIGURE 9–1
Anticlinal ridge cut by an antecedent stream, the Yakima River, cutting across Umtanum Ridge, Washington.



A.



B.

FIGURE 9–2
(A) Map of the Ventura anticline, (B) cross section of the Ventura anticline showing rates of movement. (From Rockwell et al., 1988)

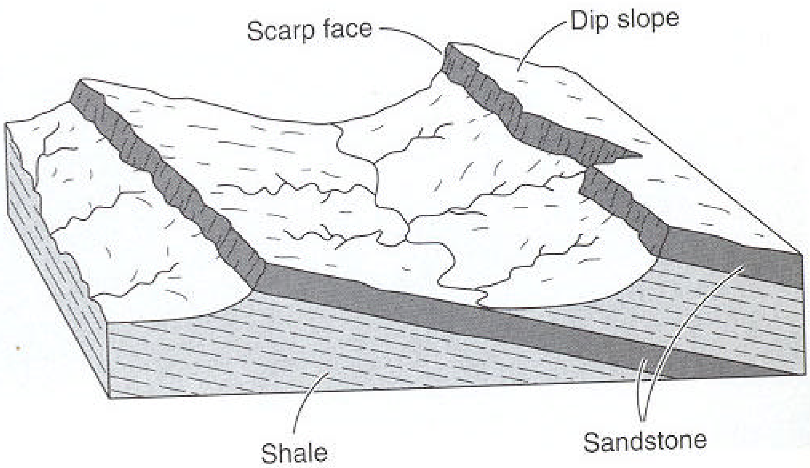


FIGURE 9–5
Adjustment of topography to geologic structure.

FIGURE 9–10
Plunging anticline, Sheep Mountain, Wyoming.

Another method of establishing geologic structures is by **projection of known dip** along the strike of one part of a complexly folded area to permit determination of an entire set of folds. For example, Figure 9–16 shows a complexly folded area in the Appalachian Mountains. Analysis of the structure may be made by examining critical localities. At X, the tapering nose of the structure indicates that it is a plunging anticline. Thus, the bed making the ridge diagonally across the photo to the southwest must dip to the southeast, away from the axis of the anticline. At Y, the short, blunt nose of the structure is diagnostic of a synclinal plunging to the northeast. Projection of dips along the strike from the known points then allows determination of dips of all of the beds making up the linear ridges.

The bowing up of **domes** or elliptical folds may be accomplished either by tectonic warping or by intrusion of material from below. In either case, the resulting landform in initial stages is an oval-shaped hill or mountain. Until

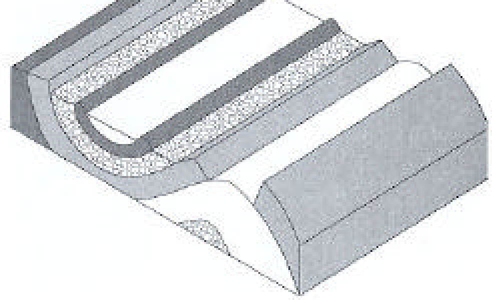


FIGURE 9–11
Topographic expression of nonplunging folds.

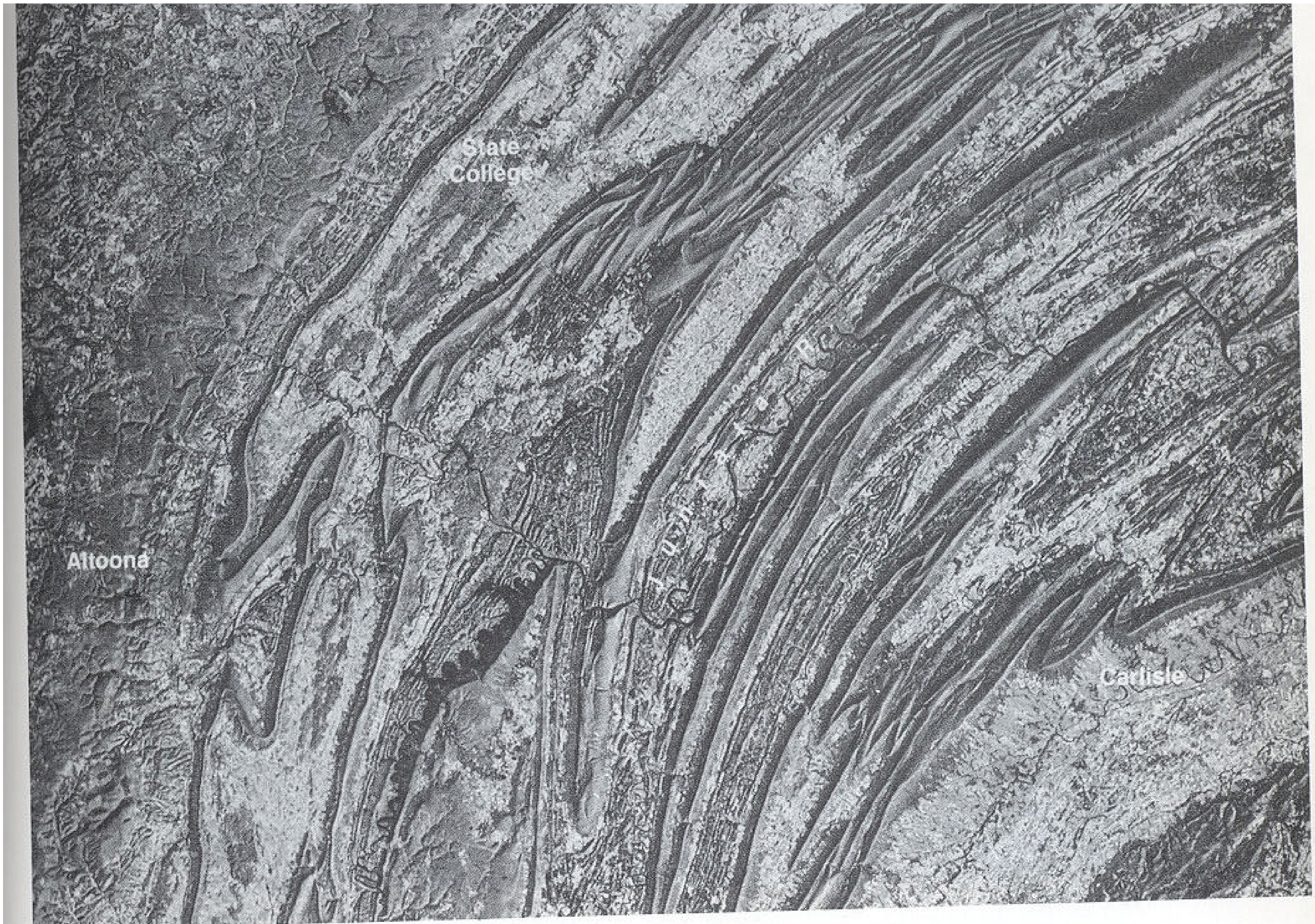


FIGURE 9–16
Plunging folds, Appalachian Mountains, Pennsylvania. (Enhanced NASA photo, Earth Satellite Corp.)

FIGURE 9–25
Susquehanna River cutting across ridges of folded Paleozoic beds, Appalachian Mountains. (Enhanced NASA photo, Earth Satellite Corp.)

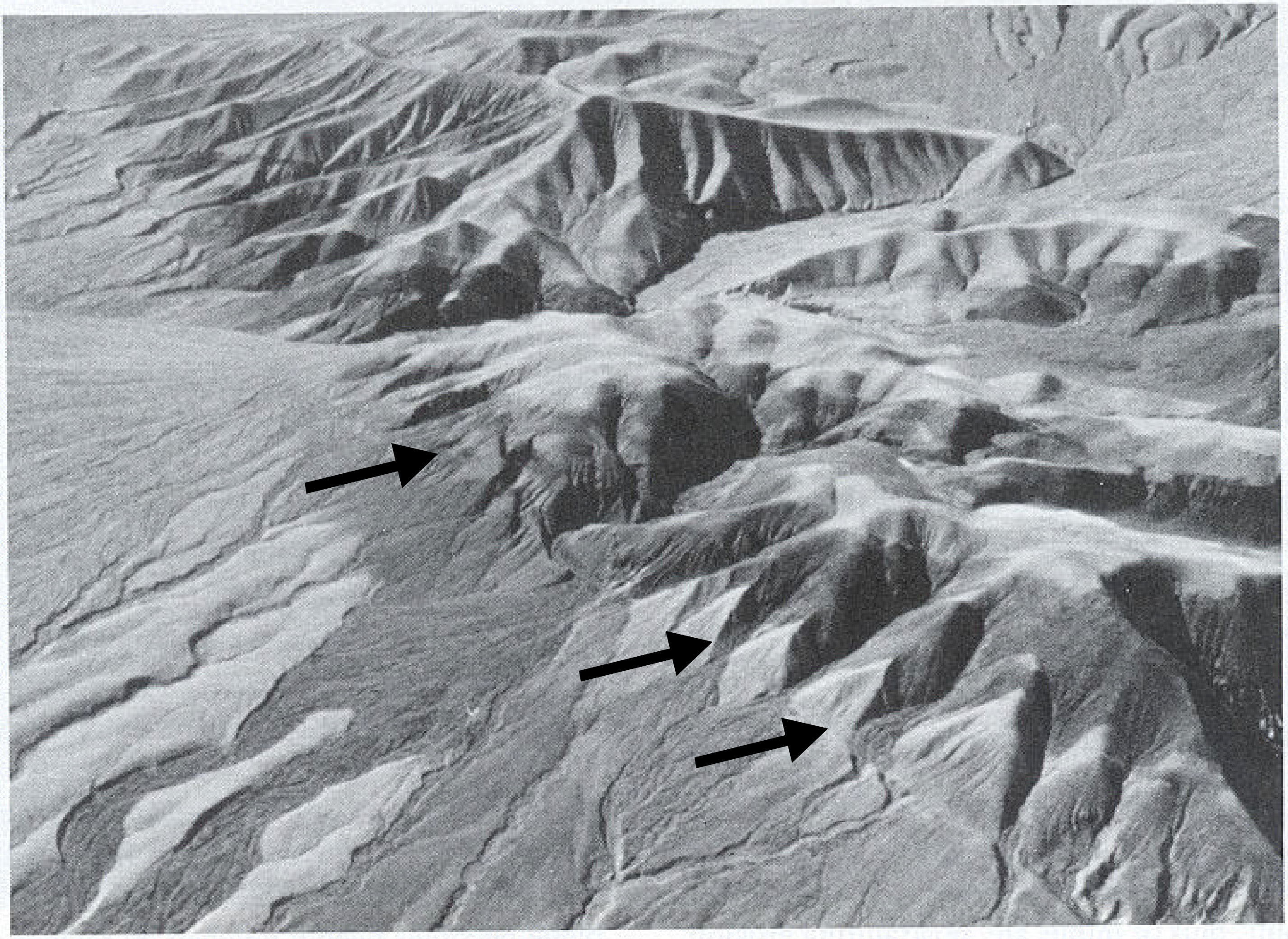
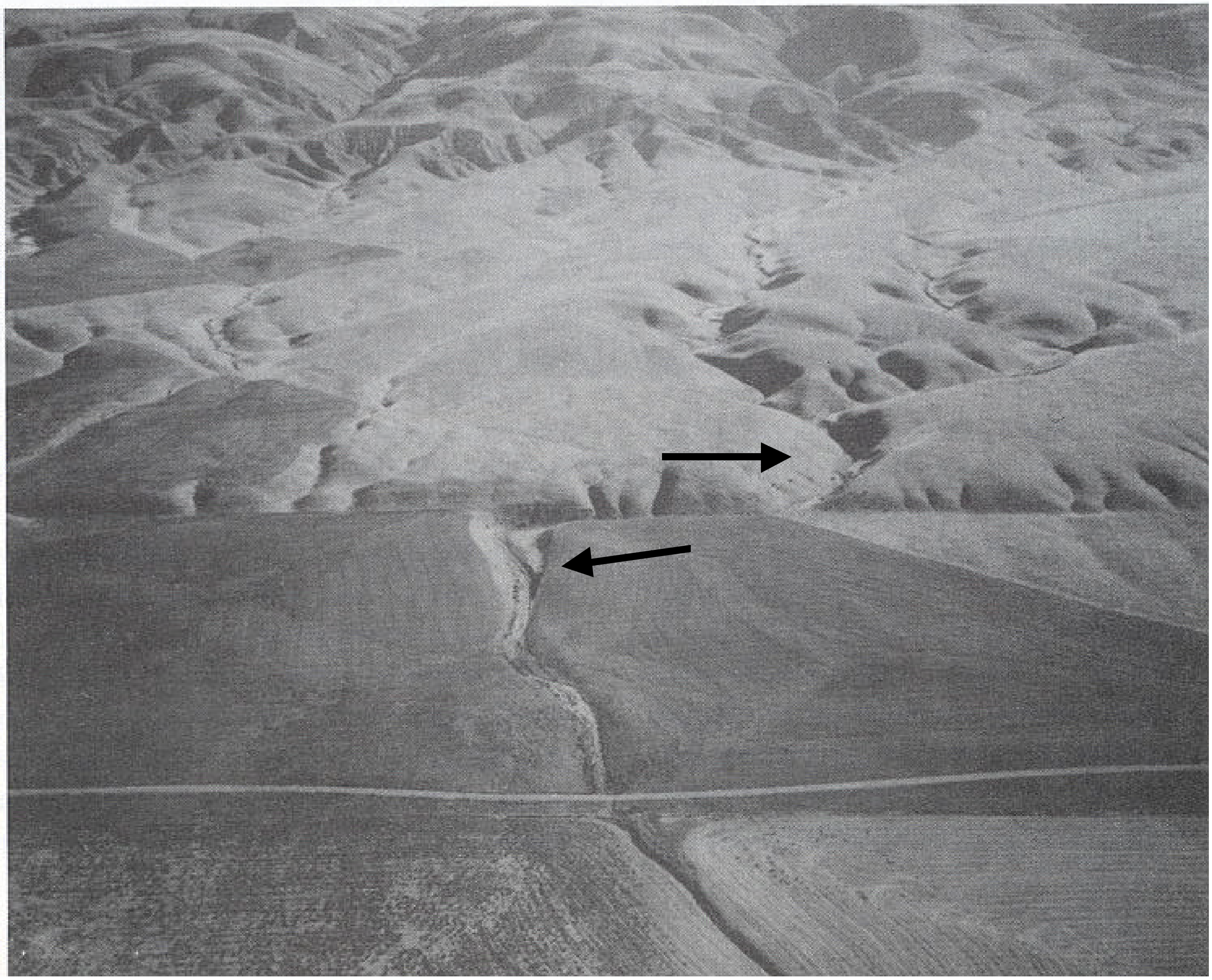


FIGURE 10–8
Fault scarp cutting across alluvium. Triangular facets occur along the upthrown block, and new alluvial fans are forming on the downthrown block.

FIGURE 10–9
Discontinuity of geologic structures truncated by a fault. (Photo by U.S. Geological Survey)

FIGURE 10–29
Offset streams along the San Andreas fault in California. (Photo by R. Wallace, U.S. Geological Survey)



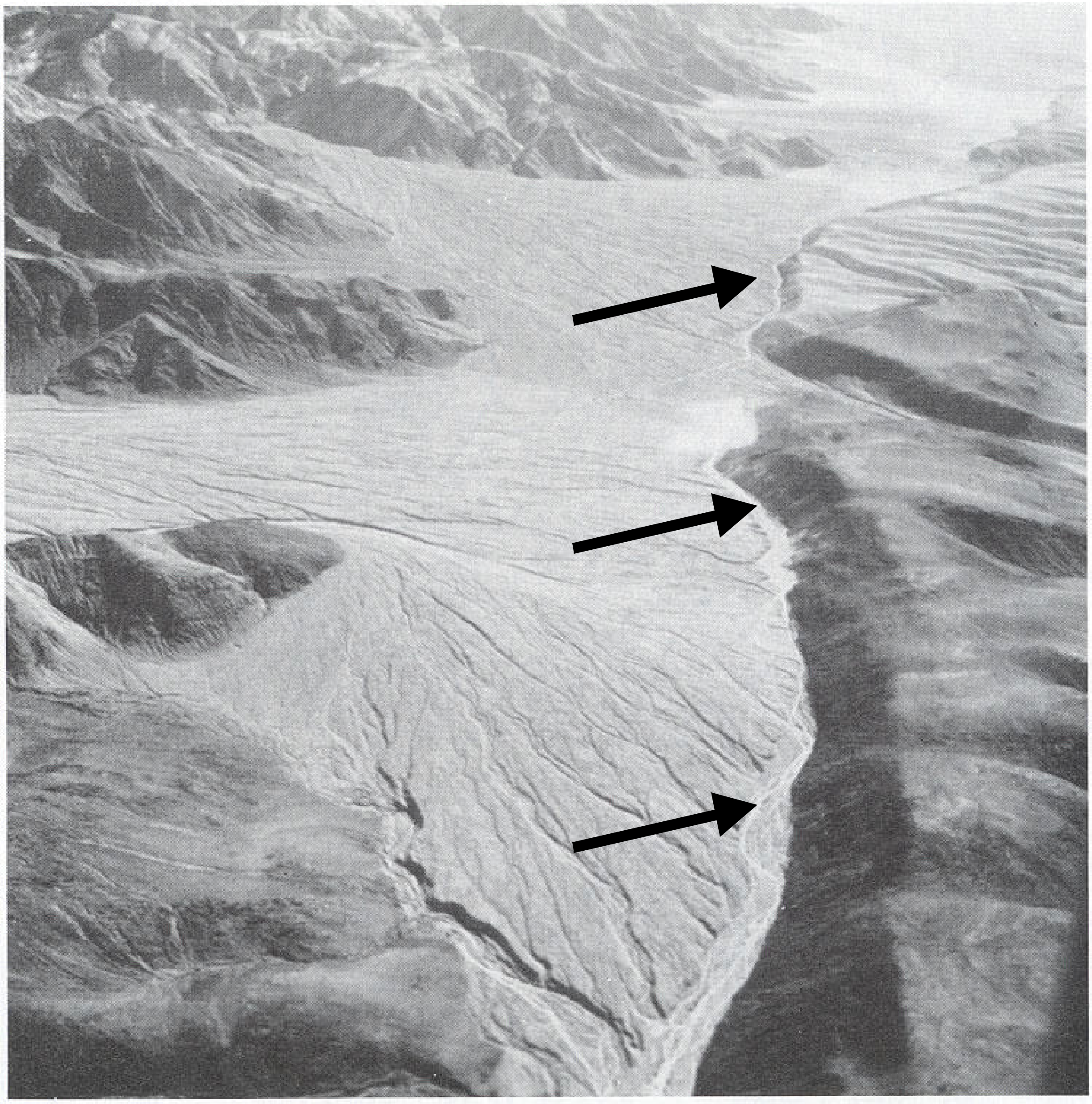


FIGURE 10–20
Fault scarp across an alluvial fan, Death Valley, California. Note the new alluvial fans on the downthrown block (left) and the collection of drainage against the scarp on the upthrown block (right).

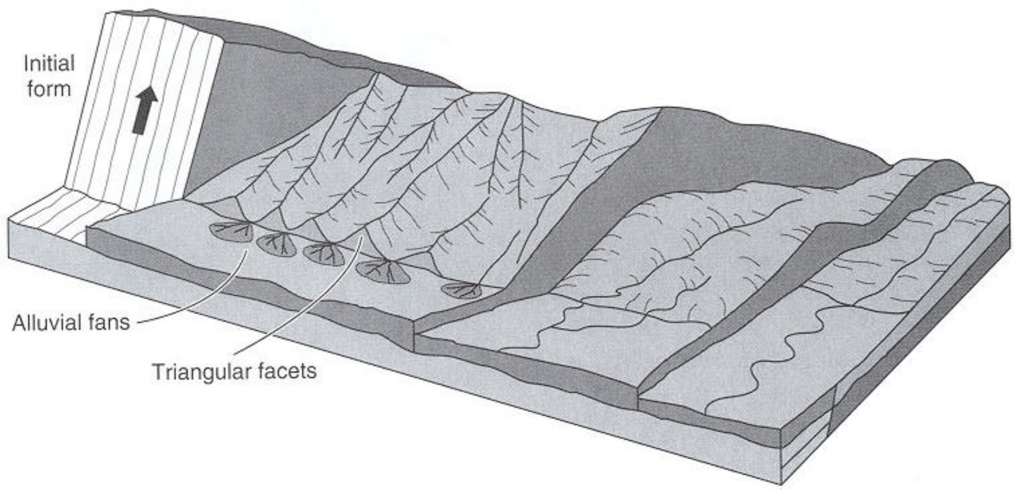


FIGURE 10–14
Progressive erosion of a fault scarp.

maintains a generally straight base along the fault plane. Because scarps can be created by other geomorphic processes in addition to faulting, such as from resistant beds, joint planes, or ancient shorelines, a scarp is not necessarily proof of faulting.

Although faults may occur as clean breaks on single planes, they often break into thin, parallel slices, along which the total displacement is distributed, or they may be splintered into several branching fault planes (Figures 10–15 and 10–16). Where **splintering,** also known as **splays,** occurs, the height of the fault plane diminishes and is re-

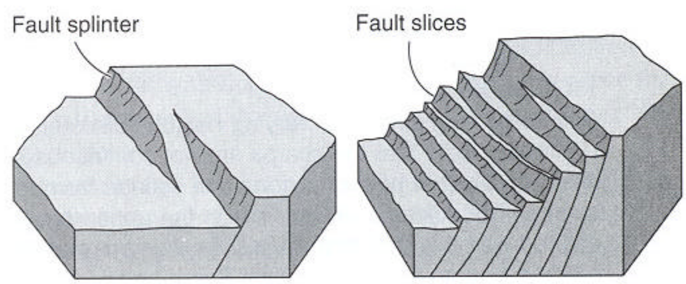


FIGURE 10–15
Fault splinters and slices.