I. **Structural geology**
   A. tectonic and other forces deform the earth’s crust
   B. structural geologists
      1. observe the results of deformation
      2. attempt to unravel the events responsible
      3. predict subsurface features between data points
         a) outcrops
         b) drill hole data
         c) geophysical investigations
   C. structures include
      1. faults
      2. folds
      3. joints
      4. foliation
   D. practical importance
      1. subsurface structures can trap petroleum
      2. design of major construction projects
         a) possible weakness in the rock mass
      3. earthquake safety

II. **Rock deformation**
   A. deformation
      1. change in the volume or shape of a rock unit
      2. occurs in response to application of stress
      3. strain
         a) measure of how much deformation occurs
         b) usually expressed as a percentage
   B. stress
      1. force that acts on a rock unit
      2. changes shape or volume of the rock
      3. confining stress
         a) applied by the load of overlying rocks
         b) acts uniformly in all directions
         c) also called hydrostatic pressure
         d) leads to a reduction in volume
         e) makes rocks more ductile (bend rather than break)
      4. differential stress
         a) acts in a direction
         b) often in addition to confining
         c) compressional
C. types of deformation
   1. elastic
      a) rock returns to original volume and shape when stress is removed
      b) small deformations are usually elastic
   2. plastic
      a) rock will flow and take on a new shape that is permanent
      b) likely to occur when rock is hot, under confining pressure
   3. brittle
      a) rock breaks when stressed
      b) common at earth’s surface (no confining pressure)

D. laboratory testing
   1. we can recreate heat, confining pressure, stresses
   2. we can not recreate geologic time
      a) we can only surmise effect of time on deformation
      b) we do know that fast deformation is more likely to cause brittle failure
         than slow deformation

III. Mapping structure
   A. most geologic structure is hidden beneath ground
   B. we explore structure by a variety of means
      1. geophysical investigations
      2. drill hole data
      3. outcrop data
   C. data is used create maps of subsurface information
      1. topographic maps of given rock layers
      2. cross sectional maps of structure (folds/faults)
   D. surface mapping
      1. done on outcrops of sedimentary rocks
      2. data is collected on the orientation (tilt) of layers
      3. sedimentary rocks should have been initially horizontal
      4. deformation tilts and deforms sedimentary layers
      5. dip and strike are measurements of tilt
   E. dip
      1. maximum angle of inclination from horizontal
      2. measured with an inclinometer
      3. measured on planar geologic features
a) bedding plane  
b) fault  
c) contact between two units  
d) joint  

F. strike  
1. map direction in which the feature itself extends,  
2. intersection of a dipping plane with horizontal forms a line  
3. map direction of that line is the strike  

IV. Joints  
A. fractures along which no appreciable displacement has occurred  
B. joints form  
1. during cooling of lava  
   a) shrinkage creates vertical cracks, like in mud  
   b) intrusions cool slowly, much less cracking  
2. in response to unloading  
   a) erosion, excavation, glacial melting  
   b) parallel to stress reduction  
3. tectonic forces  
   a) apply shear, tensional forces  
   b) joints tend to form in roughly parallel sets  
      (1) sets are oriented according to stresses  
      (2) commonly 2 or more distinct joint sets  
C. joints are important  
1. rock strength  
2. groundwater flow  
3. cavern formation  
4. subsequent mineral deposition  

V. Faults  
A. basics  
1. fractures in the earth’s crust that display evidence of differential movement; i.e., the two sides have shifted with respect to each other  
2. sudden movement along faults causes most earthquakes  
3. most faults are inactive  
B. evidence of movement  
1. offset  
2. scarps - long low steep cliffs exposed at the surface  
3. slickensides - polished and striated fault surfaces  
4. fault gouge - ground up rock fragments  
5. mylonite  
   a) metamorphic rock  
   b) stretched and elongated grains  
   c) hard to identify
C. categories of faults
   1. Dip-slip
      a) primary movement along dip of the fault surface
      b) hanging wall - fault block above a dip-slip fault
      c) footwall - fault block below a dip-slip fault
      d) normal fault
         (1) hanging wall drops with respect to footwall
         (2) indicates tensional stresses
            (a) stretching during uplift
            (b) horizontal tension (pull apart)
         (3) common in western US
      e) reverse fault
         (1) hanging wall rises with respect to footwall
         (2) results from compressional stress
         (3) forces hanging wall to override the footwall
         (4) associated with folding and complex mountain building
         (5) common in the Alps, Appalachian mountains
      f) thrust fault
         (1) a reverse fault with a very shallow dip angle
         (2) have moved rocks more than 50 kilometers
         (3) can place older rocks on top of younger ones
   2. strike slip
      a) primary movement is horizontal, along strike
      b) movements is either left-lateral, or right-lateral
         (1) stand on one fault block
         (2) look across to the other side
         (3) if the other block has moved to the right, it is a right-lateral fault
            (San Andreas)
   3. transform faults
      a) largest strike-slip faults
      b) occur along plate boundaries
         (1) e.g., San Andreas fault
         (2) moved ~560 KM in the last 30 million years

D. landforms caused by faulting
   1. graben
      a) block drops down between two large normal faults
      b) produces elongated valleys
      c) valleys are bounded by uplifted blocks called horsts
      d) e.g., East African Rift Valley
   2. fault-block mountains
      a) sedimentary rocks tilt on sub-parallel normal faults
         (1) hanging wall drops at the fault
         (2) the ‘back side’ of the block tilts up
      b) builds rugged mountains “quickly”
(1) Grand Tetons created in 5-10 million years
(2) also responsible for the Sierra Nevada and mountains of the Basin and Range Province

3. fault zones
   a) rather than a single fracture, large strike-slip faults consist of fault zones of roughly parallel faults
   b) may be kilometers wide and 100’s of KM long
   c) individual movements usually occur in a part of the zone, not all of it
   d) rocks tend to be ‘beat up’ and may weather and erode faster than the surrounding rock
   e) create long surface features that are often visible from the air
      (1) valleys
      (2) vegetative changes
      (3) altered drainage patterns

VI. Folds
   A. basics
      1. during mountain building, flat-lying sedimentary and volcanic rocks are often bent into a series of undulating folds
      2. folds usually occur in groups
      3. occasionally a single fold is encountered
   B. terminology
      1. sides of a fold are called limbs
      2. limbs are separated by the axial plane
         a) imaginary surface
         b) passes through the points of maximum curvature within the fold
      3. axis
         a) imaginary line drawn along the crest of the fold
         b) described by a map direction and plunge, which is analogous to dip
      4. symmetrical fold
         a) both limbs dip at about the same angle
      5. asymmetrical fold
         a) limbs dip at different angles
      6. overturned fold
         a) at least one of the limbs is rotated past vertical
      7. recumbent fold
         a) at least one of the limbs is rotated past vertical to horizontal
   C. types of folds
      1. anticline
         a) fold formed by upwarping of rock
         b) if you were to slice one horizontally
            (1) you would find the oldest rocks in the center
            (2) outcrop pattern points in the plunge direction
2. syncline
   a) fold formed by downwarping of rock
   b) if you were to slice one horizontally
      (1) youngest rocks are in the center
      (2) outcrop pattern points away from the plunge
3. groups of folds
   a) limbs of a syncline are likely to also be limbs of adjacent anticlines, and vice-versa
   b) folds have a locality of maximum intensity, die out further away
4. monoclines
   a) broad flexural features
      (1) only one limb
      (2) e.g., Colorado Plateau
   b) thought to result from vertical faulting at great depth in what is referred to as the basement rock
5. domes
   a) surface sedimentary layers upwarped to form domes
      (1) broad upwarping of basement rock
      (2) igneous intrusions
      (3) buoyant migration of salt
   b) if you were to slice a dome horizontally
      (1) bullseye pattern
      (2) you would find the oldest rocks in the center
   c) softer sedimentary rocks can erode (e.g., Black Hills)
      (1) leave an igneous or metamorphic core
      (2) resistant rock layers create meandering ridges called hogbacks
6. basins
   a) downwarping of the basement rock
   b) thought to result from weight of the overlying sediments
   c) if you were to slice a dome horizontally
      (1) bullseye pattern
      (2) find the youngest rocks in the center
   d) basins tend to be large with very gentle dips
      (1) makes them difficult to identify in the field
      (2) e.g., Michigan Basin
D. landforms associated with folds
   1. synclines do not necessarily form valleys, nor do anticlines necessarily form ridges
   2. actual landforms result from differential weathering of the rock units
   3. crest of anticline may be shattered
      a) weathers easily
      b) Cushing anticline