Introduction to Faults

I. Basic Terminology

A. Fault: a planar surface or narrow zone along which there is slip between the two blocks of rock.

1. Fault = mode 1 or 2 "shear fracture"
   a. "Fault": > 1m or more
   b. "Shear Fractures": on centimeter scale
   c. "micro-fault": on order of micrometers, under scope
      (1) single mineral shear fractures

2. Fault = "brittle rock failure" + shear motion

3. Occurrences of Faults

   a. Fault: Single, discrete fault plane
   b. Fault Zone: Anastomosed network of branching faults
   c. Ductile Shear Zone: a zone of ductile deformation

B. Fault Terminology

1. Fault Blocks: two masses of rock cut by fault
2. Hanging Wall: block of rock above fault plane
3. Footwall: block of rock below fault plane
   a. Vertical Faults: hanging wall/footwall do not apply

4. High angle Fault: > 45 degrees dip
5. Low angle Fault: < 45 degrees dip

6. Slip or Relative Displacement: net distance and direction the hanging wall block has moved with respect to the footwall block

   a. Throw: net vertical offset of marker horizon along fault
   b. Heave: net horizontal offset of marker horizon along fault

C. Fault Classification

1. Dip-slip Faults: net slip parallel to dip direction of fault plane
2. Strike-slip Faults: net slip parallel to strike direction of fault plane
3. Oblique-slip Faults: net slip at some acute angle to strike and dip of fault plane
   a. strike-slip vector component + dip-slip vector component

4. Normal Faults: dip-slip fault in which hanging wall moves down relative to footwall

5. Reverse Faults: high-angle, dip-slip fault in which hanging wall moves up relative to footwall

6. Thrust Faults: low-angle, dip slip fault in which hanging wall moves up

relative to footwall

7. Strike Slip Faults: hanging wall and footwall offset along strike of fault plane (neither up or down)

    a. Dextral Strike Slip Faults = Right Lateral Strike-Slip Faults: when looking across fault plane, block on opposite side appears to move to the right

    b. Sinistral strike slip faults = left lateral strike slip faults: when looking across fault plane, block on opposite side appears to move to the left

8. Oblique Slip Faults

    a. Sinistral/Dextral Normal
    b. Sinistral/Dextral Reverse

II. Recognition of Faults

A. Intrinsic Features

1. Textures/structures imparted to rocks deformed by the fault process:

    a. Cataclasis: mechanical crushing/grinding of rocks along shear zone

        (1) Fault Breccia: angular blocks of rock broken apart and consolidated in shear zone

            (a) "breccia": broken clasts > 2mm in diameter, angular in shape

        (2) Fault Gouge: finely pulverized rock powder found in shear zone

        (3) Pseudotachylite: glassy or vitrified rocks found in shear zone,

            (a) formed at great pressures (10-15 km) under very dry deformation conditions

    b. Mylonites

        (1) Ductile shear deformation at temps > 250-300 C

        (2) mylonite = "foliated shear zone"

            (a) common in deep fault structures, associated with metamorphism

c. Slickensides

(1) Slickenlines or slickenside lineations: linear grooves etched along fault plane due to shear polishing action

(2) Asperites: grain plucking along direction of shear

(a) smooth direction vs. rough direction allows determination of relative shear offset along fault

d. Secondary mineralization

(1) rock fracture provides conduits for fluid flow

(a) quartz, calcite vein fillings

B. Effects on Geologic or Stratigraphic Units

1. Vertical Repetition of Strata

a. Thrust or Reverse faulting will "tectonically thicken" the stratigraphic sequence, and result in artificially repeating portions of the stratigraphic section

2. Omission of Strata

a. Normal faults essentially remove portions of the stratigraphic section, resulting in anomalous stratigraphic relations

3. Drag Folds

a. secondary folding of bedding in the vicinity of the fault plane due to secondary stress

(1) Reverse faults: strata down-turned in hanging wall

(2) Normal faults: strata up-turned in hanging wall

4. Rollover Anticlines

a. anticlinal structures found in the hanging wall of "listric" normal faults

(1) "listric normal faults": curving normal fault plane, in which the dip < with depth

(2) A great place for oil and gas accumulation

C. Tectonic Geomorphology and Faulting

1. Erosional Phenomena

a. Faults represent relatively narrow, linear zones of crustal deformation

(1) Avenues of enhanced physical and chemical weathering

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

b. Fault Line Scarps: escarpments along fault zone that result from differential erosion of rocks of contrasting resistance juxtaposed by displacement

c. Fault Scarp Landforms

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

(a) Triangular facets = "flat irons"

(2) 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

(3) Spring Development

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

(4) 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

3. 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

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

d. Thrust Faults: low-angle reverse faults,

(1) 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

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

III. Determination of Fault Displacement

A. Defining Factors of Displacement

1. Magnitude of Displacement: how much shear motion along fault

2. Direction of Displacement

a. Magnitude + Direction = "vector" in physics

B. Complete Determination of Displacement

1. Process: I.D. pre=existing linear feature that has been cut and offset by fault plane

    a. Piercing points: points of intersection between linear feature and fault plane

        (1) I.D. Offset piercing points
            (a) vector connecting two piercing points = direction and magnitude of fault displacement

    b. Linear features of Use

        (1) two other faults that form a line of intersection
        (2) intersecting dikes/veins
        (3) hinge line of a fold

C. Partial Determination of Displacement

1. Slickenlines
2. Pinnate fractures
3. drag folds
4. en echelon gash fractures
5. fractured mineral grains, showing offset
6. Porphyroblast rotation

D. Partial Determination of Displacement from Large-Scale Structures

1. Isopach Maps

    a. Contour maps showing formation thickness

        (1) Fault = mismatched thickness contours

2. Structure Contour Maps
    a. Contour maps showing elevation on a structural surface (e.g. top of formation)

        (1) Fault = mismatched structure contours

E. Offset of Planar Features in 2-dimensions

1. Problem: commonly we are only presented with a two dimensional view of fault displacement (e.g. offset of bedding planes as shown in map view or a road-cut)

    a. Offset in 2-D can give a sense of diplacement, but can not uniquely define the displacement vector in 3-D.

    b. Cutoff Line

(1) Line of intersection formed by a planar feature with a fault plane

(a) Hanging wall cutoff line : line of intersection as viewed in hanging wall

(b) Footwall cutoff line: line of intersection as viewed in footwall

2. Separation: distance of offset of a planar feature (e.g. a beddinging plane) measured on opposite sides of a fault

a. strike separation : offset of planar feature measured along strike of fault plane

b. Dip Separation: offset of planar feature measured along dip of fault plane

c. stratigraphic separation: offset of a bedding plane measured perpendicular to bedding plane

IV. Faults in Three Dimensions

A. Problem:
1. At small scale in 2-D: faults = planar fractures
2. On larger scale in 3-D: faults may...
a. curve vertically
b. curve horizontally
c. branch into a number of fault segements

B. Terminology and 3-D Relationships

1. Fault Trace: orientation of line formed by fault and intersection with the earth's surface

a. i.e. map pattern of fault at earth's surface
b. i.e. trace = "cutoff line" of fault with earth's surface

2. Fault Termination Line: terminus or end points of fault in all directions

a. "all good faults must come to an end"

3. Curving and Branching Faults

a. Fault Splays: branching of single fault into several imbricate faults

(1) Horse: block of rock bounded by faults on all sides

b. Fault Ramps: abrupt > in dip angle to form a "ramp"

(1) common in thrust faults

c. Fault Duplex

(1) stacked imbricate thrust sheets

d. Blind Fault

(1) A fault that does not intersect the earth's surface

(a) termination before cutting surface