Deformation and Brittle Fracture

I. Primary Rock Structure

A. Tectonic Control of Rock Structure

1. Lithospheric Plates

a. plate = crust + upper mantle above asthenosphere
(1) Layered Crust
(a) oceanic crust =
i) volcanic/"basalt"
ii) oceanic sediments
(b) continental crust
i) crystalline/"granite"
ii) sedimentary cover
a) marine sediments
b) continental sediments
(c) depth of crust: 5-10 km

b. plate motion response to internal heat flux
(1) internal heat source: radioactive decay
(2) plate motion = rock motion = "geologic work"
(a) work = (force)(displacement)
(b) plate motion = force applied to rocks

B. Primary Rock Structure/Architecture

1. Primary Structure/Architecture:

a. geometries formed at the time of rock origin
(1) deposition or crystallization
b. Secondary Structure
(1) geometries imparted by strain in response to stress applied after the rock forms
2. Rock Layering
(1) Tendency for layered stratification in volcanic and sedimentary environments
(2) Layered Plutonic Rocks
(a) magmatic differentiation processes
(b) diapiric intrusives
(3) Deposition under force of gravity =
(a) "blanket deposits"
(b) ~parallel to horizontal

3. Examples of Primary Rock Structure

a. Stratified bedding (volcanic or sedimentary)
(1) beds = layers > 1 cm
(2) laminae = layers < 1 cm

b. bedding contacts = breaks or discontinuities in depositional

process
(1) Textural and compositional discontinuities
(2) stratigraphy = study of time with respect to the rock record

c. Unconformities = significant bedding contacts
(1) = break or gap in rock-stratigraphic record
(a) erosional truncation or removal
(b) periods of non-deposition

d. Internal stratification: internal organization of sediment within bed

(1) Graded Bedding: a layer of sediment in which particle sizes change systematically in a vertical and/or lateral direction (applicaple to both beds and laminae)

e. Cross-bedding: Sets of internal strata, beds and/or laminae are not oriented parallel to the bounding surfaces of the bedset. Applicable to both beds (>1 cm) and laminae (<1 cm).

(1) Tabular Cross-stratification: bounding surfaces are planar
(2) Trough Cross-stratification: bounding surfaces are curved and intersecting

f. Common Primary Sedimentary Structures

(1) Current Ripples: found at relatively low flow strengths in sands less than 0.7 mm in diameter, asymmetric in cross-sectional profile.

(2) Flute Casts: current-formed erosion structure, bulbous cast formed by scouring of sediment interface, bulbous end generally points up-current.

(3) Load Casts: irregular knobs found on sandstones overlying shale beds.

(4) Tool Marks: groove casts; infilling of mold formed by dragging object across sediment interface

(5) Imbricate Structure (Pebbles): under high energy flow conditions pebbles may take on inclined imbricate orientation, with inclination pointing upstream.

(6) Brush, Bounce, and Prod Marks: formed by dragging of sticks or pebbles across sediment interface.

(7) Scour and Fill (Gutter Casts): channelized sediments can become back-filled with overlying deposits.

g. Common Deformational Structures in Sedimentary Rocks

(1) Convolute Laminations/Slump Structure: complexly folded

and deformed internal laminae within bed, thought to be associated with "hydroplastic" deformation of fluidized sediment. Commonly associated with conditions of rapid deposition

(2) Flame Structures: flamed shaped projections of mud that extend upward into overlying bed of different composition (e.g. sandstone).

(3) Ball and Pillow Structure: Occurs in basal portions of sandstone beds overlying shales, sand masses detached and forced down into mud matrix.

(4) Synsedimentary Folding: unconsolidated sedimentary layers of sediment become folded in response to oversteepened surface of deposition.

(5) Trace Fossils: i.e. Ichnology:

(a) Tracks, trails, burrows
(b) Bioturbation: general mixing of sediment by dirt eaters.

(6) Mudcracks and Raindrop Imprints: evidence of subaerial exposure of semi-consolidated sediment surface.

(7) Stylolites: suture structures derived from partial dissolution and interlocking crystal growth under pressure (common in limestone)

h. Primary Volcanic Structures

(1) layered bedding
(2) pillow structure
(a) pillow-shaped structures that result from extrusion of lava under aqueous conditions
(3) Vesicules/Gas Escape Structure
(a) de-gassing from upper portion of lava

i. Plutonic/Intrusive Structures

(1) Dikes, Sills
(2) Stocks, Batholiths
(3) Compositionally layered plutons

4. Use of Primary Structure To Determine "Stratigraphic Up"

a. "younging" relationships: identifying the direction in the bedding sequence of older to younger

(1) layer cake stratigraphy: law of superposition
(a) oldest at bottom

(b) youngest at top

b. Problem: Structurally Overturned Beds

(1) Intense rock folding may result in overturning of beds...
(a) stratigraphic up may be oriented down

c. Indicators of up

(1) Fossil shell lags: convex portion of shell commonly up
(2) Paleontological relations/stratigraphy
(3) Ripple laminations: crest = up
(4) Mudcracks: curved up morphology
(5) Planar cross-bed morphology
(a) commonly asymptotic at base of bed
(6) sole markings, scour features on base of beds
(7) vertical burrows: commonly from top, down
(8) Vesiculated zones in volcanic rocks: commonly at top
(9) Pillow morphology in volcanic rocks
(10) erosional lag conglomerates; commonly overlie abrupt erosional discontinuities

II. Overview of Secondary Rock Deformation

A. Process: subjecting primary rock sequences to tectonic stresses over time

1. Result: rock deformation

B. Critical Factors

1. Driving Forces:

a. Heat transfer, plate tectonic motion
b. Gravity: downward compression

2. Physical Conditions

a. Temperature
(1) depth controlled
(2) internal heat flux/volcanism
b. Pressure
(1) depth controlled
(2) horizontal plate motion
c. Chemical Conditions
(1) Interactions of chemically-active fluids with rock under conditions of temperature and pressure

3. Resisting Medium

a. Rock Body
(1) lithologic composition
(a) Lithologic control of mechanical properties of rock

body
(b) From Field Trip
i) defomation in shale vs. limestone
(2) pre-existing primary structure
(a) bedding, sed. structures, etc.
(3) pre-existing secondary structure
(a) faults, joints, folds, etc.

4. Stress vs. Strain

a. stress = force applied per unit area of rock material

(1) "vector" = magnitude + direction in space

b. Strain = deformational response of rock to stress applied

C. Deformational Products of Stress Applied to Bodies of Rock

1. fractures
a. vein fillings
2. faults
3. folding
4. rock cleavage, schistosity, foliation