Field Trip Guide and Class Notes
ES458/558 River Environments of Oregon
Western Oregon University

August 4 – 9, 2007

- Santiam River Basin
  Landscape Analysis
- Newberry Volcano
  Caldera Hydrology
- Columbia Gorge
  Missoula Flood History
- Deschutes River
  Paleohydrology

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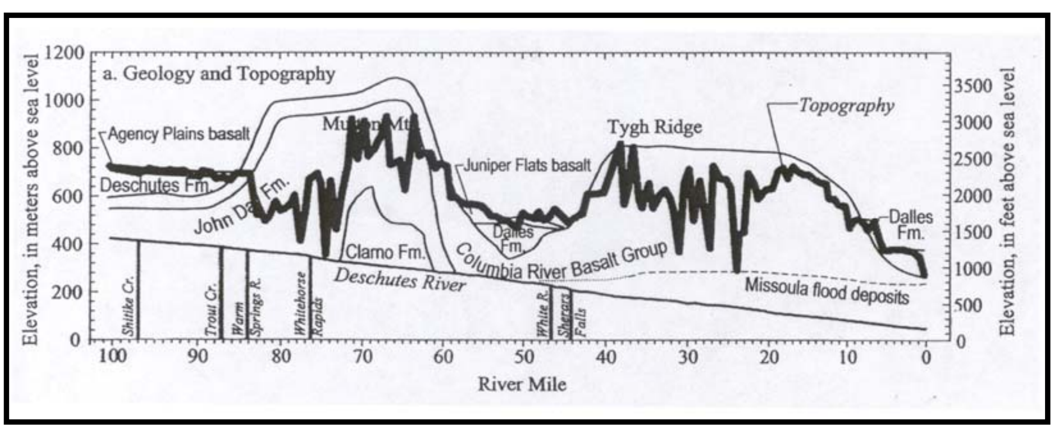

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ES458/558 River Environments   Tentative Field Trip Itinerary – Summer 2007

Day 1 Sat. August 4 "The Adventure Begins"

Stop 1-1	Natural Science Building Roof
Stop 1-2	North Santiam State Park east of Salem
Stop 1-3	Bigl Cliff Dam / Detroit Lakes
Stop 1-4	Suttle Lake
Stop 1-5	Lava Butte / Benham Falls

Camp at La Pine State Park

Day 2 Sun. August 5 "From Volcanoes to River Canyons"

Begin Day	Campground Worksheets / Lab Exercises
Stop 2-1	Paulina Peak
Stop 2-2	Little Cone Campground / Paulina Lake
Stop 2-3	Paulina Lake (Paulina Creek Outlet)
Stop 2-4	Paulina Falls
Stop 2-5	Paulina Creek Field Exercise (Ogden Group Camp and McKay Crossing)
Stop 2-6	Hwy 197 – Overview of Columbia River Basalts and Loess Hills

Camp at Deschutes River Recreation Area

Day 3 Mon. August 6 "Missoula Floods and the Columbia Gorge"

Begin Day	Campground Worksheets / Lab Exercises
Stop 3-1	(O'Connor Stop 3.2) Hwy 197 Roadcut South of The Dalles
Stop 3-2	(O'Connor Stop 1.1) Petersburg Bar
Stop 3-3	(O'Connor Stop xx) Fairbanks Divide
Stop 3-4	(O'Connor Stop 1.2) Celilo Falls Overlook
Stop 3-5	(O'Connor Stop 1.4) Scabland

Drive to Maupin / Camp at Trout Creek

Day 4 Tue. August 7 "Rafting, Rapids, and Rays"

Raft Preparation

Stop 4-1	Lower Trout Creek – Road Cut
Stop 4-2	(Bebee et al. Stop 3) Warms Springs Confluence / Railroad Cut
Stop 4-3	(Bebee et al. Stop 4) Axford Flood Deposits (cutbank river left)
Stop 4-4	(Bebee et al. Stop 5) River Mile 78.5 Whiskey Dick; Camp-site lecture on Deschutes River hydrology and geomorphology

Camp at Whiskey Dick

Day 5 Wed. August 8 "Another Day Floating the River"

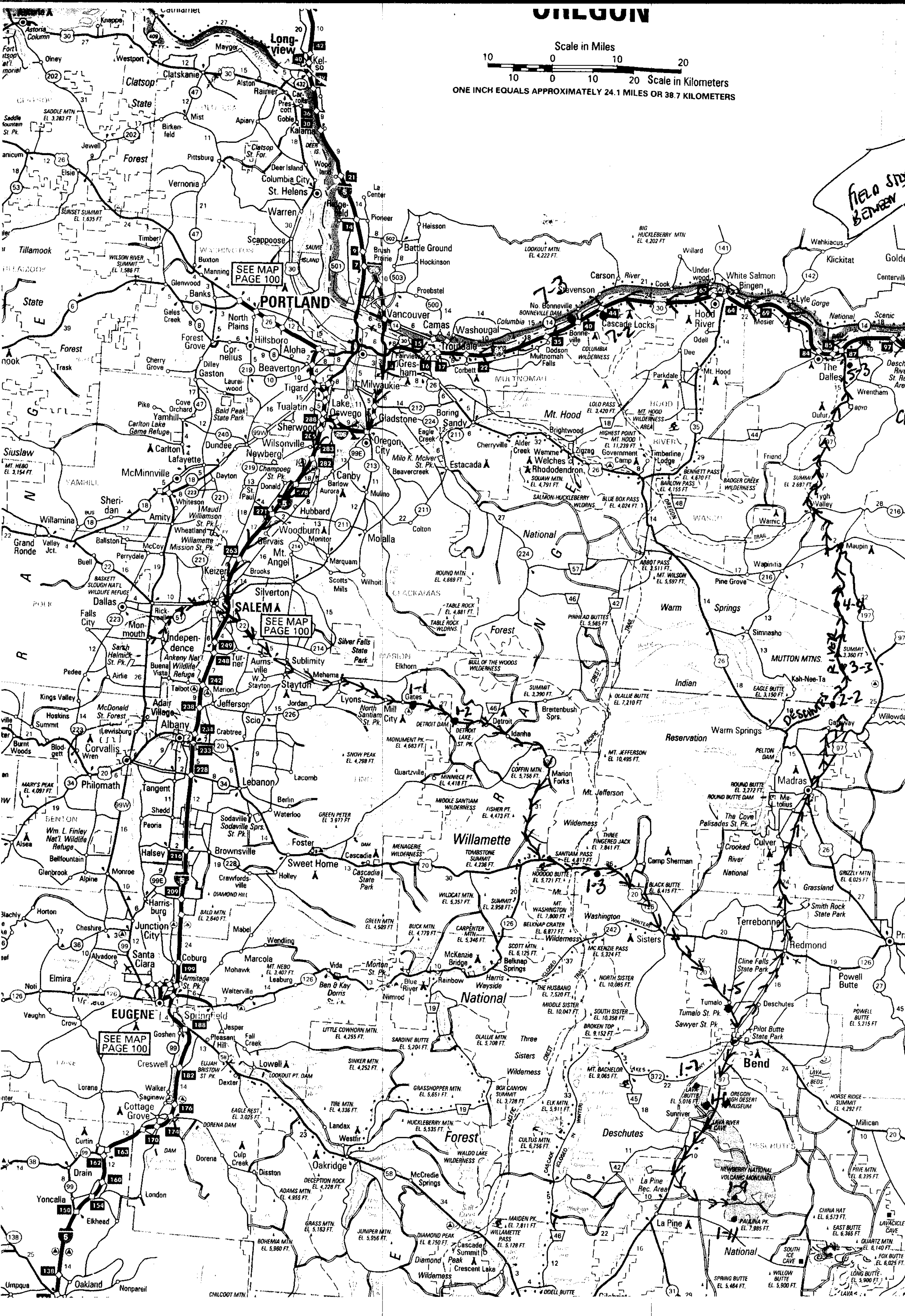
Begin Day	Campground Worksheets / Lab Exercises
Stop 5-1	Morning Hike to "The Pot" Overlook (from Whiskey Dick)
River Mile 77	Whitehorse Rapids (Yee Haw!)
Stop 5-2	(Bebee et al., Stop 6) River Mile 76 – The Pot – lower end

Camp at Buckskin Mary

Day 6 Thurs. August 9 "Out of the 'Chutes and Into the Gorge"

Stop 6-1	(Bebee et al., Stop 8) River Mile 64 – Buckskin Mary / Dant DF Overlook
Stop 6-2	(Bebee et al., Stop 9) River Mile 62.5 – Outhouse Flood Bar
Stop 6-3	(O'Connor Stop 3.4) Cascade Locks Marine Park / Bridge of the Gods
Stop 6-4	Bonneville Dam

Return to Monmouth via Portland



Towns with asteris
are keyed to map
page 100.

Ada............
Adair Village
(554)............
Adams (223).....
Adel...............
Adrian (131).....
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Introduction to Landscape Analysis

I. Introduction

A. Geomorphology: The study of surface landforms, processes and the historical evolution.
  1. Interdisciplinary Study: cross-over with scientific disciplines of sedimentology, soil science, geography, climatology, hydrology, glaciology, civil engineering and volcanology.

B. Physiography
  1. Physical composition of the landscape (on continental areas)
    a. climate
      (1) long-term average meteorological condition
        (a) precipitation
        (b) air temperature
    b. vegetation
      (1) Trees
        (a) Conifers
        (b) Deciduous
      (2) Grasses
      (3) Shrubs
      (4) "undergrowth"
    c. soils
      (1) physical characteristics
        (a) mineral material
        (b) organic material
      (2) chemical characteristics
    d. bedrock geology
      (1) rock types
        (a) igneous
        (b) sedimentary
        (c) metamorphic
      (2) rock age
      (3) rock structure
        (a) faults
        (b) folds
    e. topography
      (1) slope angle
      (2) slope aspect
      (3) relief
    f. surface hydrology
      (1) streams / rivers
        (a) watersheds = stream networks
      (2) groundwater / springs
    g. land use / anthropogenic activity
      (1) e.g. urban vs. rural

2. Physiographic Provinces
   a. Geographic grouping of land areas by similar characteristics
      (1) "classification" - grouping / categorization by features

C. Surficial Processes
   1. All near-surface Earth processes that affect the landscape
      a. Rock Weathering and Erosion
      b. Fluvial Systems (rivers)
      c. Glacial Systems
      d. Mass Wasting
         (1) Gravity-driven processes (e.g. landslides)
      e. Eolian (wind) Processes
      f. Anthropogenic Activities
         (1) e.g. strip mining
      g. Groundwater Activity
         (1) hydrothermal / volcanic
         (2) karst / solution
            (a) limestone
            (b) evaporites
      h. Active Tectonics (Neotectonics)
         (1) mountain building
            (a) Crustal thickening
               i) folding
               ii) faulting
               iii) volcanism
         (2) active surface uplift
         (3) active surface subsidence
            (a) tectonic
            (b) compaction
            (c) fluid withdrawl / anthropogenic
      i. Ocean Systems
         (1) Coastal - land-ocean interface

   2. Agents of Surface Erosion and Transportation
      a. Wind (eolian)
      b. Water (fluvial / groundwater)
      c. Ice (glacial)
      d. Gravity (mass wasting)

II. Ultimate Driving Forces at the Earth's Surface

A. Driving Force vs. Resistive Framework
   1. Driving Forces
      a. Force = (mass)(acceleration); expressed as a vector with magnitude and direction

      b. Energy: capacity to do work
         (1) Kinetic Energy: energy of motion
         (2) Potential Energy: energy of position

      c. Work = Fs; where F = Foce and s = distance

      d. Driving Force: Application of energy in the context of performing work on earth materials (e.g. hydraulic force + particles = erosion)

      e. Driving Forces in Geomorphic Systems: <u>Climate, Gravity, Internal Heat/Tectonics</u>

(1) Climate (Exogenic Force: from without)- average weather conditions at any place over a long period of time.

(a) Climate and the sun
i) Driven by solar energy of sun, i.e heat

ii) solar insolation variable around planet depending upon geometry and latitudinal position (highest at equatorial belt, lowest at poles)

iii) Solar energy transfered as heat in atmospheric/oceanic systems of the earth-----climate systems driven by the heat transfer of these systems (i.e. atmospheric and oceanic circulation patterns)

(b) Climate largely driven by heat transfer of suns energy about atmosphere and ocean waters

(c) Climate as a 1st order controlling factor, influences:
i) rainfall/solar insolation of area
ii) vegetative growth
iii) style of weathering/erosion process
iv) hydrologic processes (fluvial, glacial)

(2) Gravity as a controlling factor

(a) Force of attraction between the earth's center of mass and surface materials (sediment, soil, water) drives landscape evolution

(b) $F = G [(m_1m_2)/r^2]$; where F = force of gravity, G = gravitational constant, m = mass of 2 objects in space, r = distance separating the two objects in space. Given all other variables constant, F > with < r, and F < with >r. Each body exerts an equal force of attraction

i) g = acceleration of a falling object (e.g. sediment) due to gravitational force F, assumed to be constant at 9.82 m/sec^2

(c) Weight = "pulling force" = (mass)(g) , units in Newtons
i) shear force vs. normal force

(d) Gravity obviously influnces surface water flow, mass wasting/hillslope movement processes, serving as a driving force
i) Driving force for flowing water and ice

(3) Internal Heat of the Earth (i.e. Tectonics)

(a) Internal Heat of Earth: supplied primarily by:
i) radioactive decay with exothermic heat loss
ii) frictional heat by earth tides and internal rock deformation

(b) Based on seismic analysis: earth's outer core is thought to be of high enough temperature to be molten

(c) Internal Heat Transfer
   i) Mantle convection: physical movement of rock material as a heat transporting medium

      a) hot, deeper mantle rises as it is of < density
      b) cooler, shallower mantle sinks as it is of > density

(d) Internal heat transfer of the earth thought to be the driving mechanism of plate tectonics and plate motion
   i) oceanic spreading centers/volcanism
   ii) plate subduction and volcanic arcs
   iii) plate collision and rock uplift/deformation/mountain building

      a) crustal folding, faulting, and fracturing

   iv) Rates of seafloor spreading can influence sea level
      a) fast-spreading: greater displacement of ocean water, higher sea levels.

2. Resisting Framework (that which the force in acting upon to create landscape)

   a. Geology of Land Area
      (1) Lithology: rock types
         (a) various rock types have variable resistance to erosion depending on mineralogy and chemistry and the climatic/weathering regime

         (b) Igneous, Metamorphic, Sedimentary

      (2) Rock Structure
         (a) Folded rocks
         (b) Faults, Fractures, Joints
         (c) Mountain Belts/Uplifted Rock Areas

      (3) Rock Structure generally forms zones of weakness upon which other surface processes can act to carve the landscape

III. Hierarchy and Scale of Geomorphic/Landscape Units

A. Global Planetary Body: "Geoid"-reference surface of earth as if it were covered entirely by water; Earth oblate Spheroid

   1. Morphotectonic Regions: regions or landscapes characterized by similar tectonic and stuctural character

   2. Continents and Ocean Basins

      a. Physiographic Provinces- division of continental land masses into units of land area of similar physical geomorphic character

         (1) Landforms- element of the landscape that has consitence of form or regular change of form throughout. Generally similar landforms result from similar processes and condtions

(a) Scenery- assemblage of landforms that can be viewed from a single vantage point

E.g. Central Lowlands Province includes a Till Plain Section made up of glacial moraine landforms.

IV. Time/Evolution/Rates of Change

A. Landscape Evolution: concept of progressive change of landforms in response to surface processes operating over a period of time.

1. Landforms/landscapes will display characteristic features at successive stages of development.

a. Provides and avenue for relative dating of landforms on the basis of developmental stage

(1) If rates of process/change are known, ages of landforms and landscapes can be determined through deductive reasoning

B. Time is an essential ingredient in any geologic process

1. In terms of geomorphic process, variable levels of time are required for desired products of change

a. e.g. time scale variation between slow steady-state soil creep vs. instantaneous slope failure

C. Cyclicity and Time

1. Geologic processes are by nature cyclic and repetitive over time.

2. Geologic cyclicity readily evident in geomorphic systems

a. e.g. Flood cyclicity of river basins

V. Constructional vs. Destructional Processes

A. Constructional Landforms: those land units that have been or are being built (i.e. increasing in mass, height, or area)

1. Constructional Landforms created by mass redistribution

2. Examples

a. Tectonic

(1) Volcanic Accumulation/Mountain Building (Orogeny)
(2) Fold/Fault Block Mountains (Orogeny)
(3) Epeirogenic Uplift of land areas
(4) Isostatic Uplift of Land areas

B. Destructive and/or Erosionally-Derived Landforms: those landforms that are derived by weathering and erosion (destruction)

1. Includes erosion of rock material and deposition of sediment

2. Examples

a. Glacial rock scouring and depositional landforms
b. Fluvial erosion and depostional landforms
c. Eolian Landforms
d. Coastal Landforms

VI. MORE ON GEOMORPHOLOGY, CLIMATE AND TECTONICS

A. Mass Balance: Exogenic vs. Endogenic Processes

1. Exogenic Processes: destructive geomorphic processes that originate at or above the earth's surface

a. Weathering-erosion-denudation processes
(1) e.g. Chemical/Physical Rock Weathering
(2) e.g. Rilling/Gullying/Fluvial Erosion
(3) e.g. Glacial scouring/erosion

b. Theoretically: if exogenic processes were to operate on a landscape, unimpeded by opposing forces, there would be a tendancy to reduce the landscape to a relatively flat, featureless surface with few topographic irregularities ("Peneplanation" concept)

(1) "Base Level" = theoretical surface of erosional equlibrium at which, the land surface will no longer be eroded.
(a) Ultimate baselevel: Sea level, theoretical end point of continental erosion.

c. Climate is an exogenic process that flucutates and upsets geomorphic equilibrium in the landscape.

2. Endogenic Processes: internal processes within the earth that result in uplift and rejuvenation of the landscape

a. e.g. Tectonic Mountain Building Processes
(1) Rock Folding, Faulting, Uplift
(2) Epeirogeny

b. Volcanism

c. Endogenic Processes result in an influx of lithospheric mass and energy, rejuvenating the landscape and tipping geomorphic equilibrium out of balance

B. Endogenic Effects

1. Diastrophism or Tectonism: Collective processes that deform the earth's crust

a. Epeirogeny: regional uplift or depression of the earth's crust over large areas with little internal deformation of original rock structure (broad, regional, gentle uplift)

b. Orogeny: relatively intense deformation of the crust to form structural mountains (folded, faulted, uplifted terrane).

c. Isostacy: principle based on density contrasts within the crust of the earth. Less dense rock material (e.g. granitic continental rocks) will tend to ride at a higher elevation compared to more dense rock material (e.g. basaltic oceanic rocks).

(1) The driving force of isostacy is gravity, which is responsive to a heterogenous distribution of rock density.

(2) Isostatic Equilibrium: Masses of crustal rock of a given density will adjust themselves relative to the earth's gravitational field, density and loading.

(a) As loads are removed from the crust (e.g. melt of ice sheets or denudation via erosion), the upper mantle should adjust in combination with the over-riding crust, resulting in net "bouyant" uplift of the crustal surface

(b) As loads are added to the crust (e.g. glacial ice advance, or sediment accumulation in a basin), the upper mantle should adjust in combination with the over-riding crust, resulting in net depression or subsidence of the crustal surface.

(c) Much of the isostatic compensation is likely taken up by the asthenosphere or "plastic" upper mantle between 60 and 200 km depth beneath the earth's surface.

(d) Rates of isostatic rebound decay exponentially as the crust gets closer to equilibrium/stasis. Conversely, rates of isostatic rebound are high initially as crustal disruption occurs

(3) Isostacy intimately related to epeirogenic movements of the earth's crust on a regional scale

2. Uplift of earth's crust: creates potential energy that available for conversion to kinetic energy via exogenic geomorphic systems

a. In Comparison: Rates of crustal uplift are much higher than those of crustal denudation (a much slower process)

b. E.g. calculations of vertical displacement rates based on dated events: Range -1200 cm/1000 yr (subsidence) to +2400 cm/1000 yr (uplift).

(1) Problem with determing rates from stratigraphic record: end up with minimum rate nos., it is not known if vertical displacement was instaneous, continuous over long periods, or some combination thereof.

C. Mass Balance: Endogenic vs. Exogenic Processes

1. Thus exists a balance between crustal uplift (endogenic) and crustal denudation (exogenic) in the form of "dynamic equilibrium"

2. If rates of uplift far exceed rates of denudation, equilibrium threshold will be crossed and the geomorphic/landscape system will be thrown into disequilibrium

3. e.g. climatic conditions could be such to trigger extensive erosion and denudation of the landscape, resulting in "de-loading" of the crust, thus promoting regional epeirogenic uplift.

4. Equilibrium System: based on principles of mass balance and mass distribtution
   a. uplift: addition of mass to crustal region
   b. denudation: redistribution of mass out of region

D. Climate, Process, and Landforms

1. Climate Classifications: based on regional classification by observed temperature and precipitation values (ranges, averages, etc.)

a. e.g. Koppen Climate Classification

2. Climatic Geomorphology: examining the relationship between landforms, processes of landform evolution, and climate

a. Geomorphic mechanics vary in type and rate according to the particular climatic zone in which they function

b. Basic Notion: Climatic regime imparts exogenic energy into the geomorphic system, energy that is available to do geomorphic work (erosion, transportation, deposition).

3. Climate-Process Systems

a. Attempt to empirically relate occurrences of Holocene landforms with Modern climatic regimes

(1) Problems:

(a) relict landforms derived form earlier, different Quaternary climate regime

i) e.g. morainal deposits in Illinois are a relict of a past glacial climate, however the morainal landforms have not yet re-adjusted to the present climatic regime

(b) climate-landform response processes are poorly understood, little direct observation exists, little laboratory experimentation exists.

b. Based on Quaternary Studies: we know that dramatic climatic fluctuations have occurred in the recent past (and are still occurring?)

(1) e.g. glacial ages as evidence by deposits

4. Possible Controls of climate and climate fluctuation

a. Atmospheric Composition

(1) e.g. Carbon dioxide content and greenhouse effect

(2) volcanic ejecta and particulate matter

(a) solar blocking

b. Astronomical motions affecting the pattern and intensity of solar insolation of the earth

(1) tilt of earth's axis

(2) variations in orbital path around sun

(3) rotational wobble of earth's axis

(a) calculated astronomical periodicity: 20,000 to 100,000 years

c. Tectonic configuration of landmasses

(1) e.g. oceanic circulation and climatic patterns were likely much different 200 m.y. ago durin the time of Pangaea

(2) The orientation and latitudinal position of land masses will have an influence of regional climates and oceanic circulation patterns

E. Climate and Sea Level Fluctuation

1. Based on ocean floor sediment cores, oxygen isotope data and paleoecology (fossil) studies suggest that sea level has fluctuated drastically compared to that of present

2. Relative sea level change due to (relative to continents)

   a. continental uplift or depression (apparent sea level change)

   b. Eustatic rise/fall of sea level: in which absolute water level is rising or falling.

3. Basic Model:
   a. glacial age/ice advance: sea level decline due to storing of evaporative waters as glacial ice

   b. Interglacial/ice retreat: sea level rise due to melting of ice and return of waters to oceans

4. Thus climate must be conducive to particular state of glacial flux; in turn influencing relative sea level

5. Example of Climate, Sea Level and Geomorphic Response:
   a. Fluvial Systems generally very responsive to base level/sea level change
      (a) during glacial advance; sea level lowstand; Fluvial systems will tend to erode and entrench valleys to attain condition of decreased potential energy during glacial retreat; sea level highstand; Fluvial systems will tend to infill valley in response to rising base level.

   (1) Alternating Filling followed by cutting: result in depositional river terraces left high above modern river stage/floodplain.

a. Other Climatic Effects

   i. Climate can also effect:
      (1) Hydrologic conditions: regional runoff patterns
      (2) vegetation patterns
         (a) hence, in turn hillslope stability
         (b) or sediment load in streams/rivers
         (c) Fire Occurrence

Fluvial Geomorphology

I. Introduction
  A. Key Terms
    1. Fluvial = "river"
      a. channelized, flowing water
        (1) water in liquid state
        (2) fluid (changeable shape)
      b. Driving Mechanisms
        (1) Solar Energy (climate / hydrologic cycle)
        (2) Gravity ("water flows downhill")

  B. Water Budget
    1. Moisture Inventory:
      a. Oceans: contain 97% of earth's water
      b. Glaciers: 2% of all moisture, comprising 75% of worlds fresh water
      c. Ground water: 0.5% of total
      d. Surface Water: 0.2%
      e. Soil Moisture: 0.1%
      f. Atmospheric Moisture: 0.0001%
      g. Biological Water: negligible

  C. Hydrologic Interactions
    1. Stream Discharge = climate controlled
      a. rainfall
      b. snowmelt
      c. groundwater discharge

    2. Discharge = volume of water flow per unit time

II. Variables of the Fluvial Process
  A. Water Budget
    1. Input Mechanism into surface water process = atmospheric precipitation
      a. Precipitation = runoff + interception + storage
        (1) Interception = evapotranspiration + evaporation + infiltration
        (2) Storage = groundwater and/or snow pack and ice

    2. Precipitation: atmospheric moisture release (rain/snow fall)
      a. Regional climatic and seasonal control on amount in any given region
        (1) Storm/precipitation cycles
          (a) Intensity: volume precip / unit time (> volume/time > intensity)
            i) rainfall volume measured in inches of rain
            ii) may graph time vs. inches of rain

          (b) Recurrence Interval = statistical chance of a storm of a given intensity occurring within a prescribed time period

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i) RI = $\frac{\text{Total No. of Years of Record}}{\text{No. Storms > Given Intensity}}$

a) e.g. 20 RI over 100 years observation = 5 occurrences

b) Generally the larger the event, the greater the recurrence interval

(c) Duration: length of storm occurrence
- i) Intensity inversely proportional to duration and RI
  - a) High intensity, long duration storms will produce the greatest amount of geomorphic change to the landscape

3. Interception
   - a. interception of rainfall by plants, leaves, groundcover prior to reaching the ground
     - (1) Interception = "energy dissipator" in terms of rain fall impact on landscape (reduces erosion rates)

   - b. Evapotranspiration: atmospheric evaporation of moisture directly from plant tissue and/or in-take of moisture into plant system prior to reaching ground surface
     - (1) Foliage Evaporation = function of air temp. and humidity

   - c. Amount of interception = function of:
     - (1) type and species of plant cover
     - (2) density of foliage/plant cover

   - d. Approximating Regional Interception
     - (1) Measure total precipitation for drainage basin
     - (2) Measure total stream discharge at mouth of basin
       - (a) difference ~= interception + infiltration
       - (b) generally difficult variable to measure

4. Infiltration
   - a. water/precipitation that seeps into soil/subsurface rock
   - b. Infiltration function of:
     - (1) vegetative cover
     - (2) soil permeability/porosity
     - (3) slope grade
     - (4) moisture content of soil
   - c. Porosity and permeability
     - (1) <u>Porosity:</u> ratio, in per cent, of the volume of void space to the total volume of sediment or rock

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(2) Permeability: the degree of interconnectedness between pore spaces and fractures within a rock or sediment deposit. A measure of the capacity of a porous material to transmit fluids

5. Rainfall-Runoff Relations

a. Runoff = free water flowing on continental surfaces of earth

b. Runoff = Total Precipitation - (infiltration + evapotranspiration)

B. Surface Water Flow and Erosion Processes

1. Rain impact or splash erosion

a. Effectiveness influenced by

(1) presence/absence of vegetation

(a) >vegetative cover, < erosive potential

(b) moisture content of soil

i) >saturation, > erosive potential as infiltration rates decrease

2. Sheet Erosion-

a. Horton overland flow (sheet flow = unchannelized)

(1) sheet flow of water over the surface of the earth, carrying loosened earth materials with it.

(a) e.g. parking lot during rain storm

(2) As overland flow continues downslope, the > in volume transforms the flow into channelized flow or rilling

(3) side slopes / heads of hollows = sheet flow

3. Rill Erosion-

a. concentrated flow pattern in numerous parallel seams flowing downslope, rills may coalesce into larger features known as gullies

4. Gully Erosion-larger, channelize flows carrying the potential for large amount of sediment.

a. Rill and Gullies common in semi-arid areas with sparse vegetative cover and high erosion potential.

b. Deforestation and devegetation can result in greatly accelerating the erosion process.

5. Erosion by stream flow: enlarge volumes of flowing water in large stream and river channels greatly increase the capacity to do work in form of erosion and transportation.

a. Hydraulic Shear Force- shear force exerted by moving water on sediment particles, has drag effect on moving sediment. Can result in considerable bank and channel floor erosion.

b. Abrasion- impact from collisions of pebbles and boulders during stream transport result in physical fragmentation of these sediment, gradually increasing roundness and decreasing grainsize down stream

c. Corrosion- chemical solution action via hydrolysis

6. Hierarchy of Runoff Processes

a. Rills and rivulets: small scale channels of surface runoff (inches wide and inches deep)
   (1) found on upper portions of hillslopes
   (2) servicing runoff only during precipitation events

b. Gullies: medium scale channels of runoff (on scale of several feet in width and depth)
   (1) upper to lower portions of hillslopes
   (2) servicing runoff only during precipitation events

c. Open Stream channels (scale of several feet to 10's of feet)
   (1) major sites of surface runoff
   (2) In humid areas, sites of year round flow
   (3) may be ephemeral in arid areas

d. Overland Sheet Flow
   (1) sheets of runoff freely flowing, unchannelized over the landscape.
      (a) common under saturated ground conditions or very intensive rainfall events.

7. Quantifying Channelized Runoff

(1) Discharge: volume of flow/unit time:

Q = VA **V = L/T** **A = wd** where,

Q = discharge (L^3/T)V = average velocity (L/T) A = cross-sectional area (L^2)
w = channel width d = channel depth

(a) As Q>, V> in channelized flow, i.e. stream flow is faster during flood periods

(2) Wetted Perimeter = wetted portion of channel base and sides

(a) P = 2d + w

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(b) wetted perimeter = zone of friction interface between flowing water and channel boundaries

i) water velocity lowest around margins of channel (due to friction), highest in central portion of channel

(c) Hydraulic Radius of Channel: R

R = A/P (L)

(d) Manning Equation

$$v = \frac{1.49\, R^{0.66} S^{0.5}}{n}$$

where v = mean velocity, n = coefficient of roughness R = hydraulic radius S = slope

C. Stream Discharge and Flooding

1. Gaging stations: measure discharge of stream/river over period of time (daily, monthly, annually)

   a. RI = Recurrence Interval of Discharge Data =

$$\frac{\text{Total No. of Years of Record}}{\text{No. of Discharge Occurrences} > \text{Given Value}}$$

   b. Discharge Observations (Y axis) vs. Recurrence Interval (X axis)

   c. Flood periodicities and frequencies of occurrences are important calculations for watershed planning, land use analysis, and emergency management operations

D. Water Motion and Velocity

1. Water Motion
   a. Potential Energy = function of height of water mass above base level
   b. Kinetic Energy = hydraulic energy of flowing water

      (1) Ep converted to Ek as water drops under force of gravity

      (2) "Energy Expenditure" - Ek is dissipated largely as frictional energy
         (a) internal shear friction between water molecules
         (b) external shear friction with channel sides and bottom

            i) frictional shear applied to loose particles is fundamental component of sediment transportation

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ii) velocity is controlled by frictional shear

a) friction defined by n = roughness coefficient

c. Force of water = capacity to do work (i.e. flow, erode, transport)

$$\mathbf{F_p = F_g \sin(\theta)}$$

where F_p = force parallel to channel bottom/slope
F_g = force of gravity, perpendicular to center of earth
theta (θ) = slope angle

(a) as slope angle (i.e. gradient) increases, Force and velocity increase

(1) <u>Patterns of Shearing and Slope</u>.

(a) <u>Slope:</u> resting slope of particles may be inclined or horizontal

(b) <u>Gravity Shear:</u>

i) Tangential Force (gt): acts parallel to slope on inclined planes

(c) Resistance to Gravitational Shear: Frictional forces (electrostatic, surface-contact roughness, and gn), thought of as a force parallel to slope, directed upslope.

i) If Frictional force > gt = no sediment movement

ii) If Frictional force < gt = sediment movement

d. Momentum = tendency of a moving mass to remain in motion

(1) M = mass x velocity(as mass or Vel > , M >)

e. Velocity-depth relations

(1) essentially frictional forces are greatest around channel perimeter

(2) water velocity is slowest along bottom of channel and along channel sides

(a) water velocity greatest along central/interior portion of channel above channel floor

III. Introduction to Fluid Mechanics

(1) Fluid Properties: Two most common fluids = air and water

(a) <u>Viscosity</u>: measure of the resistance of a fluid to change shape (i.e. strain). May vary as function of temperature, >T,<V

(b) Suspended sediment flows (e.g. mudflows) can become very viscous in nature.

(c) <u>Newtonian Fluid:</u> e.g. water, fluid does not deform plastically, i.e. stress is applied and strain occurs instantaneously.

(d) <u>Bingham Fluid:</u> e.g. viscous lava or debris flow, fluid deforms plastically, i.e. a certain magnitude of yield stress must be applied before strain occurs.

(e) <u>Thixotropic</u> substances: those that display variable viscosity dependent upon amount of shear stress applied.

(2) <u>Density</u>: mass per unit volume (M/L^3). May also vary as function of temperature, > T,< D

(3) Fluid Flow: a function of shear displacement of fluid

(a) <u>Laminar Flow</u>: fluid flow in which shear surfaces conform to the shape of the boundary of the fluid

i) Laminar Flow Regime: at low shear rates, with relatively high resistance to shear

ii) resistance to shear > with > viscosity

(b) <u>Turbulent Flow</u>: fluid flow is characterized by vortices and eddies,

i) Characterized by higher rates of shear

ii) Turbulent flow is highly effective as a transport mechanism in that "up eddies" provide a vertical lift component for sediment transport.

iii) Helicoidal Flow Tubes: special case of turbulent flow involving spiraling component of flow in longitudinal direction of movement.

(c) <u>Reynolds Number:</u> Analytical technique defining the conditions of laminar vs. turbulent flow

Defined by: $Re = \frac{pdu}{v}$ where :

p = fluid density, v = viscosity of fluid, d = depth of flowing water, u = velocity of flowing medium, Re = dimensionless number defining laminar vs. turbulent flow.

for pipes and open channel, transition from laminar to turbulent flow: Re = 500-2000.

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(d) Froude Number: dimensionless number defining the effect that gravity plays in causing flow

Defined by: Fr = u/(SQRT(dg)) where:

u = velocity of flowing medium, d = depth of flow, g = gravitational acceleration

Essentially = ratio of flow velocity to the velocity of a small wave created in the flow (as a function of gravitational attraction).

Fr < 1, then wave velocity (under gravity) > flow velocity = "tranquil flow", e.g. waves from a pebble throwr into the flow can propagate upstream

Fr > 1, then wave velocity (under gravity) < flow velocity = "rapid" flow. e.g. waves from a pebble thrown into the flow would only propagate in direction of flow.

Fr=1 critical flow

(4) Boundary Conditions: comprised by physical boundaries of the fluid flow system (e.g. stream channel), i.e. points of friction interface.

(a) Composition of substrate: e.g. soft sediment vs. bedrock

(b) Surface roughness: > surface roughness, > flow turbulence. Create lower bounding layer of increased friction, decreased velocity, and > turbulence.

IV. Slope as a Controlling Variable

A. As slope or gradient of channel increases... velocity increases

a. As slope and velocity increase: the capacity of stream to transport sediment also increases

b. in formula Q =wdv

(1) if Q is held constant, then an increase in velocity due to increased gradient, would have to result in a corresponding decrease in d if constant Q is to be maintained

(a) Hence, and increase in slope, at constant Q, would result in increase in velocity, with decrease in depth

i) higher velocity and < d would result in greater shear force on channel, and results in channel erosion and downcutting

V. Sediment Load and the Fluvial Process

A. Sediment Supply to Rivers

1. Function of:

a. Topographic Relief

> Relief, > gravity > denudation rates

b. Hillslope geology/lithology: dictates composition of sediment load

c. Climate: influences weathering process and vegetation

d. Vegetative cover: stabilizing force on hillslope

(1) low vegetative cover: high hillslope sediment yield

(2) High vegetative cover: low hillslope sediment yield

2. Types of Sediment Load

a. Dissolved Load: dissolved ions in solution

b. Rafted/Flotation Load (e.g. organic debris/garbage)

c. Suspended Load

(1) fine sediment carried within body of fluid medium

(2) dependent on water velocity and grain size

(a) coarser the sediment, > velocity required

d. Bed Load: very coarse sediment transported along the channel substrate under shear force

e. Capacity vs. Competence of a Stream

(1) Capacity- expression of the potential load that a stream can transport, in vol. of material per unit area.

(2) Competence- the largest particle diameter that the stream is capable of transporting given its velocity and shear force

B. <u>Methods of Particle Entrainment</u>:

Fluid Shear Force > (Force of Friction + Force of Gravity)

1. <u>Fluid "lift force"</u>: "airfoil" fluid principle in which fluid flow above a particle creates a low pressure zone, allowing particles to lift vertically and overcome force of gravity (Bernoulli Effect)

a. Wind/Air can lift particles up to medium sand

b. "Lift Force" becomes negligible as particle height = 0.5 diameter

c. Fluid Viscosity can further entrain particles through advective shear transport.

d. Pressure aboe is less than pressure below = net lift

2. <u>Fluid Impact</u>: Direct water-particle impact and particle mobilization

3. <u>Turbulent Support</u>: Upward flow component of turbulent eddies may provide a source of energy for particle entrainment. As Upward Flow Force > Force of Gravity (i.e. "force of settling"), the particles will remain in suspension

4. Grain-Grain Impact ("dispersive force")

C. <u>Mechanical Transport Mechanisms</u>

1. <u>Suspension</u>: fluid currents transport sediments within the main body of flow (primarily fine sand, silt and clay under normal ranges of water viscosity) (Driving Force: Turbulent Flow Conditions, eddy transport)

2. <u>Traction</u>: "Bed Load" - transport concentrated at the basal flow boundary under the "drag force" of fluid shear.

   (1) <u>Saltation</u>: bouncing of particles via upcurrents, and trajectory fall under force of gravity.

   (2) <u>Surface Creep:</u> The forward movement of particles resulting from collisions with saltating particles.

In general, > particle diameter, > force necessary to mobilize particle, given equal particle diameter: > viscosity, < force necessary to mobilize particle.

VI. River/Stream Channel Morphology

A. Channel Morphology

1. Shape of river channel
   a. Plan View
      (1) Straight
      (2) Meandering
      (3) Braided
      (4) Anastomosed

   b. Cross-sectional View
      (1) width-to-depth ratio

2. Sinuosity of River Channel
   a. Magnitude and degree of bends in the river course

   b. Sinuosity Index: quantitative measurement of twisting of river course

      (1) $S = \frac{\text{absolute stream length}}{\text{valley length}}$ or $\frac{\text{thalweg length}}{\text{valley length}}$

(a) Thalweg = line connecting deepest points of river course

B. Meandering Streams

1. Basic Processes

a. Characterized by high-sinuosity, large single channel fluvial systems

b. Finer sediment load and lower gradient as compared to braided fluvial

(1) Meandering Fluvial Systems tend to be fine-load/suspended load (silt and clay) dominated rivers

c. Meandering channels migrate across large floodplain resulting in distinctive deposits

(1) Coarser cross-bedded channel sandstones

(2) Finer silt and mud-dominated "overbank" or floodplain deposits

(3) **Meandering systems tend to be dominated by suspended load

d. Morphological elements of meandering river system include:

(1) meander loops

(2) point bar sedimentation

(3) cut-bank erosion

(4) levee sedimentation

(5) oxbow lake sedimentation

(6) floodplain sedimentation

e. Meandering channel migrates across floodplain

(1) leaving coarse channel and pointbar deposits in its wake

(a) "ALLUVIUM": stream deposited debris.

f. Flood-stage processes (i.e. catastrophic events)

(1) move greatest volume of sediment and result in greatest morphological changes

(2) Crevasse splay: breaching of river channel banks with sand/sediment laden water spilling onto floodplain

(3) Overbank deposits:

(a) fine mud and silt deposited during recession of flood water

2. Meander Wavelength

a. Wavelength (L) of meander system directly proportional to discharge of system

(1) i.e. as Q >, L > and vice versa

(a) large Q rivers = larger meanders

(b) small Q rivers = small meanders

3. Meandering Process
   a. Centrifugal Force
      (1) Water flow in channel with mass of water thrown towards outside edges of bends
      (2) Momentum + Centrifugal Force result in higher velocity and shear force to occur on outside of river bends
         (a) Net Result = erosion and lateral meander migration on outside of channels

   b. Helicoidal Flow
      (1) Lateral components of flow vector are such that surface water is thrown to outside of meander bend and forced downward along the channel floor to the inside of the bend
         (a) net result = helicoidal flow = cork-screw/spiral flow around meander bends

   c. Cut Bank/Point Bar Process: Meander Migration

      (1) Cut Bank = erosive bank cut on outside of meander bend (owing to centrifugal force and increased velocity)
      (2) Point Bar: sediment carried from cut bank erosion is transported to the next river bend.

         (a) Point Bar = deposition on inside of meander bend in response to reduced velocity conditions

   d. Meander Cutoff

      (1) Extensive meander looping + cutbank erosion = river cutting off itself and meander loop
         (a) result: stranding meander loop and forming oxbow lake

C. Braided Streams
1. Basic Processes
   a. Characterized by braided network of low-sinuosity channels separated by mid-channel sediment bars or islands.
      (1) Commonly bed-load dominated (sand and gravel) rivers

   b. Commonly found in
      (1) Glacial outwash plains
      (2) Distal reaches of alluvial fans
      (3) Mountainous drainage systems

   c. Associated with:
      (1) low vegetative cover, high runoff
      (2) high rate of sediment supply

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2. Depositional Processes
   a. Sand to gravel dominated sediment transport
   b. bedload transportation dominant
   c. Rapid shifting of migrating sediment bars
   d. High-gradient, bedload dominated, low-sinuosity river system

      (1) Braided Rivers = higher gradient as compared to meandering rivers

3. Sinuosity

   a. Braided Rivers characterized by low-sinuosity form
   b. Coarse sand and gravel = low relative cohesion compared to fine silt and clay

      (1) much more easily eroded channel walls
      (2) Wide, shallow channels tend to develop

D. Anastomosed Channels

1. Hybrid morphologic form: a cross between meandering and braided morphologies
   a. Multiple channel system analogous to braided, however
   b. Low-gradient, narrow, deep channels with stable banks
      (1) common in high vegetation ecosystems where vegetative bank stabilization is prevalent

VII. Equilibrium Concepts and the River System

A. The Graded Equilibrium Model

1. Base level: an imaginary surface of streamflow equilibrium, approximated by sea level. For the most part, the ultimate destination of fluvial drainage is the sea, which forms a surface, below which deposition takes place, above which erosion takes place, and at which transportation only takes place.

   a. Inland base level: maintains a gentle gradient to allow water drainage
   b. Ultimate base level: sea level.

2. Local or temporary base level: inland equilibrium surfaces (not at sea level), that form lower limits of downcutting because of specific structural, geologic, or drainage conditions.

   a. e.g. a local base level is formed by the confluence of a lower order stream with a higher order one, a lower order stream can not cut lower than its downstream higher order cousin

b. Impoundments or lakes form temporary base levels for local stream drainages.

3. Stream Equilibrium Model: A "graded" stream is one in which the longitudinal gradient of the stream has become modified through the erosion/deposition process such that equilibrated-transport is the only process occurring.

a. Graded Stream: equilibrium between energy, velocity and load available for transport.

(1) Ideal Graded Stream: a purely transportational system with no erosion or deposition, transport from head to mouth of stream

4. Controlling Factors of Equilibrium System

a. Slope/Gradient

(1) graded slope:

(a) concave up

(b) steepest gradient at head

(c) gently flattening gradient to mouth

(2) Slope Adjustment

(a) fluvial adjustment of slope in response to changes in sediment load

(b) > slope, > velocity, > carrying capacity

(3) Local and regional base level changes will result in adjustment of slope

(a) local change = damming of river

(b) regional change = sea level rise/fall

b. Discharge

(1) Discharge influences Velocity

(a) Q >, V>

(2) As Q>, V>, sediment carrying capacity increases

(a) Net result: erosion-----lowering of gradient

(3) As Q<, V<, sediment capacity decreases

(a) Net result: deposition----steepening of gradient

(4) Short Term vs. Long Term Changes in Discharge

(a) Seasonally vs. Climatically controlled

c. Sediment Load

(1) Sediment Load and Supply function of...

(a) climate/weathering

(b) vegetative cover

(c) bedrock geology/structure

(2) Load as a controlling Factor

(a) If Load > (i.e. volume and grain size), deposition occurs, > slope, > velocity, > carrying capacity of stream to equilibrium

(b) vice-versa for decreasing load

(3) Down-gradient Relationships

(a) decreased gradient

(b) decreased grain size

i) abrasion and grain breakdown

(c) increased discharge

i) increased discharge + decreased grain size = excess velocity, result in downcutting to form lower gradient

Relationship Summary:

Action	Response	Slope
Increase in Load	Aggradation	Increases
Decrease in Load	Degradation	Decrease
Increase in Discharge	Degradation	Decrease
Decrease in Discharge	Aggradation	Increase

Degradation = erosion and downcutting
Aggradation = long-term accumulation of sediments

5. Base Level and River Equilibrium

a. Rise Base Level ------ Aggradation of River Upstream

b. Lowering Base Level ------- Degradation and Downcutting

B. Valley Deepening or "Entrenchment" (Degradation)

1. Downcutting Process: wherever a stream possesses a high velocity or a large volume flow, a stream will expend most of its energy downcutting the valley.

a. process most effective in upstream portions where the gradient is steep and the valley narrow.

Result: Classic V-Shaped Cross-Sectional Profile of River Valleys

b. features in downcut valleys include: waterfalls, rapids, and cascades.

1) Knickpoints: abrupt, steep irregularities in a stream profile, perhaps due to resistance characteristics of bedrock

c. Terrace Development: vertical erosion results in abandonment of floodplains

Terrace = abandoned / elevated floodplain

Paired Terraces = terraces of equal elevation on both sides of valley

Strath Terrace = erosional terrace cut into bedrock, with thin alluvial veneer

Fill Terrace = depositional terrace = valley fill + incision cycle

c. Headward Erosion: backcutting and grading of stream profile occurs in a headward direction, with upstream erosion and retreat of knickpoints.

VIII. Drainage Patterns

A. Drainage Patterns Controlled By:

1. Slope of Land
2. Random Headward Erosion
3. Selective Headward Erosion
   a. Preferred Paths along Geologic Weakness of Underlying Framework
      (1) Lithologic/Mineralogic Weakness (preferred path of erosion)
         (a) Lithology and resistance to weathering and erosion

      (2) Structural Weakness (preferred path of erosion)
         (a) Joints, faults, bedding planes

**Streams/Rivers will find path of least resistance and minimum energy/work in relation to gravity; these paths of least resistance are often geologically/structurally controlled within the bedrock framework of the landscape

B. Drainage Patterns: Plan view geometric pattern of tributary network of drainage system. Often strongly controlled by underlying geology/structural relationships.

1. Dendritic- branch-like or leaf-like pattern with random merging of streams at acute angles.

   a. Most common pattern
   b. commonly associated with relatively homogenous underlying geology
      (1) horizontal sedimentary rocks or homogenous igneous rocks
      (2) Little to no zones of weakness in rock

   c. Consequent development

2. Trellis Pattern- parallel streams with elongated valleys connected to trunk drainage at high angles.

   a. Commonly found in fold belts with alternating layers of erosionally soft and resistant rock
   b. Subsequent development
3. Rectangular Pattern- pattern formed by right angle intersections of tributaries

a. Common in faulted/jointed terrane
(1) igneous or sedimentary
(2) May be used to characterize structural geology of region
b. Subsequent development

4. Radial Pattern - radially away from center high point
a. E.g. volcano
b. Consequent development

5. Centripetal - opposite of radial, merging of streams in a bowl-shaped depression.
a. Structural/closed topographic basins
(1) Basin and Range
b. Karst terranes/sinkholes
c. consequent Development

6. Annular- a cross between trellis and radial, where drainage follows alternating layers of resistant and non-resistant rocks found in a structural dome or basin.
a. Circular/parallel drainage patterns
b. Subsequent Development

IX. Stream Terraces and Erosion Surfaces

1. Stream and/or river terraces- planar surfaces of erosion, remnants former valley floors, that now stand above (in elevation) active stream channels and their flood plains

a. elevated surfaces of erosion

b. Implies that active stream/river channels have incised and/or downcut to deeper levels of erosion, stranding erosional terraces at higher elevations

(1) Causes of Stream/River Downcutting
(a) base level; eustatic sea level change
i) lowering global sea level creates down-cutting in channel to re-establish a graded (equilibrium) profile tapered to base level

(b) Tectonic Uplift of land area
i) increases gradient of drainage
ii) elevates stream channels above base level, resulting in down-cutting

(c) Climatic Excursions
i) Increased discharge --- increased velocity/shear force---- increased erosion and downcutting

2. Types of River Terraces

   a. "Strath" or "Cut-in-bedrock" Terraces (comprised of bedrock, erosional in origin)
      (1) erosional surfaces cut by river through lateral planation
      (2) surfaces cut into bedrock with thin veneer of gravel cover

   b. Fill Terraces (comprised of alluvium)
      (1) Valley fill sequence (depositional in origin)
         (a) aggraded depositional sequence
            i) original valley downcutting, followed by aggradation, followed by renewed downcutting and surface abandonment

   c. Cut In Fill Terraces (comprised of alluvium, erosional in origin)
      (1) Valley-Fill + erosion sequence
         (a) original valley downcutting (erosion)
         (b) aggradation of alluvial fill (deposition)
         (c) renewed lateral planation of floodplain (floodplain erosion)
         (d) renewed vertical downcutting and abandonment

   d. Nested Fill Terraces

3. Correlation of Terraces

   a. Detailed surveying with cross-sections
      (1) matching of accordant relief, grade and elevations
   b. Correlation of Soils Chronosequences developed on surfaces
   c. Correlation of numerical age dates (e.g. C 14 dating of wood/charcoal)

4. Other Erosion Surfaces

   a. Stripped/eroded structural surfaces
      (1) dip-plane erosion
         (a) controlled by differences in lithologic resistance to erosion
   b. Marine erosion surfaces
      (1) sea terraces
         (a) derived from wave-base erosion along beach areas
         (b) subsequent uplift/sea level drop with surface abandonment

X. Paleohydaulic Methods

A. Critical Question: What is the flood history of a river beyond the recorded data record?

1. Why - to examine the extreme flood events in the context of landuse planning and floodplain management.

2. Problem - river gage / discharge records only extend back to 100 years or less. What about all the other floods not recorded?

B. Tool kit for the paleohydrologist

1. Ecosystem Response to Flooding
   a. Vegetation adjacent to floodplain
   b. Species adjustment to flood frequency
      (1) "Disturbance Regime"

   c. Individual organism records
      (1) Tree rings, scars, sycamore tipping etc.

2. Slackwater Deposit Analysis ("bathtub rings of sediment / deposits")

   a. Slackwater = quiet flood waters
      (1) fine-grained sedimentation (sand, silt, clay)

   b. Locations for Slackwater Record
      (1) Side Tributaries
      (2) Caves
      (3) Floodplains

3. Tractive load size (Grain Size Analysis - what moved when?)
   a. How to determine what moved.
      (1) flake scars bruises on sheletered surfaces,
      (2) multiple impact marks,
      (3) Fe staining (Cheat),
      (4) imbricated w/ tires, plastics, lumber, etc.,
      (5) aerial photography
      (6) BFR Analysis:
         (a) BFR = Big F.... Rocks, how did they get there, what was the hydraulic regime?

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