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