Lecture Outline

Geography 175

"Landforms of the world"

I. COURSE INTRODUCTION

A. The **goal** of this course is to help you understand how landforms develop. The term *geomorphology* is often used for the topic.

1. This knowledge is an essential part of our comprehension of the world because of the many ways in which landforms affect the human and non-human environments.
2. The skills involved in landform study are important because they are so easy to generalize to other inquiries: the basic lesson is that we can teach ourselves about the world through our own powers of observation and analysis.

B. Course **objectives ...**

1. content goal: we will ask *"Why is the world as it is?"*
    a. this is a generic question in **science**
        i. science is the source of *formal knowledge*…and then of technology as well, as we apply the knowledge
        ii. represents an *ordinary human activity*…inquiry, curiosity…
            1) primitive people asked & answered questions about the sun, food, water, animals, health
            2) you ask about the world when you get dressed to go outside, choose a way home, try to make a new program work
        iii. science is an *organized* version of this activity
            1) shared *standards* of evidence and proof
            2) common intellectual *tools*: physics from Newton, e.g.
    b. the question, in this course, is specific to aspect of the world: geomorphology
        i. **movement** of material – rock and water – on surface
        ii. **products** of movement: *landforms, streams, deposits*
        iii. **effect** on humans: *landscape, resources, hazards* (much of what we define as our **environment**)
2. **intellectual** goals of the course
    a. this is not a course for geography majors…most students in this room are here to satisfy science course requirements
    b. skills & perspectives of the course are meant to be general, of value for anyone:

i. recognize *elegance, power, coherence* of broad organizing principles, and of mechanical explanation

ii. trust your own ability to *observe* the world, *see* problems, and *seek* solution

> *Stop this day and night with me and you shall possess the origin of all poems,*
> *You shall possess the good of the earth and sun, (there are millions of suns left,)*
> *You shall no longer take things at second or third hand, nor look through the eyes of the dead, nor feed on the spectres in books,*
> *You shall not look through my eyes either, nor take things from me,*
> *You shall listen to all sides and filter them from your self.*
>
> *Walt Whitman*

iii. know some *facts* about a wonderful aspect of the world

3. topic is *concrete* to us all…our **environment**
   a. we relate to it with ordinary activities: homes, streams, travel, scenery, industry
   b. and also with extraordinary activities: catastrophes (floods), dramatic degradation (greenhouse effect), traces of enormous past events

C. approach will be **analytic & synthetic**, rather than merely descriptive

1. differences are this:
   a. ask how the parts of this system work together (synthesis)
   b. don't ask what the biggest river in Nebraska is (description)
2. long-term value of **ways-of-thinking** exceeds any facts you would retain …you can look up the facts in the encyclopedia
   a. what you need to know in short term for the course isn't the facts
   b. *stuff* vs. *things* dichotomy … you can look up all that **stuff**; remember the important **things**
   c. you will do badly on the first exam if you know lots of stuff…you only need to know one number, for example, and it is 7 … details later.
3. if you know the **principles**, you can *reconstruct* the specifics
   a. "the Reagan principle"
   b. the meandering of streams, as an example…if you've seen one meander you've seen them all

D. **Organization** of the course (see syllabus)

1. lecture, readings for material
2. the purpose of the outlines
3. using the text
4. quizzes & three exams…Why so many?
5. … learning the names of the states
5. labs … the power of direct experience; maps. samples, excursions
6. help…office hours

E. An **overview** of the subject matter of the course: *landforms*

1. definition of landforms … recurring topography forms (so, what's topography?)
2. concept of 4 spheres
   - *a.* *atmo-, bio-, hydro-, and litho- spheres*
   - *b.* *driving forces*: sun [atmo, bio, & hydro] vs. geothermal heat [litho]
   - *c.* different *rates of movement* & time scale of change
3. the importance of **gravity** in the affairs of humans…and in the lithosphere
4. *endogenic* and *exogenic* forces constructing the landscape
   - a. creating a *framework*, from within (**endogenic**)
   - b. *wearing* it away, from outside, sculpting (**exogenic)**
5. the importance of **slopes**, **streams**, and the **equilibrium** profile
6. also…how landforms create our environment:
   - a. the earth as the home of humans – **topography** & human industry
   - b. the value to us all of earth material (**resources**)
   - c. risk & **hazard**…the many ways in which the world can hurt us

II. SYSTEMS & CYCLES

WHY DO WE STILL HAVE MOUNTAINS? THEY ARE ERODED EVERYDAY, SO WHY AREN'T THEY GONE?

A. "**System**" as a concept: any part of the universe that we can think of as a *unit* is a system

1. value of the concept
   - a. helps us understand how parts of the environment interact with one-another
   - b. we also can understand properties of only *that* part
2. underlying principle: *conservation of matter and energy* (**First Law of Thermodynamics**)
   - a. the first law: "energy [or matter] is neither created nor destroyed"
   - b. everything that went into the system is either still in there or has come out
   - c. matter and energy are ***cycled***; never created nor destroyed
   - d. …although energy is degraded, so it doesn't cycle so well (the Second Law of Thermodynamics)

B. natural systems tend to be in ***balance***: relatively stable over the long run

1. we know that any system with an ***outflow*** ("Rivers take sediment from continents to the sea") must have an ***off-setting inflow*** ("Something brings sediment back onto the land")
   - a. formula: ***I***(input) = ***O***(output)
   - b. the input always ends up as output
   - c. the output can only come from input

2. *even if we cannot see it,* we should believe the return flow is there:
    a. otherwise we would have run out of mountains (or whatever) a long, long time ago
    b. we don't expect to see significant net change in a planet 5,000,000,000 years old within our paltry lifespans

C. but ***in the short run,*** systems don't need to be in balance because of *storage*
1. it rains today, but the output (stream flow) doesn’t happen immediately
2. lakes, soil, groundwater, glaciers hold water between rainfall and runoff from the rivers
3. **I = O + ΔSt**
4. the input can go to increase storage, or the output can come from decreasing storage, in the short run
5. however, ΔSt = 0 in the long-run; all the water going into lakes will leave eventually

D. It is not a coincidence that natural systems are stable, but rather an outcome of the fact that natural systems that are **homeostatic** – inherently resistant to change – survive, while others are destroyed. Key ideas in homeostasis:
1. **feedback**: the state of the system affects inputs or outputs
2. **negative feedback**: an increase in storage will decrease input or increase output
    a. example: thermostat: too much heat (↑St of heat) turns off furnace (↓input of heat) or turns on air conditioner (↑O)
    b. very common in natural systems: animal population, stream flow, climate, physiological systems
    c. physical analog to negative feedback: a marble in a bowl…rolls back into center of bowl when displaced (“perturbed”)
3. **positive feedback**: more storage yields more input…yields more storage yields more input…(or less storage means less input …)
    a. continues until input (energy) is gone or system is broken…the positive feedback system destroys itself
    b. ex: bonfire, earthen (or ice) dam, snow cover & temperature
    c. self-destructive systems like this are uncommon in natural circumstances…for obvious reasons
    d. positive feedback systems can be stable for a long time, until a **threshold** is crossed…a pile of firewood is stable until it crosses a certain temperature
    e. physical analog of threshold: pop bottle on its neck; stable until it tips past a certain point

E. The **equilibrium state**
1. If the state of a system is the difference between two opposite forces – average temperature balances the day's sunshine against night's cooling, e.g. – we should see the system find a balance which reflects equally the influence of the two factors

2. this is the ***optimum***: an intermediate value (of anything – slope, for example) toward which a system will tend
3. the Goldilocks principle: "Not too hot, not too cold, but *juuuust* right"
4. "optimum" doesn't necessarily mean "good"…the ecologically optimum number of mosquitoes is more than none

F. Storage and **lag**

1. storage **smoothes** out variation over a time (a big bank account smoothes out changes in income)
2. storage **delays** the response of the system to change (a lake fills and empties more slowly than a pond; a big truck speeds up or slows down later than a little one)
3. the **time difference** between external change and internal response is called ***lag***

III. SURFACE AND SUB-SURFACE PROCESSES

THE LANDSCAPE AT ANY PLACE IS A BALANCE BETWEEN THE MANY PROCESSES THAT ARE & HAVE BEEN AT WORK ON IT.

A. Overview: general earth processes:

1. ***uplift***
2. ***leveling***
3. enough ***time*** has been available for the slowest of processes to have changed the entire world
4. the name for the shape of the surface of the earth is ***topography***
   a. a *very* ordinary concept
   b. examples: hill, valley, plain

B. Uplift…***tectonics*** (= "build")

1. "great forces within the earth" *move* the surface from below…probably convection of hot plastic rock, warmed by radioactive decay…like the scum on simmering chicken soup
2. creates primarily *horizontal* movements of the crust (the lithosphere)…plate tectonics
3. compression ("press") creates uplift → /\ ←…may make mountains (orogeny)
4. extension ("tension") often opens basins ← _/ →…may make oceans
5. crust "floats" upon a semi-molten layer (the ***asthenosphere***)
   a. light rocks float higher
      i. *continental* rock is *less dense* than *oceanic* rock
      ii. mountains must have light "roots": sticking down into a denser layer, to float them upward
      iii. e.g., errors in Sir George Everest's Great Trigonometrical Survey of India
   b. erosion lightens the crust & permits it to rise
      i. this is feedback…which kind?

ii. called ***isostasy***…the “float” of crust on asthenosphere and the response of land elevation to loading, unloading

6. ***pattern*** of mountain, plains, ocean, and trench is highly regular…chains of mountain, opening oceans, mid-ocean rifts
    a. compression or extension gives characteristic landforms where each has happened
    b. zones of compression or extension usually continuous & linear
    c. because of simple pattern of ***plate tectonics***, as we will see in more detail soon

C. Leveling returns land to lower elevation
  1. material moves from upland (***erosion***) to oceans or lowlands (***deposition***)
  2. potential energy from uplift drives the processes (it's gravity: the 3rd Law of Plumbing)
  3. agents that facilitate this work are usually forms of *water* – streams, glaciers, weathering, (muddy) slope failures, waves
  4. climate, slope, soil will “chose” which agency is at work…glaciers vs. streams, e.g.
  5. each agency sculpts in a distinctive fashion…stream valleys, beaches, dunes, moraines
  6. feedback: more uplift = more leveling

D. How long does it take?
  1. how long do you need? Time is an *abundant* commodity in earth science
  2. some landscape surfaces are 300,000,000 yr. old; some rocks are 3,000,000,000 yr. old

E. Landscape everywhere carries history of two forces
  1. type of uplift
  2. type of leveling
  3. we can also see:
      a. changes in type (streams upon a previously glaciated landscape)
      b. relative rates (one area is more leveled, another is more uplifted)

F. The insight of **William Morris Davis** –
  1. same ***structure*** (= tectonic history), ***process*** (= leveling), & ***stage*** (= age) creates the same landform feature
  2. landscape ***feature*** names are **genetic** terms:
      a. “cliff” is a **generic** (= “general”) topographic term
          i. any steep slope is a cliff
          ii. anything can make one – a bulldozer, an earthquake, a flood
      b. “bluff” (for example) is a **feature** name
          i. only cliffs formed by the lateral movement of waves or streams are bluffs
          ii. it is a genetic term because the name specifies the *genesis*

G. The insight of **Nevin M. Fenneman**:
   1. similar landforms occur in extensive areas
      a. because the structure, process, stage are similar over those area
      b. this is the definition of **region**, a fundamental concept in geography
   2. results in "***physiographic provinces***" (= landform regions)
      a. regions of similar landforms
      b. e.g., Ridge & Valley (here), Piedmont (most of Philadelphia, Baltimore), Coastal Plain (South Jersey, Delaware, and all the way to Florida)

IV. WATER CYCLE

*WATER DOES MOST OF THE **WORK** OF LEVELING…AS STREAMS, AS GLACIERS, AS DRIVING FORCE FOR WEATHERING*

A. Overview of the water cycle: $P = R + E + \Delta St$
   1. translation: Rain (**P**recipitation) has two fates
      a. it is returned to the atmosphere (**E**vapotranspiration)
      b. or it flows toward the ocean (**R**unoff)
      c. perhaps having spent some time as groundwater (**St**orage)
   2. source of water is rain (**P**)
      a. hydrological cycle…ocean → air → land → ocean
      b. amount of rain varies from place-to-place, mainly on how far from the ocean you are…deserts behind mountains & in centers of continents, etc.
      c. this is weather and climate, well covered in the book, but for our purposes, we can simply look at the map
   3. plants evaporate water back to the atmosphere (**E**)
      a. move water from roots upward in stem & out leaves
      b. they need to do so, to stay alive…cool selves & move nutrients
      c. there is more evaporation when plants grow more…if it is hot, sunny, tropical, etc.
      d. and water evaporates off streams & lakes &c, of course
   4. all other water runs off toward the sea, eventually (**R**)
      a. direct runoff, across the surface, to the streams very soon
      b. indirect runoff, into the ground
      c. … although some dry places drain internally; not to the sea
   5. groundwater is **St**
      a. (as are lakes, glaciers, water in streams, drops stuck to leaves, etc.,)
      b. becomes spring flow, or emerges beneath streams & oceans, to become E and R again
      c. most St is moving downhill, too, but slooooowly
      d. water stored in soil becomes available for later plant growth

6. the numbers for typical places
    a. Pennsylvania: P = 35”; E = 25”; R = 10”; amount of water in soil St varies by 5”
    b. Arizona: P = 5”; E = 4”, R = 1” (often in big floods); St varies little and is always low
    c. Brazil: P = 80”; E = 65”, R = 15”; amount of water in St varies by 10”

B. The importance of groundwater storage
1. what is **groundwater**?
    a. water held in saturated rock materials .. called an ***aquifer***
        i. it is confined below by solid rock
        ii. held in pore spaces between rock particles…1% - 25% of rock volume
    b. visible in wells, holes on the beach, etc.
    c. top of the ground water is the **water table**
    d. **recharged** from surface, discharge in springs & seeps
    e. always moving **downhill** (of course)
2. water in storage is *traveling* all the time in storage
    a. *very* slow rate:
        i. moves through small fractures
        ii. 10 m/day to 0.0000001 m/day (compared to 1 m/sec in a river)
        iii. the smaller the fractures, the slower the movement (more friction)
    b. important analogy: *viscosity*
        i. resistance of a fluid to flow (like honey)
        ii. example: at a well the groundwater is lowered in a “cone of depression” because it cannot flow to the well quickly enough
        ii. *cf.*: viscosity of semi-molten rock creates lag in response to isostasy,
    c. viscous fluids *resemble* slow flow of groundwater (g.w. acts *as though it were* viscous…it isn't)
3. indirect runoff gets to streams *much* later…storage creates ***lag***
    a. delay between event (rain) and effect (runoff)
    b. lag is a general effect of storage…hide under a tree in a storm sometime
    c. but there is storage an dlag in direct-runoff systems, too.
4. more storage means (therefore) less variability…visible on **hydrograph**, (chart of stream flow vs. time) as the *peak* after the storm and the longer term *base*line of the curve
    a. **peak flow** is (more-or-less) all direct runoff
        i. *enters* stream *soon* after rainfall
        ii. *decreases* soon, too
        iii. note that peak flow goes through storage, too…soil, grass, channels
    b. **base flow** is stream flow that comes from ground water

i. continues *long after* rain stops

ii. base flow is often clearer, cooler in summer & warmer in winter (temperature lag) because it is delayed and naturally filtered *ground water*

iii. flow rate *falls slowly* as level of ground water (water table) falls…negative feedback like a bucket with a hole in it: less St is less flow

c. a hydrological system with less storage (for example, a paved city or overgrazed & eroded hillside) has

i. lower base

1) like the loss of springs after clearing for agriculture

2) it is the loss of a free reservoir

3) used intentionally in many places with injection wells and infiltration basins

ii. sooner peak (shorter lag)

iii. higher peak

1) water gets into stream all at once

2) therefore more flood hazard (loss of free reservoir, again)

iv. probably more total flow (less St in the soil for subsequent evaporation)

d. the time in lag time is travel; the water is always moving toward the sea and it takes it a while to get out of storage and through the stream.

C. *Wetlands* as an example of storage –

THE *STORAGE* THEORY OF EVERYTHING

1. Definition of a wetland…water table and ground surface within inches of each other [= wet soil or shallow water]

2. We recognize them in the field by

a. soil (organic-rich and iron-mottled … low oxygen)

b. vegetation (cattails, sedges & other water-lovers)

c. long-term observations of water level

3. How many kinds of storage in a wetland?

a. store water (flood control, groundwater recharge)

b. store sediment (that’s why wetlands are at water table)

c. store organisms…(baby fishes)

d. store pollutants & nutrients (e.g., wetland soils)

e. store information for geologists & archeologists

4. Why are wetlands threatened? The hubris of “reclamation”.

a. lower productivity

b. “worthless” environments

c. disadvantages of slow movement of nutrients, etc., to us…we’re in a hurry

d. impede our own motion through the area

d. current law obliges us all to make a huge investment in protecting them

V. STREAMS

Streams are the major agents in the sculpture of the earth.

A. Definition: ***channel flow of water***

1. it is *consolidated*…water acting together, sharing friction, momentum, etc.
2. any *size*…Mississippi or a trickle on the sidewalk
3. importance:
    a. streams do much of the leveling work on most landscapes
    b. behavior of streams (which is highly predictable & understandable) is the single most important control upon most landforms
    c. major source of water for human use

B. Some simple variables to understand:

1. **gradient**
    a. *angle* of stream bed…how steep it is (This term is just like how we usually use “slope”, but we reserve that word for hill sides.)
    b. units: *feet per mile*, or could be degrees (or % or m/km)
    c. stream gradients are very *low* compared to most everything else on the landscape
        i. 100'/mile for mountain streams to 4”/mile for the Amazon
        ii. essentially flat compared to most everything else (hillslopes, geologic structure)
2. **velocity**…**V**
    a. how fast water is flowing
    b. units such as *feet per second*
    c. increases with:
        i. *gradient*…more gravitational energy per distance (= steeper)
        ii. *stream size*…less friction per unit water

> *This is an example of an important concept: surface-to-volume ratio – more surface is more interaction with the environment…we'll see the idea again & again*

        iii. channel *roundness* (less surface-to-volume, again)
        iv. channel *smoothness* (rough bed slows water)
        v. *location* of measurement in channel…V is greatest furthest from bottom
3. **discharge**…symbolized as **Q**
    a. amount of water moving in the stream
    b. units are volume per unit time…gallons per second, acre-feet per year, *cubic-feet per second*
    c. must be *calculated* for any real-size stream

i. Q=AV … six cubic meters per second is two meters per second of flow in a three square meter channel

ii. actual measurement of a big messy stream is sum of many little q's (for little, simpler a's & v's): $Q = (a_1v_1 + a_2v_2 + a_3v_3 + \ldots)$

d. Q represents a contribution from landscape

i. it is the R, runoff, of "P = E + R"

ii. remember that the rain water fell *all over* the landscape, not just into the channel

e. Q is constant along any stretch of stream unless water is added or removed (conservation of matter)

C. Geometry/geography of steams and how they meet; some terms:

1. **drainage basin** (= **watershed**)

a. area contributing water to *this* stream

b. all the land sloping downward toward this stream, finally

c. roughly basin-shaped (higher at edges, like a shell)

2. **tributary**

a. a stream joining another – the Ohio is a tributary of the Mississippi

b. Q of big stream is the sum of the Q's of the tributaries

3. drainage **divide**

a. line separating two drainage basins

b. often in uplands, a ridge-crest

VI. THE WORK OF STREAMS

A. Stream **energy**

1. energy is from gravity

a. same work that drives hydro-electric plants

b. water gains energy as it moves down hill (like a car speeds up on a descent)

c. more vertical distance fallen is more energy, and steeper streams gain energy faster

d. e.g., Niagara River water is 1/2 degree warmer after falling over Niagara

2. most of energy is dissipated as ***turbulence***

a. water is viscose … it resists moving against itself like honey does (but not as much)

a. water swirling, moving against water & using up stream energy by making heat

b. turbulence & friction greatest near bed (… bottom induces shear in water)

c. turbulence higher in bed with higher "roughness".

3. small amount of energy does work on stream bed

   a. moving water exerts a force or "drag" on sediment (***sediment*** = broken rock in transit)
   b. *entrains* (picks up or dislodges), then ***transports*** (moves) material
   c. this is what does all of stream **erosion** (= the export of sediment)
4. transport ability increases rapidly as velocity increases
   a. *"Gilbert's 7th Power Law"*…twice the velocity is 2^7 (= 128) times the transport capacity [ah! here' s the '7' we need to know]
   b. (the law is a fair approximation of what happens in a stream but it is not actually that simple … the important point is a little more V is a lot more transport)

B. Erosion and transport
1. the ***energy*** comes from stream velocity (from gravity, etc.)
2. **sediment***:* fancy name for mineral particles stream moves
   a. produced by ***weathering*** (the processes that make soil .. which we'll see later)
   b. named by sizes: ***boulders, cobbles, gravel, sand, silt, clay***
   c. ***clast*** is generic term for a piece of sediment
3. ***settling time*** .. how quickly a particle will drop out of the water column .. is a fair measure of transport ease
   a. reason: Transport happens only if a stream can carry sediment off before it falls out of water column.
   b. settling time *much* slower for small items…surface-to-volume ratio again…there is much more friction for small object
4. there are three ways to move material, at different stream velocities – compare settling-rate against typical upward-movement in water column
   a. ***suspension***…days-long settling time (clay in a turbid stream)
   b. ***saltation***…seconds-long period in the fluid … bouncing along, as sand hitting your ankles on windy beach
   c. ***traction***…dragged by force on upstream face of clast (as a boulder would have to be)
   d. the higher the velocity, the more material moves in the water column … pebbles can be in suspension in a catastrophic flood
5. a complexity: harder to *entrain* smaller particles
   a. they hide below the "zero-velocity" ***boundary layer*** (like the layer on a moving fan where dust settles)
   b. *fine sand* is easiest to pick-up-and-transport —"optimum transport size"; an optimum between easy to entrain (bigger) and easy to transport (smaller)
6. erosion removes material from the ***channel*** and ***banks*** of the stream (not from entire landscape)
   a. if stream energy is high, stream will cut down
   b. called ***degradation***

        c. eventually forms a feature called a ***valley*** (duh)

    7. as a valley gets deeper, it is harder – and less likely – for the stream to change course (negative feedback)

C. Deposition .. it’s easy to understand; the opposite of erosion

    1. when stream energy (velocity) decreases below some threshold (where the stream gets flat, for example), transport ends and material is ***deposited***

        a. stream-lain material (sand, silt, etc.) is called ***alluvium***

        b. process of a stream building up bed through deposition called ***aggradation***

    2. deposition fills the stream's channel, and forces the stream to another place…aggrading streams are ***unstable*** with respect to channel location

    3. long-term (sweeping) deposition forms a flat feature called an ***alluvial plain*** (such as a floodplain)

D. The ***graded profile***…the gradient of a mature stream is in an equilibrium controlled by two (and only two) factors: ***Q*** and ***sediment size.***

    1. a very important characteristic of the work of streams…for every set of those two conditions, we expect a stream to be at the same gradient, and therefore smooth and continuous in long profile.

(This is a **heuristic** *.. a concept that help us understand the world even if it isn’t precisely and literally true. The ideal gas, negative feedback, and democracy are other heuristics you might be familiar with. This is what we* ***expect****; nature will always be a bit different.)*

There is an ***expected*** profile, an equilibrium profile, to streams; they will be just steep enough to carry their bed load

    2. Explanation:

        a. underlying assumption: the landscape gives water and sediment to the stream, both of which will get to the ocean

        3. if stream velocity is *insufficient* to remove sediment of size it is given

            a. sediment will *remain*

            b. stream will ***aggrade*** and ***steepen***

            c. until stream is juuuust steep enough to move its bedload

        4. if stream velocity is very high (lots of water) for size of sediment

            a. material will be *removed*

            b. channel will be cut down (degradation)

            c. stream will ***erode*** and ***flatten***

            d. until stream is juuuust steep enough to move its bedload

    5. changes in grade:

        a. a process which ***increases sediment size*** or ***decreases Q*** (mining, climate change, e.g.) will cause stream to ***aggrade*** (steepen) downstream of there

        b. and vice versa

6. raising a stream in one place (a fault, a dam, sediment from a tributary stream, e.g.) will cause stream to aggrade *upstream* of there
7. drop channel in one place (fault, lower sea level, glacial scour), will cause rapid erosion *at one place*, and the site of erosion – a rapids or a falls – will *propagate upstream* as a ***knickpoint*** (such as Niagara Falls, headed toward Lake Erie)
8. “***baselevel***” is the generic term for the level at the outlet of a stream…sealevel, for the biggest rivers. Changing baselevel changes the whole graded) stream above it.
9. standard “long-profile” of a mature stream is
   a. ***smooth*** (if it has had enough time to be graded)
   b. ***concave upward*** – steeper at upper end where
      i. Q is lower
      ii. sediment is still large
10. a “***graded stream***” is a stream that has reached this equilibrium

E. Alluvial surfaces…they are *graded*, *depositional*, and *sediment-covered*

1. **floodplain**…flat area adjacent to stream occupied periodically by stream
   a. often depositional (alluvium)
   b. *might* be erosional, bedrock
2. **terrace**…abandoned floodplain on the margin of a stream valley; sign of changed conditions: stream entrenched into part of the old floodplain by relatively recent *down-cutting* from
   a. higher Q
   b. smaller sediment (e.g., the postglacial Susquehanna right here), or
   c. localized uplift
3. **delta**…transport is zero in still water; graded surface grows outward into the water and *atop* material dropped in water
   a. “bird's foot” (like Mississippi) shows shifting courses, shows stream's aggrading nature
   b. size (and shape) of delta is an optimum controlled by rate of addition, rate of removal, sea level change
4. **alluvial fans**
   a. rapid drop in stream energy…mouth of canyon out of mountains, e.g.
   b. rapidly aggrading
   c. shifting stream position

F. **Headward erosion**

1. background idea is ***drainage density***:
   a. length of *channel* (not necessarily *waterway*) per area
   b. varies between 1 and 7000 miles/square mile
   c. (number is related to inverse of typical distance between channels)
2. an *optimum*…not too much, not too little channel…balance between forces for

   a. *more* channel – a result of more work being done on environment
      i. steeper slope
      ii. higher storm intensity
      iii. low infiltration
      iv. *not* P…that only changes *rate* at which channels form
   b. *less* channel – result of processes or features that
      i. resist erosion…vegetation, larger sediment
      ii. erase channels…ordinary slope and soil movement
3. drainage density of mature (stable) system will depend on several factors…
   a. slope, storm intensity, vegetation
   b. actions of humans can also change drainage density…much soil erosion on farms is an increase in drainage density
   c. compare the USDA’s “Universal Soil Loss Equation”, used for farm planning

The significance of "USLE" is:
1. erosion is a widespread loss of soil value
2. eroded soil is itself a pollutant & carries pesticides & nutrients
3. less erosion also means less flooding
4. less erosion also means more groundwater storage
5. these same factors affect *drainage density* in a natural environment.

The equation is **A = R x K x L x S x C x P**. It says:

A, the predicted loss of soil in tons per acre per year, is the product of:

R: Rainfall & runoff factor .. erosive force of rainfall, including *total rainfall*, *intensity*, and *seasonal distribution* (on frozen ground, for example). R ranges from <20 in central Nevada, to 500 on the Gulf Coast. It's about 150 here.

K: Soil erodibility factor .. "inherent erodibility of a soil"; expected soil loss from a plot 22 m long on a 9% slope and no vegetation. Two most important factors: *infiltration capacity* [how much water can enter it and therefore not erode it] and *structural stability* [chunks of soil; how well it resists movement]; also *texture, organic content, soil depth*. K is low for sand, tropical clays [good structure]; high for silt. Ranges from 0.05 for rocky sand, to 0.33 for the local Hagerstown, to 0.69 for the loess under campus.

SL: Topographic factor .. *longer* slopes move more water; more water runs off *steep* slopes and it moves faster. More water is *much* more erosion, of course (the 7th power law). Ranges from 0.16 for a 15 m slope at 2% (that is, 16% of the "standard" 9%, 22 m slope), to 3.13 for 12% & 92 m. Twice the length is 2.6 times the erosion per m^2, in one study.

C: Cover & management factor .. How well is the soil covered, and how long is it covered throughout the growing season? Cover is good. The number is relative rate of erosion compared to bare ground. Ranges from 0.001 for forest or meadow (one-tenth of one percent of the rate on an unprotected slope), to 0.05 for best farming practice, to 0.50 for conventional farming.

P: Support practice factor .. protection, from good farming practice,

-- *contour plowing* .. furrows make "dams"; factor is about 0.6 (60% as much erosion)

-- *strip cropping* .. insures absorbing cover every 80 m or so .. factor is 0.35

-- also: *terraces* cut into the slope will decrease S; *diversion* ditches across slope decrease L; leaving *stubble* in field decreases C.

(after *Nature and Properties of Soils*, by Nyle C. Brady)

4. if drainage density is too low (streams are too far apart), it is increased by ***headward erosion***…channel extending itself uphill. This concept is seemingly offensive to our sensibilities, but ..
   a. a channel is an *absence* of sediment, a hole…no *objects* are moving uphill
   b. compare to *knickpoints*, which retreat upstream
5. as they develop, channels tend to spread out away form each other
   a. cover maximum area with fewest channels (minimize channel/area for a given amount of stream)
   b. think of the channels as "repelling" each other
6. a (hypothetical … heurtisical) perfect stream system will result in lines (tributaries) meeting at 120 degrees…a "**dendritic**" pattern, like a tree
   a. this is a common "solution" by nature to lines-filling-space
   b. soap bubbles, mud cracks, tree branches are dendritic patterns
7. dendritic stream pattern will *not* happen if there are other controls on the stream, such as
   a. pre-existing slope
   b. zones of weakness (a fault in the rock, say)

VII. Flood Hazard

A. Definition of hazard: something which can harm you…your person or property

B. Hazards specific to this course:
   1. geophysical, natural hazards
   2. i.e., those caused by the earth-building & erosional forces we have been looking at here: stream, slope, coastal, and tectonic processes

C. What is a hazard? Each includes:
   1. an ***event*** – stream gets big; hurricane hits a coast
   2. an ***exposure*** – someone is in the way, is vulnerable…people live on that coast and are *exposed*
   3. people have the ability to foresee, escape, or recover from the event; but people's **response** to the hazard is limited by limited information or resources
   4. people may live on in dangerous areas because of how they **perceive** the risk…is it rare, or (seems) to be ancient history

D. ***Flooding***
   1. "Good" example of a hazard
      a. familiar process ... it is what streams do, and we understand streams, don't we?
      b. widespread & frequent
      c. considerable effort & expense is invested in decreasing this hazard
   2. The ***event***: a stream rises overbank
      a. usually high Q, usually from P or snow melt

   b. ***discharge-rating curve*** tells how high water will get (="stage") for given Q, floods are deeper in skinny valleys
   c. flood prone areas:
      i. ***alluvial*** (aggrading) streams [the Mississippi, or an alluvial fan] flood frequently because channel is persistently sedimented
      ii. mountainous areas prone to flooding because of higher rainfall, narrow valleys, greater runoff efficiency (more R per P)
   d. **recurrence interval** describes size of flood according to its probability of happening
      i. assumes that big floods (or other random events -- storms, landslides, droughts) are less likely than little ones, in a predictable way
      ii. expressed as average time between events: (n+1) / r
      iii. not predictive of *when* next event will happen; better to think of 1/RI as probability per year (100 year flood is a 1% probability)
      iv. useful to decide how big a dam, bridge, or levee to build to prevent damage 49 years out of 50 (or whatever)...we cannot afford to stop *all* damage
      v. but we can only guess how representative our short record is of the "actual" behavior of the river
3. The ***exposure***:
   a. there are many reasons why people live on floodplain: flat, fertile, watered, pretty, etc.
   b. note that most of the cities in America are on navigable rivers ...
   c. and people get wet
4. ***Response***: we stop flood damage by controlling the event, or limiting the exposure
   a. *control **event***:
      i. watershed management
         1) maximize infiltration, contour plowing, small ponds to increase storage & therefore lag-time
         2) relatively inexpensive, but not much fun to engineer
      ii. work in stream to decrease size or area of flood
         1) dams ... hold back water
         2) levees and floodwalls ... keep water our of towns
         3) floodways, meander cut-offs ... divert, speed water away
      iii. "in-channel" efforts create new problems (as is almost always the case when one messes with a complex system like a stream)
         1) narrowing channel, speeding peak will increase stream energy and flood size downstream; cause scour & deposition; stream will seek original form
         2) there *is* a flood bigger than your protection ... 200 year flood *will* happen on one of any 200 basins about every year; but investment in a 200 year floodwall will often exceed value of material protected

3) protection *encourages* exposure ... as investment in flood control goes up. so does average loss

b. *decrease* ***exposure***

i. spread the loss, through disaster relief

ii. structural solutions ... house-on-stilts, the Milton Old-Folks Island, etc.

iii. zoning ... there are appropriate uses of flood plains

1) parks, ball fields, parking lots

2) federally underwritten flood insurance requires community zoning

5. ***Perception*** -- why do people remain in risky environments?

a. general point: decisions are made on the basis of what we *think*, which isn't always what is *true*

b. a series of beliefs "help" people ignore risk

i. lightning doesn't strike twice

ii. if your number is up ...

iii. the government will provide

c. "natural hazard syndrome" ... we worry for only a few years after the event

d. maybe risk *is* acceptable; non-economic values overwhelm economic

VIII. LANDSCAPE EVOLUTION

A. "**Ages**" of the landscape

1. *general idea*:

a. relative influences of uplift & leveling determine the general form of the landscape at a place

b. the shape of the landscape reflects, broadly, the erosional history at that place

c. Will uplift or erosion dominate at a particular place? Use the ideas of plate tectonics

2. concept is only a heuristic and uses out-dated terminology …"age", from William Morris Davis, in 1890

a. "*initial, youthful, mature, old*" are increasingly leveled

b. (must actually refer to *relative* age…some places [soft rock or strong streams] will "age" in many fewer actual years)

c. the "organic" metaphor, that the land aged like you or me, was more believable in those times

3. ***initial***

a. (in tectonic terms) – newly, or currently being, uplifted

b. little mark of stream work

c. Davis' model for this is newly emerged sea floor or drained lake; we should also think of great mountains, Tibetan plateau

d. rather metaphoric in the real world, where nothing is new

4. ***youthful***
   a. streams developing drainage by rapid headward erosion
   b. rate of leveling limited by incomplete stream network (low drainage density) .. streams cannot work on the landscape effectively yet
   c. ex: Colorado Plateau
5. ***mature***
   a. (in tectonic terms) – near equal influence of uplift and leveling
   b. stream network well developed
   c. all land in slope; most rapid leveling
   d. ex: West Virginia
6. ***old age***
   a. (in tectonic terms) – dominated by the influence of leveling
   b. low relief; few, large streams
   c. leveling limited by low amount of material above baselevel
   d. found in stable interiors of plates (Illinois or Siberia) or at large streams (Bangladesh at mouth of Ganges)
7. ***rejuvenated***
   a. renewal of uplift after long period of stability
   b. start over at *youthful*
   c. Davis andhis followers believed that rejuvenation left behind remnants of extensive, thoroughly leveled uplands … characterized as **peneplains;** Pennsylvania contains premier examples of these presumed features..
8. Most big streams don’t get their course by headward erosion…the path of the stream is likely to be older than the mountains
   a. ***superposed*** streams’ courses developed on flat, old-age landscape; rejuvenation causes streams to become hung-up on resistant rock
      i. ex.: “peneplain” (ancient surface of low relief, now mostly dissected) in Pennsylvania?
      ii. evidence is: concordant uplands (ridges all the same height) cut by water gaps
   b. ***antecedent*** streams…present before uplift creates mountains
   c. as time goes by, headward erosion *improves* drainage pattern by cutting into weak rock & capture of big streams by littler (but more efficient) streams

B. Landscape evolution is different in *different climates*:
   1. ***arid*** (dry) climate: desert landforms
      a. steeper streams
      b. straight slopes
      c. sharp slope crests

   d. because of larger sediment size, slide & wash as slope processes (no vegetation, less clay)

2. ***cold*** climate: periglacial landforms
   a. large sediment (freeze-thaw weathering)
   b. flat, rounded slopes
   c. ground-ice features
   d. many relicts of this climate found locally, dating from Pleistocene
3. ***humid*** climate
   a. chemical weathering, little sediment, deep weathering, etc.
   b. *karst* as an example of "humid cycle of erosion"

IX. HILLSLOPES

A. Significance:
   1. most of the *transport of material* across the landscape is across hillslopes, most of the *landscape* is shaped by slope processes
   2. steams are just sewers, conveying off what slopes give them
   3. example: Did the Colorado cut the Grand Canyon?
   4. given their importance, it is too bad that slope processes are slow and dull

B. ***Angle of repose***
   1. concept: *maximum angle* loose material will sustain under its own weight – if the slope gets steeper it will collapse
   2. example: back side of a *sand dune*, with wind adding sand to the top, cannot be steeper than 32^{o} (+/-), or the slope will fail
   3. (angle of repose is an ideal concept, truly applicable only to loose, dry sand; we will use the phrase more generally, to refer to the maximum stable slope)

C. Slopes as ***equilibrium transport surfaces***…like the graded stream profile
   1. mature slopes are like streams in that they will maintain an angle *just steep enough* to transport the material they are provided under the existing environmental conditions
   2. consider the down-wind side of the sand dune again:
      a. *too steep*: slope fails, to the angle of repose (*flattens*)…How would it have gotten too steep in the first place?
      b. *too flat*: no transport & material accumulates at top (*steepens*)
   3. general principle:
      a. slopes, as elements of stable landscapes, are *equilibrated*
      b. when active, material is being added at top & removed at bottom at *same rate*
      c. stream work (export of sediment from the base of slopes) important to *maintaining slope activity*; active down-cutting steepens and accelerates slopes

d. slope movement often *limited by rate of detachment* (= provision of loose sediment; weathering)…a rocky cliff is too steep because the rock doesn't move

4. but, because these are such slow processes, many slopes are not in equilibrium
   a. too steep ("oversteepened")…shows "fresh" (ca. 1000's years) undercutting
   b. too flat…a relict of previous conditions when slopes were flatter (colder, wetter times)

D. ***Slope processes***

1. rates and types of movement very different according to conditions
   a. more *moisture* speeds them up
      i. increases weight of slope
      ii. decreases coherence (sticking together; friction) between particles
   b. particle size, shape, and uniformity…try stacking bowling balls
   c. freeze-thaw, dry-wet, earthquakes are external influences to accelerate movement
2. deep plastic movement: ***creep, flow***…requires water
   a. predominant style in humid climates…freeze-thaw, wet-dry cycles doing "work"
   b. creep is extremely slow; flow can be extremely fast
   c. creep is widespread but nearly invisible
3. movement with distinct boundary of failure: ***slide, slump***
   a. can be very fast & destructive
   b. features like scree, talus slopes, "avalanches"
4. shallow transport of sediment: ***wash*** (under influence of rain on soil)
   a. attacks bare ground
   b. important in desert, on farmland

E. Slope processes as hazards…the example of slopes in California

X. WEATHERING

A. Weathering is a *key step* in the movement of material at the surface, and the formation of landscapes on the earth

1. ***weathering*** is the process of breaking down rock; making small pieces outta big ones
2. only broken ***sediment*** gets moved, which permits the processes of leveling to feed streams & the depositional systems, to lower the landscape (do erosion)
3. rock must be weathered into ***soil*** for this to happen
4. differences in weather makes differences in landscape…landforms, for example

B. Two general types

1. ***physical*** (mechanical)…*mechanical stresses* act to detach parts of rock

a. simple example: hit it with a hammer; flex 'til it breaks
b. most common form: *freeze-thaw*…what happens to pop bottles in the freezer
c. also streams, roots, tectonic unloading, salt crystals
d. silt is about as small a particle as physical weathering can make: cannot induce stress in tiny piece…how do you get hold of it?

2. ***chemical***…*changes in chemistry* create detached pieces
   a. *solution* of matrix…(preexisting) clay weathered out of limestone
   b. form *new compounds*…hydrolysis of mica into clay (& disintegration of surrounding rock)
   c. can make very small pieces; e.g., colloidal (roughly water-molecule size)
3. weathering fastest closest to surface
   a. all types take solar energy
      i. heat & cool, grow plants, “distill” clean water
      ii. that's why we say **weather**ing
      iii. (all take *water*, too)
   b. less solar energy available as you get deeper into the ground

C. Weathering and ***feedback***
1. the limits to the various rates
   a. rates of weathering *decrease* as the soil gets *deeper*…less energy
   b. rates of erosion limited by *supply of weathered soil* to transport
   c. rates of *uplift* responsive to *erosional lightening* of the crust
2. the interaction
   a. fast uplift → steep slopes → fast erosion → thin soil → faster weathering
   b. slow weathering → slow erosion → little unloading → slowed uplift…(orogenic [not isostatic] uplift is relatively insensitive to weight of continent)

D. Weathering and rock types…our first interest in weathering is its effect on landscape evolution through limiting erosion
1. weathering of sedimentary rocks tends to release the kind of sediment that the rock was made of
2. weathering of igneous & metamorphic rocks (the other two kinds) release quartz crystals of typical sizes (sand or silt), or to yield clay from mica and feldspar
3. rate of weathering is dependent on
   a. climate – wetter is faster, and wetter means more chemical weathering and therefore more clay in the soil
   b. rock type…stronger cement means slower weathering in sandstones, for example; compact granite resists the attack of water & roots

E. ***Soil***
Our other interest in soil is its enormous effect on the operation of all natural systems, such as farmland.

1. Importance to natural systems:
    a. holds, stores and releases water and plant nutrients
    b. this provides *storage* to smooth out variability
        i. maintain life between rainfall
        ii. hold nutrients between death & growth
2. Soil components:
    a. mineral component…pieces of rock
    b. organic material…humus, or humic acids stains
    c. air, water, nutrients, salt, etc.
3. Soil properties: tells whether a soil can or cannot do the job we want
    a. texture…*size* of mineral elements…
        i. clay, silt, sand, or mixture (loam)…(ignore rocks > .25 inches)
        ii. clay is the most important material in the natural world (or just about)…clay content key to many other properties
            1) most processes are surface processes, and clay has lots of surface (small platelets…like little pieces of mica)
            2) example of importance of surface-to-volume ratio…break rock into pieces and you make *lots* of surface
    b. field capacity
        i. maximum unconfined water storage
        ii. stored on surfaces of clasts
    c. cation exchange capacity
        i. can the soil hold & release nutrients?
        ii. key to maintaining nutrient cycles
        iii. caused by unmatched charges on some types of clay or humus
    d. structure: how the particles aggregate into *peds*
        i. “good” structure (large peds) more likely with higher clay content
        ii. important to increase permeability, descries erodibility of fine soils
    e. erodibility:
        i. clay decreases infiltration capacity (to increase runoff)
        ii. clay washes away quickly (because particles are small)

XI. ROCK CYCLE

EVERYTHING COMES FROM ROCK. EVEN OTHER ROCKS.

A. Three rock types are named for how they are formed
1. ***igneous*** (name means “fire”)…“*froze*” from a melt (magma) formed within the earth
2. ***sedimentary***…cemented pieces of *sediment*

3. ***metamorphic*** (= “changed form”)…*transformed* by heat and pressure within the earth

B. All rocks (usually) carry **marks of their formation**
   1. igneous (usually) interlocking crystals
   2. metamorphic (usually) interlocking crystals with flattened structure at right angles to stress (“strike of the schistosity”)
   3. sedimentary rock (often) shows individual pieces of sediment

C. Types of ***igneous*** rocks: *two variables give four types*
   1. ***rate of cooling***
      a. *fast*
         i. small crystals (takes too much time for molecules to line up onto big crystals
         ii. happens near surface (where heat can get out)…***extrusive***
      b. *slow*
         i. large crystals
         ii. deep in earth; 100,000's of years to cool…***intrusive***
   2. ***chemistry***…elementary constituents
      a. ***mafic*** (= basic)
         i. high in iron, manganese (hence the name)
         ii. dark color, high density
         iii. commonly *oceanic*…heavier plates are lower
      b. ***sialic*** (= acidic)
         i. silicon, aluminum
         ii. light color, light weight
         iii. *continental*
      c. examples

	intrusive	extrusive
mafic	***gabbro***	***basalt***
sialic	***granite***	***rhyolite***

D. ***Sedimentary*** rocks are named according to the sediment from which they are made
   1. ***clastic***…actual individual pieces
      a. sandstone, shale from sand, shale
   2. ***non-clastic***…formed out of solution
      a. rock salt, limestone, coal
   3. fieldtrip hint: essentially all rocks within 70 miles of Bucknell are sedimentary

E. ***Metamorphic*** rocks differ according to the *previous type of rock*…
slate from *shale*; *gneiss* from *granite*; *marble* from *limestone*, e.g.

F. ***Rock cycle*** implies any rock type can be turned into any other
   1. *melt*, then freeze into igneous
   2. *weather*, then cement into sedimentary
   3. *squeeze & cook* into metamorphic

G. The geomorphologist's interest with rocks is primarily the **different rates** at which they weather, and the **different sediment** types they produce
   1. weathering sedimentary rock tends to release the sediment it was made from: shale to clay, sandstone to sand
   2. rates of weathering are fast for shale, limestone (in a humid climate)
   3. rates of weathering are slow for sandstone (if cemented with silica), most igneous rocks

XII. GLOBAL TECTONICS

THE BIG, COMPLEX GEOLOGICAL PATTERN OF THE WORLD IS THE RESULT OF A FEW TECTONIC RELATIONSHIPS

A. Big picture (as summarized in the third lecture)
   1. ***construction*** of the globe (uplift) driven by horizontal movements of plates
      a. ***compression***
      b. ***extension***
   2. surface manifestation is moving plates
      a. about 30 of them
      b. *oceanic* & *continental* components are *basaltic* & *granitic*, respectively
      c. bulk of topography is formed at *plate margins*
   3. plate tectonics is the *most powerful idea* in modern earth science; accounts for many patterns
      a. highly systematic patterns of relief at global scale
      b. course of evolution of life
      c. location & nature of earthquakes
      d. nature of deformation at almost every spot
      e. (but not all patterns obey what we would expect from first glance…Hawaiian volcanoes, New Madrid earthquakes)

B. Plate movements…three relative motions of plates possible
   1. ***constructive***
      a. ***extension***; pulls apart
      b. makes new land area, as old plate is split
      c. is, or could become, ocean floor
   2. ***destructive***
      a. ***compressional***

   b. makes less land area at that spot
   c. the plate that was there is mushed into mountains
3. ***conservative***
   a. plates ***slide*** *by* each other
   b. no change in amount of land area
   c. often little topography created

C. *Evidence* **–** Why do we believe that this is happening? It is a very new theory, and was resisted for a long time because the driving mechanism is counter-intuitive (“Ships of granite plowing through a sea of basalt.”)

1. suggested on basis of continental *shapes*
2. first strong scientific argument on basis of ancient glaciation covering South American *and* Africa…suggested by Alfred *Wegener*, a climatologist
3. symmetrical *magnetic reversals* (found by WW II sub hunters) on ocean floor best explained by common ages to the rocks
4. similar *fauna* on opposite sides of oceans…ratites, marsupials on Gondwana
5. similar *fossils*, symmetrical features (“anti-Appalachians” in Morocco)
6. and now, direct *measurement* of plate motion

XIII. PATTERNS OF DEFORMATION

EACH TYPE OF PLATE MARGIN IS ASSOCIATED WITH SPECIFIC FORCES ON, AND CHANGES IN, THE ROCKS AT THAT PLACE

A. ***Destructive*** margin

1. slow ***compressive*** forces
   a. ***fold*** rock…plastic response to slow pressure…Central Pennsylvania is the eroded roots of ancient compression zone
   b. ***thicken*** crust
   c. generate ***reverse faults*** ↗ / ↙
      i. upper layer rides over lower
      ii. note that amount of surface *decreases*
      iii. low angle reverse fault called a ***thrust*** fault
2. destructive interaction of plates involves one plate riding over the other
   a. continental over oceanic…Andes, Japan
      i. *ocean* - *trench* - *mountains* - *foreland* (plateau) sequence
      ii. *melting* of subducted plate evident from earthquakes, volcanoes
      iii. high mountains and lowest oceans products of *same collision*…this is isostatically logical (weight of mountains sinks trench)
      iv. processes “accrete” islands, pieces of continent onto continents…S. Alaska (which will accrete Los Angeles in 50,000,000 yr.)
   b. “***suture***” — continent over continent …Himalayas

i. doubling of granitic crust along thrust
ii. deep basin (filled with sediment) on sinking plate (India)
iii. high plateau on overriding plate (Tibet)

3. specific type of volcanism
   a. these volcanoes return terrestrial (stream-borne) sediment as magma
   b. magma is ***wet, sialic*** (= *explosive, viscous & light*)
   c. high energy, episodic, hazardous eruption…Mt. St. Helens

B. Constructive margin

1. slow ***extensive*** forces
   a. little deformation…rock is weak under tension (Do they make concrete rope?)
   b. net effect is to thin crust
   c. ***normal faults*** (block faults) ↙ / ↗
      i. lower layer pulls out from under upper
      ii. amount of surface increases
      iii. often involves considerable vertical movement
      Basin & Range in Nevada; Sierra Nevada are block faulted mountains
2. interaction of plates involves a fracture, then progressive growth of ***rift***, ***basin***
   a. break a continent
      i. East Africa Rift, Dean Sea, Gulf of California
      ii. basaltic inflow, mineralizing, below-sea-level basins
      iii. fossil versions in eastern U.S.: *Triassic Lowlands*…Connecticut Valley, the Palisades
   b. grow an ocean
      i. functionally a rift…splitting crust & emerging basalt
      ii. observations of hydrothermal vents show non-sun-based life
      iii. mid-ocean *ridge*…isostatically elevated because it is hot
      iv. age increases, elevation decreases (cooling) out from center
   c. ***basaltic*** magma is the mantle…deep molten rocks
      i. ***highly fluid***, low water content
      ii. gradual, calm Hawaiian volcanoes
3. ocean floors have a short life span
   a. zero net growth of crust, and continental crust doesn't get destroyed
   b. ocean gets “too big” for forces upon it; undersides of continents get “too hot” & fail
   c. few parts of ocean floor older than 60,000,000 yr.
   d. cycle of opening and closing…Atlantic Ocean, e.g.

C. ***Conservative*** plate margin

1. little or no movement toward or away from fault

2. little generation of topography
3. fault type is “***strike-slip***”, or transcurrent
    a. moving side-by-side … little vertical movement
    b. no change in crust amount
    c. *e.g.*: San Andreas Fault shows little topographic expression, but plenty of energy

XIV. EARTHQUAKE HAZARD

A SYNTHESIS OF SEVERAL GEOMORPHIC TOPICS

A. Event
1. rapid release of stress at an active fault
2. produces shock wave, acceleration at distance from fault
3. occur (mostly) in recognizable areas --- active faults, especially destructive plate margins (pressure across fault greatest)
4. occur at moderately predictable intervals…
    a. after enough stress has built up (approximately 20-500 years in most cases, depending on rate of movement of fault & size of “sticky-ness” in fault)
    b. faults that move freely don't cause big earthquakes
    c. fault segments that don't move at all, while nearby segments do, (“quiet zones) cause concern…stress is building up there
    d. concept of flood-like frequency-magnitude relationship is not useful; more like beach-retreat
    e. a big earthquake can happen in a slow fault zone (New Madrid, Missouri, 1812-13), at a long interval

B. Exposure
1. structural damage causes almost all earthquake deaths
    a. Native Americans feared quakes little; Spanish, a lot
    b. biggest earthquake tragedies from drowning, fires, collapse
2. building collapse
    a. acceleration, oscillation takes rigid structures apart
    b. block construction – stone, adobe – has little shear strength, much mass to accelerate (or fall)
    c. medium size buildings become resonant & amplify motion
    d. settling, fracturing earth damages structures
3. unconsolidated earth material (fill, saturated alluvium) increases damage
    a. seismic wave slows, amplitude increases
    b. sediment “sloshes”, resonates
    c. liquefies, fractures, settles
4. other geophysical events triggered by earthquake: slides, tsunamis

C. Response:
   1. decrease event…modern technological humans can do anything – even lubricate faults to decrease the average size of earthquakes – if we are stupid enough
   2. decrease exposure
      a. earthquake-resistant construction…for billions of dollars
         i. shear panels to transmit stress upward & therefore let building not break
         ii. flexible big buildings
         iii. zoning…keep people from dangerous environments
            1) high seismic energy (next to fault)
            2) ancillary hazard (slide, tsunami, liquefaction)
      b. prediction?
         i. ability severely limited…now seen as a "chaotic" system
         ii. we can say "70% chance in 30 years", but that is not useful
         iii. precursors (pre-shocks, water table changes, radio waves?) hard to interpret
         iv. cost of false prediction is considerable, in panic and loss of real estate value

XV. DIFFERENTIAL EROSION

Structural (geologic) control on topography

A. topography may come to *reflect* the underlying structure through the process of ***differential erosion*** .. two important terms:
   1. ***structure*** is folded rock ("differences in the hardnesses and geometry of the rock");
   2. ***topography*** is the plain old landscape
B. the principle of differential erosion: erosion is slower on "harder" rock
   1. bench-and-slope topography, plateaus show how *caprock* resists erosion (especially from rain)
   2. streams tend to excavate valleys into zones of weaker rock
C. at a local scale – and especially in an old age landscape like Pennsylvania – most uplands remain because they are made of harder rock than the surrounding land…e.g., sandstone, granite, basalt
D. the ***cuesta***: product of differential erosion of dipping sedimentary rock
   1. a linear (***strike***) ridge of resistant dipping rock amidst a lowland of softer rock
   2. see them as tilted plateaus
   3. extremely common around the world…since the components are common, too
   4. the edge of a big plateau is usually a cuesta, since they big plateaus are usually basins…called an escarpment
E. cuestas are formed by retreat toward lower dip
   1. soft rock beneath cuesta erodes faster than hard rock

2. slope processes (not weathering) remove the harder rock

F. cuestas are (almost always) asymmetrical
   1. dip slope is bare structural surface; slope is (relatively gentle) dip
   2. scarp slope (down dip) is the steeper angle-of-repose slope

G. Differential erosion on ***folded structure***:
   1. ***synclines*** (down-warps) show up as cuestas facing away from each other,
      a. ***anticlines*** the opposite
      b. differential erosion makes them consistently symmetrical features…one ridge is mirror image of other
   2. ***plunge*** is the tilt of the fold (syncline or anticline)…measured down axis of fold
      a. resulting mountains are curving (hairpin) cuestas --
         i. syncline curves with sharper scarp-slope out…"canoe" shape
         ii. anticline curves with gentler dip-slope out…"cigar" shape

H. The example of the physiographic provinces of Pennsylvania

XVI. GLACIATION

THE WORLD WE KNOW STILL "REMEMBERS" PLEISTOCENE GLACIATION VERY CLEARLY.

A. Importance:
   1. second most widespread agent of erosion
   2. distinctive set of landforms result from its action
   3. sculpted significant area of the world, including 1/3 of the US
   4. but resembles the general principles as fluvial erosion
   5. major time of ice advance was Pleistocene
      a. global temperatures lowered
      b. many ice advances (cold periods)…evidence for four in U.S.
      c. most recent ended "yesterday"…10,000 years ago
      d. and we're sure they'll be back

B. Types of glaciers
   1. ***continental glaciers*** **–**
      a. *ice sheet*…flowing away from its own high point
      b. typical of the Pleistocene ice covering eastern U.S.
      c. still present in Greenland, Antarctica
   2. ***alpine glaciers***
      a. *valley glaciers*…flowing down a valley, touching it up & making it U-shaped
      b. present now at high elevations…greater snowfall & lower temps
      c. still around; bigger during Pleistocene

C. Glacial movement:

1. occur where the land is *too cold for rivers*
2. snow accumulates, turns to ice, and ***flows plastically*** below about 300' depth
3. glacier flows until it melts, or evaporates, or calves into the ocean
4. *top* of glacier a graded surface, like a stream…"just steep enough to move"
5. bottom of glacier moves slowly or not at all (the mass of ice creeps and deforms)
6. glaciers *follow* ***pre-existing*** *topography*…old stream valleys

D. Glacial erosion (and weathering):
1. very effective in removing material
2. left almost no soil in New England
3. grinding motion with great weight atop it, makes very fine sediment…and big chunks, too
4. also plucks (freezes onto & drags) outcrop…differentially erodes
5. sediment moves in "suspension" – wholly entrained in ice mass

E. Glacial deposition
1. glacier ends where rate of ice loss (ablation) matches rate of arrival
2. position of snout changes with change in ice supply, local temperature
3. at end of glacier sediment is deposited
    a. unsorted — clay & boulders together; ***till*** is general name for material deposited by ice
    b. glacier acts as conveyer (move sediment in ice to end) not as bulldozer (shove sediment along ahead)
4. ***moraine*** is *feature* (landform) deposited by glacier
    a. ***ground moraine*** mixed, streamlined material beneath ice (drumlins in New York state, e.g.)
    b. ***end moraine*** is dumped at end of glacier…lobate in form, reflecting lobe shape of glacier
    c. just beyond the moraine is an extensive alluvial surface called an ***outwash plain***
5. generic term for till & outwash is "drift"

F. The previous existence of glaciers has major effect on waterways
1. ***deranged drainage*** where they scour & deposit
    a. ***scour*** ponds, oversteepen channels into falls (Catskills, Adirondacks)
    b. ***dam*** streams with till & moraine (Lake Ontario)
    c. ***kettle holes*** lefts as casts of ice blocks melted out of sediment
    d. the many lakes (and, therefore, mosquitoes) in New England are a gift of Ice Ages
2. energetic streams downhill from glacier cut and aggrade, from extra water and sediment

a. call "***spillways***"…oversized stream valleys, often with wide depositional features (Susquehanna, and nearly every other river in northern U.S.)

b. dramatic spillways downstream from ice-dammed lakes…Channeled Scablands in Washington State

3. continental glaciers affected sealevel

a. Pleistocene glaciations lowered sealevel world wide:

i. tied up water as ice & contracted ocean by cooling it

ii. mastodon teeth, arrowheads are dredged up 50 miles east of Atlantic City

b. (also lowered land beneath the ice through isostasy)

c. sealevel now rising world-wide, after Pleistocene

d. streams cut deeper valleys in many places during Pleistocene…now filled in as sea returns…called ***estuaries***…ex: Chesapeake Bay

XVII. IMPACTS OF THE PLEISTOCENE ON HUMANS

A. erosion removed soil from New England, much of Canada, creating harsh farming & rapid emigration

B. deposition of landforms important in New England area: e.g.: Long Island, Cape Cod, Martha's Vineyard, Nantucket, Block Island, Staten Island all moraines

C. Harbors in New England are the product of scouring away the Coastal Plain and deepening of water…hence travel & trade & fisheries there but not in South

D. Falls (creating water power for textiles & other machinery) produced in New England (& Niagara Falls &c.) by glacial derangement

E. Many lakes (and swamps) created for recreation, water supply, mosquitoes

F. Spillways – widened & flattened & filled by meltwater – attract railroads & other "graded" activities (roads, canals)…Susquehanna, for example

G. Deposition of till – especially down-ice from shale & clay – can create very good soils

H. Loess – wind re-working of silt from outwash – can be very good soil, indeed

I. Estuaries – re-advance of the ocean into glacial-era valleys – are essential habitats for sea creatures

J. Rising sealevel, world wide, affects human use of the shore, creating a hazardous habitat by driving beach retreat…accelerated by Greenhouse effect?

K. Did rising sealevel "force" the invention of agriculture 10,000 yr. ago by abruptly increasing the population density?

XVIII. COASTAL PROCESSES

A. The process: work of **waves** upon the landscape…only locally significant, but very significant in those places

B. Source of **energy**

1. **wind** on water in distant parts of ocean, induces waves

2. more wind, longer "*reach*" provides more energy…huge Pacific more energetic the Atlantic

3. stronger waves at/from higher latitudes where storms are stronger
4. waves *propagate* though water (without moving the water); big waves go further (around the world, in some cases)

C. wave energy *dissipated* upon the shore

1. wave ***"feels bottom"*** & crests when depth < (wavelength / 2)
2. ***breaks***, and ***entrains*** & ***transports*** sediment, like a stream
3. means that wave energy works only *at* sealevel…not above or below
4. eroded & filled feature resulting from this effect ("marine planation") is ***wave-cut bench***
5. sand is the most common sediment in beach systems, but gravel & mud &c. also found
6. limit of beach erosion is a ***bluff***…familiar term?

D. waves *bend* toward shallower water as they move

1. because one part moves more slowly; called ***refraction***
2. means that wave energy is ***concentrated*** on headlands, and is ***decreased*** in embayments
3. *protrusions erode* much more quickly than average
4. *embayments accumulate* sand in low-energy environment
5. thereby, waves *straighten* coasts…process equivalent to smoothing of a graded stream…cut points, fill hollows

E. oblique waves (which are most of them) transport sand down coast

1. wave breaks obliquely, net movement is down-coast, transporting sand that way
2. ***long-shore transport*** moves ca. 300,000 m^3/yr. past a spot on US coast…usually southward
3. creates ***spits***: elongate depositional features connected to & fed by the mainland
4. best spits are fed by sandy mainland, & stream or river mouths

F. ***barrier islands*** form on gentle, sandy coast…(e.g., east U.S.)…

1. occur off-shore from mainland from New York to Mexico
2. perhaps originated as sand bars where the largest storm waves "feel bottom"
3. behave much like spits…source of sand "up-drift"
4. barrier islands retreat toward mainland (maintaining constant separation) as sealevel rises
    a. low gradient of coastal plain means 100's of ft. of retreat per vertical foot sealevel rise
    b. sand moves back by overwash in big storms, wind moving sand, sand washing into inlets, or sand just leaves down-coast
5. dunes are highly important to stability of barrier islands:
    a. store sand that feeds longshore transport
    b. stops overwash

6. inlets are necessary on barrier islands to let tides in, but they're ephemeral
    a. form, as storm tides cut new ones
    b. fill, as drift brings sand

G. change in (relative) sea level creates distinctive features

1. given rising *land* (tectonic uplift, or growing glaciers) we get an **emergent** shoreline:
    a. *marine* features are left *above* water
    b. abandoned beachlines common
    c. wave-cut benches become *marine terraces* when exposed
    d. common on west coast of U.S.
2. given rising *sealevel* (melting glaciers, e.g.) we get a **submergent** shoreline
    a. made up of drown terrestrial features
    b. drown rivers = estuaries
    c. wave-cut benches exist below new sealevel (but who cares?)
    d. barrier islands roll back over themselves, as waves wash sand across them
    e. large areas of shallow water fill to high tide by vegetation and silt…salt *marshes*
    f. marshes, estuaries crucial habitat but also vulnerable to pollution
    g. all common the world around (because of the end of Pleistocene)

XIX. COASTAL HAZARD

A. *Event*

1. beach erosion happens in response to rising sea level & retreating beaches…undercuts, floods structures
2. episodic beach response to long-term change (i.e., sea level is always rising, but beaches retreat during occasional big storms)
    a. storms exhibit flood-like R.I.
    b. but most retreat will happen if last big storm was decades ago
3. rate of retreat probably increasing from greenhouse effect…6"/100 yr. at 1900; 10"/100 yr. now?; faster soon?
4. rate accelerated where dams stop sediment supply from rivers to beaches

B. *Exposure*

1. beaches have retreated since the Pleistocene; problem is construction, ownership
2. beaches are attractive (right?) and encourage development
3. investment even in a stupid environment can pay off quickly if it is attractive enough: Ocean City, MD
4. many people buy into risky environments because they don't have information…retirees moving onto west coast of Florida, e.g.

C. *Response*

1. stop event?
   a. stopping long-shore transport (groins, jetties) causes beach impoverishment down-shore…one person's gain is another's loss
   b. beach nourishment…expensive to get sand; gets more expensive over time as we take all the easy stuff; submarine beach face oversteepens
   c. "hard" defenses (walls) merely divert wave energy (while beaches, dunes absorb wave energy); erosive power works nearby
   d. preserving dunes fosters natural defenses (and increases distance between waves & construction)
2. limit exposure:
   a. risky environments easy to identify; zoning effective
   b. forecast storms, publicize wise behavior, evacuation routes
   c. but commercial interests favor expensive structural solutions (least disruption)

XX. SUMMARY

THEMES OF THE DISCIPLINE OF GEOGRAPHY EXHIBITED IN "LANDFORMS OF THE WORLD

A. The earth as the home of humans
   1. understanding processes that shape the earth (most of what we did)
      a. sculpture of the earth as balance between endogenic and exogenic forces
      b. the activity of science as a *negotiation* about "explanation"
         i. relying on a few powerful models … "systems", laws of physics, etc.
         ii. evolving ideas of important processes
            1) 19th century reliance on Biblical mechanisms
            2) growth of plate tectonics (and evolution and uniformitarianism and Pleistocene glaciation) as a difficult, but powerful, models

B. Human-environment relations
   1. human "environments" shaped by the natural landscape
      a. fertile land, accessible routes
      b. resources
      c. hazards
   2. unintentional human activity changing the shape/character/quality of those environments
      a. sedimentation, flooding, dam construction, levees
      b. sea level rise, beach
      c. watershed changes, mining, fires
   3. change happening at an increasing rate, a more global scale
      a. more intervention … farming & urbanization everywhere
      b. global

4. human efforts at control … often clever, sometimes counter-productive

C. Organization of activity in space
   1. shape of the landscape controlling economic, cultural activity
      a. why are cities where they are?
      b. why have peoples spread as they have?
   2. human impact of hazards created by geomorphic process
      a. floods & New Orleans; volcanoes and the Minoans

D. Constructing the world into "places"
   1. our interactions with the environment are mediated by perception … the world as we believe it to be
      a. "regions" … plains, mountains, coasts
      b. amenities … recreation, scenery,
      c. hazard perception as an impediment to "economically rational" landuse
   2. the efforts of science to decrease the influence of the subjective in decision-making
      a. hazard mapping & RI's
      b. knowledge of feedback, unexpected consequences
   3. comprehending the world before us, as the product of a small number of processes that we can understand