Coastal Processes and Landforms - With Special Emphasis on Oregon

I. Water, Waves and Coastal Dynamics

A. Beach and coastal areas represent sites of dynamic sedimentation, erosion and re-working of river-borne sediments as they reach coastal regions

1. Dynamic interaction between wind, waves, sedimentation and erosion

2. Coastal areas noted for extremely variable meteorologic conditions

3. Hurricanes and storms profoundly influence coastal morphology

a. Wave energy and wind energy during coastal storms exhibit great capability to do work in the form of erosion and transportation of sediment
(1) Eg. storm wash-over processes
(2) storm surges
(3) changes in coastal morphology via erosion and sedimentation

4. Gross coastal configuration primarily a function of
a. plate tectonic history,
b. global sea levels (eustacy)

B. The Ocean and Wave Activity

1. Beach/coastal sand/sediment profoundly influenced by wave action
a. waves provide motion/energy for transportation and erosion of sediment

2. Waves generated by wind shear blowing across ocean surface for long distances
a. shear creates orbital rotation of water to form water waves

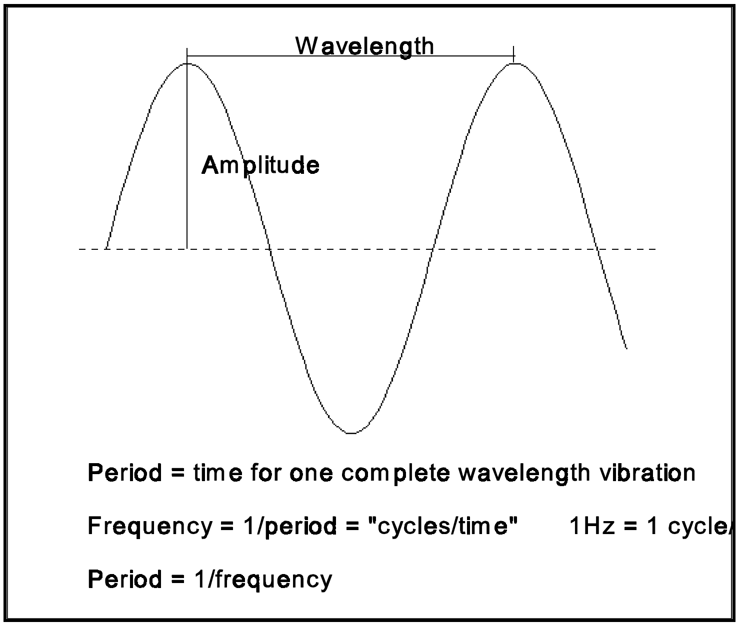
(1) orbital motion = circular to and fro motion, diminishing in intensity at depth from surface

(2) Although the wave is passed through the water as a medium; actual water molecules are NOT displaced as the wave is propagated

b. Wave form controlled by:
(1) wind velocity
(2) duration of wind / storms
(3) fetch- distance over which wind blows (length across water) (> fetch, > wave amplitude)

increase velocity, wind duration, fetch = increase in wave height

3. Wave Morphology



a. Wave crest: high upper peak of wave train
b. Wave trough: low separating two crests
c. Wave Height: vertical distance between crest and trough

(1) Avg. Wave Ht = 1 to 15 Feet
(2) Storm Waves up to 50 Ft wave height

d. Measuring wave height
(1) microseismometers
(a) measures inland vibration caused by waves
(b) e.g. coastal waves can be measured from Corvallis!!!

(2) pressure transducers
(a) measure height of wave related to water pressure

e. "Tsunami" = seismically induced water wave, produced by tectonic displacement of sea floor, accompanied by earthquakes
(1) Very long wavelengths: ~ 100 km, and low amplitudes (1 m or less)
(2) As wave approaches land, breaking to heights of 100 m or more
(a) highest "tidal wave" recorded = 278 Ft off coast of Japan.

f. Storm Surges: piled mass of water pushed shoreward by very high winds
(1) Common by-product of hurricanes

(a) upward bulging of ocean surface due to low atmospheric pressure above ocean surface

(b) Wind pile-up
i) Surge in sea level of 2-5 m common

g. Typical Wave Characteristics
(1) Wave Length: horizontal straight line distance between two crests or two troughs
(a) Avg. wave length = 130-1300 Ft

(2) Wave Velocity: average 15-55 mi/hr

(3) Wave base: depth at which the energy of the wave is totally dissipated in water
(a) Wave Base = 0.5 (Wavelength)

4. "Surf" Zone: zone along coastal area where waves overturn and "break" upon themselves

a. High energy water environment

b. Wave breaking occurs in response to shallowing of water depth as wave approaches beach

(1) As depth < wave base, wave "feels" bottom and wedges water upward
(a) Wavelength decreases as waves approach shoreline, "piling" up of water according to resistance of near-shore beach area.

(b) "Breaker" a wave that is oversteepened to the point of the crest toppling forward (moving faster than main body of wave)

(c) "Surf Zone": coastal zone characterized by numerous breakers
i) high turbulence zone
ii) characterized by to and fro swash action
a) Swash = incoming motion, Backwash = seaward drag of water
b) effective sediment sorting mechanism

C. Nearshore Circulation Processes

1. Wave Refraction: Tendency of wave to become "refracted" or bent as it reaches shore
a. net result is wave train becoming more parallel to shore

2. Wave Crests usually approach shore at some angle other than parallel.
a. Results in sweeping of wave along coastal interface

3. Longshore Currents:

a. Current established as wave crest approaches beach at some angle to shore

b. Sweeping action of wave along shoreline

c. Longshore Current: current forms parallel to shore as more and more waves refract in that direction

(1) Seaward Edge of Current: outher surf zone

(2) Landward Edge of Current: Shoreline

(3) Longshore currents can effectively transport large volumes of sediment along a shoreline (parallel to shore)

4. Rip-Currents

a. Narrow Currents that flow perpendicular to shoreline in a seaward direction (seaward return flow of water)

b. Highest velocity at surface, dying out at depth

c. Effective seaward sediment transportation mechanism, moving sediment beyond beach zone onto shelf

d. Characterized by low wave height and variable wave orientations

5. Tides: diurnal, vertical fluctuation of sealevel under the influence of planetary gravity. Results in bulging of sealevel sytematically throughout the day, around the world.

a. tides set in motion by gravitational attraction of the moon and sun (heavenly bodies close and large enough respectively to influence force of gravity on earth).

(1) gravitational pull of sun and moon result in pulling at the ocean surface, causing it to bulge. Since the earth's crust in rigid and relatively unaffected by this gravitational pull, tidal fluctuations of sea level occur relative to land. (tidal pull is relatively negligible in surface bodies of water, i.e. lakes)

(2) Moon has most significan daily impact on tidal levels. Gravitational effectiveness of sun relative to the moon in 44%.

b. Normal tidal bulges: influenced by moon primarily, moon in line with equator, pulling bulge equatorially, low tides at top and bottom, hide tides at equator

(1) tidal bulge follows the moon as it orbits around earth, water facing the

moon is drawn/bulged towards the moon, side opposite moon is also bulged outward because the solid portion of the earth (facing the moon) is pulled away from the ocean on the side opposite the moon.

(a) at same time as tidal bulge, there are compensating low tides at 90 degrees to the bulge

(2) Entire effect is complicated by the earth's revolution from east to west, also coupled with moons revolution around earth: result in 2 complete tidal cycles every 24 hours and 50 minutes. (i.e. 2 high and 2 low tides in a little over each day)

c. Spring Tides: sun and moon in alignement equatorially, result in highest tides possible, largest bulge at equator.

d. Neap Tides: sun aligned with equator, moon with poles, perpendicular to one another, results in lowest tides possible at equator.

e. Tidal Cycles: rising tide or flood tide occurs for 6 hr and 13 min, reaches high tide, then falling tide or ebb tide for 6 hr and 13 min, until low tide, happens twice each day about.

(1) tidal range: vertical difference between high and low tide. Height of tidal range varies with configuration of coastline, from several feet to perhaps 50 feet, as the highest tidal fluctuation noted.

f. Tidal Currents: ebb and flood tide sets up currents through tidal channels, inlets and coastal rivers

D. Beach Morphology

1. Beach: strip of sediment (sand or gravel) that extends from low tide line to a zone of permanent vegetation inland (or rock cliff as applicable).

a. Beaches subject to breaking waves
b. Subject to tidal influences

2. Beach Subdivision

a. Foreshore: zone between mean high and low tide

(1) Beach Face: steepest inclination of beach exposed to wave action at high tide level

b. Backshore: upper portion of beach landward of high-tide water line
(1) Beach Berm: wave deposited platforms sloping gently landward

c. Marine Terrace: gently sloping platform seaward of the foreshore/beachface.

(1) Wave Built Terraces: constructed of wave sorted sediment

(2) Wave-Cut Terraces: rock benches erosionally cut by wave action

(3) Wave Cut Notches: undercutting of steep rock faces along coast line

(a) Landward erosion of seacliffs
i) Undercutting and collapse at cliff-wave face

3. Beach Composition
a. Commonly sand
(1) Quartz and feldspar sand beaches: quartz resistant to weatherin
(2) Black sand beaches:
(a) volcanic lithic fragments
(b) Heavy mineral "lags"

(3) Carbonate sand beaches in tropical areas

b. Gravel beaches
(1) imbricate "shingle" fabric to gravel orientations

4. Beach Climatic Cycles

a. Seasonal summer-winter cycles

(1) Winter: waves higher and of shorter wavelength
(a) storm waves common
(b) beach erosion high

(2) Summer: low height, longer wavelength waves
(a) berm deposition dominant

E. Longshore Drift and Coastal Morphology

1. "Longshore Drift": Longshore currents move sediment parallel to shore as waves strike shore at angle

2. Surf zone transport of sand and sediment
a. sand transported parallel to shoreline

3. Depositional Features

a. Spit: a "tail" or fingerlike ridge of sediment built by longshore drift off of a point of land, extending out into open water

b. Baymouth bar: ridge of sediment deposited so as to cut a bay off from the open ocean
   (1) result of sediment migrating across the mouth of an open bay
   (2) storm processes may be effective mechanisms for "closing" off bay inlets.
   (3) Back-bar lagoon sheltered from wave energy

c. Tombolo: a bar of sediment connecting a former island to the mainland
   (1) result of wave refraction around the island, converging on the landward side of the island forming a depositional bar built outward from the mainland.

4. Beach Erosion Control

a. Jetties: rock walls built along each side of a bay or harbor mouth

b. Groins: rock walls (perpendicular to shore) used to form barriers to longshore drift and sediment erosion

c. Breakwater: energy dissipator built parallel to shore to lessen wave energy
   (1) may create "slack water" areas behind breakwater and result in sediment infilling of the area.

5. Sediment Sources
   a. local insitu weathering of rock (minimal volume)
   b. regional drainage/sedimentation from seaward flowing rivers

II. Coastal Geomorphology

A. Coast Defined: marginal land area near sea
   1. includes beach and strip of land inland from it
   2. Coastal Character
      a. Rocky to mountainous
         (1) e.g. New England, Pacific Northwest

      b. Broad, gently sloping sediment plains
         (1) southeastern U.S.

B. Erosional Coasts
   1. Wave erosion dominant process
      a. wave action against rock, associated with both mechanical and chemical weathering and erosion

   2. Headlands: protrusions of land/rock separated by irregular coastal bays
      a. Tendency for coastal straightening with time via the coastal/wave erosion process

3. Sea Cliffs: wave-cut erosion of headland areas
    (1) Process: undercutting, stoping and slope retreat
        (a) Sea Caves: stoped-out undercuts at the base of a cliff face via wave erosion

    (2) Up to several feet of erosional retreat per year
    (3) Mass Wasting, oversteepened slopes, rock fall and landslides... unstable hillslopes under influence of travity

    (4) Rip-rap or seawalls may be constructed as energy dissipators to slow undercutting and wave erosion process

4. Wave-cut Platform or Terrace: horizontal bench of rock formed beneath the surf zone as a coasts retreats by wave erosion
    a. Water depths above platforms 20 Ft or less
        (1) within wave base

5. Sea Stacks: resistant erosional remnants left seaward as the coast retreats landward via erosion

6. Sea Arches: bridges of rock left above sea stacks, forming a arch via differential erosion
    a. weak zones due to fractures of compositional variation in rock

C. Depositional Coasts

1. Gently sloping coastal plains forming primarily as a result of sediment deposition
    a. much lower land gradients compared to erosional coasts
    b. sites of low-lying coastal wetlands, swamps and marshes

2. Barrier Islands: emergent ridges of sand formed parallel to the shoreline, forming off shore island "barriers" for wave activity relative to the shore proper
    a. Back Barrier Lagoons: slack or quiet water areas that lay between the seaward island and the land.

    b. Lee side barriers: high energy wave activity

    c. Tidal Inlets
        (1) Tidal currents erode channels through barrier island deposits

        (2) Bidirectional tidal currents may result in tidal deltas formed both landward and seward of barrier complex.

3. Back-beach Eolian Processes
    a. Eolian beach dunes

4. Deltas: accumulations of sediment formed by sediment-laden rivers emptying into standing bodies of water

a. Deltas Influenced by
   (1) sediment supply
   (2) wave energy
   (3) tidal energy

D. Drowned Coastal Areas (i.e. "Submergent" coast lines)

1. Common presently as result of current interglacial period
   a. sea level has been rising over the past 10,000 years as glacial ice from the last ice age (Wisconsin) has melted
      (1) During glacial advance: much ocean water is locked up in ice via evaporation

         (a) net result: worldwide lowering of sea level

         (b) evidence that sea level may have been 300-600 Ft below its present level at various stages during the Pleistocene

      (2) During interglacial periods: ice melts and sea level rises

2. Estuaries: "drowned" river valleys

   a. lower reaches of river valleys inundated as sea level rises

   b. characterized by
      (1) mixing of fresh and saline seawater (brackish salinity conditions)
      (2) quiet, tidally influenced estuarine conditions
      (3) abundant marine life and wetlands

3. Fjords: drowned or submerged glacial valleys

E. Tectonically Uplifted Coasts (Emergent Coasts)

1. Coastal areas elevated by tectonic forces
   a. e.g. coast of central and southern California
   b. Land areas uplifted relative to sea level

2. Principal Feature: Uplifted marine terraces
   a. formed by wave-cut erosion within surf zone
   b. subsequent uplift of coast results in stranding of wave-cut platform above sea level

III. Introduction to Oregon Coast Issues

A. Landuse / Development
   1. recreation / tourism
   2. housing development / recreational property
      a. cliff / spit development

3. fisheries

B. Geologic Hazards

1. Coastal Erosion / Sedimentation
   a. cliff retreat
   b. beach erosion
   c. bay filling / sedimentation

2. TectonicActivity
   a. Tsunami hazards
      (1) wave run-up
   b. ground shaking / seismic hazards
   c. coastal subsidence

3. Other Geomorphic Hazards
   a. Landslides
   b. flooding

C. Importance of Coastal Geomorphology

1. wise land use and planning
2. hazards mitigation

IV. Tectonic Setting and Geomorphology of Oregon Coast

A. Tectonic Setting

1. subduction / plate convergence
   a. Juan de Fuca Plate / North American Plate
   b. Cascade volcanic arc
   c. coastal uplift / subsidence cycles
   d. accreted marine sedimentary and volcanic rocks (Coast Range)
      (1) basalts - rocky headlands
      (2) marine clastic sedimentary rocks
   e. Uplifted marine terraces
      (1) stair-step uplift of coast
      (2) overall: Oregon = coast of emergence
   f. Tsunami / bay sediment record of earthquakes
      (1) 6 major quakes / last 4000 years
      (2) Recurrence Interval ~ 300-1000 years / quake
      (3) Last major quake ~ 300 years ago

B. Tectonic Motion vs. Eustatic Sea Level Change

1. relative sea level change on coast a function of:
   a. tectonic uplift and subsidence
   b. sea level rise and fall (via glacial climate cycles)

2. Global Warming Perspective

   a. global warming trends increasing = ice cap melting = sea level rise

b. model predictions
   (1) net global temperature increase by 2050 = +1.5-4.5° C
   (2) net global sea level rise by 2025 = +10-21 cm
      (a) net shoreline effects: x100 magnification in horizontal direction

3. Tide Gauge Sea Level Data
   a. Net Global Sea Level Rise Presently: ~ 2 mm /yr

4. Re-leveling Coastal Elevation Data

5. Net Oregon Coastal Neotectonic Motion

   a. South Coast (Florence, OR to Crescent City, CA)
      (1) net tectonic uplift = 2-3 mm/yr
      (2) rate of uplift > rate of sea level rise
   b. North Coast (Astoria / Seaside)
      (1) net tectonic uplift = 1-2 mm /yr
      (2) rate of uplift > rate of sea level rise
   c. Central OR Coast (Newport - Tillamook)
      (1) No net change in sea level
         (a) net tectonic uplift ~2 mm / yr = net sea level rise ~2 mm /yr

C. Wave Processes along the Coast of Oregon

1. Wave Sources
   a. greater Pacific storm systems / wind
   b. largest waves related to: winter storm systems in Gulf of Alaska

2. Example of High Energy Wave Events
   a. Christmas 1972
      (1) breaker heights averaged up to 7 m (23 feet) = "significant wave height"
      (2) maximum instantaneous waves up to 12.6 m (41 ft)

   b. Largest wave documented (via offshore ship)
      (1) 1960's = up to 29 m (95 ft)

   c. Largest wave globally recorded: 1933 in Pacific, up to 112 ft height

3. Seasonal Wave Activity
   a. Summer Months: average wave height ~ 2 m (7 ft)
   b. Winter Months: average wave height ~ 4 m (13 ft)

4. Moral of Story: Oregon Coast associated with very high energy wave environment!

D. Seasonal Beach Cycles on Oregon Coast

1. Seasonal Erosion Model
   a. Winter Storms = high energy waves = beach erosion = low gradient beach profile
      (1) erosion of beach berm
   b. Summer Conditions = low energy waves = beach replenishment = high gradient beach profile
      (1) well-developed beach berm

2. Grain Size Control on Beach Slope and Erosion
   a. Increasing grain size: Increasing Beach Slope
      (1) gravel beaches: 25- 30 degree slopes
      (2) fine sand beaches: 1-2 degreee slopes

   b. Grain size control on beach erodibility
      (1) > grain size: > rate of erosion
      (2) < grain size: < rate of erosion

   c. Examples
      (1) Gleneden Beach
         (a) median grain size ~0.35 mm (relatively coarse grained)
         (b) steeper beach profile
         (c) enhanced seasonal beach erosion / replenishment
         (d) faster rates of storm-related beach erosion

      (2) Otter Rock Beach
         (a) median grain size ~0.23 mm (relative fine grained)
         (b) lower gradient beach profile
         (c) less sensitive seasonal erosion
         (d) slower rates of storm-related beach erosion

E. Near-Shore Currents and Sediment Transport on Oregon Coast

1. Wave-Shoreface Geometry
   a. Generally: wave crests arrive parallel to Oregon Coast

      (1) Tendency for cell circulation and rip currents offshore
      (2) rip currents drive sand offshore
         (a) result: scalloped beach embayments in beach berm

      (3) Results in enhanced storm-wave erosion as waves pass through berm scallops to cliff zone

   b. Seasonal Longshore Drift on Oregon Coast

      (1) Winter Winds / Storms: from southwest
         (a) longshore (littoral) drift to north

(2) Summer Winds: from northwest
  (a) longshore (littoral) drift to south

(3) Net Annual Longshore Drift on Oregon Coast = 0!!!

  (a) Result: in jetty areas of Oregon:
    i) net symmetrical sand deposition
    ii) lack of significant down-current erosion
      a) Contrasts with other areas of U.S.

F. Oregon Pocket Beaches and Sources of Coastal Sand

1. OR Coastal Morphology
  a. Rocky headlands separated by short stretches of beach
    (1) pocket beaches

2. Pocket Beaches
  a. Closed sand budgets
  b. headlands prevent along-coast transport
  c. seasonal north (winter) and south (summer) transport within pocket zone, but no external flux
  d. Pocket Beach = "Littoral Cell"

3. Exception to Pocket Beach System: Clatsop Plains (Columbia River to Tillamook Head)
  a. southward drift of Columbia River sand
  b. Bulk of Columbia river Sand = directed north to Washington
    (1) active beach building in southwest WA

4. Sand Sources for Closed Littoral Cells

  a. Sand Provenances Based on Heavy Minerals (black sand grains)
    (1) Klamath Mountains
      (a) metamorphic mineral assemblages
    (2) Central Coast Range
      (a) augite / brown hornblende
    (3) Columbia River
      (a) varied heavy minerals

  b. Pocket Beach Sand Source
    (1) Most of Oregon = Klamath mountain sand source
      (a) northward sand transport during last low sea level stand

    (2) Last sea level low stand (~18,000 years ago)
      (a) - 300 feet compared to today
      (b) sand-dominated coastal plain
      (c) lack of rocky headlands
      (d) free flow of sand northward from Klamaths

5. Estuaries and Sand Transport

a. Estuaries
(1) freshwater / fluvial
(2) saltwater / marine
(3) zone of mixing
(a) salt water wedge (denser / bottom)
(b) fresh water (less dense / top)

b. Saltwater intrusion landward
(1) net trapping of sand in Estuaries
(2) net infilling of Estuaries / bays
(3) no net offshore transport

G. Summary of Coastal Erosion Processes and Factors
1. Storm-Generated Waves
2. High Tides
3. Elevated Water Levels
a. wind changes
b. temperature changes
4. Eustatic rise in sea level (glacial melting)
5. Enhanced erosion of embayments due to rip currents
6. Longshore Drift
7. Man-made, jetty disruption of beach sand movement
8. Lateral migrations of tidal inlets and river mouths

V. El Nino Cycles and the Oregon Coast

A. Overview

1. Western North America / South America Coastal Processes
a. Upwelling System
(1) Wind Patterns: East to West
(a) forces surface water of Pacific westward
(b) stimulates upwelling of deep, cold nutrient-rich water along the coast
(2) Cold Current System

2. El Nino Process
a. Weaking of easterly trade winds along equator, west of South America, across the Pacific
b. Cessation of cold upwelling system
c. Warm water currents off coast of South America
d. Disrupts weather systems, alters coastal processes

B. Oregon El Nino Events
a. Recent Events
(1) 1982-1983

(2) 1997-1998
b. Summary of Effects and Processes
(1) Higher tide levels: up to + 1.5 ft higher
(2) Elevated water levels, extend shoreline erosion to seacliffs / dunes
(3) Higher than normal wave erosion
(4) Enhanced, high-energy storm systems

C. El Nino Mechanism
1. Weaking of easterly winds in equatorial Pacific
a. Release of wind-surge water from western Pacific to eastern

2. Wave Surge across Pacific from west to east, towards South America
a. Over course of months

3. Wave Surge Impact South America, runs up coast to North America
a. South to North wave surge
b. > tide levels, > erosion of back beach
c. Rate of El Nino wave surge migration: ~50 mi / day up west coast of U.S.

4. Faltering of coastal upwelling of cold water
a. > surface temperature of offshore water
b. > thermal expansion, >relative sea level, enhanced erosion

5. Jet Stream dips to more southerly position
a. southwesterly storms, high moisture, high thermal energy
(1) impact California coast
(2) impact Pacific Northwest Coast
b. High-energy storms
(1) high wave base + higher tide levels = > energy / erosion of back beach / sea cliffs

D. 1997-1998 El Nino Erosion Events on Oregon Coast

1. Port Orford / southern Oregon
a. southern littoral cell erosion
b. erosion of back-beach sand dunes
2. Alsea Spit
a. Alsea river inlet migration
b. spit erosion
3. Cape Lookout State Park
a. seawall erosion
4. The Capes
a. north of Netarts
b. cliff erosion / condo collapse
(1) development on old landslide deposit
(2) reactivation of landslide