1

2 ***Chapter 20 – Shorelines***

3 **The Shoreline: A Dynamic Interface**

- The *interface* is the common boundary where different parts of a system interact.
- The Coastal Zone
  - The shoreline is constantly modified by waves
  - Present-day shorelines
    - The shore is affected by a complex interaction between sea level and local geology.
  - Human activity
    - Despite being fragile, short-lived features, humans treat the coastal zone as a stable platform.

4 **Cape Cod and Point Reyes**

5 **Hurricane Sandy**

6 **The Shoreline: A Dynamic Interface**

- Basic Features
  - The *shoreline* is a line that marks the contact between land and sea.
  - The *shore* extends between the lowest tide level and the highest elevation affected by storm waves.
  - The *coast* extends inland from the shore as far as ocean-related features are found.
  - The *coastline* marks a coast's seaward edge.

7 **The Coastal Zone**

8 **The Shoreline: A Dynamic Interface**

- Basic Features
  - The shore is subdivided
    - The *foreshore* area is exposed at low tide and submerged at high tide.
    - The *backshore* area is found landward of the high-tide mark.
    - The *nearshore zone* lies between the low-tide shoreline and the point where waves break at low tide.
    - The *offshore zone* is seaward of the nearshore zone.

9 **The Coastal Zone**

10 **The Shoreline: A Dynamic Interface**

- Beaches
  - A *beach* is an accumulation of sediment found along the landward margin of an ocean or lake.
    - Beaches are composed of one or more berms (the relatively flat platform composed of sand)
    - The *beach face* is the wet sloping surface that extends from the berm to the shoreline
  - A beach is composed of locally abundant material.
    - Derived from the erosion of adjacent cliffs or nearby mountains
    - Example: black sand beaches in Hawaii; shell beaches in Florida

11 **Beaches**

12 **Waves**

- Waves travel along the ocean–atmosphere interface
  - Waves are the *visible evidence of energy* passing through a medium
- Wind-generated waves provide most of the energy that shapes and modifies shorelines

13 **Waves**

- Wave Characteristics
  - Most waves derive their energy and motion from the wind.
    - Components of simple, nonbreaking waves are:
      - The *crest* is the top of the wave.
      - The *trough* is the bottom of the wave.

- *Wave height* is the vertical distance between crest and trough.
- *Wavelength* is the horizontal distance between successive crests (or troughs).
- *Wave period* is the time it takes for one full wavelength to pass.

14 **Waves**

- Wave Characteristics
  - Height, length, and period of a wave depend on:
    - Wind speed.
    - Length of time wind has blown.
    - *Fetch* (the distance that the wind has traveled across open water).
  - Waves can travel great distances
  - *Wave energy* moves forward, not the water itself
    - As a wave moves through water, the water passes the energy along by moving in a circle
    - This is called circular orbital motion.

15 **Wave Basics**

16 **Passage of a Wave**

17 **Waves**

- Waves in the Surf Zone
  - Deep water waves are unaffected by water depth
  - When waves approach the shallower water at the shore, this influences their behavior
  - As waves “feel bottom,” the seafloor interferes with water movement and the wave begins to slow down
    - Faster deep-water waves catch up and the wave starts to grow higher
    - As the wave gets higher, it becomes too steep and eventually collapses or breaks
      - Surf is the turbulent water created by breaking waves

18 **Waves Approaching the Shore**

19 **Shoreline Processes**

- Wave Erosion
  - Breaking waves exert a great force
    - Atlantic winter waves average 10,000 kg/m^2
    - The force during storms is greater still!
  - Erosion is caused by wave impact and pressure, and also.
  - *Abrasion*, which is the grinding action of water with rock fragments.
    - Very intense in the surf zone

20 **Storm Waves**

21 **Abrasion – Sawing and Grinding**

22 **Shoreline Processes**

- Sand Movement on the Beach
  - Movement perpendicular to the shoreline
    - Swash and backwash move sand toward and away from the shoreline
      - Net loss or gain depends on level of wave activity
        - »Summer typically has light waves and the berm widens (swash dominates)
        - »Winter typically has powerful storm waves that erode the berm (backwash dominates)

23 **Shoreline Processes**

- Sand Movement on a Beach
  - *Wave refraction*
    - Wave refraction is the bending of a wave
      - Causes waves to arrive nearly parallel to the shore
    - Consequences of wave refraction
      - Wave energy is concentrated against the sides and ends of headlands
      - Weakened in bays

    – Over time, wave refraction straightens irregular shorelines

24 **Wave Refraction**

25 **Shoreline Processes**

- Sand Movement on the Beach
  - *Longshore transport*
    - Waves seldom approach the shore straight on, but rather at an angle
      - Sediment is transported along the beach face in a zig-zag pattern called beach drift
    - Longshore currents easily move fine suspended sand along the coast
  - Both rivers and coastal zones move water and sediment from upstream to downstream
  - Beaches are often characterized as “rivers of sand”

26 **The Longshore Transport System**

27 **Shoreline Processes**

- Sand Movement on the Beach
  - *Rip currents* flow in the opposite direction of breaking waves
    - Most backwash from waves moves back to the open ocean as sheet flow along the ocean bottom
    - Rip currents are concentrated movements of backwash on the ocean surface

28 **Rip Current**

29 **Shoreline Features**

- Features vary depending on several factors, including:
  - The proximity to sediment-laden rivers.
  - Degree of tectonic activity.
  - Topography and composition of the land.
  - Prevailing winds and weather patterns.
  - Configuration of the coastline.

30 **Shoreline Features**

- Erosional Features
  - Wave-cut cliffs, Wave-cut platforms, and marine terraces
    - *Wave-cut cliffs* originate by the cutting action of the surf against the base of the coast.
    - *Wave-cut platforms* are flat, bench-like surfaces left behind by the receding cliff.
    - A tectonically uplifted wave-cut platform is a marine terrace.

31 **Wave-Cut Platform and Marine Terrace**

32 **Shoreline Features**

- Erosional Features
  - Sea arches and sea stacks
    - Headlands are the focus of wave erosion due to wave refraction
    - Rocks in headlands do not erode at the same rate
      - Soft and fractured rocks erode faster than hard rocks, forming sea caves
    - A *sea arch* forms when two sea caves meet
    - A *sea stack* forms when the arch of a sea arch falls

33 **Sea Arch and Sea Stack**

34 **Shoreline Features**

- Depositional Features
  - Spits, bars, and tombolos
    - A *spit* is an elongated ridge of sand extending from the land into the mouth of an adjacent bay.
    - A *baymouth* bar is a spit that extends across a bay to seal it off from the ocean.
    - A *tombolo* is a ridge of sand that connects an island to the mainland or another island.

35 **Coastal Massachusetts**

36 **Shoreline Features**

- Barrier Islands
  - *Barrier islands* are low ridges of sand that parallel the coast 3 to 30 kilometers offshore.

- Found mainly along the Atlantic and Gulf Coastal Plain
- Most are 1 to 5 kilometers wide and 15 to 30 kilometers long
- Probably form in several ways
  - Some originate as spits
  - Some originate from sand piled up offshore
  - Some are flooded sand dunes from the last glacial period

37 **Barrier Islands**

38 **Shoreline Features**

- The Evolving Shore
  - Shorelines continually undergo modification
  - If the shoreline remains *tectonically* stable, shoreline erosion eventually produces a straighter coast

39 **The Evolving Shore**

40 **Coastal Classification**

- Emergent Coasts
  - Develop because of uplift of an area or a drop in sea level
    - Examples:
      - California coast
      - Hudson Bay
  - Features of an emergent coast
    - Wave-cut cliffs
    - Wave-cut platforms
    - Marine terraces

41 **Coastal Classification**

- Submergent Coasts
  - Caused by subsidence of land adjacent to the sea or a rise in sea level
    - Example:
      - Atlantic Coast
  - Features of a submergent coast
    - *Estuaries* (drowned river mouths)
    - Highly irregular shorelines

42 **East Coast Estuaries**

43 **Relocating Cape Hatteras Lighthouse**

44 **Contrasting America's Coasts**

- Atlantic and Gulf Coasts
  - Most coastal development occurs on barrier islands
    - Receive the full force of major coastal storms
- Pacific Coasts
  - Biggest problem is shrinking beaches
    - Dams on rivers prevent sediment from reaching the coast
    - Thinner beaches cannot protect cliffs
      - Houses built on cliffs
  - Erosion is sporadic because coastal storms are sporadic

45 **Pacific Coast**

46 **Pacoima Dam**

47 **Hurricanes – The Ultimate Coastal Hazard**

- Hurricanes are the greatest storms on Earth
  - Called typhoons in the western Pacific and cyclones in the Indian Ocean
  - Among the most destructive of natural disasters
- Over 50 percent of the U.S. population lives within 75 kilometers of a coast
  - Millions of people at risk

48 **Super Typhoon Haiyan**

49 **Hurricanes – The Ultimate Coastal Hazard**

- Profile of a Hurricane
  - Hurricane formation
    - Form in late summer and early fall
      - Sea surface temperatures must reach 27°C to provide heat and moisture for the storm
      - Warm ocean water temperatures is why hurricane formation over the South Atlantic and South Pacific is rare, and anywhere poleward of 20° latitude
      - Hurricanes do not develop within 5° of the equator because the Coriolis effect is too weak there

50 **When do hurricanes occur?**

51 **Sea Surface Temperatures**

52 **Hurricane Source Regions**

53 **Hurricanes – The Ultimate Coastal Hazard**

- Profile of a Hurricane
  - Hurricanes are intense low pressure centers
  - Pressure gradient
    - Moving toward the center of a hurricane, the pressure decreases
    - A pressure gradient is a measure of how fast the pressure changes per unit distance (e.g., from the outside to the inside of the storm)
      - Steep pressure gradients result in stronger winds
      -

54 **Hurricanes – The Ultimate Coastal Hazard**

- Profile of a Hurricane
  - Storm Structure
    - As warm, moist air approaches the core of the storm, the air rises in a ring of cumulonimbus clouds
      - The wall of this rising air column is called the *eye wall*.
        - » Greatest wind speeds and heaviest rain occur at the eye wall
    - The center of the storm is called the *eye*.
      - Precipitation and wind speed decrease in the eye
    - Near the top of the hurricane, the airflow is outward
    -

55 **Cross Section of a Hurricane**

56 **Hurricanes – The Ultimate Coastal Hazard**

- Hurricane Destruction
  - The amount of damage from a hurricane depends on:
    - Size and population density of the area affected
    - Shape of the ocean bottom near the shore
  - Most important factor is the strength of the storm
    - Saffir-Simpson Hurricane Scale
      - Ranks relative intensities of hurricanes
      - Examples:
        - » Hurricane Katrina was a category 4 storm.
        - » Hurricane Camille (1969) was a category 5 storm.

57 **Saffir-Simpson Scale**

58 **Hurricanes – The Ultimate Coastal Hazard**

- Hurricane Destruction
  - Storm surge
    - Most devastating damage in the coastal zone
    - A *storm surge* is a large dome of water that sweeps across the coast when a hurricane makes landfall.

–Intensified by tremendous wave activity superimposed on top of the dome of water
–In the Northern Hemisphere, storm surge is more intense on the right side of the eye
»Winds are blowing toward shore
»On the left side, winds blow away from shore

59 **Storm Surge Destruction**

60 **Hurricanes – The Ultimate Coastal Hazard**

- Hurricane Destruction
  - *Wind damage*
    - Most obvious type of hurricane damage
    - Affect a much larger area than storm surge
    - Hurricanes occasionally produce tornadoes
  - *Heavy rains and inland flooding*
    - May affect areas hundreds of kilometers from the coast several days after the hurricane has passed
    - Examples:
      - Hurricane Floyd—1999
        - »Largest peacetime evacuation in U.S. history
      - Hurricane Camille—1969
        - »Greatest number of deaths associated with flooding in the Blue Ridge Mountains in Virginia

61 **An Approaching Hurricane**

62 **Hurricanes – The Ultimate Coastal Hazard**

- Detecting and Tracking Hurricanes
  - Prior to weather satellites, few storm warnings were given to the population
    - Example: Galveston, Texas—1900
    - Huge storm with lack of adequate warning
    - Killed 8000 people
  -

63 **Aftermath of the Historic Galveston Hurricane**

64 **Hurricanes – The Ultimate Coastal Hazard**

- Detecting and Tracking Hurricanes
  - *Satellites*
    - Can monitor vast areas of open ocean
  - *Aircraft reconnaissance*
    - Special planes fly into hurricanes to measure details
  - *Radar*
    - Basic tool in the observation and study of hurricanes

65 **Hot towers**

66 **Stabilizing the Shore**

- Hard Stabilization
  - During past 100 years there has been increasing development to many coastal areas
  - Hard stabilization includes structures built to protect the coast from erosion
  - *Jetties* are built perpendicular to the shoreline and extend into the ocean near the mouths of rivers and harbors
    - Usually built in pairs to develop and maintain harbors
    - May act as a dam against the longshore current

67 **Jetties**

68 **Stabilizing the Shore**

- Hard Stabilization
  - *Groins* are built perpendicular to the beach and extend into the ocean
    - Built to maintain or widen beaches
    - Constructed at a right angle to the beach to trap sand

- Erosion occurs downstream of the groin
- No longer a preferred method to stop beach erosion
  - Because they are essentially ineffective

69 **Groins**

70 **Stabilizing the Shore**

- Hard Stabilization
  - Breakwaters and seawalls
    - Built parallel to the shore
    - A *breakwater* is built offshore
      - Protects boats from wave energy
      - Creates a region of sand accumulation between the breakwater and the shoreline
    - A *seawall* is built onshore
      - Designed to protect property from breaking waves
      - Causes severe erosion seaward of the seawall

71 **Breakwater**

72 **Seawall**

73 **Stabilizing the Shore**

- Alternatives to Hard Stabilization
  - Beach nourishment involves adding large quantities of sand to the beach
    - Costly and not a permanent solution
    - The same processes eroding the beach in the first place will also erode the imported sand
    - Typically costs millions of dollars per mile
  - Relocation
    - Abandoning or relocating buildings away from the beach
    - Letting nature reclaim the beach
    - Very controversial

74 **Beach Nourishment**

75 **Tides**

- *Tides* are daily changes in the elevation of the ocean surface
- Causes of Tides
  - Tidal bulges are caused by the gravitational forces of the Moon, and to a lesser extent the Sun
  - The position of the Moon only changes moderately in a day
    - Earth rotates “through” tidal bulges

76 **Bay of Fundy**

77 **Idealized Tidal Bulge Causes by the Moon**

78 **Tides**

- Monthly Tidal Cycle
  - *Spring tides* produce especially high and low tides
    - Large daily tidal range
    - Occur during new and full moons
      - Gravitational forces of the Moon and Sun are added together
  - *Neap tides* produce a small tidal range
    - Occur when the Sun and Moon are at right angles to each other

79 **Spring and Neap Tides**

80 **Tides**

- Tidal Patterns
  - Other factors that influence tides
    - Shape of the coastline
    - Configuration of the ocean basin
  - A *diurnal tidal pattern* is characterized by a single high tide and a single low tide each tidal

day

- Example:
  - –Northern shore of the Gulf of Mexico

81 **Tides**

- Tidal Patterns
  - – A *semidiurnal tidal pattern* is characterized by two high tides and two low tides each tidal day
    - Example:
      - –Atlantic Coast of the U.S.
  - – A *mixed tidal pattern* is also characterized by two high tides and two low tides each tidal day
    - Large inequality in high or low water heights
    - Example:
      - –Pacific Coast of the U.S.
      - –

82 **Tidal Patterns**

83 **Tides**

- Tidal Currents
  - – Tidal currents are the horizontal flow of water accompanying the rise and fall of the tide
  - – Water movements induced by tidal forces
    - *Flood currents* are associated with landward moving currents.
    - *Ebb currents* are associated with seaward moving currents.
      - –Flood and ebb currents separated by slack water
    - *Tidal flats* are affected by tidal currents.
    - *Tidal deltas* are created by tidal currents.
      - –May develop as flood deltas or ebb deltas

84 **Tidal Deltas**

85