




1 2  **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.

3  **Cape Cod and Point Reyes**4  **Hurricane Sandy**5  **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.

6  **The Coastal Zone**7  **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.

8  **The Coastal Zone**9  **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

10  **Beaches**11  **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

12  **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.

13 **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.

14 **Wave Basics**

15 **Passage of a Wave**

16 **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

17 **Waves Approaching the Shore**

18 **Shoreline Processes**

- Wave Erosion
 - Breaking waves exert a great force
 - Atlantic winter waves average 10,000 kg/m²
 - 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

19 **Storm Waves**


20 **Abrasion – Sawing and Grinding**

21 **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)

22 **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

23  **Wave Refraction**24  **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”

25  **The Longshore Transport System**26  **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

27  **Rip Current**28  **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.

29  **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.

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

32  **Sea Arch and Sea Stack**33  **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.

34  **Coastal Massachusetts**35  **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

36 **Barrier Islands**

37 **Shoreline Features**

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

38 **The Evolving Shore**

39 **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

40 **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

41 **East Coast Estuaries**

42 **Relocating Cape Hatteras Lighthouse**

43 **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

44 **Pacific Coast**

45 **Pacoima Dam**

46 **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

47 **Super Typhoon Haiyan**

48 **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

49 **When do hurricanes occur?**

50 **Sea Surface Temperatures**

51 **Hurricane Source Regions**

52 **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
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53 **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
 -

54 **Cross Section of a Hurricane**

55 **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.


56 **Saffir-Simpson Scale**

57 **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

58  **Storm Surge Destruction**

59  **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

60  **An Approaching Hurricane**

61  **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

62  **Aftermath of the Historic Galveston Hurricane**

63  **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

64  **Hot towers**

65  **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

66  **Jetties**



67  **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

68  **Groins**69  **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

70  **Breakwater**71  **Seawall**72  **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

73  **Beach Nourishment**74  **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

75  **Bay of Fundy**76  **Idealized Tidal Bulge Causes by the Moon**77  **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

78  **Spring and Neap Tides**79  **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

80 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.
 -

81 Tidal Patterns

82 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

83 Tidal Deltas

84