

EENS 2040	Natural Disasters
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<b>Coastal Zones</b>	

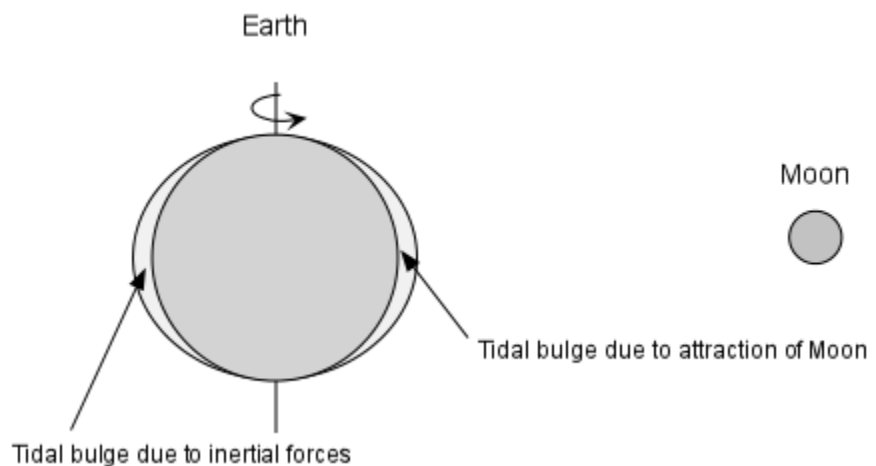
This document last updated on 16-Nov-2011

## Coastal Zones

A coastal zone is the interface between the land and water. These zones are important because a majority of the world's population inhabit such zones. Coastal zones are continually changing because of the dynamic interaction between the oceans and the land. Waves and winds along the coast are both eroding rock and depositing sediment on a continuous basis, and rates of erosion and deposition vary considerably from day to day along such zones. The energy reaching the coast can become high during storms, and such high energies make coastal zones areas of high vulnerability to natural hazards. Thus, an understanding of the interactions of the oceans and the land is essential in understanding the hazards associated with coastal zones. Tides, currents, and waves bring energy to the coast, and thus we start with these three factors.

### Tides

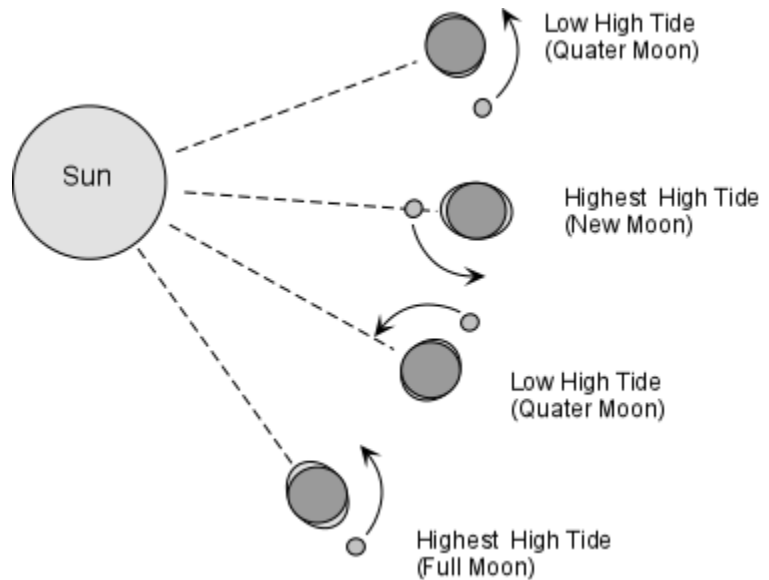
Tides are due to the gravitational attraction of Moon and to a lesser extent, the Sun on the Earth. Because the Moon is closer to the Earth than the Sun, it has a larger affect and causes the Earth to bulge toward the moon.



At the same time, a bulge occurs on the opposite side of the Earth due to inertial forces (the explanation is beyond the scope of this course). These bulges remain stationary while Earth rotates.

- The tidal bulges result in a rhythmic rise and fall of ocean surface, which is not noticeable to someone on a boat at sea, but is magnified along the coasts. Usually there are two high tides and two low tides each day, and thus a variation in sea level as the tidal bulge passes through each point on the Earth's surface.
- Along most coasts the range is about 2 m, but in narrow inlets tidal currents can be strong and fast and cause variations in sea level up to 16 m.

- The highest high tides occur because the Sun also exerts a gravitational attraction on the Earth, there are also monthly tidal cycles that are controlled by the relative position of the Sun and Moon. When the Sun and the Moon are on the same side of the Earth (new Moon) or on opposite sides of the Earth (full Moon). The lowest high tides occur when the Sun and the Moon are not opposed relative to the Earth (quarter Moons).



These highest high tides become important to coastal areas during hurricane season and you always hear dire predications of what might happen if the storm surge created by the tropical cyclone arrives at the same time as the highest high tides.

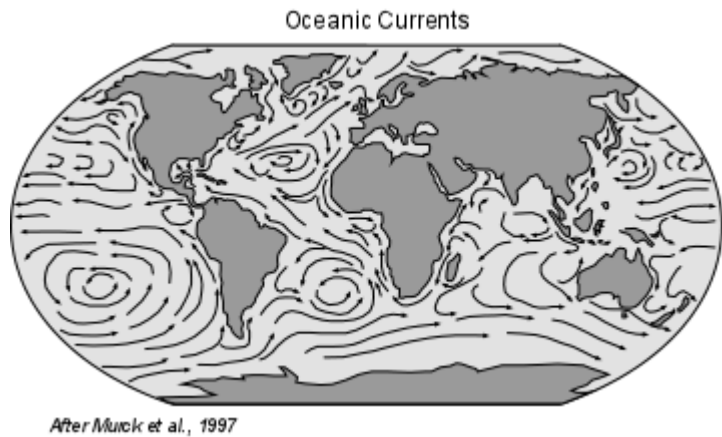
### Fluctuations in Water Level

While sea level fluctuates on a daily basis because of the tides, long term changes in sea level also occur. Such sea level changes can be the result of local effects such as uplift or subsidence along a coast line. But, global changes in sea level can also occur. Such global sea level changes are called *eustatic* changes. Eustatic sea level changes are the result of either changing the volume of water in the oceans or changing the shape of the oceans. For example, during glacial periods much of the water evaporated from the oceans is stored on the continents as glacial ice. This causes sea level to become lower. As the ice melts at the end of a glacial period, the water flows back into the oceans and sea level rises. Thus, the volume of ice on the continents is a major factor in controlling eustatic sea level. Global warming, for example could reduce the amount of ice stored on the continents, thus cause sea level to rise. Since water also expands (increases its volume) when it is heated, global warming could also cause thermal expansion of sea water resulting in a rise in eustatic sea level. Changing the shape of the oceans occurs if volcanic output on the sea floor or at oceanic ridges increases substantially, thus raising the floor of the oceans.

### Oceanic Currents

Oceanic circulation is three dimensional. Most visible to humans are the surface ocean currents that are mainly driven by the wind. Vertical currents and deep ocean currents are driven by upwelling and downwelling near the coasts and differences in density, temperature and salinity between the surface waters and the deep ocean waters.

The surface of the oceans move in response to winds blowing over the surface. The winds, in effect, drag the surface of oceans creating a current of water that is usually no more than about 50 meters deep. Thus, surface ocean currents tend to flow in patterns similar to the winds as discussed previously, and are reinforced by the Coriolis Effect. But, unlike winds, the ocean currents are diverted when they encounter a continental land mass.



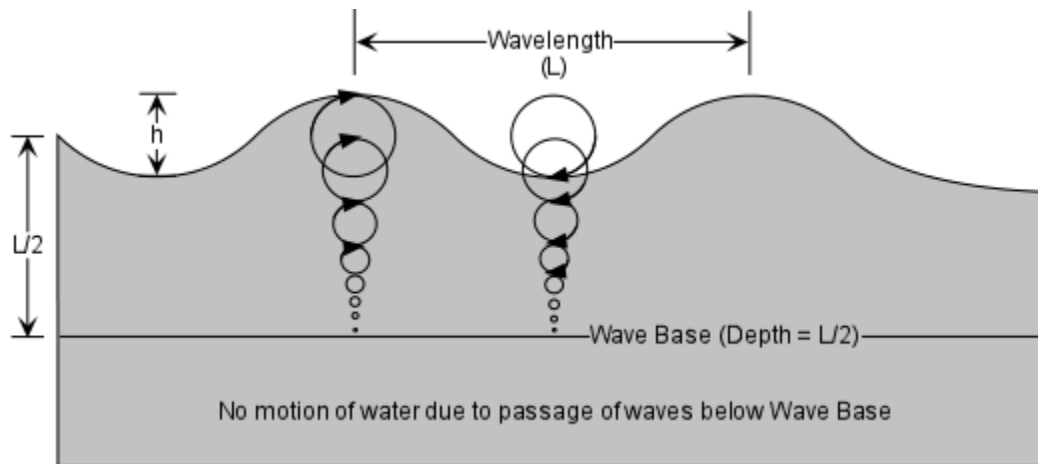
The surface currents have the following properties:

- Because of the Coriolis effect, circulation is clockwise in the northern hemisphere and counterclockwise in the southern hemisphere.
- In each hemisphere cooler waters from higher latitudes circulate toward the equator where they are warmed and circulate back toward the poles.
- As surface waters approach the coast, they have to push the water down in order to make room for more water to come in. This results in downwelling currents. If surface waters move away from the coast, water from below rises to replace the water removed, resulting in upwelling.
- In the middle latitudes ocean currents run generally eastward, flowing clockwise in the northern hemisphere and counterclockwise in the southern hemisphere. Such easterly flowing currents are deflected by the continents and thus flow circulates back toward the west at higher latitudes. Because of this deflection, most of the flow of water occurs generally parallel to the coasts along the margins of continents. Only in the southern oceans, between South America, Africa, Australia, and Antarctica are these surface currents unimpeded by continents, so the flow is generally in an easterly direction around the continent of Antarctica.

Seawater also circulates vertically as a result of changes in density controlled by changing salinity and temperature. Because it controlled by both temperature and salinity differences, is called thermohaline circulation.

## Ocean Waves

Waves are generated by winds that blow over the surface of oceans. In a wave, water travels in loops. But since the surface is the area affected, the diameter of the loops decreases with depth. The diameters of loops at the surface is equal to wave height ( $h$ ).



Wavelength ( $L$ ) = distance to complete one cycle

Wave Period ( $P$ ) = time required to complete one cycle.

Wave Velocity ( $V$ ) = wavelength/wave period ( $L/P$ ).

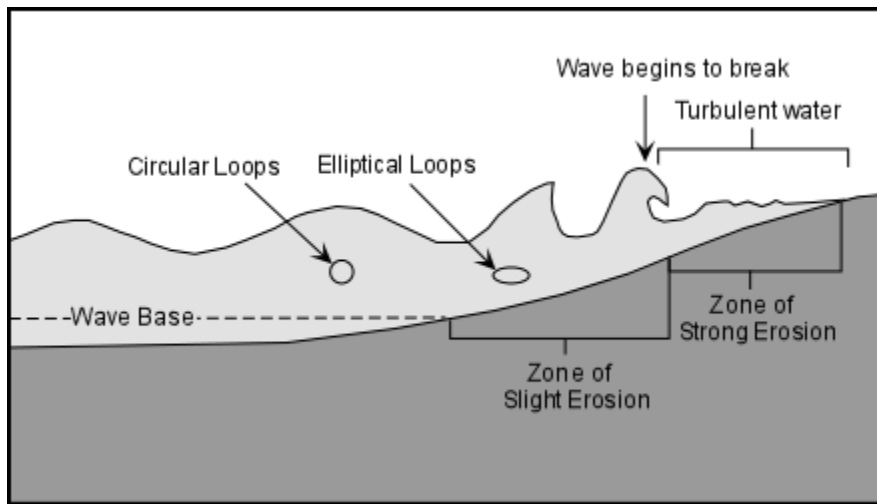
See animation at <http://www.youtube.com/watch?v=7yPTa8qi5X8>

**Wave Base** - Motion of waves is only effective at moving water to depth equal to one half of the Wavelength ( $L/2$ ). Water deeper than  $L/2$  does not move. Thus, waves cannot erode the bottom or move sediment in water deeper than  $L/2$ . This depth is called wave base. In the Pacific Ocean, wavelengths up to 600 m have been observed, thus water deeper than 300m will not feel passage of wave. But outer parts of continental shelves average 200 m depth, so considerable erosion can take place out to the edge of the continental shelf with such long wavelength waves.

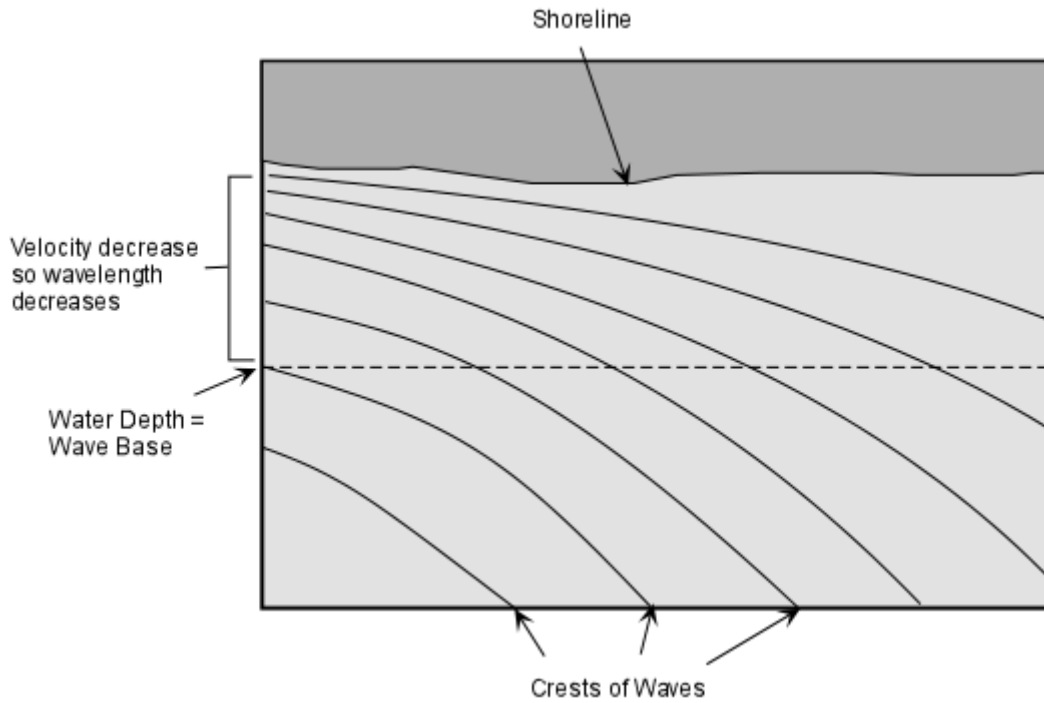
When waves approach shore, the water depth decreases and the wave will start feeling bottom. Because of friction, the wave velocity ( $= L/P$ ) decreases, but its period ( $P$ ) remains the same. Thus, the wavelength ( $L$ ) will decrease. Furthermore, as the wave "feels the bottom", the circular loops of water motion change to elliptical shapes, as loops are deformed by the bottom. As the wavelength ( $L$ ) shortens, the wave height ( $h$ ) increases. Eventually the steep front portion of wave cannot support the water as the rear part moves over, and the wave breaks. This results in turbulent water of the surf, where incoming waves meet back flowing water.

Waves that crash onto the beach are called breakers. Wave energy is dissipated by turbulence, which creates frothy white water in the surf zone. A surge of water (swash) rushes up the beach face. Gravity pulls the backwash down the slope of the beach.

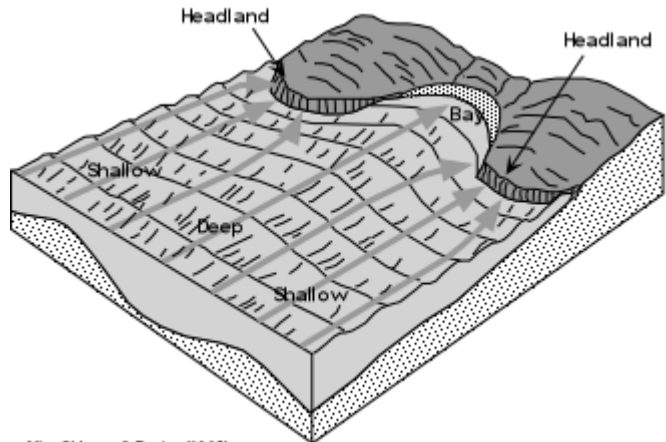
Rip currents form where water is channeled back into ocean.



**Wave refraction** - Waves generally do not approach shoreline parallel to shore. Instead some parts of waves feel the bottom before other parts, resulting in wave refraction or bending.



Wave energy can thus be concentrated on headlands, to form cliffs. Headlands erode faster than bays because the wave energy gets concentrated at headlands.



After Skinner & Porter (1985)

## Coastal Erosion and Sediment Transport

Coastlines are zones along which water is continually making changes. Waves can both erode rock and deposit sediment. Because of the continuous nature of ocean currents and waves, energy is constantly being expended along coastlines and they are thus dynamically changing systems, even over short (human) time scales.

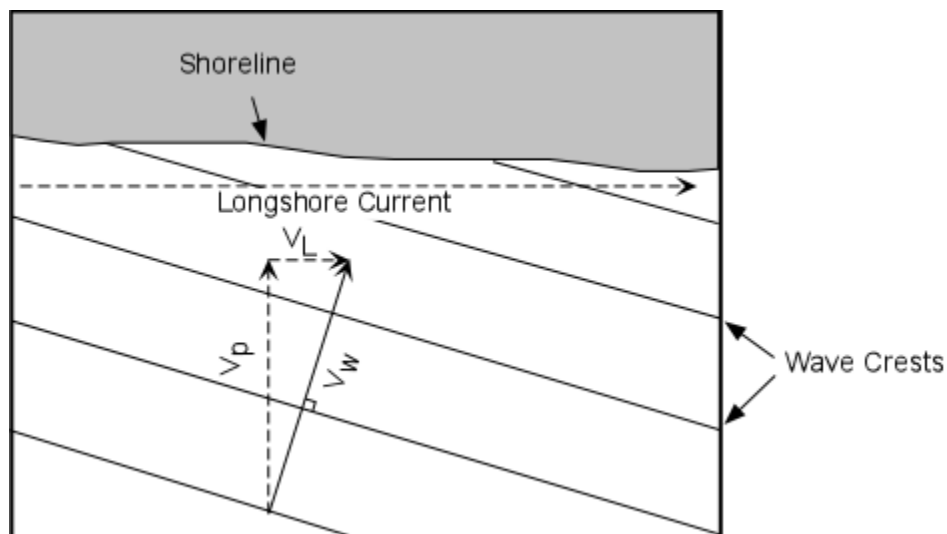
### Erosion by Waves

As we discussed previously, the motion of waves is only felt to a depth of  $1/2$  times the wavelength. Thus, waves can only erode if the water along a coastline is shallower than  $1/2$  times the wavelength. But, when the wave breaks as it approaches the shoreline, vigorous erosion is possible due to the sudden release of energy as the wave flings itself onto the shore. Rigorous erosion of sea floor takes place in the surf zone, i.e. between shoreline and breakers. Waves break at depths between 1 and 1.5 times wave height. Thus for 6 m tall waves, rigorous erosion of sea floor can take place in up to 9 m of water. In the breaker zone rock particles carried in suspension by the waves are hurled at other rock particles. As these particles collide, they are abraded and reduced in size. Smaller particles are carried more easily by the waves, and thus the depth to the bottom is increased as these smaller particles are carried away by the retreating surf. Furthermore, waves can undercut rocky coastlines resulting in mass wasting processes wherein material slides, falls, slumps, or flows into the water to be carried away by further wave action.

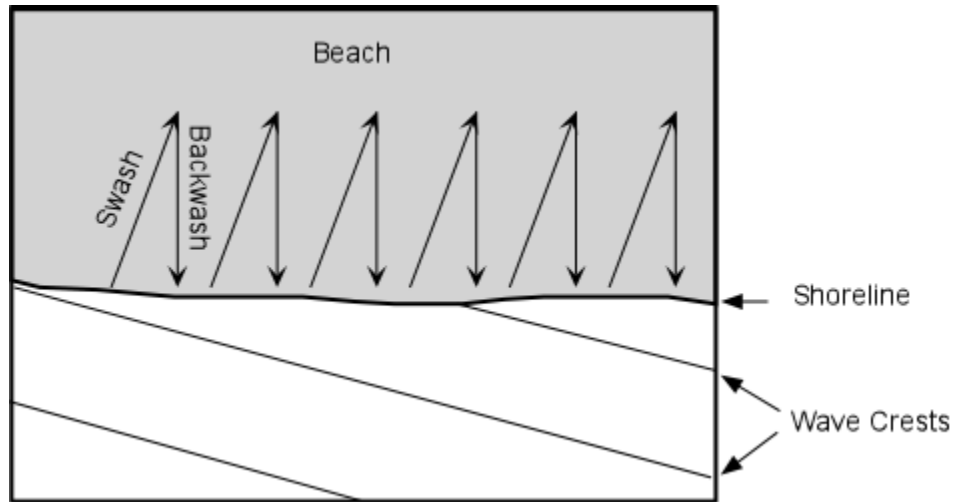
### Transport of Sediment by Waves and Currents

Sediment that is created by the abrasive action of the waves or sediment brought to the shoreline by streams is then picked up by the waves and transported. The finer grained sediment is carried offshore to be deposited on the continental shelf or in offshore bars, the coarser grained sediment can be transported by longshore currents and beach drift.

- **Longshore currents** - Most waves arrive at the shoreline at an angle, even after refraction. Such waves have a velocity oriented in the direction perpendicular to the wave crests, but this velocity can be resolved into a component perpendicular to the shore ( $V_p$ ) and a component parallel to the shore ( $V_L$ ). The component parallel to the shore can move sediment and is called the **longshore current**.



- **Beach drift** - is due to waves approaching at angles to beach, but retreating perpendicular to the shore line. This results in the swash of the incoming wave moving the sand up the beach in a direction perpendicular to the incoming wave crests and the backwash moving the sand down the beach perpendicular to the shoreline. Thus, with successive waves, the sand will move along a zigzag path along the beach.



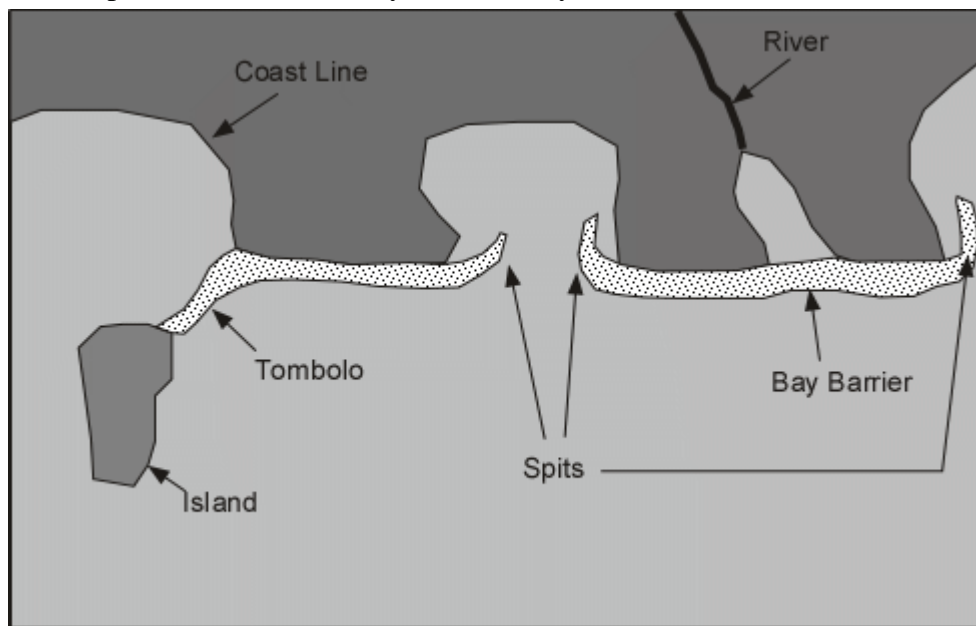
### Coastal Processes

Coastlines represent a balance between wave energy and sediment supply.

If wave energy and sediment supply are constant, then a steady state is reached. If any one of these factors change, then shoreline will adjust.

For example, winter storms may increase wave energy, if sediment supply is constant, fine grained beach sand may be carried offshore resulting in pebble beaches or cobble beaches.

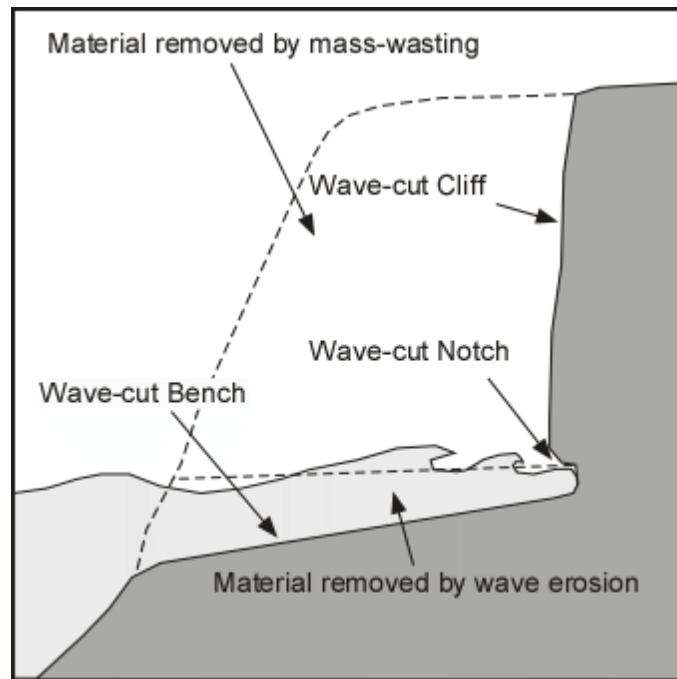
Due to input of sediment from rivers, marine deltas may form, due to beach and longshore drift such features as spits, tombolos, and bay barriers may form



## Types of Coasts

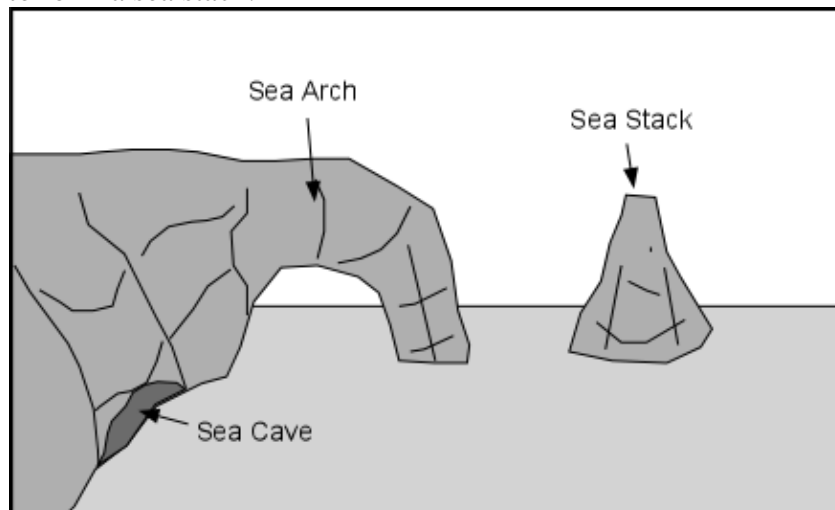
The character and shape of coasts depends on such factors as tectonic activity, the ease of erosion of the rocks making up the coast, the input of sediments from rivers, the effects of eustatic changes in sea level, and the length of time these processes have been operating.

- **Rocky Coasts** - In general, coastlines that have experienced recent tectonic uplift as a result of either active tectonic processes (such as the west coast of the United States) or isostatic adjustment after melting of glacial ice (such as the northern part of the east coast of the United States) form rocky coasts with cliffs along the shoreline. Anywhere wave action has not had time to lower the coastline to sea level, a rocky coast may occur. .



Because of the resistance to erosion, a wave cut bench and wave cut cliff develops. The cliff may retreat by undercutting and resulting mass-wasting processes. If subsequent uplift of the wave-cut bench occurs, it may be preserved above sea level as a *marine terrace*.

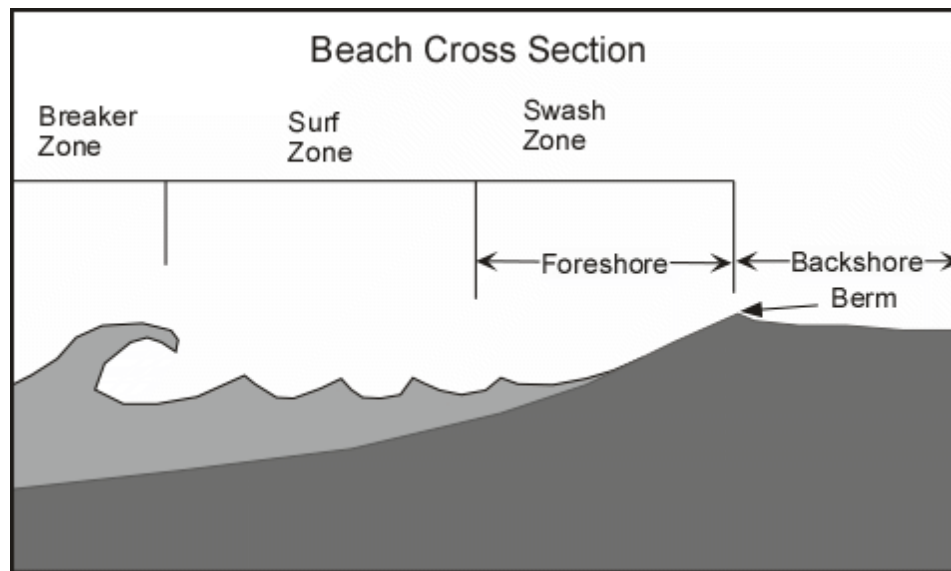
In areas where differential erosion takes place, the undercutting may initially produces sea caves. If sea caves from opposite sides of a rocky headland meet, then a sea arch may form. Eventual weakening of the sea arch may result in its collapse to form a sea stack.



Because cliffed shorelines are continually attacked by the erosive and undercutting action of waves, they are susceptible to frequent mass-movement processes which make the tops of these cliffs unstable areas for construction as you noted in your homework on mass movement processes.

Along coasts where streams entering the ocean have cut through the rocky cliffs, wave action is concentrated on the rocky headlands as a result of wave refraction, as discussed previously.

- **Beaches** - A beach is the wave washed sediment along a coast. Beaches occur where sand is deposited along the shoreline. A beach can be divided into a foreshore zone, which is equivalent to the swash zone, and backshore zone, which is commonly separated from the foreshore by a distinct ridge, called a berm. Behind the backshore may be a zone of cliffs, marshes, or sand dunes.



- **Barrier Islands** - A barrier island is a long narrow ridge of sand just offshore running parallel to the coast. Separating the island and coast is a narrow channel of water called a lagoon. Most barrier islands were built during after the last glaciation as a result of sea level rise. Barrier islands are constantly changing. They grow parallel to the coast by beach drift and longshore drift, and they are eroded by storm surges that often cut them into smaller islands. Barrier islands are common along the east and Gulf coasts of the United States.
- **Reefs and Atolls** - Reefs consist of colonies of organisms, like corals, which secrete calcium carbonate. Since these organisms can only live in warm waters and need sunlight to survive, reefs only form in shallow tropical seas. Fringing reefs form along coastlines close to the sea shore, whereas barrier reefs form offshore, separated from the land by a lagoon. Both types of reefs form shallow water and thus protect the coastline from waves. However, reefs are high susceptible to human activity and the high energy waves of storms.

In the deeper oceans reefs can build up on the margins of volcanic islands, but only do so after the volcanoes have become extinct. After the volcanism ceases, the volcanic island begins to erode and also begins to subside. As the island subsides, the reefs continue to grow upward. Eventually, the original volcanic island subsides and is eroded below sea level. But, the reefs trap sediment and a circular or annular island, called an atoll, forms.

- **Estuaries**- Coastal river valleys flooded by sea water are called estuaries. They are characterized by mixing of fresh and salt water. Most modern estuaries are related to sea level rise since the last glaciation.
- **Tidal Flats** - These are zones along the coast that are flooded during high tides and form in the intertidal zones lacking strong waves. They are common behind barrier islands or in estuaries.

### Coastal Variability

The shape of coast is controlled mainly by tectonic forces and climate, both of which act to determine the elevation of the coast. Plate tectonic setting governs the style of coastline. In general, along passive margins where not tectonic activity is currently taking place, broad low lying coastal plains dominate.

Along active margins, uplifted rocky coasts dominate.

- **Emergent coasts** result from local tectonic or uplift or from a drop in eustatic sea level. Emergent coasts are characterized by rocky coasts with sea cliffs and raised wave cut benches (marine terraces). The west coast of the U.S. is a rugged **emergent** coast with many sea cliffs and raised wave cut benches (marine terraces). In this case is due to a recent episode of uplift of the land relative to the sea by tectonic forces. The coast of New England is also an emergent case, but in this case, the rise of the land surface has been due to removal of glacial ice which had depressed the land during the last glaciation which ended about 10,000 years ago.
- **Submergent coasts** result from either subsidence along the coast due to tectonic forces or eustatic sea level rise. These are characterized by gentle shorelines, flooded river valleys (estuaries and fjords), and barrier islands. Much of the East Coast and Gulf Coast of the U.S. has these characteristics which are attributed to the rise of eustatic sea level since last glaciation.

### Coastal Hazards

- **Sea Level Rise** - Sea level is presently rising and the rate of sea level rise may increase due to melting of continental ice sheets like now cover Greenland and Antarctica. Human habitation of low-lying coastlines may be in jeopardy in the near future. Higher sea level will make these coastal areas more susceptible to other hazards, like storms and tsunamis.
- **Storms** - great storms such as hurricanes or other winter storms can cause erosion of the coastline at much higher rate than normal. During such storms beaches can erode rapidly and heavy wave action can cause rapid undercutting and mass-wasting events of cliffs along the coast, as noted above. Note that the El Niño driven storms on the west coast caused extensive coastal erosion in 1998.

High winds blowing over the surface of the water during storms bring more energy to the coastline and can cause more rapid rates of erosion. Erosion rates are higher because:

- During storms wave velocities are higher and thus larger particles can be carried in suspension. This causes sand on beaches to be picked up and moved offshore, leaving behind coarser grained particles like pebbles and cobbles, and reducing the width of the beach.

- During storms waves reach higher levels onto the shoreline and can thus remove structures and sediment from areas not normally reached by the incoming waves.
- Because wave heights increase during a storm, waves crash higher onto cliff faces and rocky coasts. Larger particles are flung against the rock causing rapid rates of erosion.
- As the waves crash into rocks, air occupying fractures in the rock becomes compressed and thus the air pressure in the fractures is increased. Such pressure increases can cause further fracture of the rock.

As we have seen in our discussion of tropical cyclones, wind driven storm surge and can flood coastal areas and cause much death and destruction.

- Tsunami - a *tsunami* is a giant sea wave generated by earthquakes, volcanic eruptions, or landslides, as we have discussed before. Such waves can have wave heights up to 30 m, and have great potential to wipe out coastal cities.
- Landslides - On coasts with cliffs, the main erosive force of the waves is concentrated at the base of the cliffs. As the waves undercut the cliffs, they may become unstable and mass-wasting processes like landslides or rockfalls will result. Massive landslides can also generate tsunami.

### **Mitigating Against Coastal Hazards**

Shoreline protection can be divided into two categories: hard stabilization in which structures are built to reduce the action of the waves and soft stabilization which mainly refers to adding sediment back to a beach as it erodes away.

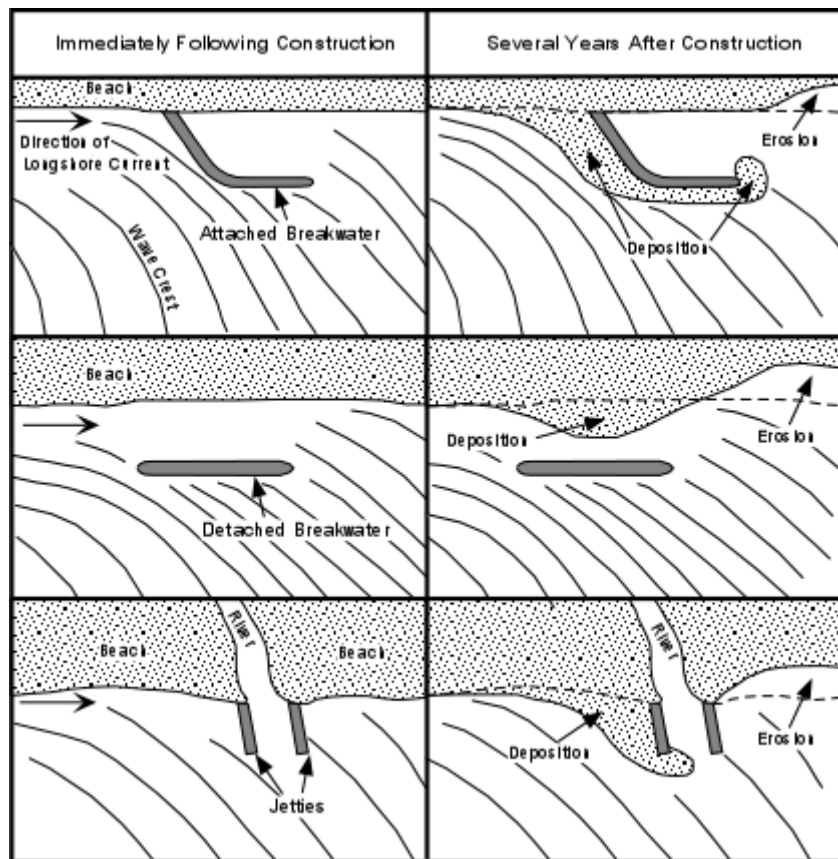
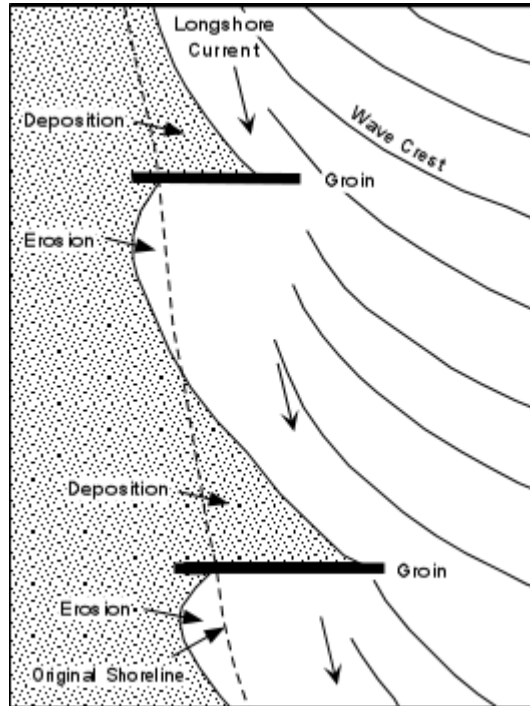
#### **Hard Stabilization**

Seacliffs, since they are susceptible to landslides due to undercutting, and barrier islands and beaches, since they are made of unconsolidated sand and gravel, are difficult to protect from the action of the waves. Human construction can attempt to prevent erosion, but cannot always protect against abnormal conditions.

Two types of hard stabilization are often used.

- One type interrupts the force of the waves. Seawalls are built parallel to the coastline to protect structures on the beach. A seawall is usually built of concrete or piles of large rocks. Waves crash against the seawall and are prevented from running up the beach. Breakwaters serve a similar purpose, but are built slightly offshore, again preventing the force of the waves from reaching the beach and any structures built on the beach.
- The other type interrupts the flow of sediment along the beach. These structures include groins and jetties, built at right angles to the beach to trap sand and widen the beach.

While hard stabilization does usually work for its intended purpose, it does cause sediment to be redistributed along the shoreline. Breakwaters, for example cause wave refraction, and alters the flow of the longshore current. Sediment is trapped by the breakwater, and the waves become focused on another part of the beach, where they can cause significant erosion. Similarly, because groins and jetties trap sediment, areas in the downdrift direction are not resupplied with sediment, and beaches become narrower in the downdrift direction.



Soft stabilization is primarily accomplished by adding sediment to the coastline, usually by dredging sediment from offshore and pumping it onto the coastline. Adding sediment is necessary when erosion removes too much sediment. But, because the erosive forces are still

operating, such addition of sediment will need to be periodically repeated.

### **Coastal Protection Controversies**

As noted above, hard stabilization usually affects areas in the downdrift direction of the longshore current. The net result being that some areas of a coastline are protected while other areas are destroyed. Nearly all human intervention with coastal processes interrupts natural processes and thus can have an adverse effect on coastlines. Three examples of human interference are discussed below.

- Barrier Islands along the North Carolina Coast show a noticeable difference among the islands that have been built upon and those that have not. The undeveloped islands have beaches 100 to 200 meters wide, while the developed islands have beaches with widths less than 30 m.
- In order to protect southern California cities from flooding caused by heavy rains, most of the streams draining into the ocean have been dammed. The dams trap sediment that would normally be carried to the ocean by stream flow. Since this sediment is not being supplied to the ocean, longshore currents cannot resupply the beaches with sediment, but do carry the existing sediment in the downdrift direction, resulting in significant erosion of the beaches.
- Most of the state of Louisiana has resulted from the deposition of sediments by the Mississippi River during floods over the last 10,000 years. Humans, however, have prevented the River from flooding by building a levee systems that extends to the mouth of the River. As previously deposited sediments become compacted they tend to subside. But, since no new sediment is being supplied by Mississippi River flooding, the subsidence results in a relative rise in sea level. This, coupled with a current rise in eustatic sea level, is causing coastal Louisiana to erode at an incredible rate, estimated at 25 square miles a year (equivalent to the area one football field disappearing every 45 minutes). An excellent series of articles concerning the coastal erosion problem in Louisiana was published recently by the Times-Picayune newspaper. See the article and the accompanying flash animation at:

<http://www.nola.com/speced/lastchance/multimedia/>

Many have suggested that the best way to adjust to coastal erosion is to leave the coastlines alone. This, of course will not solve the problems of southern California or Louisiana, because both areas need the flood protection measures. Nevertheless, in some coastal areas zoning laws have been enacted to prevent development along beaches, and in other areas building codes are enforced to protect the natural environment.

### **Examples of questions on this material that could be asked on an exam**

1. Define the following (a) eustatic sea level, (b) wave base. (c) wave refraction.
2. What is beach drift and longshore current? Explain how these operate to move sediment along the coast.

3. What differences are there between the east and west coasts of the United States and how is this difference best explained?
  4. Why are coastal zones so vulnerable to natural hazards/disasters and what are the main coastal hazards?
  5. What measures can be taken to slow or inhibit coastal erosion?
  6. What are the main factors that have contributed to the rapid loss of coastal areas in south Louisiana?
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