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| EENS 1110 | Physical Geology |
| Tulane University | Prof. Stephen A. Nelson |

# Oceans and Coasts

This page last updated on 06-Nov-2015

## The Oceans

- Cover about 71% of the surface of the Earth.
- The greatest ocean depth of 11,035 m occurs in the Mariana Trench
- Have an average depth of 3,800 m.
- Have a present volume of about 1.35 billion cubic kilometers, but the volume fluctuates with the growth and melting of glacial ice.
- Help to regulate transfer of mass and energy between biosphere, lithosphere and atmosphere.
- 40 to 50% of the world's population live within 100 km of a coast.

The Oceans exist because of differences in lithosphere as reflected by isostasy. Continental lithosphere "floats higher" on the asthenosphere because the embedded continental crust has a lower density. Oceanic lithosphere "floats deeper" in the asthenosphere because is it is denser. The ocean basins collect water because they are "lower."

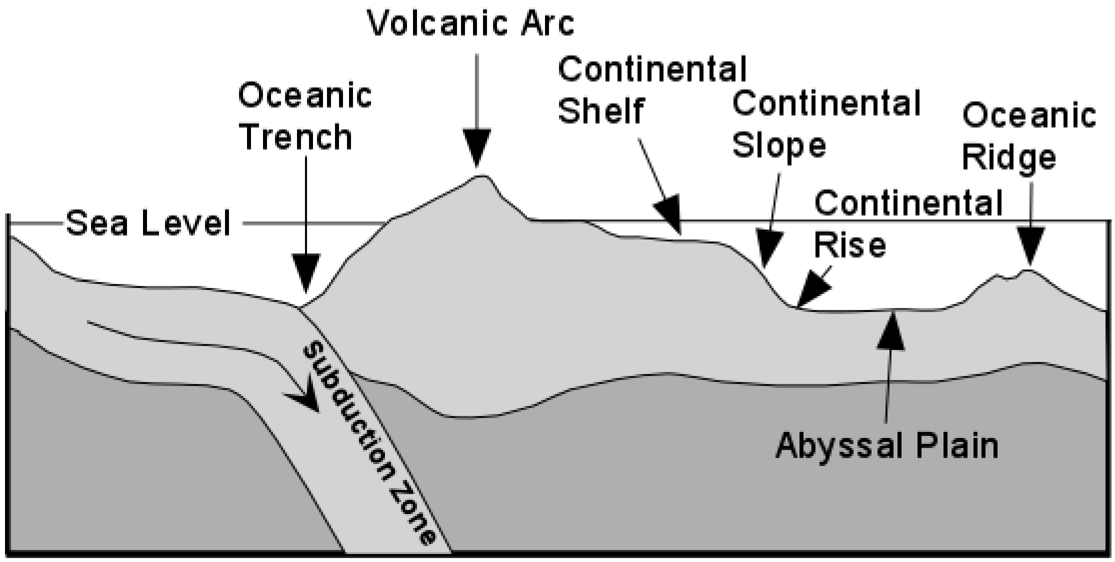
### The Ocean Floor

The ocean floor was very much unknown until the late 1800s when the first scientific expeditions were undertaken. Our knowledge greatly expanded during and after World War II. Bathymetry was mapped, and oceanic ridges and trenches were discovered, This was accomplished through sonar soundings of ocean depth and submarine exploration of the deep oceans. Later drilling of the sea floor for the collection of samples was undertaken. It was a better understanding of the ocean floor which led to the theory of Plate Tectonics.

The most important bathymetric features of the sea floor are

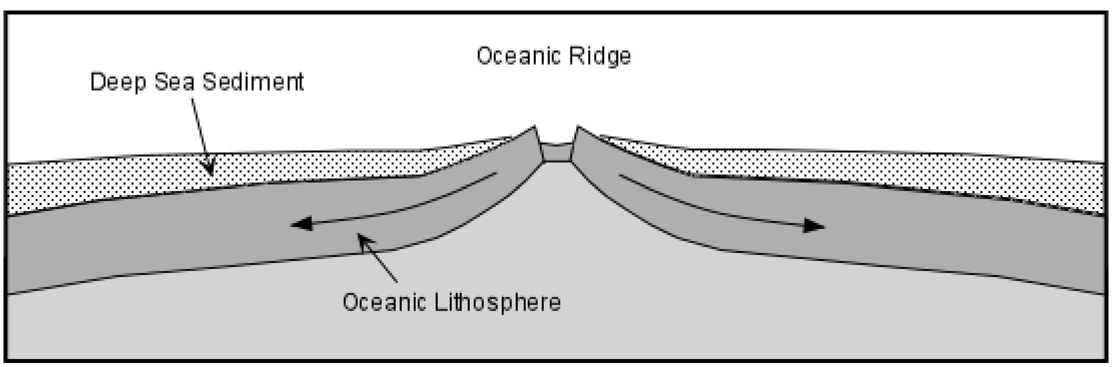
- ***Continental Shelf, Slope, and Rise***
- ***Abyssal Plains***
- ***Oceanic ridges***
- ***Oceanic Trenches***

The bathymetry of the sea floor reflects tectonics. The Continental shelf is underlain by thinning continental crust. The continental slope and rise are transitional between crustal types, and the abyssal plain is underlain by mafic oceanic crust. Oceanic ridges are diverging plate boundaries where new oceanic lithosphere is formed and oceanic trenches are converging plate boundaries where oceanic lithosphere is subducted.



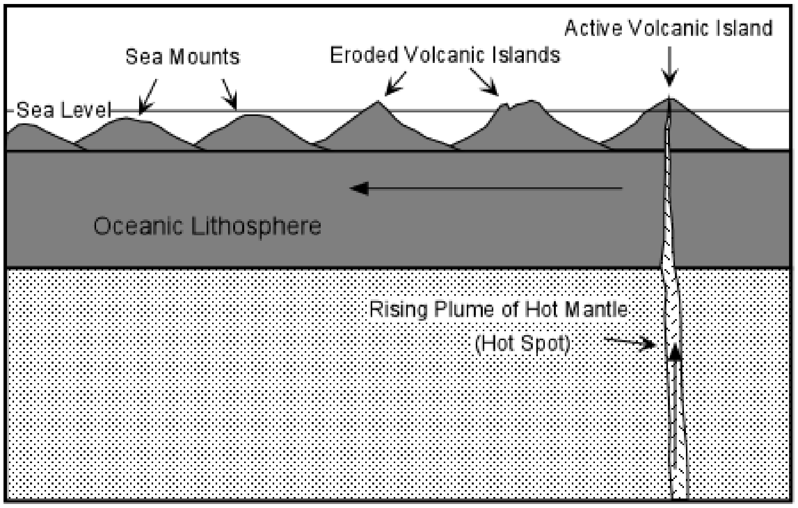

Because oceanic lithosphere may get subducted, the age of the ocean basins is relatively young. The oldest oceanic crust occurs farthest away from a ridge. In the Atlantic Ocean, the oldest oceanic crust occurs next to the North American and African continents and is Jurassic in age (see figure 4.9 in your text). In the Pacific Ocean, the oldest crust is also Jurassic in age, and occurs off the coast of Japan.

Because the oceanic ridges are areas of young crust, there is very little sediment accumulation on the ridges. Sediment thickness increases in both directions away of the ridge, and is thickest where the oceanic crust is the oldest.

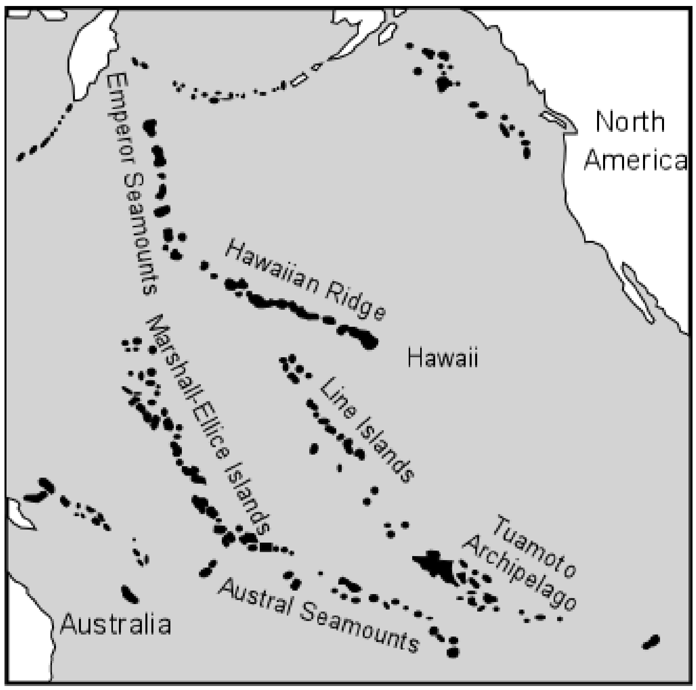



Sediment on the abyssal plain is mainly fined grained sediment (clay size) that was input into the oceans by streams and winds from the continents. The accumulation of the remains of silica secreting planktonic organisms like radiolaria and diatoms, has produced chert and the accumulation of the remains of foraminifera has produced biogenic limestones.

Besides the oceanic ridges, oceanic islands and seamounts occur in the ocean basins. These are mostly volcanic islands that were formed above hot spots. The volcanoes formed over the hot spot and after the volcano goes extinct, it is eroded to sea level. Continued cooling and subsidence submerges the island to form seamounts (also called guyots).

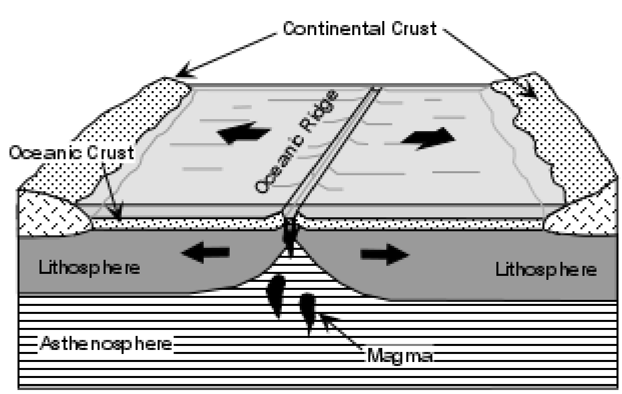



Examples include: the Hawaiian Islands and the Emperor Seamount chain and others in both the Atlantic and Pacific Oceans.




Where the continents meet the oceans, the continental margins are characterized as being of one of two types: Passive or Active.

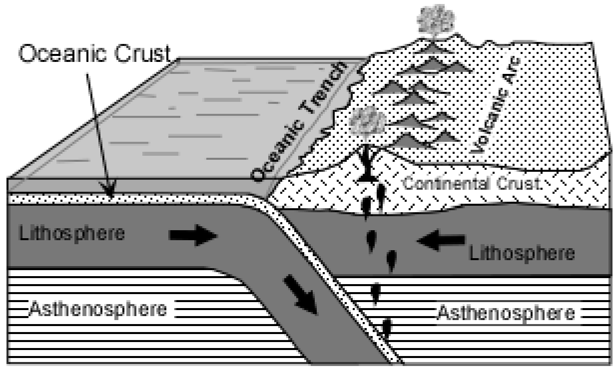
***Passive Continental Margins -*** A passive continental margin occurs in the interior of plate, far away from any plate boundary. Present examples of passive continental margins are the Atlantic coast of North and South America, Europe, and Africa. No current deformation is taking place along these margins because they are not close to plate boundaries. The passive continental margins developed as a result of rifting of a former larger continent.



Diverging Plate Boundary
Oceanic Ridge - Spreading Center

A passive continental margin is characterized by a broad continental shelf overlying thinning continental lithosphere. The shelf is made of relatively shallow oceanic sediments that have been shed by the continents.

***Active Continental Margins-*** Continental convergent margins occur where the margin of the continent coincides with a convergent plate boundary. Examples of a current active continental margins occur along the Pacific coast of South America and in the Cascade Mountains of the western U.S.



Ocean - Continent Convergence

An active continental margin is characterized by a narrow continental shelf, again composed of sediments shed from the continents.

Submarine canyons crosscut the continental shelves. These are associated with large rivers from the continents. Erosion carved the canyons during times when sea-level was lower than at present. The submerged canyons funnel sediments to deeper water producing submarine fans where the canyons empty onto the continental rise.

## Ocean Water

***Salinity***, a measure of amount of dissolved ions in the oceans, ranges between 33 and 37 parts per thousand.

- The dissolved ions have been concentrated in seawater as a result of chemical weathering (Na, Ca, Mg, S, K, Br, and $HCO_3$ ) and degassing of the mantle by volcanic activity (Cl & S).
- Seawater would contain higher concentrations of dissolved ions if some were not removed by chemical precipitation, plants and animals, and absorption onto clay minerals.
- Salinity varies in the oceans (see figure 18.9 in your text) because surface waters evaporate, rain and stream water is added, and ice forms or thaws.
    - Salinity is higher in mid-latitude oceans because evaporation exceeds precipitation
    - Salinity is higher in restricted areas of the oceans like the Mediterranean and Red Seas (up to 41 parts per thousand).
    - Salinity is lower near the equator because precipitation is higher.
    - Salinity is low near the mouths of major rivers because of input of fresh water.
- The temperature of surface seawater varies with latitude, from near $0^{o}$ C near the poles to $29^{o}$C near the equator. But restricted areas can have temperatures up to $37^{o}$C. (See figure 18.9 in your text.)

- Properties of seawater also vary with depth.
    - The density and salinity of seawater increase with depth.
    - Temperature decreases with depth.

**Ocean Circulation**

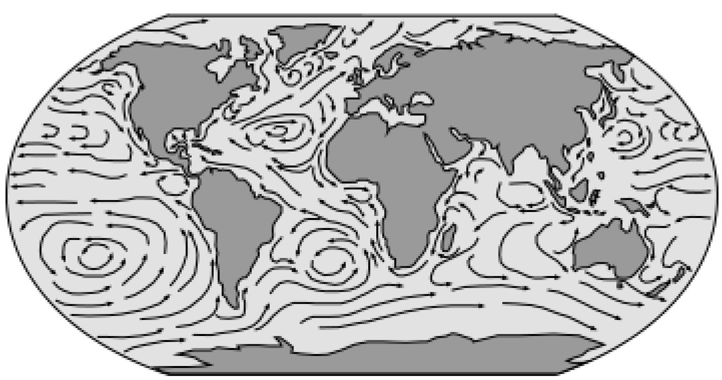
Oceanic circulation is three dimensional. Most visible to humans are the surface ocean currents that are mainly driven by the wind. Vertical currents and deep ocean currents are driven by upwelling and downwelling near the coasts and differences in density, temperature and salinity between the surface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

Surface Ocean currents are result of drift of the upper 50 to 100 m of the ocean due to drag by wind. Thus, surface ocean currents generally follow the same patterns as atmospheric circulation with the exception that atmospheric currents continue over the land surface while ocean currents are deflected by the land. 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.

Oceanic Currents



After Murck et al., 1997

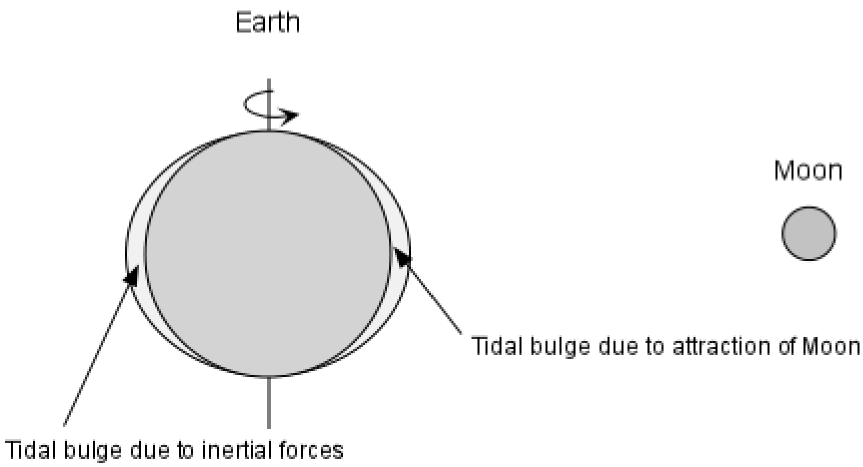
- As surface waters approach the coast, they have to push the water down in order to make room for more water to come in. This results in downwelling currents.

- If surface waters move away from the coast, water from below rises to replace the water removed, resulting in upwelling.

In addition to surface circulation, seawater also circulates vertically as a result of changes in density controlled by changing salinity and temperature (see figures 18.12 in your text). Such circulation, because it controlled by both temperature differences and differences in salinity of the water, is called ***thermohaline circulation***.

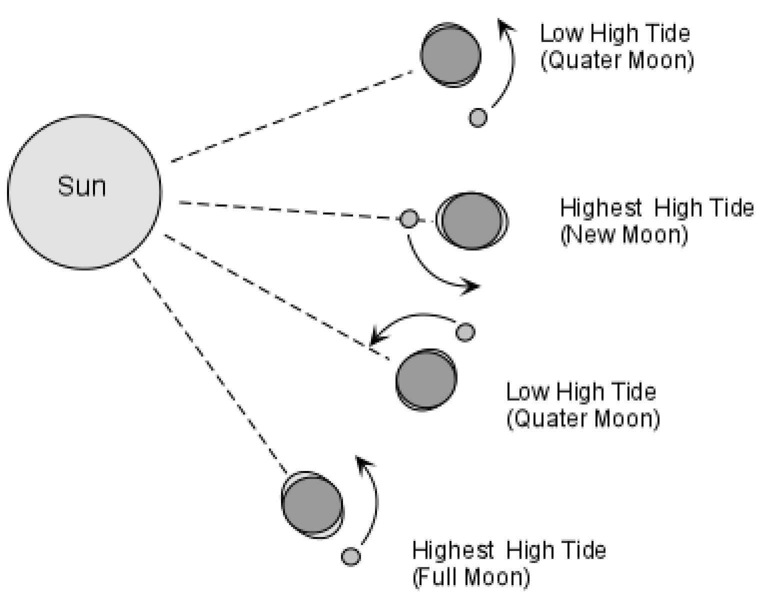
**Ocean Tides**

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 effect 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 (this is explained well in the book on pages 670-671, if you are interested).




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.

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. The highest high tides occur 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). These are called Spring Tides.

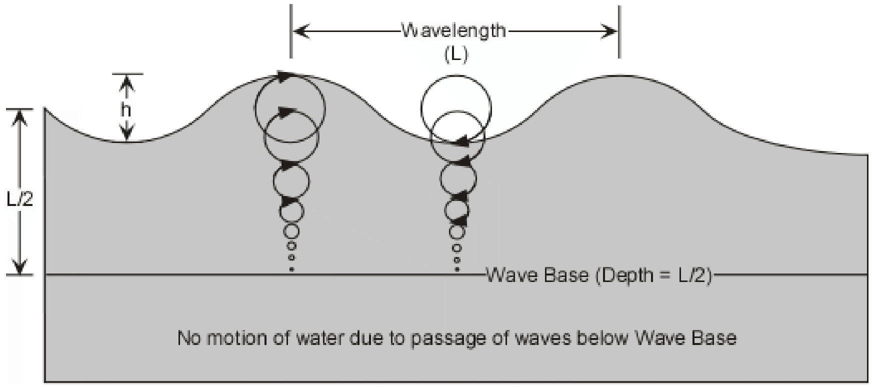



The lowest high tides occur when the Sun and the moon are not opposed relative to the Earth (quarter moons). These highest high tides become important to coastal areas during hurricane season and you always hear dire predications of what might happen if the storm surge created by the hurricane arrives at the same time as the highest high tides.

**Ocean Waves**

Waves are generated by winds that blow over the surface of oceans. Wave height, length, and period depend on wind speed, wind duration, and distance of travel (fetch).

In a wave, water travels in circular 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). (See animation at http://www.youtube.com/watch?v=7yPTa8qi5X8)




Wavelength (L) = distance to complete one cycle

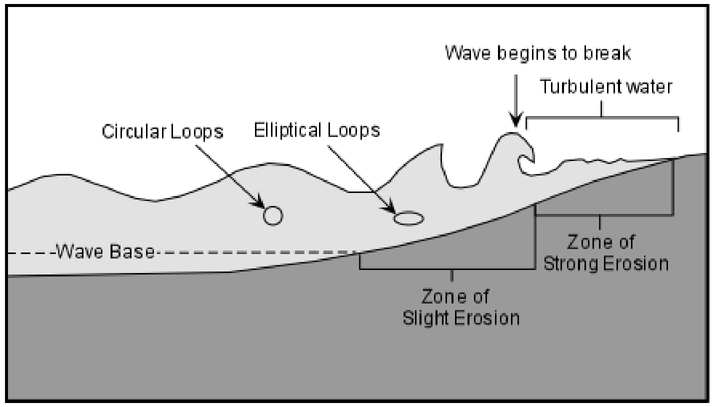
Wave Period (P) = time required to complete on cycle.

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

- ***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.

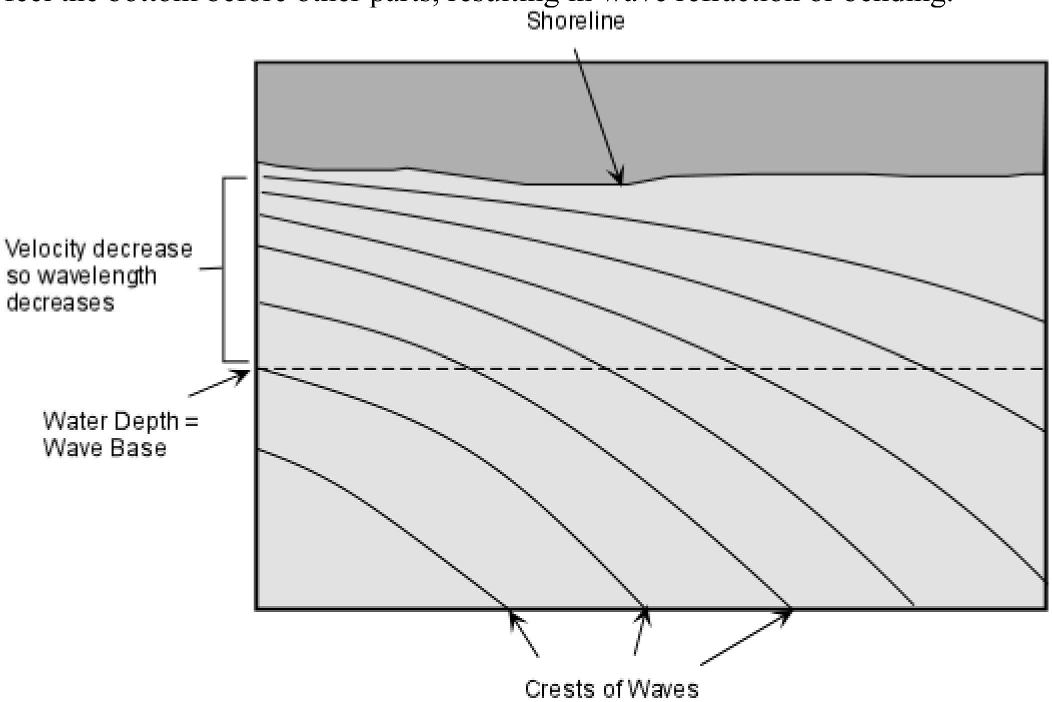



Waves that crash onto the beach are called breakers. Wave energy is dissipated by turbulence, which creates frothy white water in the surf zone. A surge of water (swash) rushes up the beach face. Gravity pulls the backwash down the slope of the beach. (See video at http://www.youtube.com/watch?v=2_N7C9vdpV8)

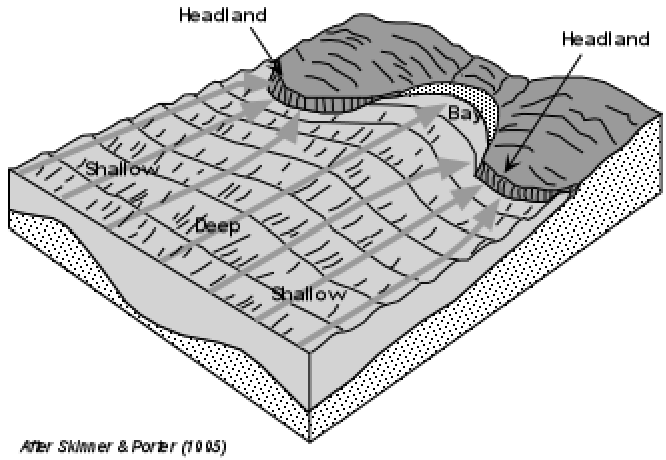
Rip currents form where water is channeled back into the ocean.

- **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




**Wave Erosion**

Rigorous erosion of sea floor takes place in surf zone, i.e. between shoreline and breakers. Waves break at depths between 1 and 1.5 times wave height. Thus for 6m tall waves, rigorous erosion of sea floor can take place in up to 9 m of water.

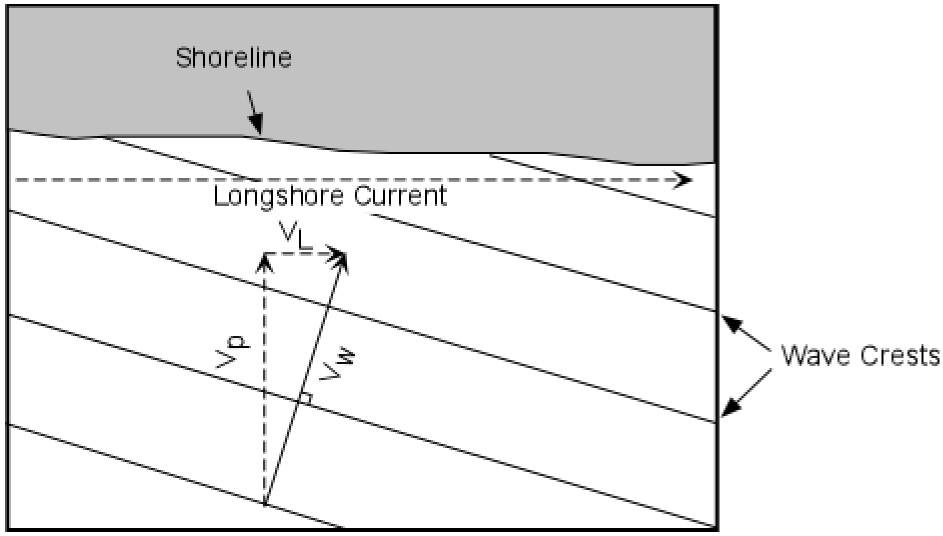
Waves can also erode by abrasion and flinging rock particles against one another or against rocks along the coastline.

**Coastal Sediment Transport**

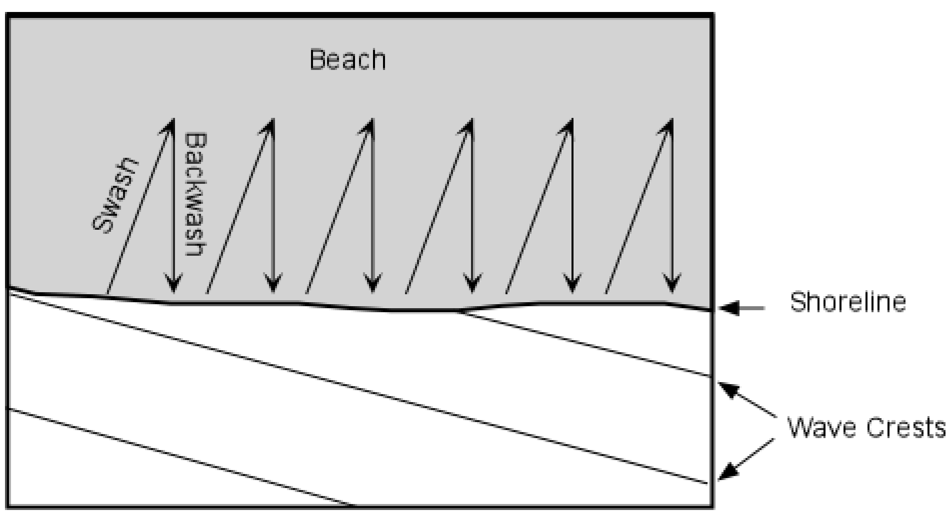
Coastlines are zones along which water is continually making changes. Waves can both erode rock & deposit sediment.

Because of the continuous nature of ocean currents & waves, energy is constantly being expended along coastlines & they are thus dynamically changing systems, even over short (human) time scales.

- ***Longshore currents*** - Since 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 ($V_w$), but this velocity can be resolved into a component perpendicular to the shore (Vp) 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.




- **Offshore Transport and Sorting**

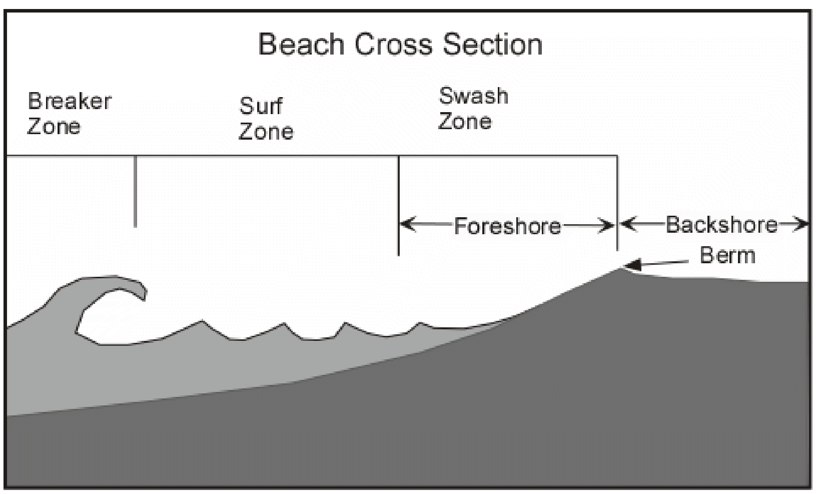
  Particles picked up by wave motion move down slope, but the deeper the water, the less energy is involved in wave motion, so smaller and smaller particles are moved farther off shore. This results in size sorting of sediment, with grain size decreasing away from coast. (see video at http://www.youtube.com/watch?v=2_N7C9vdpV8).

**Coastal Deposits and Landforms**

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, bay barriers, and tombolos may form.

Coast represents the boundary between sea and land. When waves hit the coast, they can erode by breaking up rocks into finer particles and abrading other rocks by flinging rocks, sand and water against them. Over time, the effects can be large. Sediment is moved and redeposited to increase the size of continental shelves.

- 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.

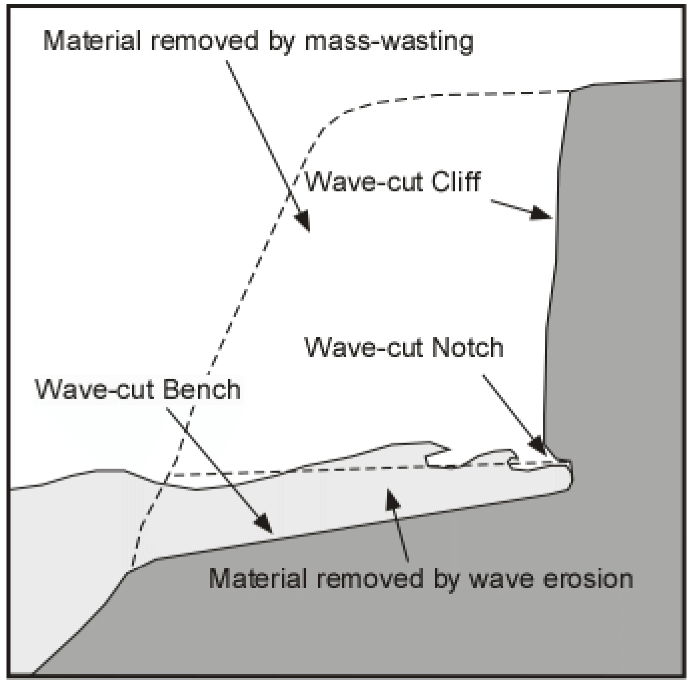



Sandy beaches are the most common. The sand tends to be very well sorted and well rounded. The sorting is a reflection of the wave energy reaching the beach - the waves are energetic enough to carry away the finer grained sediment, but not energetic enough to carry in the coarser grained sediment. Beach deposits usually show cross-bedding.

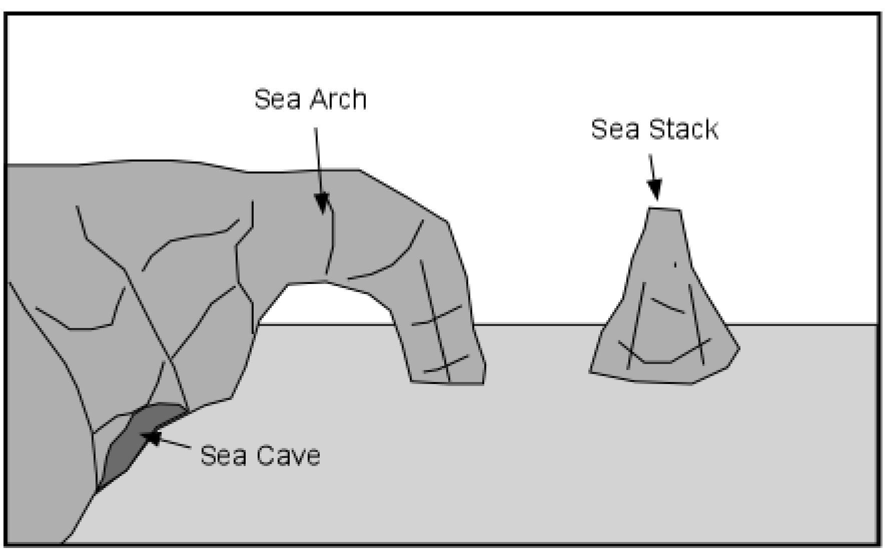
Sediment compositions reflect the local geology. Quartz is the most common, although calcite is common where the coastal rocks are made of limestone or where there are offshore carbonate reefs. In other environments, only minerals that are resistant to chemical weathering occur.

In temperate climates, energy reaching coast is seasonal. Winter storms bring high energy – wash sand offshore, forming a narrow gravel beach. In the summer, less energy reaches the beach, sand returns, and creates a wider beach (See figure 18.20 in your text).

- Rocky Coasts - Where 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. If subsequent uplift of the wave-cut bench occurs, it may be preserved above sea level as a ***marine terrace***.




The cliff may retreat by undercutting and resulting mass-wasting processes. 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 & undercutting action of waves, they are susceptible to frequent mass-wasting processes which make the tops of these cliffs unstable areas for construction.

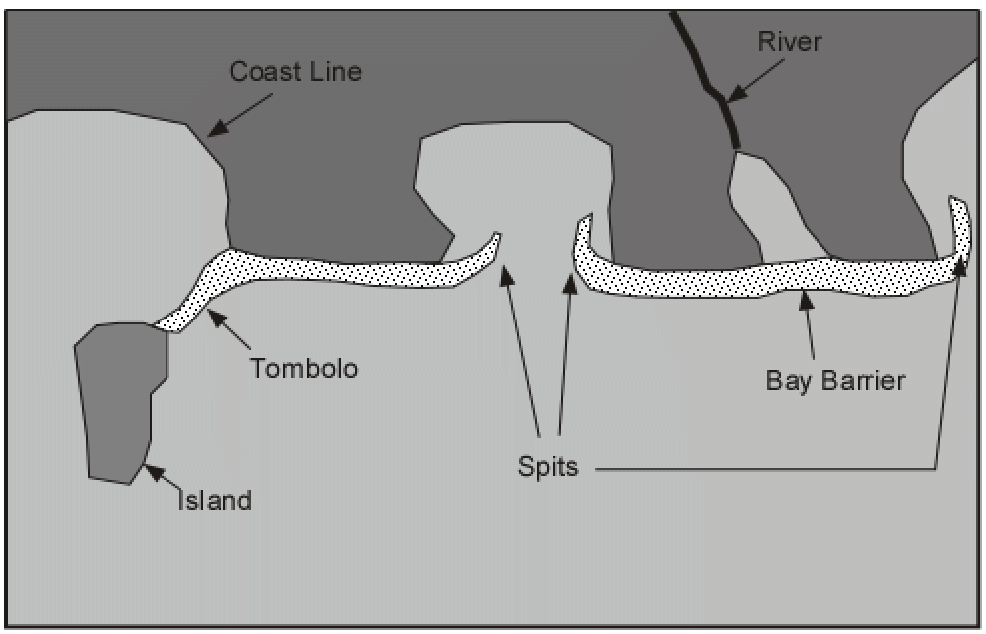
Depositional Features along coasts.

- ***Deltas*** -- Deltas form where sediment supply is greater than ability of waves to remove sediment. An example is the Mississippi River Delta, which is composed of several lobes that were deposited within the last several thousand years. Erosion of the older delta lobes has taken place due to subsidence, sea level rise, and lack of new sediment being supplied to the delta because of the human-made levee system.

- ***Spits*** - elongated deposits of sand or gravel that projects from the land into open water. Spits usually form at the mouth of a bay due to long shore current and beach drift. Generally they curve inward towards the bay due to refraction of the waves around the mouth of the bay.

- ***Bay Mouth Bars*** - if a spit extends across a bay, it is called a bay mouth bar. Exchange of water between the bay and the ocean is accomplished through the groundwater system.

- ***Tombolos*** - a spit that connects the mainland to an offshore island is called a tombolo.




- ***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.

- ***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. 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, due to the weight of newly added material. 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 (see figures 18.27 in your text).

- ***Estuaries*** - River valleys flooded by marine water are estuaries. They are characterized by mixing of fresh and salt water. Modern estuaries are related to glaciation. During glacial periods, when sea level was lower, rivers carved canyons along the coasts. When the glacial ice melted and returned water to the oceans, the resulting rise in sea-level flooded these canyons.

- ***Tidal Flats*** - Form in intertidal zones lacking strong waves. They are common behind barrier islands or in estuaries. The sediment consists of thinly laminated sand and mud often showing ripple marks.

- ***Fjords*** - Flooded U-shaped valleys carved by glaciers. They form spectacular bedrock-bounded troughs. Notable examples are found in Norway. British Columbia, and New Zealand.

**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,broad low lying coastal plains dominate. Along active margins, uplifted rocky coasts dominate.

Sea level changes can be local or global. Rise of fall of local sea level occurs as a result of tectonic forces or isostatic forces. Global sea level changes, however, are referred to as eustatic sea level changes. Eustatic sea level change is controlled by:

1. The changes in the volume of water in the oceans, which can occur as a result of changing climate. During cold periods, called glacial periods, much water is tied up in glacial ice on the continents and sea level falls. During warm periods, called interglacial periods, the glacial ice melts and returns to the oceans, thus raising sea level. Warmer climates also mean warmer water in the oceans. Since the volume of water is higher at higher temperatures, this also contributes to a rise in sea level.

2. Changing the shape of the oceans can also result in eustatic sea level rise. This might occur if volcanic output on the sea floor or at oceanic ridges increases substantially, thus raising the floor of the oceans.

- ***Emergent coasts*** result from local tectonic or isostatic 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 an emergent coast and 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 the case, the rise of the land surface has been due to removal of glacial ice which had depressed the land during the last glaciation. Upon removal of the ice by melting at the end of the last glaciation, the land has been rising.

- ***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 Problems**

- Sea Level Rise - Sea level is presently rising and the rate of sea level rise may increase due to 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.

- 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.

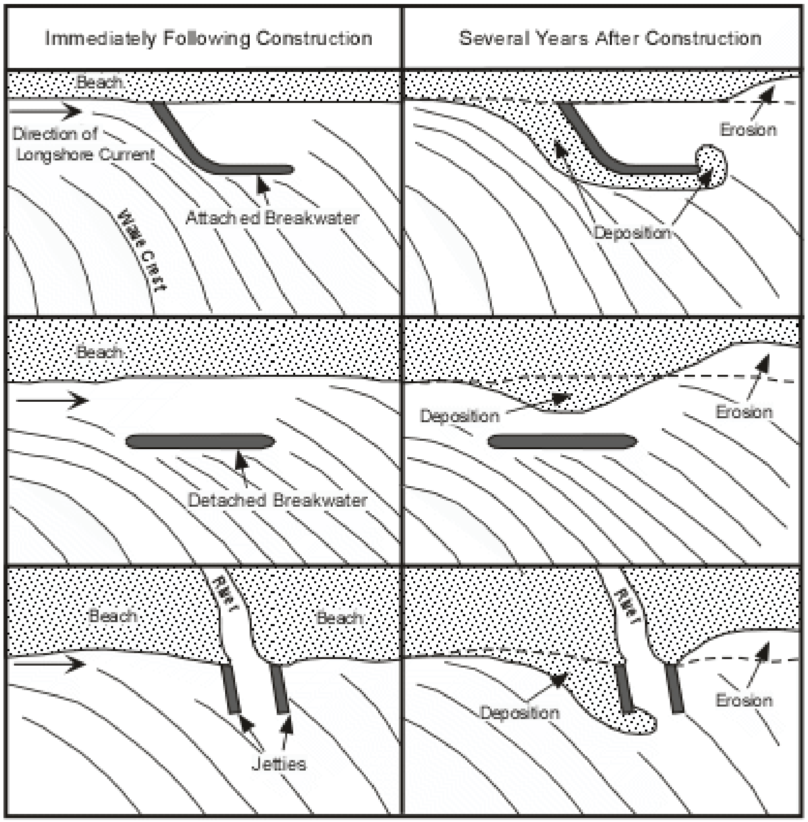
- Tsunami - a ***tsunami*** is a giant sea wave generated by an earthquake. Such waves travel at speeds up to 950 km/hr, have wavelengths up to 200 m, and upon approaching a shallow coastline, can have wave heights up to 30 m. Such waves have great potential to wipe out cities located along coastlines.

- 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 will result. Massive landslides can also generate tsunami.

- Pollution - includes garbage, especially plastic containers, sewage, agricultural runoff rich in nitrates, and oil spills, all of which affect the natural habitats that include the base of the food chain, and aesthetics of the coast, and the protection from storms that the coastal environment offers.

**Protection from Shoreline Erosion**

Sea cliffs, 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 human engineering cannot always protect against abnormal conditions. Humans construct such things as sea walls, breakwaters, and groins in an attempt to slow coastal erosion, but sometimes other problems are caused by these engineering feats. For example, construction of groin (a wall built perpendicular to the shoreline) can trap sand and prevent beach drift and longshore drift from supplying sand to areas down current along the coastline. These down current areas may then erode, causing other problems.




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

1. Define the following: (a) continental shelf, (b) continental slope, (c) abyssal plain, (d) passive continental margin, (e) active continental margin, (f) salinity, (g) wave base, (h) wave refraction, (i) spit, (j) tombolo, (k) fjord, (l) atoll, (m) estuary.
2. What are the main factors responsible for oceanic circulation?
3. Explain how longshore current and beach drift operates along a coast.
4. What are the main characteristics of beaches in terms of sediment type, sediment composition, and sedimentary structures? How does wave energy affect these?
5. Describe how the following features of rocky coasts form (a) wave cut benches, (b) wave-cut cliffs, (c) marine terraces, (d) sea caves, (e) sea arches, (f) sea stacks.
6. Why are waves effective as erosional agents?
7. What can cause eustatic sea level changes?
8. What are emergent coasts and submergent coasts, what causes each to form, and what are the characteristics of each?
9. Discuss the problems that affect coastal environments.

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