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Tulane University	Physical Geology
The Oceans and their Margins	

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The Oceans

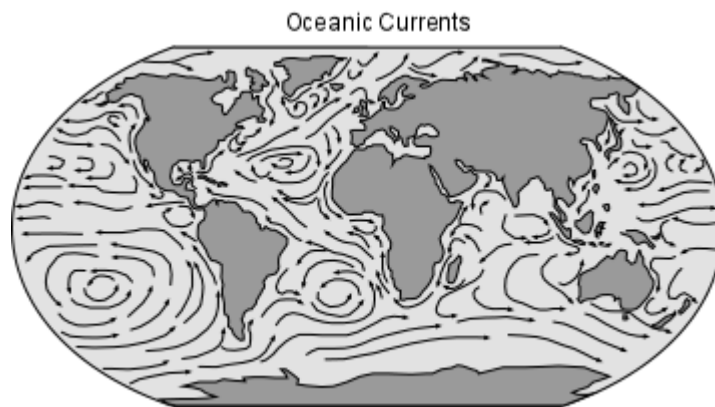
- Cover about 71% of the surface of the Earth.
- The greatest ocean depth of 11,035 m occurs in the Mariana Trench
- Have an average depth of 3,800 m.
- Have a present volume of about 1.35 billion cubic kilometers, but the volume fluctuates with the growth and melting of glacial ice.
- **Salinity**, 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 14.3a 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°C near the poles to 29°C near the equator. But restricted areas can have temperatures up to 37°C .

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

Ocean Circulation

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:

- 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.

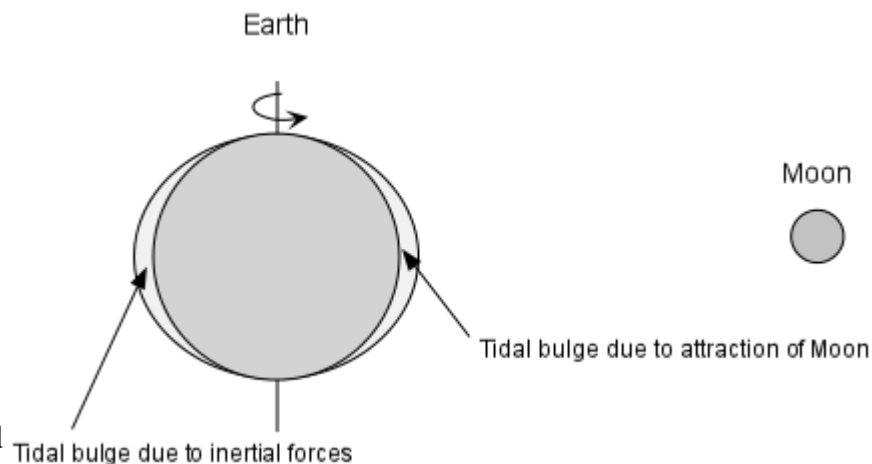


After Muick et al., 1997

In addition to surface circulation, seawater also circulates vertically as a result of changes in density controlled by changing salinity and temperature (see figures 14.5, 14.6a, and 14.6b in your text). Such circulation, because it controlled by both temperature differences and differences in salinity of the water, is called **thermohaline circulation**.

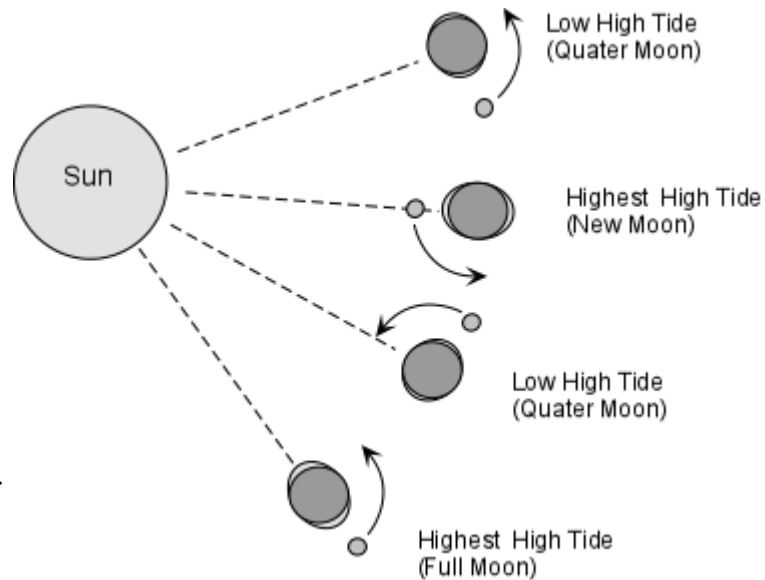
Ocean Tides

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 not explained well in the book, but the explanation is beyond the scope of this course).



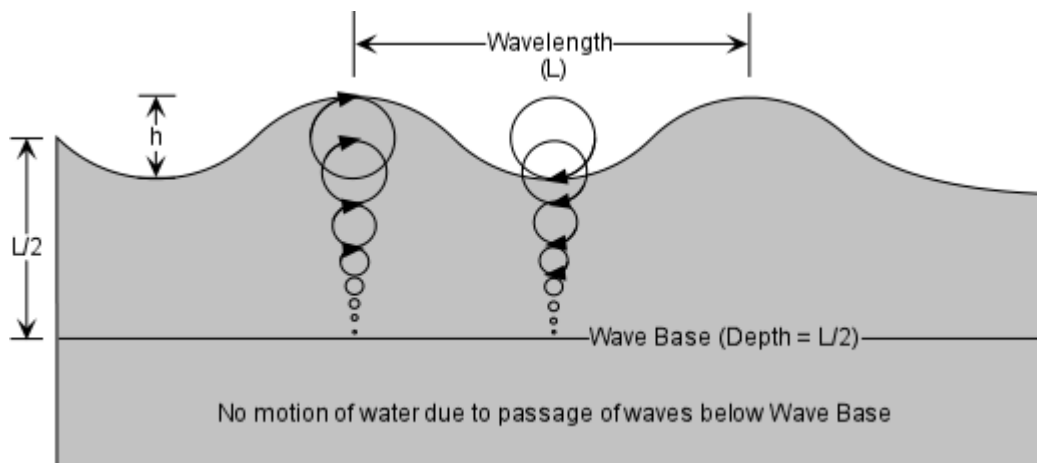
These bulges remain stationary while Earth rotates. The tidal bulges result in a rhythmic rise and fall of ocean surface, which is not noticeable to someone on a boat at sea, but is magnified along the coasts. Usually there are two high tides and two low tides each day, and thus a variation in sea level 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.

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). 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. In a wave, water travels in loops. But since 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

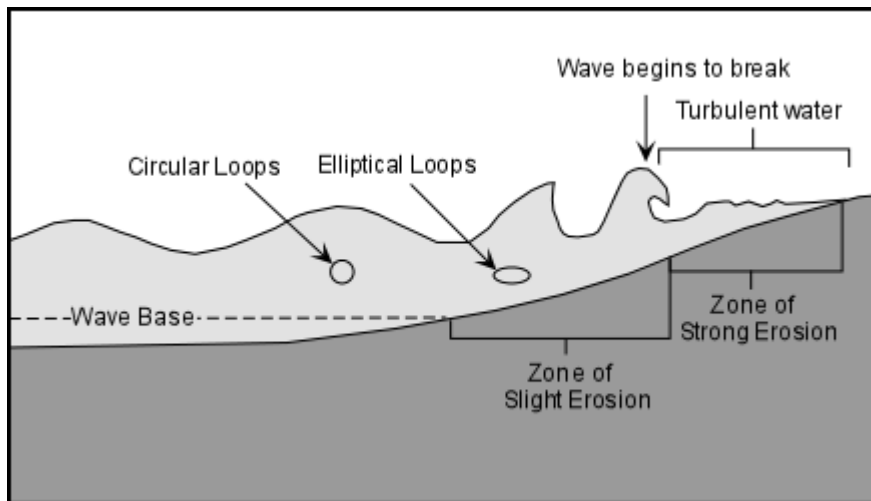
Wave Period (P) = time required to complete on cycle.

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.

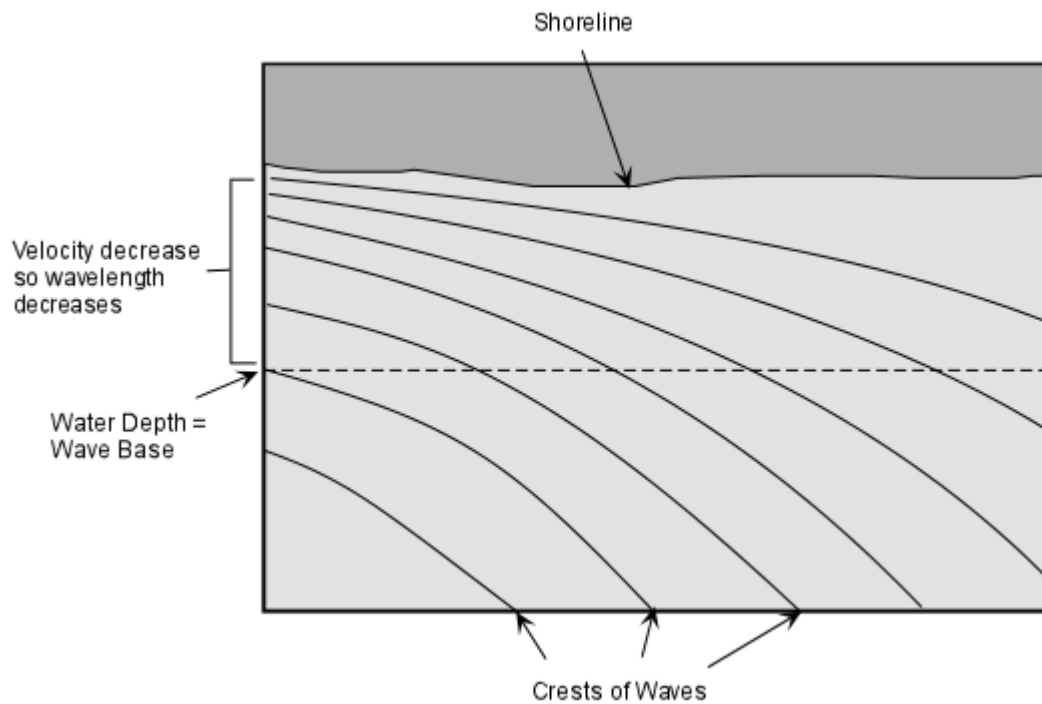


Rip currents form where water is channeled back into the ocean.

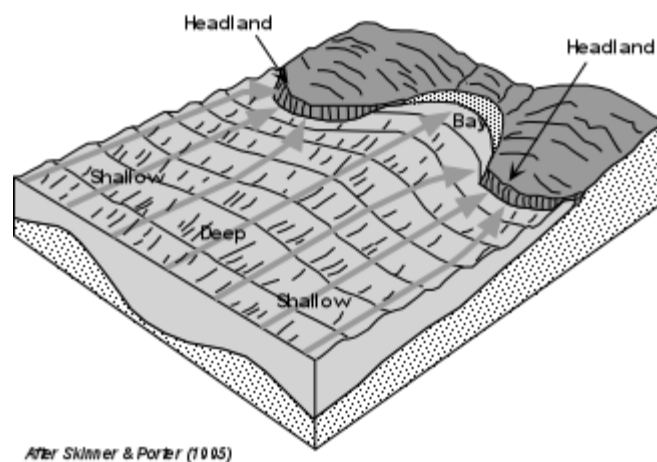
- **Wave Erosion-** Rigorous erosion of sea floor takes place in surf zone, i.e. between shoreline and breakers. Waves break at depths between 1 and 1.5 times wave height. Thus for 6m tall waves, rigorous erosion of sea floor can take place in up to 9 m of water.

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

- 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.



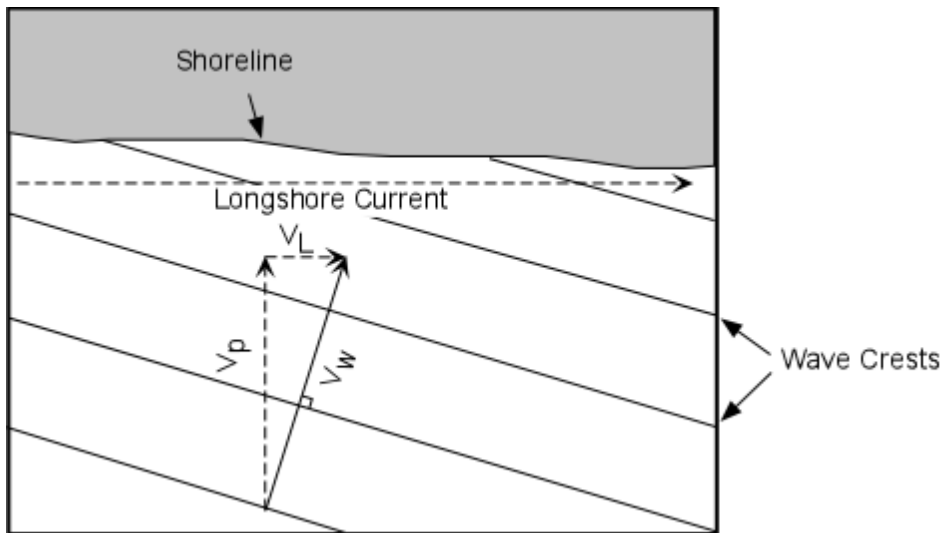
Wave energy can thus be concentrated on headlands, to form cliffs. Headlands erode faster than bays because the wave energy gets concentrated at headlands



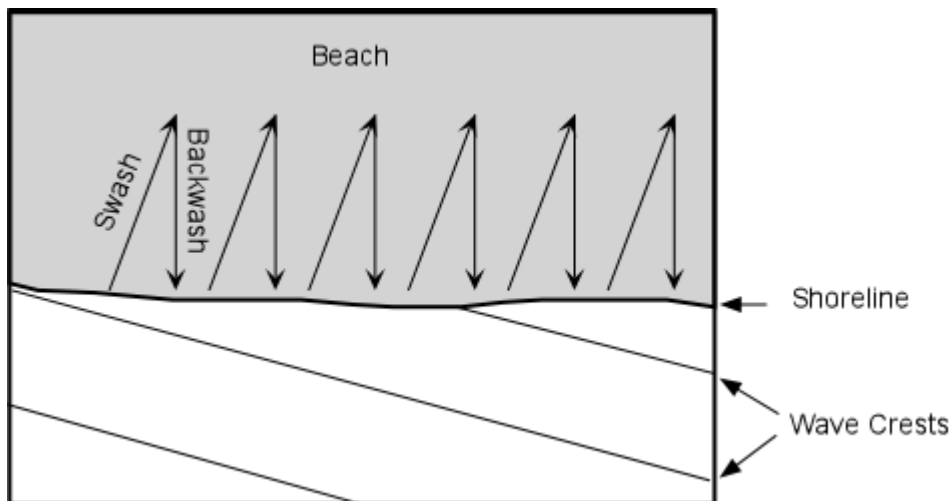
After Skinner & Porter (1905)

Coastal Erosion and Sediment Transport

- *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 (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.



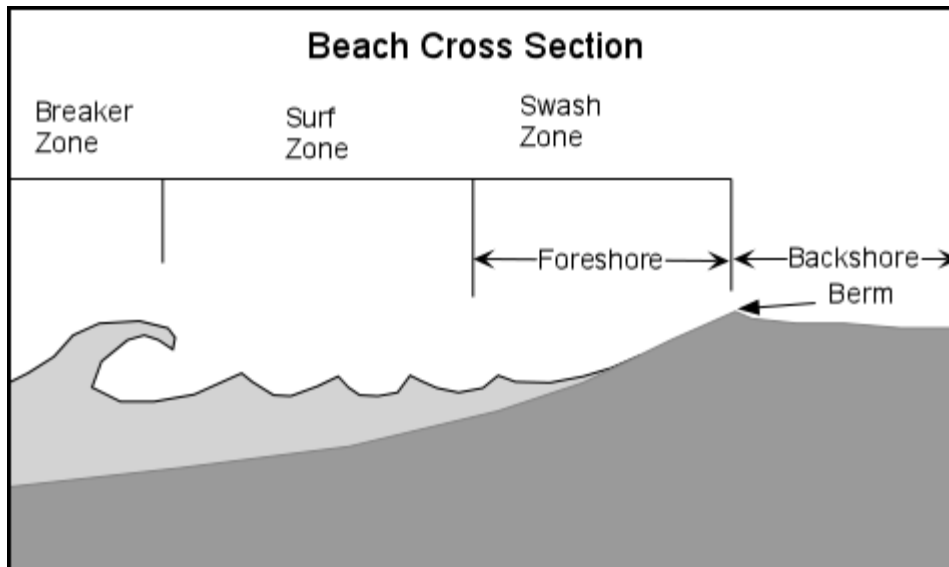
- **Offshore Transport and Sorting**

Particles picked up by wave motion move downslope, 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.

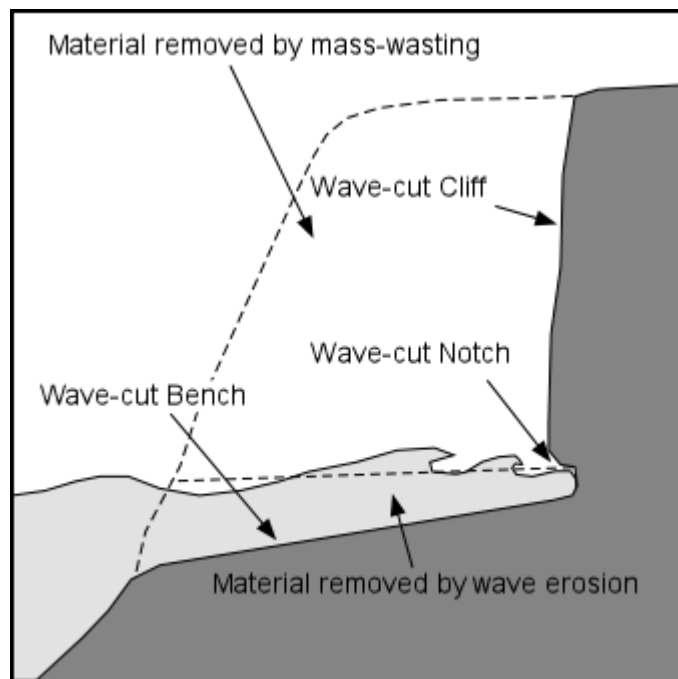
Shaping of Coasts

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. The effects on the land surface can be seen by examining the shore profile.

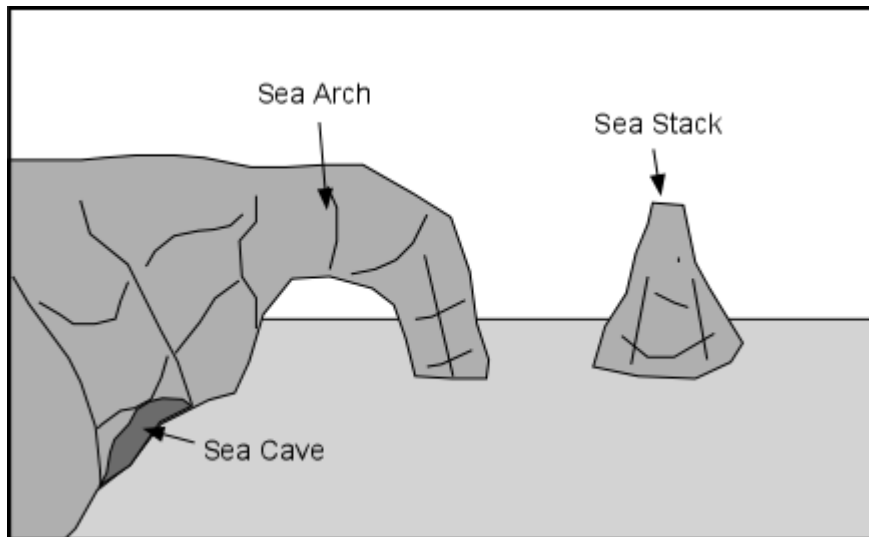
- Beaches occur where sand is deposited along the shoreline. A beach can be divided into a foreshore zone, which is equivalent to the swash zone, and backshore zone, which is commonly separated from the foreshore by a distinct ridge, called a *berm*. Behind the backshore may be a zone of cliffs, marshes,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



- 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 produce 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*.

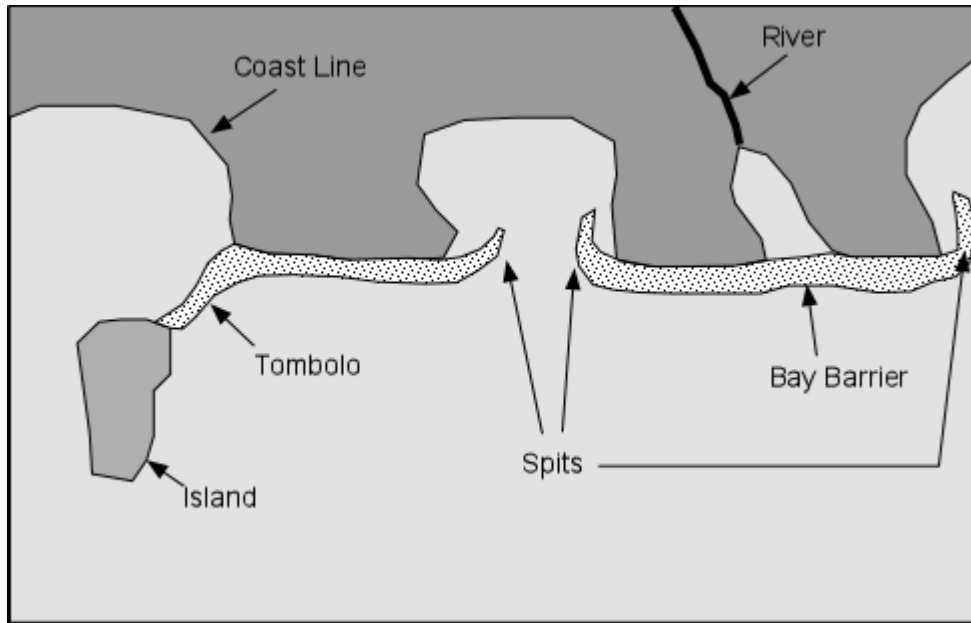


Coastal Deposits and Landforms

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 anyone 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.

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 Barriers** - if a spit extends across a bay, it is called a bay barrier. 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 14.25 and 14.26 in your text).

Coastal Evolution

The shape of coast is controlled mainly by tectonic forces and meteorological conditions.

Examples:

- The west coast of the U.S. is a rugged coast with many sea cliffs and raised wave cut benches (marine terraces). This is what is called an **emergent coastline** 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 was uplifted.

- The rest of the east coast, on the other hand, is a submerged coast, and shows **submerged valleys**, barrier islands, and gentle shorelines, all due to rise of sea level since last glaciation age (during glacial ages, seawater is tied up in ice, and sea level is lower; when the ice melts sea level rises).

Coastal Hazards

- 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.
- Tsunamis - 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 tsunamis.

Protection from Shoreline Erosion

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 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.

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