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Oceans and Shorelines

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Until 1872 when H.M.S, Challenger, a British warship converted for research, made its historic voyage, relatively little was known about the oceans. The voyage, funded by the British government, was mandated to chart the depth of the ocean, measure the various ocean currents, amass data on the composition of the ocean's water and bottom sediments, and collect information on ocean life. At the time of the voyage, except for a few soundings, almost nothing was known about the ocean bottom. Most scientists of the day had considered the vast expanses of the deep ocean basins to be nothing more than flat, featureless surfaces that, except for a few isolated volcanic islands, extending from one continent to another. The discovery of a submarine mountain range by H.M.S. Challenger was the first indication that the topography of the ocean bottom was not so simple. It is interesting to note that what H.M.S. Challenger had discovered was a portion of the Atlantic mid-oceanic ridge. It would be nearly a century before the oceanic ridges were rediscovered using sonar, an invention of the U.S. Navy, that allowed scientists their first real view of the topography of the ocean basins. Although the data amassed by H.M.S. Challenger significantly expanded our understanding of the ocean, knowledge of the ocean was to remain very limited until the mid 1900s.

Origin of Ocean Basins: Over the years, many theories have been proposed to explain the origin of the ocean basins. According to an older cosmic hypothesis, the ocean basins originated when vast amounts of rock were ripped from Earth's surface by the near-miss of some cosmic passerby such as an asteroid or meteoroid. The hypothesis went on to proposes that the rock torn from Earth's surface was thrown into space where it would become the Moon. In lieu of a more reasonable explanation for the vast ocean basins, especially the huge Pacific Ocean basin, this scenario actually seemed at the time to be within the realm of possibility. It would not be until the advent of the theory of plate tectonics in the mid-1960s that we came to understand the mechanism by which the ocean basins formed. It is interesting to note, however, that the cosmic hypothesis has recently been resurrected, but not for the origin of the ocean basins but rather for the formation of the Moon.

Previously, we saw how the rifting and subsequent movement of the continents were responsible for the formation of the ocean basins. Alfred Wegener was the first scientist to offer proof that the Atlantic Ocean had been created by the rifting of a super-continent he called Pangea and grew to its present size as the Americas drifted away from Europe and Africa. As was the case with all of his predecessors who had considered the possibility that the Atlantic Ocean had formed by the breakup of a larger continent, he unfortunately could provide neither a source of energy to accomplish such a feat nor suggest a scientifically sound mechanism by which such a source of energy could be applied to create the tensional forces required.. Wegener could not have conceived the currently accepted source of energy and mechanism by which the continents are formed and moved because the data did not exist during his lifetime. Wegener was to die on an expedition to Greenland with his great vision yet to be proved. Because plate tectonics is so important to an understanding of the oceans, it might be well to review what we know about the creation of the ocean basins.

We now know that the outermost component of Earth consists of a brittle layer called the lithosphere which includes the combined oceanic and continental crust and the outermost portion of the mantle. The lithosphere is broken into plates that are carried as passive passengers on the underlying asthenosphere which, in turn, is driven by convection cells produced by the heat generated by the breakdown of radioactive elements within the mantle and residual heat generated during the formation of the planet.

Oceans are created by the breakup of continents, although there is no universally agreement as to the mechanism that initiates rifting. Some geologists have suggested that when continents have remained stationary for long periods of time, heat accumulates beneath the continental lithosphere and initiates the development of mantle plumes and hot spots. As the lithosphere begins to dome above the mantle plume, a three-pronged fracture called a triple junction develops in the continental crust, not unlike the fractures that develop in the surface of a muffin or cupcake as it rises during baking. According to the theory, two of the fractures propagate laterally and join similar fractures generated at adjacent hot spots to crease a rift zone which opens and causes the continent to break apart. About 30 million years ago, a rift zone formed in North America along the easternmost portion of the Basin and Range Province. Called the Rio Grand Rift Zone after the Rio Grand River that follows a portion of the zone, the Rio Grand Rift extends more than 1000 km (620 mi) from Chihuahua, Mexico to Leadville, Colorado. While the most recent episode of lava eruption along the zone occurred about 5 million years ago, rifting continues to this day but at a reduced rate.

As the rifting continues, the rift zone develops into a rift valley which floods as one end of the valley eventually reaches the margin of the continent and seawater begins to encroach into the valley to form a linear ocean. When the landlocked end of the linear ocean is finally breached, the linear ocean becomes an opening ocean basin.

The third fracture, called a failed arm, aborts and usually does not progress beyond the development of a rift zone or rift valley. An example of a triple junction where the two propagating fractures opened to form the Gulf of Aden and the Red Sea, resulting in the separation of Africa and the Arabian Peninsula, while the failed arm became the East African Rift Valley. Two pieces of evidence, however, indicate that the East African Rift is still active. First, the valley is the site of active volcanism with one of Earth's most well-known volcanoes, Mt. Kilimanjaro, being located within the valley. Secondly, seawater has begun to make its way into the northern end of the valley through fractures that connect the valley and the Red sea, creating inland saltwater lakes that grow larger daily.

Another theory to explain the breakup of continents proposes that the continents rift along zones of weakness induced in the continental lithosphere by past tectonism and/or as the plate moves over a mantle plume. The movement over the hot spot not only results in the volcanic activity that characterizes rifting and the chains of volcanoes that form at the surface, but also weakens the plate, making the plate conducive to rifting by subsequent mantle convection. At the present time, it is not possible to determine which, if either, of these theories is correct. We can only surmise that whatever scenario is responsible for the initial rifting, the breakup of the continents is the result of tensional forces that develop within the continental lithosphere.

Ocean Bottom Landforms: Does the ocean bottom have landforms? Historically, the term landform has referred to surface features of the land. With our expanded knowledge of the ocean bottom, however, the realm of the physical geographer or geomorphologist, the scientist that studies landforms, has been extended beyond the limits of the land and into the ocean basins. This is consistent in that the ocean bottom is simply that part of Earth's surface lying at the lowest elevations due to the higher density of the basaltic oceanic crust.

The oceanic ridges are not only the most dominant landform on the ocean floor, but on Earth in general. It is said that if the water was removed from the ocean basins and one approached Earth from space, the oceanic ridges would be the most conspicuous surface feature. The oceanic ridge represents the zone along which the original continent rifted and is the site where new oceanic lithosphere is being created as the continents move away from each other. The elevation of the oceanic ridges above the surrounding ocean floor is due to the buoyancy of the underlying, low-density, hot rocks and magma. Away from the oceanic ridge, the ocean bottom slopes off gently as the newly-formed lithospheric rocks move away from the ridge axis, cool, contract, and increase in density. As a result, the ocean basin deepens away from the ridge with the depth to the ocean bottom being approximately proportional to the age of the lithospheric rocks.

In contrast to the steep-sloped mountain range on land, oceanic ridges are broad structures with gentle outer slopes. Typically, summits may rise to elevation of 3 km (2 mi) above the level of the adjacent ocean floor with slopes that extend for 500 to 800 km (300 to 500 mi) on either side of the summit. Except for the Pacific oceanic ridge, a rift valley occupies the summit of oceanic ridges. The Pacific oceanic ridge lacks a summit rift valley due to the high rate of spreading (~16 cm/yr) and the large volume of basaltic lavas erupted along the summit. In addition to the longitudinal fractures associated with the summit, the oceanic ridges are cut perpendicular to their trends by many fractures called transform faults that allow the plates to move over Earth's spherical surface.

Although oceanic ridges are the longest mountain ranges on Earth, they are for the most part submarine and therefore, beyond view. A well known exception is the island of Iceland which rises as a plateau along a portion of the North Atlantic oceanic ridge. The Icelandic Plateau formed over the past 16 million years because of additional basaltic magma being generated by a mantle plume fortuitously located beneath the ridge. Not only does Iceland exhibit the kind of volcanism associated with oceanic ridges, but it also exposes the summit rift valley characteristic of most oceanic ridges.

The rocks being formed at the oceanic ridges are mostly pillow lavas. Because the ocean basins cover 70% of Earth's surface, it can therefore be said that basaltic pillow lavas are the most common type of rock exposed on Earth's surface. Below the surface layers of pillow lavas, the basaltic magmas solidifies within the fractures that are constantly being created along the plate margin to form a layer composed of more or less vertical sheeted dikes. The sheeted dikes are, in turn, underlain by a layer of gabbro formed by the slow cooling of the magma within the underlying magma chamber. The entire complex of rocks is known as an ophiolite suite (Greek *ophis* = snake).

Basalt peaks and irregularities in the pillow lavas protrude above a thin layer of fine sediment on opposite sides of the oceanic ridge make up the abyssal hills. The sediment is largely composed of the remains of microscopic shelled animals, and photosynthetic organisms (plankton) that live in the sunlit waters from the surface to a depth of about 80 m (260 ft)), land-derived, windblown dust, and the contributions of micrometeorites.

The deepest parts of the ocean bottom are the deep-sea trenches. Deep-sea trenches are the opposite counterpart of the oceanic ridges. While oceanic ridges form under tensional forces and are the sites where *new* oceanic lithosphere is being created, deep-sea trenches and the underlying zones of subduction form under compressive forces and are the sites where *old* oceanic lithosphere is being consumed.

The portion of the ocean bottom located between the margin of the continent and the abyssal hills is called the abyssal plain. Within the abyssal plain, the ocean bottom is flat, featureless, and is the most horizontal surface on Earth. Under the abyssal plain, the rocks of the ocean bottom are covered with sediment, burying any irregularities that may have existed in the surface of the basaltic bedrock. Much of the sediment covering the abyssal plain is fine-grained sediment derived from the land and transported beyond the edge of the continental margins by various ocean currents. The Pacific Ocean basin is generally devoid of abyssal plains because it is nearly surrounded by deep-sea trenches that serve as traps for any land-derived sediment. Except for limited areas off the northwestern coast of North America where deep-sea trenches do not exist, abyssal hills dominate the surface of the Pacific Ocean basin.

Scattered across the abyssal ocean floor are thousands of shield volcanoes that form over mantle plumes and hot spots located beneath the moving oceanic crust. Most of these volcanoes exist as seamounts while others rise above sea level to become volcanic islands. In time, these islands re-submerge as they move off the bulge associated with the hot spot and the ocean bottom sinks, largely through cooling of the lithosphere combined with the sagging of the lithosphere under the weight of the volcanic cones. In many cases, the volcanic islands are truncated at sea level by the combination of weathering, mass wasting, and wave erosion and sink below the surface of the ocean to become a flat-topped seamount called a guyot.

Continental Margins: The structure of a continental margin depends primarily upon whether the margin adjoins an opening ocean or a closing ocean. Of the four oceans, the Atlantic, Indian, and Arctic oceans are opening oceans while the Pacific Ocean is a closing ocean. Because a continent adjoining an opening ocean is being passively carried away from the oceanic ridge by the moving plate, continental margins adjoining opening oceans are called trailing edges or passive margins. Conversely, a continental margin adjoining a closing ocean is referred to as a leading edge or an active margin.

The eastern margins of North and South America are examples of continental training edges. A major feature associated with passive continental margins is a thick wedge of land-derived sediment that accumulates along the margin of the continent called a clastic wedge. Clastic wedges begin to form during the linear ocean phase of rifting and continue to build out from the continental margin as the ocean opens. The clastic wedges associated with the Atlantic Ocean have been constructed over the past 200 million years since the breakup of Pangea.

The upper surface of the clastic wedge is called the continental shelf. Along most of the continental margin, the continental shelf is a seaward continuation of the coastal plain. The width of continental shelves varies widely. Off the coast of Newfoundland, Canada, for example, the continental shelf is about 320 km (200 mi.) wide and progressively narrows southward along the Atlantic coast to the Florida Keys where the width of the continental shelf is about 16 km (10mi.). The average depth of water at the outer edge of the continental shelf is about 180 m (600 ft). Typically, continental shelves slope seaward an angle of only 1° or 2°, which means that if the water was withdrawn, as it was during the last Ice Age, the surface would look horizontal to the human eye. Geologically, the clastic wedges are important in that they represent the depositional site from which most sedimentary rocks form, including the thick sequences that are uplifted and deformed into mountains during ocean-continent or continent-continent convergence. Biologically, the shallow-water environment of the continental shelves has been a major site of marine evolution.

From the outer edge of the continental shelf, the surface of the clastic wedge slopes toward deeper water at an angle of about 4° to 5°. While portions of the continental slope is devoid of loose sediment, most of it is covered with fine silt- and clay-sized sediments that have been transported beyond the edge of the continental shelf. The coarse materials that have been found on portions of the slope are a product of the glacial episodes when rock debris was ice-rafted beyond the edge of the shelf.

Because of the slope angle combined with the fact that the sediments are water-saturated, the sediments that accumulate on the continental slope are susceptible to sliding. From time to time, the energy form a local earthquake decreases the cohesion and friction within the sediment layer and initiates a debris flow called a *turbidity flow.* Once the downslope movement begins, the materials are carried as a turbidity current far out onto the abyssal floor at velocities that can measure in hundreds of miles per hour where it settles out to form the abyssal plain. The sediments are deposited as graded beds (beds that grade upward from coarse particle sizes at the bottom to fine particle sizes at the top) that, upon being lithified, are converted into a sedimentary rock called a turbidite.

The base of the continental slope grades into the more gently sloping continental rise which may continue basinward for hundreds of kilometers. Eventually, the continental rise merges with the abyssal plain.

Submarine canyons are V-shaped canyons that extend from the shore line to the continental slope. Considerable disagreement exists over their origin. Most submarine canyons, such as the Hudson Submarine Canyon, located east of New York harbor, is believed to have been formed during the Pleistocene Ice Age when most of the continental shelf was exposed and the mouth of the Hudson River was near the edge of the continental shelf. Today, the Hudson Submarine Canyon extends from the outlet of New York harbor about 750 km (450 mi) across the continental shelf. At its seaward end, the Hudson Submarine Canyon has cut down into the clastic wedge to a depth of about 2200 m (7,217 ft) below sea level. Cliffs within the V-shaped canyon rise as much as 1210 m (3900 ft) above the canyon floor. Once the Ice Age waned and sea level began to rise, the downstream portions of the Hudson River became the upstream portion of the submarine canyon. Today, sediments being transported by the Hudson River continue to be carried along the Hudson Canyon as a turbidity current and are deposited at the base of the continental slope, explaining why there is no delta at the mouth of the Hudson River. There are, however, submarine canyons that are not associated with river systems that geologists believe were cut by turbidity currents generated at the upper edge of the continental slope. Subsequent turbidity currents then carved the canyons landward by a process comparable to headward stream erosion.

Some deep sea fans are sediments deposited at the mouths of submarine canyons. There are, however, deep sea fans that are not associated with submarine canyons. Deep sea fans can also be built from the sediments carried beyond the deltas of major rivers. For example, the Mississippi River builds a deep sea fan into the Gulf of Mexico; the Saint Lawrence River builds one into the North Atlantic, and the Amazon River builds one into the South Atlantic.

The world's two largest deep sea fans, however, are in the Indian Ocean where the Bengal and Indus deep sea fans build out on opposite sides of the Indian subcontinent. Constructed of sediment derived from the rising Himalaya Mountains, these two fans represent 90% of the total volume of all modern deep sea fans.

Because of the presence of the deep sea trenches that encircle most of the Pacific Ocean and serve as a trap for land-derived sediments, deep sea fans are rare in the Pacific basin. The only deep sea fans within the Pacific basin are located in the Gulf of Alaska.

In contrast to the tensional forces that result in the formation of passive continental margins, compressional forces and zones of subduction dominate the tectonics of active continental margins. The western margins of North and South America are excellent examples of active continental margins. Active continental margins are sites of mountain building, deep-seated metamorphism, intrusive igneous activity, volcanism, uplift, faulting and folding. The volcanism associated with active continental margins depends on the location of the zone of subduction relative to the continental margin. If the zone of subduction is located within 80 km or so (50 mi or so) of the continental margin, volcanism in the form of a chain of continental arc volcanoes that are located along the continental margin. Examples would be the Andes Mountains of South America and the Cascade Mountains of the Pacific Northwest. On the other hand, if the zone of subduction is located hundreds of kilometers offshore, the volcanism will appear as a chain of volcanic islands that will build from the ocean floor and rise above sealevel as island arc volcanoes to form a chain of volcanic islands. Examples would be the Aleutian Islands, the Japanese Islands, and the Philippine Islands.

The water of the oceans are in constant motion. Most of us have enjoyed watching the seemingly constant arrival of waves at the shoreline. Everyone is familiar with the tides; those comings and goings of the water along the coastline in response to the gravitational pull of the Moon and Sun. Longshore currents carry sediments parallel to the shoreline and are responsible for many of the depositional features seen along some coastlines. Most important are the various density currents that exist within the vast expanse of the ocean.

Waves as Agents of Shoreline Changes: Waves are the major agents of change along the shoreline. In some cases, the change is destructive as the waves carve and erode the rocks, constantly undercutting the coast, driving sea cliffs landward, and removing the sediment to the ocean deep. In other cases, the action of the waves is constructive as the waves build and modify beaches and construct offshore sand islands.

Waves are created as wind moves across the surface of the water; transferring energy from the moving air mass to the water. Each wave is characterized by a wavelength which is the distance between successive crests or troughs and an amplitude which is the distance from the top of a crest to the bottom of the adjacent trough. Once formed, the waves move in the direction of windflow with a frequency measured by the number of crests or troughs that pass a given point in a given amount of time. A passing wave will move water to a depth of approximately one-half its wavelength, referred to as the wavebase, with the individual water molecules moving in circles that decrease in diameter with depth. Two important aspects of wave motion are that waves do not move water at depths greater than the wavebase at one-half the wavelength and that in water deeper than one-half the wavelength of the waves, the net movement of the water is zero, that is, there is no lateral motion of the water.

When first formed by wind stress, the waves have minimum wavelengths, maximum amplitudes, and affect the movement of water to the least depth. Because of their high amplitudes, newly created waves can be quite spectacular; think of the amplitudes of waves generated at sea during a storm. As the waves move away from the point of origin, the amplitude decreases, the wavelength increases, and the depth to which the wave moves water increases. As will be seen, the inverse relationship between wavelength and amplitude is very important. Typically, as waves cross the open ocean, the amplitudes are quite low, the wavelengths are very long, and the wavebase is at a maximum depth. The energy imparted to the water at the point of origin, E_O, can be looked upon as being contained within the mass of water contained between consecutive wave crests, the wavebase, and along the length of the wave. Physical geologists are primarily interested in the portion of the original wave energy remaining when the waves reach the shoreline that is available to erode and modify the coastline. As the waves move into shallow water and the wavebase touches bottom, the wavelength shortens, the amplitude increases, the cross section of the waves becomes increasingly asymmetric in the direction of the shoreline, and the water, for the first time, begins to move laterally toward the land. As the waves move shoreward, some of the original wave energy, $\mathbf{E_o}$, is consumed increasing the amplitude of the waves, moving the water laterally, and eroding the offshore ocean bottom. As the waves approach the shore, the waves become increasingly asymmetric in cross section and form breakers that eventually collapse into the surf. Any energy that remains in the surf drives the water up onto the beach where all of the original energy is eventually consumed and gravity takes over, returning the water to the sea as backwash. It is also the energy remaining in the surf that drives coastal processes such as coastal erosion and deposition

Whether a shoreline is subjected to dominantly erosional processes or to a combination of erosion and deposition depends primarily on the amount of energy remaining as the waves break into the surf. In general, the longer and more gentle the offshore slope, the greater the amount of energy that will be expended in wave modification, lateral movement of the water and in bottom erosion as the waves make their way shoreward. As a result, less energy will be available in the surf zone for erosion and sediment transport. As the slope of the offshore bottom increases, the distance between the point at which the waves "touch" bottom and the shoreline decreases. As a result, because less energy will be consumed between the point at which the wavebase touches bottom and the shoreline, more energy is available in the surf zone. The extreme example is the pounding surf one observes where the ocean bottom drops precipitously at the shoreline.

In contrast to wind-driven waves where the crests and troughs move in the direction of wind flow, seiches are standing waves where, rather than moving horizontally, the water oscillates vertically around a fixed point called a node with crests alternating with troughs at antinodes. Generally, seiche waves are generated within enclosed basins such as lakes and harbors. Typically, a standing wave originates when a strong wind blows across the surface of the water in a single direction, piling up the water as a storm surge on the downwind end of the basin. If the wind would abruptly diminish, the water will move back and forth across the basin as the water attempts to return to the pre-storm water level. While such oscillations are short-lived, if the oscillations approximate the oscillation period of the basin, a condition referred to as resonance is established which, in turn, can significantly increase the amplitudes of the standing waves at the antinodes.

Tsunamis: Tsunamis are long wavelength, low amplitude waves that are created by a number of events, perhaps the most common being the abrupt movement of the ocean floor in the vicinity of a zone of subduction. Other sources of energy that create tsunamis are the slumping of portions of volcanic islands and coastlines and earthquakes that occur along the margin of the ocean basin. The 1883 eruption of the volcanic island of Krakatau created a tsunami that overwhelmed all of the low-lying portions of the surrounding islands and carried an estimated 36.000 people to their deaths.

While the amplitudes of the waves associated with a typical tsunamis as it travels across the ocean surface may be no more than 1 m (3 ft), wavelengths may exceed 100 km (60 mi). Because of the enormous amount of energy being transported, it is not uncommon for the velocity of a tsunami to be as high as 750 km/hr (470mph). As these waves come onshore and the wavelengths shorten, waves with amplitudes as much as 30 m (100 ft) build and drive inland, laying waste to everything in its path. Because of its location, Japan has probably experienced more devastating tsunamis than any other place on Earth. For example, on June 15th , 1889, a wall of water 25-30 m (75 to 100 ft.) high crashed onto the east shore of Honshu, sweeping away more than 10,000 homes and killing an estimated 26,000 people. In 1946, the Seismic Sea Wave Warning System (SSWWS) was established to warn the inhabitants of those regions located around the periphery of the Pacific Ocean basin of a potentially destructive tsunami.

The Tides: Most individuals are aware that the tides are caused by the gravitational attraction between the ocean's water and the Moon but few are aware that the Sun also plays a role. According to Newton's laws, the gravitational attraction between any two bodies is proportional to the masses of the two bodies and inversely proportional to the square of the distance between them:

$$Fg = kM_1 \text{ x } M_2 / D^2$$

While the Moon is many time less massive than the Sun, its proximity to Earth, 383,000 km (~ 238,000 mi) as opposed to the 1.5B km (92M mi) to the Sun, results in its gravitational effect on the tides being approximately twice that of the Sun.

The question most often asked about the tides is, why are there two antipodal bulges of ocean water rather than just a single bulge facing the Moon? The answer lies in the effect of the gravitational attraction between the Moon, Earth, and the masses of water both facing toward and away from the Moon. Consider water mass **A** and water mass **B** to be the masses of ocean water closest and furtherest from the Moon respectively while **E** and **M** are the masses of material located at the centers of gravity of Earth and the Moon respectively. The important distances are the distance between Earth and the Moon, $\mathbf{d_{EM}}$, the distance between the center of the Moon and the water masses on the near and far sides of Earth**,** $\mathbf{d_{MA}}$ and $\mathbf{d_{MB}}$**,** respectively. According to Newton's laws of gravity, the force between two bodies is inversely proportional to the square of the distance between them; that is:

$$Fg \infty 1/D^2$$

Substituting the distances between the Moon and water mass A, water mass B, and the center of Earth, you can see that the three forces involved are $F_A > F_E > F_B$. Therefore, the Moon simultaneously pulls the water mass between it and Earth away from Earth while at the same time pulling Earth away from the water mass on the other side of Earth. Because Earth's hydrosphere is liquid and can flow with little resistance, the layer of water represented by the ocean deforms into an oblate spheroid with one tidal bulge facing toward the Moon (the direction of maximum attraction, F_A) while another tidal bulge develops on the opposite side of Earth (the direction of minimum attraction, F_B) facing <u>away</u> from the Moon. The Sun produces a similar but significantly lesser tidal effect.

Along most coastlines, both high and low tides occur twice each day as Earth rotates through the two tidal bulges. Because of the changing orientation of the Sun, Earth, and Moon during the monthly lunar cycle, the combined effects of the Sun and Moon change. When the Sun, Earth, and Moon are aligned, as they are during the new and full phases of the Moon, the effects of the solar and lunar tides are additive. At these two times during the lunar cycle, the tidal range is at a maximum, that is the high tides are at their highest while the low tides are at their lowest. Such tides are called spring tides; the term having nothing to do with the season of the year. During the 1st and 3rd phases of the Moon when the Sun and Moon are at right angles to Earth, the solar and lunar gravitational forces partially cancel each other resulting in a decrease in the tidal range as the highest tides decrease while the lowest tides increase. Such tides are referred to as neap tides.

The tidal range experienced by a particular coastline is dependent on many factors, one of them being the slope of the offshore ocean bottom. In areas such as the Hawaiian Islands or off the Florida Keys where the ocean bottom drops off steeply into deeper water, the tidal range is relatively small. On the other hand, where the ocean bottom slopes gently seaward, the tidal ranges may be quite large. The greatest tidal range in North America is in the Bay of Fundy, Nova Scotia, Canada, where the tidal range can be as high as 18 m (50 ft.). The extreme tidal range within the Bay of Fundy is the result of both a gently sloping bottom within the bay combined with the fact that the waters are funneled through a restricted channel that connects the bay with the open sea.

Currents: For the most part, waves approach the shoreline at an angle. As one end of the wave touches enters water shallower than its wavebase and touches down, the wave slows and bends, or refracts, becoming more parallel to the shoreline. As a result, the surf drives water both onto and along the beach, forming a longshore current within the surf zone. The velocity of the longshore current within the surf zone is dependent on the angle of wave approach with the velocity increasing with the angle of approach. The longshore currents are primarily responsible for the continuous movement of sand just offshore parallel to the beach referred to as longshore transport.

Longshore currents can also be created where the waves approach the shoreline at right angles by a process referred to as wave setup which refers to the mass transport of water that produces piles of water along the shoreline within the surf zone. As the water slides off these piles in opposite direction parallel to the shoreline, divergent longshore currents are created.

In general, the higher the incoming breakers, the greater the amount of water contained within these piles of water and the more powerful the subsequent divergent longshore currents. Where two divergent longshore currents converge, the water flow will be diverted seaward to create a very strong rip current that transports the excess water that has been brought into the surf zone back to sea. Rip currents are very dangerous to individuals who are unaware of their presence and strength. It is not uncommon for swimmers to be caught in a rip current and find themselves being carried out to sea. If they try, as the often do, to swim against the current, they discover the current is too strong and become increasingly exhausted. The solution to their problem is to swim parallel to the shore. The rip currents are very narrow and they will soon find themselves in the path of the incoming waves and safety..

Gyres: Within each ocean, surface and near-surface waters are set into motion as stresses develop between the wind and the ocean surface as energy is transferred from the wind to the water. The subsequent wind-driven ocean currents move within each hemisphere in large circular patterns called gyres. In the Atlantic and Pacific oceans, gyres exist in both hemispheres while, because most of the Indian Ocean is located in the Southern Hemisphere, it has only one gyre. The winds primarily responsible for the creation of the gyres are the trade winds which blow from east to west toward the equator between 5° and 25° north and south latitude. The trade winds create two warm water equatorial currents that move westward parallel to the equator separated by an equatorial countercurrent that flows eastward. As the two warm equatorial currents reach the continents on the western margin of the ocean basins, they are deflected by Earth's rotation to the right and left and form a northern and southern equatorial current respectively that serve as heat pumps to transport heat from the tropical equatorial regions of Earth to the higher, cooler latitudes. As the warm currents move poleward along the continental margins, they eventually come under the influence of relatively cool, dry westerly winds which blow from the west between 35° and 60° north and south latitude and are diverted eastward. It is important to point out that as the heat brought to the higher latitudes by the gyres is transferred to the westerly winds, they are not only warmed but as a result of becoming warmed, acquire moisture from the ocean. Now warm and moist, the westerly winds continue eastward to determine the climate of the continent to the east. Upon encountering the continent on the eastern side of the ocean basin, the now cooled currents are deflected toward the equator where they join the equatorial currents to complete the gyre and become reheated. You may have learned in an elementary geography course that the relatively mild, but rainy, climate of Europe is a result of the landmass being bathed in the heat brought northward by the North Atlantic gyre from more tropical climes.

While the Atlantic and Pacific countercurrents exist throughout the year, the north equatorial current and the equatorial countercurrent of the Indian Ocean exist only during the Northern Hemisphere winter months when the winds, called the winter monsoon, blow off the cold Asian continent toward the warmer waters of the Indian Ocean. During the summer months when the temperature of the Asian landmass becomes higher than that of the adjoining ocean waters, air masses rising over the Asian continent draw air masses in from the Indian Ocean. During this period, the northeastern winds are replaced by an onshore wind called the southwestern monsoon and the northern equatorial current and equatorial countercurrent are eliminated.

Because the equatorial countercurrent exists across the entire width of the Pacific Ocean, little or no exchange of surface water occurs between the Northern and Southern hemispheres. Within the Atlantic Ocean, however, some surface water moves from the Southern Hemisphere to the Northern Hemisphere as the south equatorial current is split by the landmass of Brazil. The northern portion of the split continues into the Caribbean and the Gulf of Mexico where it joins with the northern equatorial current to become the part of the North Atlantic gyre commonly referred to as the Gulf Stream.

A little known fact is that the first ocean gyre to be charted and published as a map was the North Atlantic gyre. An even lesser known fact that the map, published in 1774, was a cooperative effort of a former whaling captain, Timothy Folger and the American statesman, scientist, journalist, and inventor, Benjamin Franklin.

Vertical Currents: Ocean water is subdivided vertically into two masses, the upper water mass which extends from the surface to a depth of about 1,000 m (3,000 ft.), and the deep water mass which extends from the bottom of the upper water mass to the ocean bottom. Both of these zones experience vertical water movements. In the upper water mass, vertical movements are wind-induced. In areas where the water is carried away by one surface current and not replenished by another, replacement water moves up from below. Although such upwelling can occur anywhere within the ocean, it is most prevalent in four areas: 1) where equatorial currents deflect water away from the equator, 2) along western continental margins where strong winds blowing off the land carry water away from the coastline, 3) where winds blow steadily in one direction and generate convection cells parallel to the wind flow, and 4) in the north Atlantic and Pacific oceans where the combination of winds, heat exchange, and salinity differences cause global convective currents that will be discussed below.

Most of the vertical mixing of ocean water is due to thermohaline currents which affect the entire volume of ocean water. Thermohaline currents are density currents that originate in regions beyond 40° north and south latitude where masses of cold, dense, surface waters sink. Of the world's oceans, only the polar regions of the North and South Atlantic have surface waters with densities high enough to sink. Within the Pacific and Indian oceans, the relatively uniform conditions of temperature and salinity that characterize the surface and near-surface water masses apparently prevent the formations of density differentials large enough to cause surface water to sink.

In the South Atlantic, very cold water (less than 1°C or 33°F) sinks off the Antarctic continental shelf, flows downslope, and moves along the ocean bottom as South Atlantic bottom water (SABW) to about 20° north latitude. Another cold Antarctic surface current, the South Atlantic Intermediate Water (SAIW), sinks at about 60° south latitude. Because the temperature is slightly higher (2°C or 36°F) and the subsequent density is slightly lower than the shelf water, it only sinks to about 1 km (0.6 mi.) below the surface.

As was the case with the South Atlantic Bottom Waters, the South Atlantic intermediate waters flow northward to about 20° north latitude.

Simultaneously, in the North Atlantic between the coasts of Norway and Greenland, cold water (3°C or 37°F) sinks to the ocean bottom to become the North Atlantic Bottom Water (NABW). As the North Atlantic bottom water flows southward, it eventually encounters and over-rides the colder and higher density South Atlantic bottom water, continues to flow between the South Atlantic bottom and intermediate waters, and eventually comes to the surface between 70° and 80° south latitude. The high levels of nutrients that the North Atlantic bottom water acquired during its travel from one end of the Atlantic Ocean to the other are responsible for the high biological productivity of the waters off the coast of Antarctica where it comes to the surface.

Because deep ocean waters are not formed in either the South Pacific or Indian oceans, it is believed that the deep ocean waters found in these two ocean basins originated in the Atlantic Ocean and were driven into the adjacent ocean basins by the Antarctic Circumpolar Current.

The density of water increases with increasing salt content. Examples of salinity-induced density currents can be found wherever low-density, fresh water enters the ocean and flows out across the surface of the higher-density, saline ocean waters until they are intermixed and dispersed by the waves. In many coastal areas, it is not uncommon for saline or brackish water to flow upstream along the bottoms of streams during the rising tides. The lack of vegetation along the downstream banks of many coastal streams is due to the infusion of toxic salt water into the bank sediments.

Perhaps the best example of a major salinity current is the one responsible for the continuous overturning of the water in the Mediterranean Sea. Because of the dry, hot climate of the region, it is estimated that about 3500 km^3 (850 mi^3) of water evaporate from the Mediterranean Sea each year with less than 420 km^3 (100 mi^3) being replaced by rainfall and runoff. This difference is made up by a surface current of normal-salinity ocean waters from the Atlantic Ocean that flows into the Mediterranean through the Strait of Gibraltar.

As water evaporates from the surface of the Mediterranean, the salinity and density of the surface waters increase, sinks the bottom, and exits through the Strait of Gibraltar under the incoming current of normal salinity water. As a result of the circulation within the basin, it is estimated that the entire volume of water of the Mediterranean Sea is overturned every 100 years.

Density currents resulting from high concentrations of suspended loads are called turbidity currents. Turbidity currents can commonly be seen wherever a silt-and clay-laden stream flows into the relatively clear water of a larger body of water. As the sediment-laden water enters the larger body of water, it forms a turbidity flow that continues downward along bottom until currents within the larger body of water either dissipate the flow or until the sediment settles out. A larger-scale example of this same process was referred to earlier when we discussed the silt- and clay-sized sediments being dislodged from the continental slope. Once the sediments begin to move downslope, they form a turbidity flow that transports the sediment many kilometers out onto the abyssal ocean floor where the sediments eventually settle to the bottom to form the abyssal plain. These flows were first discovered when the first trans-Atlantic cable was broken following an earthquake. We have also discussed the role turbidity flows play in the formation of submarine canyons and in transporting land-derived sediments to the abyssal ocean floor where they are deposited as deep sea fans.

El Nino: Perhaps no ocean phenomenon has such far-reaching effects as El Nino. An El Nino is the result of the complex, but not fully understood, interaction between the Humbolt Current, the wind-induced, cold, upwelling currents along the west coast of South America, the South Pacific equatorial current, and the trade winds.

The Humbolt Current is the eastern portion of the South Pacific wind-driven gyre that brings cold water (10°C or 50°F) from the coastal areas of Antarctica northward along the west coast of South America. Winds blowing seaward along the coast of South America displace surface waters that are in turn replaced by upwelling, cold water from the deep ocean.

The combined effects of the Humbolt Current and the nutrient-rich, upwelling, coastal wind-induced currents maintain the high biological productivity off the coast of Peru. This condition is known as La Nina. For unknown reasons, once every five or so years, usually in December, the trade winds diminish in intensity or actually cease to blow. With no force being applied to contain the mass of warm water in the western Pacific, the mass of water begins to collapse under the force of gravity, driving the warm water eastward. In about two months, the warm water crosses the Pacific, overruns the Humbolt current, drives southward along the coast of South America about 800-950 km (500-600 mi), elevates sealevel about 30 cm (1ft), and raise the water temperature from 5°C to 10°C. Because the warm waters are nutrient-poor, the volume of nutrients provided by the upwelling coastal currents rapidly decrease; all signaling the beginning of El Nino which may last as long as 18 months. The immediate effects of an El Nino are seen throughout the food chain. In 1982-1983, anchovy harvests dropped from 12 M metric tons to less than 3M metric tons, devastating the economy of Peru. El Ninos also affect other members of the ecosystem. Because of the decrease in food supply following these currents bring nutrients from the deep ocean and produce a 10-20 km (6-12 mi) wide nutrient-rich zone along the coast. The nutrient-rich waters serve as the food supply for the large population of phytoplankton (microscopic floating plants) that is the basis for the regional food chain which, in turn, is responsible for the high organic productivity of the region. Because of the high productivity, the populations of upper members of the food chain are also quite large, in particular, anchovies. In peak years, the Peruvian fishing industry has harvested more than 12 million metric tons of anchovies from the coastal waters.

As the cold waters of the Humbolt Current approach the equator, they turn westward, become part of the South Pacific equatorial current, and are warmed by the tropical Sun. Under the influence of the trade winds, these warm surface waters are driven into a westward-thickening wedge that depresses the contact between the warm surface water and the cold deep water. As a result of the increased thickness of the wedge of warm water, the sea level along the western portion of the Pacific Ocean is nearly 30 cm (1 ft) higher than normal. As long as the trade winds persist, the force exerted by the winds on the mass of warm water keeps the warm waster in the western portion of the Pacific. Simultaneously, along the western margin of the South Pacific, the hatch of young sea birds experienced a sharp decline with large number of adult birds dying from starvation. Because parent seals were required to range so far for food, high mortality rates were noted for sea pups that were unable to survive the long interval between feedings.

El Ninos have also been blamed for worldwide climatic changes. During the 1982-1983 El Nino, climatic changes were noted in every continent except for Antarctica and Europe. For example, the removal of warm water from the western Pacific was linked to droughts that ranged from Australia and India and as far away as South Africa. On the other hand, the increased moisture made available in the eastern Pacific resulted in severe storms along the Pacific coast of the United States and South America with widespread flooding and slope failures within the coastal mountains. Even as far east as the Gulf coast of the United States, the 1982-1983 El Nino was blamed for torrential rainfalls. The only effect of El Nino that was not considered detrimental were the milder winters experienced throughout the eastern United States.

Types of Coastlines: No two coastlines are exactly alike. They exhibit differences in structure, rock types, or process. For our purposes, however, we will consider coastlines being of two types: 1) the emergent or high-energy coastline typified by most of the U.S. Pacific coast and portions of the northeast Atlantic coast and 2) the submergent or low-energy coastline found along most of the Atlantic and Gulf states.

Point lobos, California, is not only an exceptionally scenic portion of the California coastline but is also an example of an emergent, high-energy coastline. The scene at Point lobos is repeated along most of the Pacific coast where the continental margin is rapidly rising because of the tectonic activity associated with convergent plate margins. Because the offshore slope along coastlines such as at Point Lobos is relatively steep, waves touch bottom relatively near shore, wave amplitudes build rapidly, and little wave energy is dissipated before the waters reach the surf zone. Consequently, strong forces are generated as the waves pound against the rocks within the surf zone. Because water is incompressible, each wave impacts the rock like a sledge hammer, driving water under great pressure into fractures where mechanical weathering wears the rock away and undermine the cliff face. In some cases, fracture systems are opened up to form sea caves that further undermine the wave-cut cliff. Eventually, the rocks are so weakened by weathering and undercutting that portions of the cliff collapse into the sea, creating a wave cut cliff. After collapsing into the surf, the rock debris undergoes physical weathering. Along many segments of the coastline, the impact of boulder-sized rocks impacting each other can be heard above the roar of the surf. This mutual impact serves to not only reduce the debris into smaller particle sizes but also to round the rocks. As this procedure continues and the wave-cut cliff retreats landward, a flat bedrock surface called a wave-cut platform becomes exposed at low tide that extends from low tide landward. As the debris from the wave-cut cliff is further reduced in size, the smaller sizes are carried seaward beyond the wave-cut platform and deposited, forming a wave-built platform below low tide. Eventually, the wave-cut cliff will retreat inland beyond mean high tide to the limit of the transgression of storm waves. At that point, any further changes in the cliff will be the result of the combination of weathering, mass wasting, and streams. As the wave-cut cliff retreats, remnants of the bedrock called sea stacks or sea arches are commonly temporarily left behind rising from the wave-cut platform.

The combined processes of erosion and deposition along along the California, Oregon, and Washington coastlines; recording a former, more seaward location of the coastline with sea stacks and sea arches standing in testimony to the incredible power of wave action along high-energy coastlines. Should you ever visit the Pacific coast, a truly spectacular drive is along California Highway 1 where you will have ample opportunity to see the results of wave erosion and cliff retreat. You will probably not drive too far before you encounter a detour around a landslide or lost segment of the highway that will remind you of the efficiency with which the waves constantly reclaim the land.

Slight topographic irregularities that are commonly seen along Atlantic-type coastlines are amplified by the incoming waves. Along such coastlines, erosion by the incoming waves is concentrated at the seaward ends of the promontories. As the promontories are eroded and retreat, the sediments generated are simultaneously deposited in an adjacent area. Longshore currents carry the sediments, mostly sand-size, parallel to the shoreline, deposit them between adjacent retreating headlands, creating bay barriers or bay-mouth bars that create sheltered bays and lagoons. As sand moves parallel to the coast, long narrow deposits called spits are created that are attached to the retreating headland at one end, extend parallel to the shore, and commonly terminate with a characteristic inward curl.

In contrast to the emerging, high-energy, Pacific-style coastlines, most of the Atlantic and Gulf coastal shorelines are slowly subsiding in response to the combined effects of crustal cooling away from the oceanic ridges and the accumulation of thousands of feet of sediment within the geoclines (or clastic wedges) that border the edge of the continent. Along most of the Atlantic and Gulf coast, the coastal plain extends seaward as the long, gently sloping continental shelf. Because incoming waves touch bottom relative far from the shoreline, much of their energy is consumed by water movement and bottom erosion before they reach the shoreline. As a result, the amount of energy remaining in each wave upon arriving in the surf zone is only capable to convert the original irregular outline to a relatively straight coastal profile.

Barrier Islands: Perhaps the most dominant depositional form observed along Atlantic-type coastlines are barrier islands. The barrier island system consists of individual sand islands separated by tidal inlets. Except for large estuaries such as Chesapeake Bay, barrier islands are found along much of the Atlantic and Gulf coast. Excellent examples can be found along the Atlantic coast from just south of Ocean City, New Jersey to Miami, Florida and along the Gulf coast from the Florida Panhandle to Brownsville, Texas. The origin of barrier islands is still debated. Some geologists believe that they form when storm-built sand ridges accumulate above high tide. This idea has some validity in that storm-generated sand ridges do develop in front of the breaker zone. Another theory suggests that the barrier islands developed from near-shore depositional features such as bay barriers and spits that migrated landward as sea level rose. Other geologists, however, believe that the present system of barrier islands along the Atlantic and Gulf coasts originated as sand beaches and beach ridges that formed far out on the exposed portion of the continental shelf at the low stand of the ocean during the last glacial episode. According to this theory, as the ice melted and sea level rose, the beaches and beach ridges combined to form sand ridges that moved progressively landward and increased in height. Eventually sea level rose to the point that sea water flooded the low-lying area landward of the sand ridges, creating lagoons or bays. As the lagoons or bays became interconnected, the sand ridges became isolated as offshore barrier islands.

Once the barrier islands formed, the bays began to fill with sediment introduced both from the land as deltas built into the bays and as sand that was transported through the tidal inlets separating the individual islands during the in coming tides and deposited on the bay side of the tidal inlet as flood deltas. During the ebb, or outgoing, tide, some of the material deposited in the bay is carried back through the tidal inlet and deposited on the seaward side of the tidal inlet as an ebb delta. Because the wave energy of the incoming tide is always greater than that of the ebb tide, the amount of sediment deposited in the flood delta always exceeded that deposited in the ebb delta. In summary, over time, the bays landward of the barrier islands began to fill with sediment. The first sign the bays are beginning to fill is the exposure of the bay bottom at low tide called a mudflat. Salt-tolerant grasses begin to grow on the exposed mudflat that trap sediments that normally would be flushed through the system. In time, the grass-covered mudflat builds above high tide to form a saltwater marsh. As the marsh continues to expand, trees may begin to grow within portions of the marsh, converting the marsh into a swamp or into a mire if it accumulates layers of peat. In time, much of what had been open bays is converted into a swamp-marsh complex.

The bays, however, never completely fill with sediment. The constant movement of tidal waters through the coastal wetland maintains a network of interconnected streams, ponds and bays throughout the system. Most of the water that enters through a tidal inlet during the flood tide circulates through the wetland and exits the wetland through a different tidal inlet. This circulation of water through the system is essential for the survival of the wetland and for the offshore fisheries for which the wetland is a major source of food.

Reefs: A reef is an organically constructed, wave-resistant structure that depends on the presence of carbonate-secreting animals and plants. While the structure is commonly referred to as a coral reef, most of the mass of a reef actually consists of algae. Nevertheless, coral plays an important role in the construction of reefs by serving as the framework around which the other components accumulate. I might add that to a seaman, a reef is any barrier to shipping.

Many animals, and some plants, extract ions from seawater and secrete protective body parts. Most shell-bearing animals use calcium carbonate ($CaCO_3$) for this purpose. One of the most important of these shell-forming animals is coral. The coral animal consists of a barrel-shaped body with a single opening surrounded by tentacles equipped with sting cells that are used to paralyze their prey. After the prey is drawn down into the body cavity and the flesh of the prey is consumed, the non-digestible parts are ejected. The animal secretes a shell made of calcium carbonate in which it lives. Some corals, so-called solitary corals, occupy a single shell that is attached to the ocean bottom. Other corals, called colonial corals, join their shells together to form a larger mass. The common names assigned to many corals such as brain coral, fan coral, and staghorn coral describes the shape of the coral mass.

It was Charles Darwin who, during the voyage of H.M.S. Beagle, first comprehensibly studied coral and established their living requirements. First, the water must be warm. Although reef-forming coral will survive in water as cool as 18°C (65°F), optimal reef growth will only occur in water warmer than 20°C (68°F) which restricts their growth to a band around Earth between about 30° north and south latitude. There are so-called cold-water ***coral***, but they are small and rarely grow in sufficient numbers to form a reef. Secondly, reef-forming coral will only survive in that portion of the photic to a depth of about 80 m (260 ft.) where the intensity of the sunlight zone is sufficient to allow photosynthesis. The sunlight requirement is due to a relationship between the coral animal and unicellular photosynthetic plant cells that live in the outer layers of the polyp that provides the oxygen the coral needs for respiration while at the same time consumes the carbon dioxide generated as a waste by the animal. Lastly, coral require clear water, that is, water without suspended sediment. Any suspended sediment in the water will reduce the intensity of sunlight and thereby decrease the growth of the coral colony. At the same time, sediment that gets into the coral's body cavity will eventually kill the animal.

There are four kinds of reefs: 1) patch reefs, 2) fringing reefs, 3) barrier reefs, and 4) atolls. The term, patch reef, refers to the patchy or spotty distribution of reef complexes that grow anywhere the necessary conditions of sunlight, temperature, and water clarity are provided. The other three types of reefs were observed and named by Charles Darwin during his study of coral. Darwin observed reefs growing in shallow, fringing waters that surrounding volcanic islands and named them fringing reefs. He also saw reefs growing around islands but separated from them by a shallow, sheltered body of water or lagoon. It appeared to Darwin that these reefs served as barriers from the incoming energy of storm waves and appropriately assigned the name barrier reef to describe them. The largest barrier reef on Earth is the 1,900 km (1,200 mi.) long Great Barrier Reef off the northeastern coast of Australia. Another example of a barrier reef parallels the Florida Keys about 8 km (5 mi.) offshore.

Finally, Darwin observed rings of coral surrounding an inner lagoon that he named an atoll. Darwin was the first to suggest that the three types of reefs were related in that they developed one from the other as sea level rose. He described barrier reefs as having originated as fringing reefs. As the sea level rose, the fringing reef complex grew upward to maintain itself in the shallow water and, as it did so, the reef moved offshore and became separated from the island by a sheltered lagoon. He went on to suggest that atolls developed from barrier reefs as sea level rose to the point that the inner volcanic island became totally submerged beneath sea level. Darwin's suggestion that atolls form by coral growing around submerged volcanoes was proved to be correct when one of the two atolls used for the testing of the atomic bomb was drilled prior to the testing and the volcanic core was found. Darwin, however, was unable to satisfactorily explain what caused the change in sea level. More than a hundred years were to pass before it was demonstrated that the sea level changes involved were largely the result of the volcanic islands moving into deeper water as the oceanic lithosphere moved over a hot spot.

Coastal Construction: Natural coastal processes are often not to the liking of individuals. Schemes are constantly being implemented to modify natural processes, usually with limited success. Along high-energy coastlines, for example, attempts are made to stop the erosion of wave-cut cliffs by placing large objects ranging from junk cars to steel and concrete structures in the breaker zone. The object of such objects is to dissipate the energy of incoming waves, especially during storms, before they reach the base of the wave cut-cliff in the same fashion that barrier reefs and barrier islands protect the mainland. The success of these structures is temporary at best. Eventually the energy of the waves and tides will erode and remove such artificial barriers and return to the task of eroding the wave-cut cliff.

Perhaps the most common attempts to control coastal processes involve the manipulation of longshore sand transport. Structures called jetties are built at the mouths of harbors to prevent the deposition of sand in harbor entrances by confining the current and maintaining the velocity of water within the entrance. In many cases, the jetties are not completely successful and sand must still be dredged from the harbor entrance.

Because much of the shoreline is used for recreation, attempts are made to ensure that supplies of beach sand are adequate. Barriers called groins are constructed perpendicular to the beach in an attempt to intercept the sand being transported by the longshore current and have it accumulate on the up-current side of the groin. In almost all cases, the groins are at best marginally successful. Invariably, while additional sand does collect on the up-current side of the groin and actually extends the beach seaward, the beach on the down-current side of the groin become sand-starved and retreats due to the fact that wave action is still removing sand; sand that is not being replaced. As a result, the beach on the down-current side of the groin retreats. A common, but fruitless, solution to the problem of a sand-starved beach is to bring sand in from some distant source to replace the lost sand; sand that will eventually be removed by natural processes.

Shorelines are constantly undergoing change and attempts to modify the natural processes of erosion and deposition are eventually doomed to failure, usually after the expenditure of large sums of money. Sooner or later, we may learn not to interfere with the shoreline processes but rather to enjoy the shoreline as it is.

Even though this is a geology text, a point should be made concerning the great biological and ecological importance of the coastal wetlands. The coastal wetlands are essentially factories that produce the vast quantities of organic nutrients that occupy the bottom rungs of the marine food web. The outgoing tides flush these materials and organisms out to sea where they provide the basic food supply for a host of organisms living in the water above the continental shelf and on the ocean bottom beyond the barrier islands.

At the present time, the very existence of the saltwater wetland environment is being threatened by pollution and by exploitations of various kinds. Marshes and swamps are being drained and filled to provide land for commercial developments which, in turn, contaminate and overload the remaining wetland with pollutants of every description. The building of roadways across the wetland and the indiscriminate filling of the wetland interferes with the circulation of water that is essential for the survival of the wetland..

The elimination of the coastal wetland environment seriously affects the entire marine food web by decreasing the amount of biomass in the lower layers. In many coastal areas, the effect can already be seen in significant declines in the populations of certain fish and shelled animals. Some animals such as the bay scallop have all but disappeared from the coastal waters of the east shore of the United States. Fishing fleets are required to go further offshore to find commercial quantities of fish.

Another environmental concern is the progressive destruction of the barrier reefs. An example is the barrier reef the protects the Florida Keys. An estimated 3,000 people a day visit the reefs within the John Pennecamp Coral Reef State Park just off Key Largo, Florida. Gasoline, oil, and diesel fuel from boats pollute the water. Inexperienced operators drive motor boats onto the reef where the propellers cut into the reef complex. Commercial developments along the Keys have generated suspended materials that are carried out to sea by the tides. Many of the patch reefs that once dotted the shallow waters between the Keys and the barrier reef are gone. High levels of nitrate and phosphate pollute the waters and promote the growth of algae that covers and eventually smothers the living coral. The combined effect has been the destruction of extensive segments of the barrier reef complex. With no living coral, the barrier reef quickly succumbs to the impact of storm waves. With the elimination of the offshore barrier reef, the next barrier is the Florida Keys themselves.

Waste Disposal: Perhaps the most serious environmental problem we face to day with regard to the ocean is the dumping of waste. It is estimated that over half of the population of the United States lives within 80 km (50 mi.) of the shorelines of the Atlantic and Pacific oceans and the Gulf of Mexico. Since its passage in 1972, the Marine Protection Research and Sanctuaries Act has prohibited the dumping of certain toxic materials such as radiological, chemical, biological warfare agents, and high-level radioactive waste in the ocean while, at the same time, regulating the disposal of other materials. Nevertheless, the ocean is still the repository of a wide variety of pollutants ranging from the sediments dredged from harbors to raw sewage. The effect on the marine environment has been profound. In many case, the decomposition of organic wastes has depleted the dissolved oxygen in the waters surrounding the disposal site. The oxygen is further reduced as algae, stimulated by the introduction of nutrient-rich wastes such as sewage sludge decomposes. Because of oxygen depletion, extensive areas of the ocean bottom are now devoid of life

The introduction of toxic wastes has not only retarded the reproduction and growth of marine organisms but in many cases has led to their contamination. Contaminated fish and shellfish have been identified as sources of infection and disease. It is estimated that 20% of the commercial fisheries in the united states have been closed because of pollution..

The disposal of waste is becoming a major problem nationwide. Solid waste disposal sites are being closed because of potential groundwater contamination. Certain states have prohibited the opening of any new disposal sites; requiring wastes to be shipped to other states where it is disposed at a cost. The potential of air pollution has limited the development of incinerators as a method of disposal. With few options available for the land-disposal of waste, regulatory agencies are going to be under increasing pressure to allow more extensive ocean dumping.