Coastal landforms are valuable environmental, aesthetic, and recreational resources that are subject to natural processes as well as the effects of human activities. Beaches, dunes, barrier beaches, coastal banks, salt marshes and coastal floodplains are appreciated by the general public and regulated by government agencies to ensure protection of the beneficial functions of these landforms. Yet, in spite of these efforts, coastal landforms are vulnerable to human alterations, resulting in less stable landforms and lessening the value of these resources for future generations.

**MODULE 1: OCEAN AND COASTAL HABITATS**

**SECTION 9: COASTAL LANDFORMS**

**SUNSHINE STATE STANDARDS**


**OBJECTIVES**

- Learn about the different coastal landforms
- Understand the relationship of waves and coastal landforms
- Understand the different processes involved in a coastal landforms

**VOCABULARY**

**Abrasion**- Grooves on bedrock are product of abrasion by rock embedded in the base of a glacial as it moved across the surface. Grooves are formed when debris embedded in the base of the glacier gouges out bedrock as the ice moves across the surface
**Beach**- A beach is covered with unconsolidated material and lies between the low-tide level and upper limit of wave action.

**Beach drift**- is the movement of unconsolidated material across a beach. Water rushes up the beach at an angle as swash, then back perpendicular to the shoreline as backwash.

**Calcification**- occurs in warm, semi-arid environments, usually under grassland vegetation. Soil tends to be rich in organic matter and high in soluble bases. The B horizon of the soil is enriched in calcium carbonate precipitated from water moving downward through the soil or from upward movement of capillary water.

**Dune**- A dune is an accumulation of sand deposited by wind in ridges, mounds, or hills.

**Eolian landforms**- are formed by wind erosion, transportation and deposition.

**Fjord**- A fjord is an estuary formed by the drowning of a glacial trough due to a rise in sea level.

**Gulf Stream**- The Gulf Stream is a warm ocean current flowing along the east coast of North America.

**Isobar**- An isobar is a line connecting locations of equal atmospheric pressure. Isobars are used to depict the variation of air pressure on a surface weather map.

**Jet Stream**- A jet stream is a high velocity corridor of air moving through the winds aloft.

**Longshore currents**- are currents of water flowing parallel to the shore. Longshore currents are formed by waves striking the shore at an oblique angle. Barrier spits are formed by longshore currents.

**The Midoceanic Ridge**- is the longest continuous mountain system on earth and found on the ocean floor. The Midoceanic Ridge is a site of plate divergence where volcanic and earthquake activity occurs.

**Open System**- An open system is one that allows energy and mass exchange across the system boundary. Most natural systems are open systems. (See also system).

**Sinkholes**- are depressions typical of karst topography where limestone bedrock is weathered from below, removing support and causing the surface to collapse.

**Thrust Fault**- A thrust fault occurs when the footwall is pushed up and over the hanging wall.
**Vent** - A vent is a conduit through which magma and gases travel to be extruded on to the surface as lava, volcanic gas, or pyroclastic material. The central vent is the main conduit through which magma rises to the surface. Lateral vents may form on the sides through which flank eruptions occur.

**The zone of accumulation** - occurs where winter accumulation of snow exceeds summer loss on a glacier surface.

**The zone of ablation** - occurs where summer loss of snow exceeds winter accumulation on a glacier surface.

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**BACKGROUND**

**Water in Motion**

**Waves and water movement**

Waves are undulations in the surface of a water body. Most waves are created when kinetic energy is transferred to water by the frictional stress of wind blowing over it. The resulting transfer causes a rise in water level producing a wave crest, followed by the sinking of the surface creating a **wave trough**. The **wave length** is the distance between successive crests. The time required for successive crests to pass a point is the **wave period**. The **wave height** is the distance between the crest of the wave and the still water level. Wave height is determined by (1) wind velocity, (2) duration of the wind, and (3) the fetch. The **fetch** is the distance of uninterrupted flow over an open water surface. An increase in any these factors will increase wave height and length.
Wave Frequency
The number of wave crests passing point A each second

Wave Period
The time required for the wave crest at point A to reach point B
The rise and fall of **oscillatory waves** in an open water reflects the circular motion of water particles. There is relatively little forward motion by a water particle as a wave passes. It is simply the wave form and its energy that is transmitted across the ocean surface. Water particles move in circular orbits that diminish with depth. The radius of the circular path is greatest at the surface and decreases with toward the bottom of the wave. Larger waves exhibit larger orbital radii and extend to a greater depth than smaller waves. At some point in deep water, the wave has no effect on the motion of the water. Thus a *zone of no wave motion* exists from the base of the wave to the ocean floor.
Swells are smooth, rounded waves that travel outward from a storm center or continue as broad undulations of the ocean surface after the wind dies down. The wave slope is expressed as the ratio of the wave height to wave length, ranging from 1:25 to 1:50. A wave will become unstable at slopes greater than 1:7 and will fall over itself, or break.

As a wave approaches the coast, a depth is reached offshore where the wave touches the ocean floor. The tug of the ocean floor changes the circular wave motion into an elliptical one; the water moves back and forth over the bottom as each wave passes. The friction imparted from the floor slows the wave base. At a depth of 1.3 times the wave length, the drag causes the top of the wave to rush forward, become unstable and break. Water in the breaking wave is transported toward shore as a wave of translation.

What causes waves?

Waves are generated at sea by the wind. Small ripples form on the water as the wind blows across the ocean’s surface. The size of waves depends on three things:

1. The duration of the wind;
2. The strength of the wind, and;
3. The *fetch*, or the distance over water across which the wind blows.

The longer the wind blows the bigger the waves; stronger winds mean higher waves; and the greater the fetch, the bigger the waves. Thus the biggest waves of all occur in the storms that last the longest with the most energetic winds with hundreds of miles between the storm at sea and the beach.

Waves do not actually consist of water traveling from where the wind is blowing all the way to the beach. Instead of moving water, waves are moving energy that was transferred from the wind to the water. This energy propagates, or moves, through the ocean to the beach in the form of a wave. But the water itself is not moving forward as in a current. Instead, the energy rolls through the water in a circular motion called a *wave orbital*. The *crest* of a wave is the top of a wave orbital, and the *trough* of a wave is the bottom of a wave orbital. When the waves reach the shore they expend their energy by breaking and then moving sand and shaping the beach.

**What causes waves to break on shore?**

As waves move towards shore, they begin to "feel" the ocean floor. In a process known as *shoaling*, this causes the wave orbitals to flatten as the bottom shoals. When waves feel the bottom they slow down and bunch together (decrease their wavelength); but the time between wave crests (period) does not change. The height of the wave will initially decrease when it feels bottom, but then will steadily increase until the wave becomes unstable and breaks near the beach. The water literally falls over. Waves expend the energy they gained from the wind by transferring that energy to the beach when they break.
**Measuring waves**

The dimensions of a wave are measured both by crest height and the distance between crests. Wave height is the vertical distance from the crest (highest part of the wave) to the trough (the lowest part of the wave). Most untrained observers at sea tend to greatly overestimate wave height, which is quite understandable because they do not have any stationary reference points. And then there is the terror factor. A person holding on for dear life on a rolling, bounding vessel is easily convinced of the giant size of the waves.

Standing on a beach, a good way to estimate wave height is to assume that the surfer out there is 6 feet tall! In many cases, the amplitude is also used as a measurement of the wave’s size; wave amplitude is one-half of the wave height. The wavelength is the distance from one crest to the next crest, or from one trough to the next.

Waves travel at different speeds, and the speed is typically measured as the wave period or wave frequency. Wave period is the number of seconds it takes two successive wave crests to pass a given point. Wave frequency is the inverse of the period, or the number of waves that pass a given point during a given time period. As the length of a wave increases, so does its speed. In a general way, the higher the wave period the greater the wave height. Big storms in North Carolina may produce waves with 12 to 15 second periods, while calm weather wave periods are more likely to be 3 to 5 seconds.

**Types of waves**

![Plunging breaker](image1)

![Spilling breaker](image2)

![Surging breaker](image3)
The way each wave breaks depends on the slope and shape of the bottom. In general, the wave will break in one of three ways: as a spilling, plunging, or surging breaker. Where the beach is relatively flat and wide, spilling breakers will form. Spilling breakers look like they are crumbling as they move along. With a slightly steeper beach slope, the crest curls over and creates a plunging breaker. These breakers actually form a tube of air trapped beneath the curl. The tube of air is forced into the bottom when the wave breaks and this air helps to stir up the bottom sediment. A plunging breaker is the sensational, curling type commonly sought after by surfers. Because the energy of the plunging breaker is concentrated in a small or narrow area of the seafloor, it is able to move large amounts of sand.

On the steepest bottom slopes, the wave often does not break before reaching the beach. Instead, a surging breaker is formed where the wave surges up the beach and is reflected back to sea. These types of breakers may look just like a series of bubbling mounds of water moving ashore. All three wave types may be found on any beach at different times but often a beach has a characteristic or commonly occurring wave type.

As waves move from deep water and approach the shore at some angle, the part of a wavefront that enters shallow water first will begin to slow as it feels bottom. This portion of the wave slows down while the deep-water part keeps moving at its original higher velocity, causing the wave crest to bend or refract. Along most beaches, by the time the wave breaks, the refraction is so great that the wave crest is typically much closer to paralleling the shore orientation than it was in deep water. Since waves can, in theory, approach the beach from any direction, the amount and type of refraction varies widely. Waves that form offshore may arrive at the beach with an orientation identical to that of the beach. Such waves will undergo little refraction. But waves generated by storms may approach the shore at varying angles and are sometimes strongly refracted. The wave refraction picture is further complicated because shorelines may be oriented in many directions.

**Rogue waves**

Rogue waves are spectacular and dangerous waves. These poorly understood waves are rare on beaches, but they do occur occasionally. A few years ago, a rogue wave struck a south Florida beach, rearranging some cars, but no one was injured because it occurred in the middle of the night. As wave trains travel across the ocean from various
storms, they frequently meet each other. When this happens, the waves will either cancel each other out or reinforce each other. If the wave crests coincide with other crests, they will have positive interference, which really means that the two intersecting waves will be one wave, with the combined height of the two. Likewise if the waves of two intersecting trains are out of phase, the troughs of one set can cancel out the crest heights of the other. When several waves intersect at just the right time and phase, a rare rogue wave of immense height can form. Such a wave can bury a ship. Currents can also increase or decrease the heights of a wave train depending on the local conditions. If a wind is blowing against a current, wave height will increase. Experienced sailors fear a strong wind from the north when sailing in the north-flowing Gulf Stream.

**Tsunamis**

Tsunamis, sometimes called tidal waves, are not generated by the wind like other ocean waves. They are caused by sudden underwater disturbances such as earthquakes, volcanic eruptions and submarine landslides. The catastrophic release of energy during any one of these events forms a sudden wave of immense wavelength (sometimes hundreds of miles!). Traveling at very high speed, these waves spread out from their source until they reach an obstacle such as a shoreline.

Tsunamis are extremely dangerous because they travel so fast that there is little time to warn people of their impending arrival. A tsunami formed in Hawaii will take only hours to reach Japan, Alaska and Washington. Reaching heights of 100 feet (30 meters), tsunamis can remove all the water away from the beach as they approach the shore. Boats unfortunate enough to be in that water will be grounded by the tsunami wave, and unwary beach dwellers are likely to run out to the newly exposed land to gather stranded fish. When the wave comes ashore, it does so with such force that it literally
destroys everything in its path. And people and debris caught in the wave often get transported out to sea when the water returns to the ocean.

**What are long shore currents?**

Breaking waves form *longshore currents* that carry sand grains (and swimmers) along the beach. Longshore currents form in the surf zone because waves approach the shoreline at an angle. When a wave breaks, a portion of the energy is directed laterally along the beach and this forms the current. Even a very gentle current can carry a lot of sand because the breaking waves kick sand up into the water column as evidenced by the discoloration of the water in the surf zone.

For a given wave size, the greater the angle between the waves and the shoreline (up to 45 degrees), the stronger the longshore current. This current, sometimes called *littoral drift*, is responsible for most of the sand movement along beaches. Other things are involved in the genesis of surf zone currents. For example, winds can either decrease or increase current velocity depending on whether they blow with or against the wave formed current. Tidal currents can also be important.

**Rip currents**

A special type of surf zone current, one that everyone who swims in the ocean should be familiar with is the *rip current*, sometimes called rip tides. These are strong seaward flowing currents set up by the return flow of water held onshore by the longshore currents, waves and storm surges. Often they flow through gaps in offshore bars and thus they may occur repeatedly at the same location. The details of the genesis of these currents are beyond the scope of this chapter but it is important to note that they are a significant hazard to swimmers. While standing on the beach, watch for the telltale band of seaward flowing water and if you see such – stay out of the water. If you have the misfortune to caught in a current, swim laterally rather than directly toward shore. Be cautious and know what you’re doing when you swim at the beach.
Wave Breaking

In deep waters, only wavelength and wave period affect a wave’s speed. As the wave approaches shallow water, or water that is half the wavelength or less deep, the ocean floor begins to affect the wave's shape and speed. Wave height increases, and the crests become more peaked. As the steepness increases, the wave becomes unstable. The forward speed of the crest becomes faster than the speed of the wave, and the wave breaks.

We can describe breaking waves in three different ways: Surging Breakers, Plunging Breakers and Spilling Breakers. You see examples of these at the beach.

**Surging Breakers** happen on beaches where the slope is very steep. The wave does not actually break. Instead, it rolls onto the steep beach. These kinds of breakers are known for their destructive nature.

**Plunging Breakers** happen on beaches where the slope is moderately steep. This kind of wave normally curls over forming a tunnel until the wave breaks. Expert surfers love this type of wave!

**Spilling Breakers** occur on beaches with gentle slopes. These waves break far from the shore, and the surf gently rolls over the front of the wave.

Tides

Nearly all marine coastlines experience the rhythmic rise and fall of sea level called tides. The daily oscillation in ocean level is a product of the gravitational attraction of
the Moon and Sun on Earth's oceans and varies in degree worldwide. Tidal action is an important force behind coastal erosion and deposition as the shoreline migrates landward and seaward.

**Causes of Tides**

The gravitational attraction of the Sun is about half that of the Moon on the Earth. Gravitational attraction is a function of both the mass of the objects and the distance between them. Even though the Moon is much smaller in mass than the Sun it is closer and thus has a greater influence on the Earth than does the Sun. The gravitational pull of the Moon and the Sun stretches both solid and fluid surfaces of the Earth. This creates a tidal bulge in the atmosphere, the oceans and to a very slight extent the Earth's crust.

Gravity is not the only force responsible for a tidal bulge. **Inertia**, the tendency of moving objects to continue moving in a straight line or stay motionless, also affects the tidal bulge. As the gravitational force draws water closer to the Moon the inertial force tries to keep it in place. The tidal bulge forms as the gravitational force exceeds the inertial force on the near side. The gravitational force of the far (opposite) side is less because it is farther away from the Moon. On this side, the inertial force exceeds the gravitational force. Here the water attempts to keep going in a straight line, moving away from the Earth, creating another, smaller bulge. Thus tidal bulge, is greatest on the side of the Earth facing the Moon or Sun ("near side") simply because it's closer than the "far side" of the Earth.

**Tidal Currents**

Watching the tide "come in" one gets the impression that ocean water is moving in and out along the shoreline. The landward and seaward movements are a result the Earth rotating into and out of a semi-fixed tidal bulge as it change its position relative to the Sun and Moon. Any point on Earth rotates through two bulges every 24 hours and 50 minutes producing two *high tides* and two *low tides* called each day. The difference in
height between consecutive high and low tides is the **tidal range**. During a high tide, water moves landward as a **flood current**. During low tide water recedes seaward as an **ebb current**. The two high tides and the two low tides do not have to be of equal height because the angle between the Moon and Earth changes each day. The tidal range is the difference in height between high and low tide.

### Spring and Neap Tides

The Sun and Moon are said to be in **conjunction** with they are aligned with the Earth. The highest tides, and greatest gravitational attraction, occur when the Sun and Moon are on the same side of the Earth creating a **spring tide**. This occurs during the new moon phase. A second lower spring tide occurs when the Sun and Moon are on opposite sides of the Earth during the full Moon phase. A **neap tide** results when the Sun and moon are at right angles to the Earth. There are two neap tides, at the first-quarter and second quarter phases of the Moon.

Located on the northeast end of the Gulf of Maine between New Brunswick and Nova Scotia, the Bay of Fundy is known for its high tidal range, as much as 48 feet (14 meters). Over a 100 billions tons of water passes in and out of the bay every 12 1/2 hours each day. Watch this amazing process occur below.

### Coastal Landforms and Processes

A **coast** or the **coastal zone** is a dynamic region where land is sculpted and shaped by wave action and currents. Barring the effects of tectonic uplift and sea level change, erosion is the dominate geomorphic process acting on coasts. Coastal sediments are subject to multiple episodes of erosion, transportation and deposition, though a net seaward transport takes place on a global scale. The deep ocean floor becomes the resting place for terrestrial sediment eroded from the land.

The combined effect of waves, currents and tides result in a variety of gradational processes acting in the coastal zone. Most important is **abrasion**, caused by the scraping or impact of sediment carried by water thrown against shore materials. Breakers are particularly effective at lifting larger rocks and hurling them against the shore.
Hydraulic action caused by the direct impact of waves on the coast can be an effective geomorphic agent. Enormous pressures can build as water and air are compressed into rock fractures. Solution is locally important especially where soluble rock is exposed along the shore.

The water level in the surf zone increases as waves approach shore at an angle. The rising water moves parallel to the shore as a longshore current. Beach drifting transports sand grains along the beach as waves strike the shore at an oblique angle. Sediment is carried landward when water rushes across the beach as swash. Sediment is carried back toward the ocean as backwash. The continual up rush and backwash carries sand in a zig-zag like movement along the shore.

Depositional Coastal Landforms

A beach is a deposit of loose sediment adjacent to a body of water. Though sand is common to most beaches, a remarkable diversity of sediment size, from boulders to fine silt is found on beaches around the world. Larger particles and steeper slopes are found where wave action is high. Fine particles and gentle slopes are characteristic of beaches exposed to low wave action.

Most midlatitude beaches undergo a cycle of erosion and deposition following the seasonal changes in wave action. During the winter, midlatitude storms are more vigorous producing more wave action and erosion. Hence, beaches tend to narrow during the winter. Wave action subsides during the summer as storms weaken somewhat favoring deposition over erosion and producing broader beaches.

Spits and bars

Sand spit is one of the most common coastal landforms. A sand spit is a linear accumulation of sediment that is attached to land at one end. Sand carried parallel to shore by longshore drift may eventually extend across a bay or between headlands especially where water is relatively calm. Spits are typically elongate, narrow features built to several dozen feet by wind and waves.
Spits often form when wave energy decreases as a result of wave refraction in a bay. When a coastline turns abruptly, wave energy is dissipated by divergence of wave trajectories, causing sediment to accumulate as the water loses its ability to transport.

Spits can extend across the mouth of a bay, but wave action is usually strong enough to wash sand out to sea or be deposited in the embayment. They may curve into the bay or stretch across connecting to the other side as a baymouth bar. When the bay is closed off by a bar it becomes a lagoon.

Wave energy also dissipates in the lee of large sea stacks or islets. Wave refraction sweeps sediment behind the obstruction from two directions, depositing it as a slender finger called a tombolo.

![Diagram of barrier islands](image)

**Barrier Islands**

Coastlines paralleled by offshore narrow strips of sand dunes, salt marshes and beaches are known as barrier islands. Barrier island complexes stretch along the southeastern coast of North America from Long Island, New York to the Gulf coast of Texas. Many believe barrier islands originated as offshore bars built by waves breaking on a shallow shore. When waves begin to feel the tug of the ocean floor, they push sand toward shore as they break. The return undertow sweeps sand back to settle on the developing bar. These offshore bars were later exposed when the continent rebounded after ice age glaciers melted.

**Shoreline features related to barrier islands**
A variety of barrier-related features are seen along the shoreline of the Atlantic coast. Long Island, because of its abundant supply of sediment, has an extensive system of barrier islands and beaches, exhibiting many of these features.

Bay barriers: continuous barrier beaches that close off the entrance to a bay. In the upper reaches of a bay the bayhead barrier protects lagoon or marshland. Barriers that connect headlands together along the outer reaches of an embayment are called baymouth barriers. The eastern reaches of Long Island contain examples of baymouth barriers where the steeper shelf gradient and more vigorous wave activity have pushed the barrier islands against the indented mainland coast.

Barrier spits: beaches that are attached at one end to their source of sediment. Simple spits consist of narrow finger of sand with a single dune ridge that elongates in the downdrift direction. Double spits can form if drift transports sand in two directions across and inlet, or if a baymouth barrier is cut by a tidal channel. Wave refraction at the end of a spit will transport sand to form a recurved spit. Complex spits form when a plentiful supply of sediment is transported by both ocean and bay currents. Multiple lines of dunes can be formed by wind transport of sand across the spit.

Tombolos: Islands refract incoming waves causing them to bend inward around the island and converge along the mainland in opposite directions. This produces a net transport of sand in two directions toward the island, resulting in a spit of sand that grows outward from the shore, eventually connecting the island to the mainland by a long, narrow strip of sand called a tombolo. Examples of tombolos on
Long Island include Ashroken beach connecting Eatons Neck to Northport and the connection between the northern and southern reaches of Lloyds Neck.

**Capes:** are barrier islands that project into the open sea to form a right angle shoreline. These are generally large features that are exposed to wave attack on each side, but one side is accreting while the other is eroding. This produces a distinctive series of truncated dune ridges. Examples include Cape Fear and Cape Hatteras in North Carolina and Cape Canaveral in Florida.

**Sea islands:** these are islands created by the flooding of the mainland by sealevel rise. Many of the necks and most of the islands around Long Island are all sea islands.

**Beach ridge islands and cheniers:** These structures form along low-energy coasts where wind piles sediment into dunes with very little wave erosion. Where sand is abundant beach ridges can develop, forming an island consisting of a distinctive pattern of ridges with intervening wetlands. Cheniers are found along the Gulf coast where sand and silt are blown over salt marshes, forming ridges.

**Barrier Island Rollover**

Sea level is slowly rising (as it has been for the past 10,000 years). Currently it is rising at an average rate of **1 foot per century**. However, global warming could increase this rate to as much as **3 to 6.5 feet per century**.

The most notable current effect of sea level rise is the **rollover** of barrier islands. As sea level rises, the barrier islands slowly migrate landward (as do the lagoons, bays, and marshes). This landward migration is accomplished during storms that erode the beach and wash the sand over the dune line, depositing it on the middle and backside of the island as **washovers**. This sand builds up the back of the island and creates a reservoir of sand for rebuilding the wind-blown dune deposits landward of their former position.

Where barrier islands are narrow they can be breached by waves during large storms, creating an **inlet**. Inlets subsequently are flushed by tides, resulting in the creation of
**ebb** and **flood tidal deltas**. Usually, inlets are eventually repaired as the barrier beach migrates downdrift to form a spit closing off the breach. The ebb tidal delta then gets reworked to add to the supply of sand along the barrier front and the flood tidal delta becomes a bay bar or marshland area.

Many of our current problems with stabilizing barrier island beaches can be understood in light of rollover. For example, during the recent nor'easters that have hit Long Island's south shore barrier islands, tremendous quantities of sand have been washed over the front of the islands and through breaches in the islands, forming sand deposits offshore in the Great South Bay. What is happening here is that the storms of eroding the front of the islands and building their backsides. In effect, storms are moving the islands landward. As they move in this way they become raised above sealevel and more resistant to storms.

**Bays**

**Bays** are indentations in the shoreline that form pockets of sheltered sea. Again, many bays are shoreline valleys and depressions that were eroded during the last ice age and flooded by rising sea level (for example, the bays of Long Island's north shore and Chesapeake Bay). Bays are often partially closed off to the sea by **spits** or **tombolos** (a spit connecting the mainland to an offshore island (an excellent local example is Northport Bay - sheltered on the Sound side by Eaton's Neck and the Ashroken tombolo).

Tombolos form because waves refracted around an island impinge on the shoreline at opposite angles, causing sand to converge directly in the lee of the island. Eventually, this sand builds out as a spit from the mainland toward the island.

**Estuaries**

An estuary is a coastal wetland where freshwater from runoff and saltwater from tides mix. Most large rivers do not empty abruptly into the sea. Instead, they merge with the sea in a transitional area near their mouths called an **estuary**. Estuaries have water that is a mix of fresh and salty, called **brackish**.

Most estuaries are formed in valleys that were carved out when sea level was low during the last ice age and then flooded as sea level rose due to melting glacial ice. Most estuaries are bordered by saltwater wetlands called **marshes**. Marshes are flushed each day by tidal water flowing in and out from the sea. Tidal water is distributed throughout the marsh by a series of branching channels that form a dendritic system that empties into a main tidal channel open to the sea.

Because saltwater is denser than freshwater the saltwater coming in on the rising tide travels up the estuary as a distinct density layer beneath the overriding freshwater layer.

The lower Hudson River is an excellent example of an estuary.
Deltas

Lobate bodies of sediment deposited by rivers as they empty offshore into the sea or a lake.

Deltas build outward from the shoreline at river mouths - usually prograding the shoreline.

They tend to form in areas of subsidence (rivers flow into depressions), also, weight of sediment depresses crust, causes subsidence and creates accommodation space.

**Different types of deltas**

**Gilbert Deltas**- these are coarse-sediment-dominated deltas that commonly form in lakes from the deposition of bed-load sediments. Often seen in glacially deposited strata - can be observed in cliffs on the North Shore of Long Island.

**Wave-dominated Deltas**- these deltas form along coasts where wave activity is strong and sediment supply is moderate. Waves winnow and redistribute sediment - delta tends to be sandy and arc-shaped.

**Tide-dominated Deltas**- these deltas are shaped by strong tidal flows that tend to create long, straight distributaries and shore-perpendicular tidal current sand ridges.
**River-Dominated Deltas** - these deltas form where rivers carry large amounts of suspended sediment to shorelines with moderate wave and tide activity. Ex. Mississippi delta. Also called "bird-foot" deltas due to elongated distributary channels that build out onto the shelf.
Erosional Coastal Landforms

Some of the most spectacular scenery is found along coastlines and produced by the effects of wave erosion. Wave erosion undercut steep shorelines creating coastal cliffs.

A **sea cliff** is a vertical precipice created by waves crashing directly on a steeply inclined slope. Hydraulic action, abrasion, and chemical solution all work to cut a notch at the high water level near the base of the cliff. Constant undercutting and erosion causes the cliffs to retreat landward.

**Sea caves** form along lines of weakness in cohesive but well-jointed bedrock. Sea caves are prominent headlands where wave refraction attacks the shore.

A **sea arch** forms when sea caves merge from opposite sides of a headland. If the arch collapses, a pillar of rock remains behind as a **sea stack**.

Seaward of the retreating cliffs, wave erosion forms a broad erosional platform called a **wave-cut bench** or **wave-cut platform**. After the constant grinding and battering, eroded material is transported to adjacent bays to become beaches or seaward coming to rest as a **wave-built terrace**. If tectonic forces raise the bench above the water level a marine terrace forms. Some shorelines have several marine terraces creating during various episodes of uplift.

**Coasts**

The characteristics of a coast depend on its geologic structure, initial topographic configuration, and shoreline process that shape it. There are several ways and varying scales one can classify these complex systems. **Submerged coasts** form when river mouths are flooded due to rising sea level or subsidence of land. A drop in sea level or rise in the land surface creates an **emergent coast**. **Depositional coasts** have abundant depositional features like deltas, bars, spits and reefs where new land has been built.
Coral coasts are formed by biological rather than physical processes.

**Submerged Coasts**

Ria coasts are formed by the submergence of river valleys emptying into the ocean. "Ria" is a Spanish term for coasts with prominent headlands and embayments typical of these coasts. Wave action turns the smooth valley sides into receding cliffs with sand spits and tombolos common. Examples of ria coasts are found in New England and the Atlantic coast of Europe, especially France.

Fjord (fiord) coasts are formed when glacial troughs are flooded due to a rise in sea level. Fiord coasts are deeply indented, with steep-walled valleys. Sandy beaches are rare as sediment eroded from valley walls collects on the floor. Fjords are common in Scandinavia, British Columbia, Alaska, and Patagonia.

**Emergent Coasts**

Emergent coasts are a result of forces acting to raise the land surface or drop sea level. The incredible weight of massive ice sheets during the Pleistocene depressed the continental surfaces beneath them. The continents began to rebound as the ice melted and released the overlying pressure. The rising surface lifted the shoreline above sea level forming glacial uplift coasts along continental margins.

Raised shorelines and erosional features like wave cut terraces are also found along tectonic coasts where endogenic forces have uplifted the surface. Such coasts are common along the mountain and island arcs of the Pacific Ocean.

**Depositional Coasts**

Barrier island coasts are those paralleled by deposits of sand separated from land by a lagoon. There is some controversy over how barrier island coasts form. They begin as offshore bars of submerged sediment that migrate landward unless stabilized. Barrier islands are often cut by tidal inlets, openings that allow water to move landward and...
seaward with the tides. Barrier islands border the Atlantic coastal plain of North America.

**Delta coasts** are those formed by the deposition of sediment at the mouth of a river that enters the ocean. Deposition is caused by the rapid decrease in water velocity as it enters the ocean. Sand and silt are the first to deposit while the mixing of fresh and salt water cause clay particles to bind together forming larger particles that settle to the bottom.

**Reefs**

**Coral** is a simple marine animal having a small cylindrical sac-like body called a *polyp* and an exoskeleton of calcium carbonate. As old colonies die new form on top, ultimately forming limestone. There are an estimated 9 million species making it one of the most diverse marine ecosystems. Corals are on the decline in many regions due to human activity.

Corals thrive in warm tropical water at depths of 10 - 55 m (30 - 18 ft) from about 30° N to 30° S. Warm, east coasts encourage their development while few are found in cooler, western coastal environments. Water temperatures range from 18° to 29° C (64° - 85° F) 27% to 40% salinity. Bleaching and death result when water temperatures rise to high. There are cool water corals found deep, dark ocean water at temperatures as low as 4° C (39° F). Corals also require sediment-free water thus few are found near the mouths of rivers discharging in the ocean.

There are three kinds of coral reefs. **Fringing reefs** are platforms of coral attached to land. They tend to be wider where wave action is prominent and the water well aerated. **Barrier reefs** form offshore with lagoon in between. Many form along slowing subsiding islands, growing at a rate that keeps them near sea level. Others form on continental shelves. The largest and one of the most well known is the Great Barrier Reef of Australia at over 2025 km long (1260 m) and 16 - 145 km (10-90 mi) wide. **Atolls** are circular reefs enclosing a lagoon formed from the subsidence and disappearance of a volcanic island cone.
**ACTIVITY: WHAT’S ALONG THE COAST?**

**DURATION:** 30-60 minutes

**OBJECTIVES**

- Students research an area with at least one dominant geographical feature.
- Students display their findings in a realistic 3-dimensional presentation.
- Students prepare ancillary material to support their project.

**MATERIALS**

**Crayola supplies**

- Washable Watercolors
- Watercolor Brushes with Plastic Handle
- Model Magic®
- No-Run School Glue

**Household supplies**

- recycled newspaper
- paper towels
- masking tape
- cardboard
- container(s) of water

**PROCEDURE**

**Why?**
How does geography influence people and places? Discover how natural features such as coastlines shape architecture, jobs, and communities.

1. Do you think that geography influences culture? Being near a dominant feature such as water certainly does! In Greece, for example, you are at most only 85 miles (137 km) from the shore. Greece has more coastline than the entire mainland of the United States even though it is only as big as Florida. Greece has 9,333 miles (15,020 km) of coastline (including islands).

2. Learn more about Greece, such as the number of islands (437) and the percentage that are inhabited (50). Or choose another place along a coast to study. Find out whether there are sandy beaches, rocky cliffs, or other landforms near the water’s edge. What kinds of homes are built there? What jobs do people do? What size is the population?

3. Cover your art area with newspaper. Use Crayola® Watercolors and Watercolor Brushes to paint a cardboard base for the water. Air-dry the base.

4. Most of Greece (4/5ths) is covered with mountains. To build an armature for your sculpture, ball up newspaper and tape it to your base. Roll out realistic colors of Crayola Model Magic to cover the newspaper mountains. Add colored bits to create a craggy look. Model Magic that is fresh from the pack sticks to itself.

5. Shape human-made elements found on the landscape, such as villages, fishing piers, or boat docks. In Greece, the white stucco architecture of coastal towns is in striking contrast with the rugged cliffs. Air-dry your sculpture.

6. Use Crayola School Glue to attach the sculpture to its base.

**ADAPTATIONS**

Learn more about Ancient Greek mapmakers. Find out why the word for a book of maps is the same as an ancient Greek god.

Display different coastlines around the world. Exhibit these together for a coastlines-of-the-world tour.
Chart different geological events that have created coastlines. Figure out the percentage of each type around the world. How do scientists predict that global warming will affect coastlines?

Invite a neighbor with Greek ancestry to visit your classroom to talk about the country’s culture and landscape.

Assessment: Compare sculptures to photographs of the geographic region in question. How realistic and complete are the details? What do students know about the area’s culture and geology?
ACTIVITY: EROSION CREATES A CHANGE IN THE LANDSCAPE

DURATION: 1-2 hours

OBJECTIVES

- Students will be able to conduct experiments to show evidence of soil erosion.

MATERIALS

- 20 rulers (4 for each group)
- All-purpose sand (70 lb. bag)
- Pencils
- Tap water
- Paper
- 5 rectangular pans or plastic bins (at least 9” or 12”)

INTRODUCTION

Before introducing the topic of erosion, you should teach students about waves. What is a wave? What can it do to the landscape? After students discuss erosion, lead them through a discussion on controlling and reducing erosion.

BACKGROUND

The ocean is constantly in motion. Currents, tides, and waves that move ocean waters are the result of the Earth's position in the solar system, the rotation of the Earth, and actions that occur between the Earth and its inhabitants.

Waves are generally produced by wind. The wind moves over the surface of the water, causing the water to rise. The stronger the wind, the higher the water rises, producing larger waves. When the wind is steady, it produces a wave train, which is a series of consecutive waves. As waves approach the shore, they move over shallow water. When the bottom of the wave hits the seafloor, the top of the wave moves forward and crashes. This process forms a breaker.

When the incoming tide reaches the mouth of a river, another type of wave is formed. If the seafloor slopes at the mouth of the river and the tidal range at that point is more than five meters, a wave known as a tidal bore would be created (Greene, 1998). Sudden changes in the Earth's crust can lead to another type of wave, referred to as a
tsunami. According to Greene (1998), an earthquake on the seafloor created a tsunami off Japan in 1993.

Currents, tides, and waves move not only the water in the ocean but also move sediments along the shoreline. The movement of these sediments is called erosion. When the sediments are relocated along a beach, it is termed deposition. When a wave crashes against a beach, sand is suspended into the water and may drift with the current. During storms, waves and currents have more energy; therefore, more sand may be removed.

Governmental agencies attempt to contend with the problem of coastal erosion in a number of ways. One way is to create a barrier. A groin is a rock or wood barrier that extends from the beach into the water. A jetty is another type of barrier. Jetties are designed to trap sand drifting along the shore with the current, to prevent sand accumulations in a channel.

When a large quantity of sand has eroded from a beach, one way it can be replaced is to pump the sand in the water column back to the beach. This process is known as dredging. All of these processes are temporary methods to reduce or control erosion.

Researchers are currently testing a new erosion control theory. This new type of erosion control is a submerged artificial reef. According to Greene (1998), large concrete blocks that interlock are placed approximately 100 meters offshore. As the waves move toward the shore, they reach these concrete blocks and break. The sand then increases between the artificial reef and the shore, preventing the shore from eroding. This process may also be only a temporary solution as the sand beneath the reef eventually erodes, compromising the reef. Further studies must be conducted to determine whether this is the best and most natural course of action.

**PROCEDURE:**

1. Divide students into five cooperative learning groups.
2. Provide each group with a pan, sand, water, four rulers, paper, and pencils.
3. Have students place sand in their pan approximately 1 2" thick on one half of the pan.
4. Gently add tap water up to 2" deep on the side of the pan.
5. Label the shorter sides of the rectangular pan, east and west.
6. Have student groups draw a diagram of their respective pans.
7. One student in each group should take a ruler and create a "wave" action against the shore in a general east-to-west movement.
8. Ask the students to make a drawing after creating the wave action--noting the effects of erosion. How has the coastline changed?
9. Following Step 7, have students place two or three rulers into the sand about 4" apart to represent groins. Have them develop a hypothesis for the function of groins. Draw these groins and shoreline.
10. Use a ruler to create the same east-to-west wave movement. What happened in between the groins? What happened to the shoreline? What happened to the west of the last groin? Make a drawing after the wave action is complete.

**POSSIBLE EXTENSION**

1. Obtain a slide of beach groins. Demonstrate beach groins to the class and discuss their thoughts.
2. Compare and contrast jetties with groins. Groins protect barrier beaches. Both jetties and groins can be constructed of rock; however, jetties tend to be longer and protect channel or inlet areas.
3. Humans can modify the landscape as does mother nature. How would you feel if you could not access a beach? Would you want tax dollars spent to have the effects of erosion controlled by human technology?

**TEACHER EVALUATION**

Have student groups write possible reasons the sand was eroded to the west of the last groin. Also, have student groups write how the problem could have been prevented. Students may wish to draw a plan demonstrating how shoreline erosion should have been prevented.
ACTIVITY: THE WATER MOLECULE

**DURATION:** 2 days

**OBJECTIVES**
- Students will be able to do the following:
  - Recognize how the temperature of water affects density.
  - Define salinity, explain how it is determined, and describe some conditions that cause it to vary.
  - Explain where and how salinity influences the density of oceans.
  - Recognize the manner in which the properties of temperature, density, and salinity interact to create currents.

**MATERIALS**
- 500 ml graduated cylinder (one/group)
- Karo® syrup
- Oil
- Candle
- Cotton ball
- Freshwater
- Ice cubes
- Heat lamp
- Journal notebook (one/student)
- Glycerin
- Colored water
- Rock (1/group)
- Cork
- Penny
- Saltwater
- 100 ml beakers (2/group)
- Plastic wine glass
INTRODUCTION

- Review the previously covered concept of density (the effects and relationships of mass, volume, temperature, and pressure).
- Introduce water as a molecule that occasionally likes to "bend" these rules and obeys the rules only when you are dealing with differences in pressure.
- Construct a molecular diagram of a water molecule (containing one atom of oxygen and two atoms of hydrogen). Explain why the molecule is dipolar. The dipolar aspect gives water great dissolving and cleaning powers.
- Introduce salt and the concept of salinity.

BACKGROUND SUMMARY

Purpose: To demonstrate the various chemical properties of water and how these properties influence the oceans of the Earth. Water is one of the most unusual compounds on Earth. It has a variety of properties not found in any other liquid. A water molecule is formed from two atoms of hydrogen and one atom of oxygen. An oxygen atom has eight protons and eight neutrons in its nucleus and eight electrons surrounding the nucleus. Hydrogen has one proton and no neutrons in its nucleus and one electron surrounding the nucleus. The oxygen atom has more electrons than both hydrogen atoms and, therefore, is more negative than the hydrogen ion. The hydrogen portion of the water molecule is more positive than the oxygen portion. These opposite charges on each portion (side) of the water molecule result in an attraction that forms a weak hydrogen bond between the oxygen atom and each hydrogen atom (Greene, 1998). Because of the two opposite charges of the water molecule, it is known as a dipolar molecule and acts as a magnet. The negative portion attracts positively charged sodium ions, while the positive end attracts negatively charged chloride ions. These sodium and chloride ions separate and are surrounded by water molecules, which is why salt is dissolved easily in water (Greene, 1998).

ACTIVITY

*Density Cocktail:*

1. Divide students into cooperative learning groups of three or four.
2. Provide each group with a graduated cylinder and 2 liters of saltwater (salinity 30-35 ppt).
3. Give each group the following items -- glycerine, Karo® syrup, colored salt water (salinity 40 ppt), oil, a rock, one candle, one cork, one cotton ball, and one penny.
4. Have the students test to see which of these items float and which sink. Students should record observations after each item has been added.
5. The students will need a different volume of saltwater after testing the glycerine, oil, Karo® syrup, and colored water.
6. Fill the graduated cylinder with 300 ml of saltwater each time.
**Salinity Lab:**

1. Place students into groups of three or four.
2. Provide each group with two beakers.
3. Have each group weigh beaker one and two and record weights.
4. Place 50 ml of freshwater into beaker one.
5. Place 50 ml of saltwater (35 ppt) into beaker two; weigh each beaker again and record weights.
6. Place each beaker under a heat lamp overnight until all the water has evaporated.
7. The following day weigh each beaker and record results.
8. There should be little to no difference in weight for beaker one; determine the weight fraction of salt (salinity) of seawater based on weight differences in beaker two.

**Temperature and Density:**

1. Provide each group with a plastic wine glass.
2. Have students place as many ice cubes as possible in a glass full of water until the water level is at the edge of the glass (water looks as if it is about to overflow).
3. Have students hypothesize whether or not the water will overflow if the ice melts completely (note: it should not).
4. Explain that when water freezes, a lattice is formed and the molecules are not as close together as in fluid water; therefore, ice is less dense than water and floats.

**POSSIBLE EXTENSION**

- Create water color paintings. Show designs created by applying different volumes of water and salt to the water color paint to the class.
- Determine how varying densities (specifically salinity) affect individual cells and entire organisms. Discovery-Method Lab -- Experimenting to determine the best salinity to grow brine-shrimp (sea monkey) eggs.
- Complete a creative writing assignment: "You are a salesman trying to sell water to a planet where the inhabitants have never seen water but could benefit greatly from it."

**TEACHER EVALUATION**

Administer and grade a test on the chemical properties of water.
- Explain how ice floats.
- If one swimming pool is filled with freshwater, and another pool is filled with saltwater, in which pool would you be the "better" swimmer? Explain.
Student Performance:
- Observe student performance in the laboratory setting and review science journals.
- Observe student responses during class discussions.
- Test students on concepts.
RESOURCES


http://people.hofstra.edu/j_b_bennington/33notes/coastal_landforms.html

http://www.physicalgeography.net/fundamentals/10ac.html

http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/coastal_systems/coastal_landforms_and_processes.html

http://oceanservice.noaa.gov/education/kits/currents/media/supp_cur03a.html

http://www.uwgb.edu/DutchS/EarthSC102Notes/102Marine%20Geology.HTM

http://coastalcare.org/educate/waves/

http://www.britannica.com/EBchecked/topic/123147/coastal-landform

http://www.yourclimatyourlife.org.uk/a_coasts_dep.html

http://www.whoi.edu/seagrant/education/focalpoints/landforms.html


http://www.coast-nopp.org/index.html