

Introduction

Winds generate surface currents. They influence coastal climate and provide nutrients that affect the abundance of algae and other marine life in surface waters. Winds also produce waves that carry energy from storms to distant shores, where their impact erodes the land. In some areas, density differences create deep-ocean circulation, which is important for ocean mixing and recycling nutrients. In addition, the Moon and the Sun produce tides, which periodically raise and lower average sea level.

Circulation of the ocean

Ocean currents are masses of ocean water that flow from one place to another. The amount of water can be large or small, currents can be at the surface or deep below. The currents that are generated involve water masses in motion.

Surface currents develop from friction between the ocean and the wind that blows across its surface. Some of these are short-lived and affect only small areas. Such water movements are responses to local or seasonal influences. Other surface currents are relatively permanent phenomena that extend over large portions of the oceans.

Major horizontal movements of surface waters are closely related to the global pattern of prevailing winds. It is also strongly influenced by the distribution of major landmasses. Other factors that affect surface current patterns include gravity, friction, and the Coriolis Effect.

Winds can also cause vertical water movements. Upwelling, the rising of cold water from deeper layers to replace warmer surface water, is a common wind-induced vertical movement.

The Shoreline: A Dynamic Interface

The restless nature of the ocean's water is noticeable along the shore—the dynamic interface among air, land, and sea. An **interface** is a common boundary where different parts of a system interact. We can see the rhythmic rise and fall of tides and observe waves rolling in and breaking. The waves may be low and gentle. At other times they pound the shore.

Shorelines are dynamic environments. Their topography, geologic makeup, and climate vary greatly from place to place. Continental and oceanic processes converge along coasts to create landscapes that frequently undergo rapid change. Sites of deposition of sediments are transition zones between marine and continental environments.

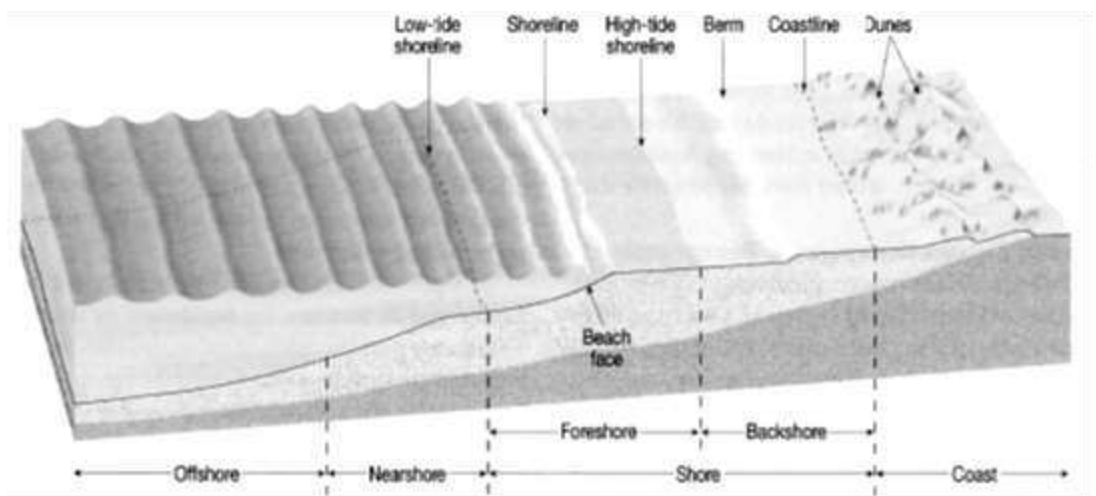
The shoreline is constantly being modified by waves. Crashing surf can erode the adjacent land. Wave activity also moves sediment toward and away from the shore as well as along it. This activity sometimes produces narrow sandbars - frequently change size and shape as storm waves come and go.

The shore has a complex character that results from multiple geologic processes. All coastal areas were affected by the worldwide rise in sea level that accompanied the melting of glaciers at the close of the Pleistocene epoch. As the sea encroached landward, the shoreline retreated, superimposed upon existing landscapes. The previously formed landscapes had resulted from diverse processes - stream erosion, glaciation, volcanic activity, and the forces of mountain building.

Today, the coastal zone is experiencing intensive human activity. People often treat the shoreline as if it were a stable platform on which structures can safely be built. Many coastal landforms, especially beaches and barrier islands, are relatively fragile, short-lived features that are inappropriate sites for development.

Coastal Zone Features

Shoreline: The shoreline is the line that marks the contact between land and sea. Each day, as tides rise and fall, the position of the shoreline migrates. Over



longer time spans, the average position of the shoreline gradually shifts as sea level rises or falls.

Shore: The area that extends between the lowest tide level and the highest elevation on land that is affected by storm waves. The shore is divided into the foreshore and the backshore.

Foreshore: It is the area exposed when the tide is out (low tide) and submerged when the tide is in (high tide).

Backshore is landward of the high-tide shoreline. It is usually dry, being affected by waves only during storms.

Two other zones – i) The nearshore zone lies between the low-tide shoreline and the line where waves break at low tide. ii) Seaward of the nearshore zone is the offshore zone.

Coast: The coast extends inland from the shore as far as ocean-related features can be found. The ***coastline*** marks the coast's seaward edge, whereas the inland boundary is not always obvious or easy to determine.

Beaches

A beach is an accumulation of sediment found along the landward margin of the ocean or a lake. Along straight coasts, beaches may extend for tens or hundreds of km. Where coasts are irregular, beach formation may be confined to the relatively quiet waters of bays.

Beaches are composed of whatever material is locally abundant. The sediment for some beaches is derived from the erosion of adjacent cliffs or nearby coastal mountains. Other beaches are built from sediment delivered to the coast by rivers.



Beach on Florida's Sanibel Island - shells and shell fragments. The black sands at the beach on Hawaii were derived from dark volcanic rock.

Composition: Mineral makeup of many beaches is dominated by durable quartz grains, other minerals may also be dominant. Where there are no mountains or other sources of rock-forming minerals nearby, most beaches are composed of shell fragments and the remains of organisms that live in coastal waters. Some beaches on volcanic islands in the open ocean are composed

of weathered grains of the basaltic lava that comprise the islands, or of coarse debris eroded from coral reefs.

Berms: Beaches consist of one or more berms, which are relatively flat platforms often composed of sand that are adjacent to coastal dunes or cliffs and marked by a change in slope at the seaward edge.

Beach face: The wet sloping surface that extends from the berm to the shoreline.

The material that comprises the beach does not stay in one place; crashing waves are constantly moving it. Thus, beaches can be thought of as material in transit along the shore.

Waves

Ocean waves are energy traveling along the interface between ocean and atmosphere. They also transfer energy from a storm far out at sea over distances of several thousand kilometers.

While observing waves, we are watching energy travel through a medium (water). If we impart energy to the water, the waves we see are just the visible evidence of the energy passing through.

Wind-generated waves provide most of the energy that shapes and modifies shorelines. Where the land and sea meet, waves that may have travelled unimpeded for hundreds or thousands of kilometres suddenly encounter a barrier that will not allow them to advance farther and must absorb their energy.

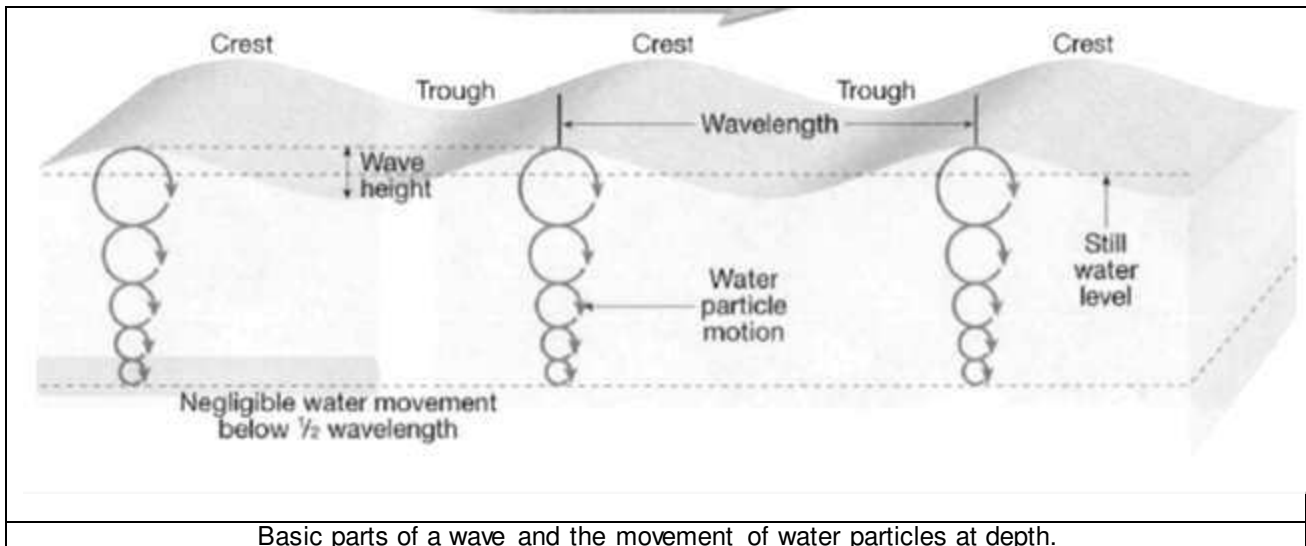
Formation of Waves: Most ocean waves derive their energy and motion from the wind. When a breeze is less than 3 kilometers per hour, only wavelets appear. At greater wind speeds, more stable waves gradually form and advance with the wind.

Characteristics of ocean waves: The tops of the waves are the *crests*, which are separated by *troughs*.

Halfway between the crests and troughs is the *still water level*, the level that the water would occupy if there were no waves.

The vertical distance between trough and crest is called the *wave height*, and the horizontal distance between successive crests (or troughs) is the *wavelength*.

The time it takes one full wave - one wavelength - to pass a fixed position is the *wave period*.



Basic parts of a wave and the movement of water particles at depth.

The height, length, and period that are eventually achieved by a wave depend on three factors: (1) wind speed; (2) length of time the wind has blown; and (3) fetch, the distance that wind has travelled across open water.

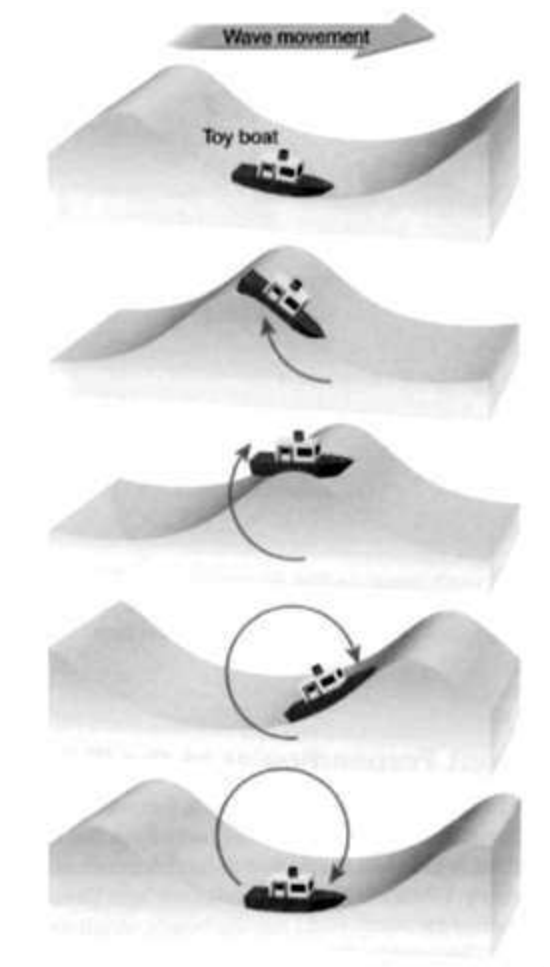
As the quantity of energy transferred from the wind to the water increases, both the height and steepness of the waves also increase.

Circular Orbital Motion: Waves can travel great distances across ocean basins. The water itself doesn't travel the entire distance, but the wave form does. As the wave travels, the water passes the energy along by moving in a circle - circular orbital motion.

An object floating in waves shows that it moves up and down and also slightly forward and backward with each successive wave.

The boat moves in a circle and it returns to essentially the same place. Circular orbital motion allows a waveform (the wave's shape) to move forward through the water while the individual water particles that transmit the wave move around in a circle.

The energy contributed by the wind to the water is also transmitted downward. However, beneath the surface the circular motion rapidly diminishes until, at a depth measured from still water level, the movement of water particles becomes negligible. This depth is known as the **wave base**.



Waves in the Surf Zone: As long as a wave is in deep water, it is unaffected by water depth. However, when a wave approaches the shore, the water becomes shallower and influences wave behaviour. The wave oscillations reaches the sea floor. Such depths interfere with water movement at the base of the wave and slow its advance (Figure, center).

As a wave advances toward the shore, the slightly faster waves farther out to sea catch up, decreasing the wavelength. As the speed and length of the wave diminish, the wave steadily grows higher. Finally, a critical point is reached when the wave is too steep to support itself and the wave front collapses, or breaks (Figure, right), causing water to advance up the shore. The turbulent water created by breaking waves is called surf.

On the landward margin of the surf zone, the turbulent sheet of water from collapsing breakers - **Swash**, moves up the slope of the beach.

When the energy of the swash has been expended, the water flows back down the beach toward the surf zone as **backwash**.

The cracks and crevices are quickly opened in cliffs, coastal structures that are subjected to these enormous shocks. Water is forced into every opening, causing air in the cracks to become highly compressed by the thrust of crashing waves. When the wave subsides, the air expands rapidly, dislodging rock fragments and enlarging and extending fractures.



A. Abrasion can be intense in the surf zone. Smooth rounded stones along the shore
B. Sandstone Cliff undercut by wave erosion

Sand Movement on the Beach

The energy from breaking waves often causes large quantities of sand to move along the beach face and in the surf zone roughly parallel to the shoreline. Wave energy also causes sand to move perpendicular to (toward and away from) the shoreline.

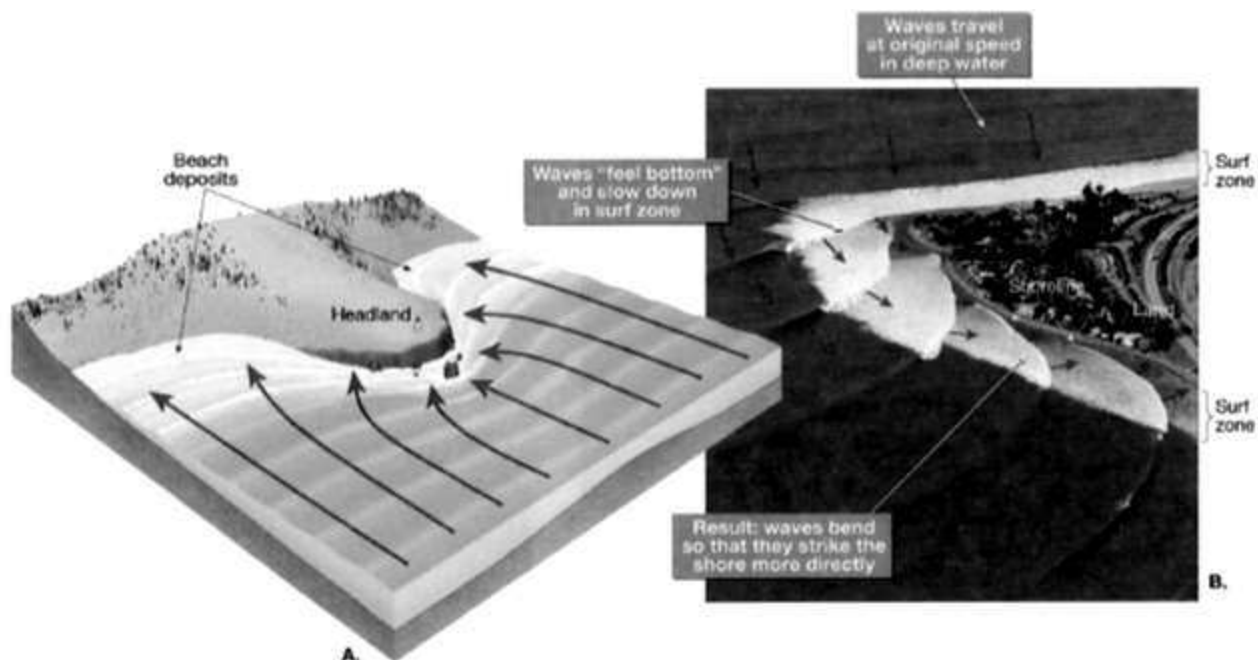
Wave activity erodes and narrows the berm. A wide berm that may have taken months to build can be dramatically narrowed in just a few hours by the high-energy waves created by a strong storm.

Wave Refraction

The bending of waves, called wave refraction plays an important part in shoreline processes (Figure). It affects the distribution of energy along the shore and thus strongly influences where and to what degree erosion, sediment transport, and deposition will take place.

Most waves move toward the shore at a slight angle. However, when they reach the shallow water of a smoothly sloping bottom, the wave crests are refracted (bent) and tend to become parallel to the shore.

Cause: Bending occurs because the part of the wave nearest the shore touches bottom and slows first, whereas the part of the wave that is still in deep water continues forward at its full speed. The net result is a wave that approaches nearly parallel to the shore regardless of its original orientation.



As waves first touch bottom in the shallows along an irregular coast, they are slowed, causing them to bend (refract) and align nearly parallel to the shoreline. A. In this diagram, waves approach nearly straight on. Refraction causes wave energy to be concentrated at headlands (resulting in erosion) and dispersed in bays (resulting in deposition). B. Wave refraction at Rincon Point, California.

Effect: Because of refraction, wave energy is concentrated against the sides and ends of headlands that project into the water. Wave attack is weakened in bays. This differential wave attack along irregular coastlines is illustrated in Figure. As the waves reach the shallow water in front of the headland before they reach adjacent bays, they are bent more nearly parallel to the protruding land and strike it from all three sides.

By contrast, refraction in the bays causes waves to diverge and expend less energy. In these zones of weakened wave activity, sediments can accumulate and form sandy beaches. Over a long period, erosion of the headlands and deposition in the bays will straighten an irregular shoreline.

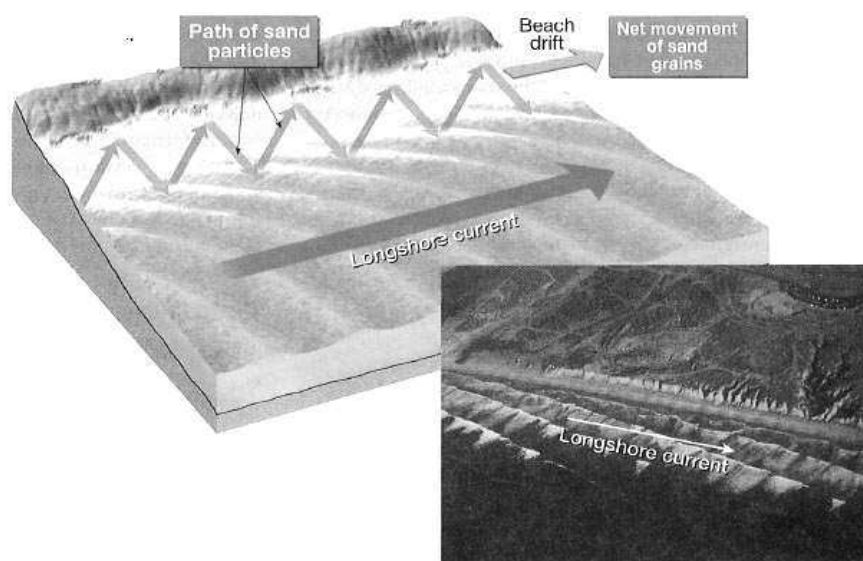
Longshore Transport

Although waves are refracted, most still reach the shore at a slight angle. Consequently, the uprush of water from each breaking wave (the swash) is at a slight angle to the shoreline. However, the backwash is straight down the slope of the beach.

The effect of this pattern of water movement is to transport sediment in a zigzag pattern along the beach face (figure). This movement is called **beach drift**. It can transport sand and pebbles hundreds or even thousands of meters daily.

Because the water here is turbulent, these longshore currents easily move the fine suspended sand and roll larger sand and gravel along the bottom.

Beach drift and longshore currents, however, move in a zigzag pattern, whereas rivers flow mostly in a turbulent, swirling fashion. Additionally, the direction of flow of longshore currents along a shoreline can change, whereas rivers flow in the same direction (downhill).



Beach drift and longshore currents are created by obliquely breaking waves.

Rip Currents

Rip currents are concentrated movements of water that flow in the opposite direction from breaking waves. Sometimes a portion of the returning water moves seaward in the form of surface rip currents.

These currents do not travel far beyond the surf zone before breaking up and can be recognized by the way they interfere with incoming waves or by the sediment that is often suspended within the rip current (Figure). They can be a hazard to swimmers, who, if caught in them, can be carried out away from shore. The best strategy for exiting a rip current is to swim parallel to the shore for a few tens of meters.



A rip current (arrow) extends outward from shore and interferes with incoming waves.

Shoreline Features

The shoreline features vary depending on the type of rocks exposed along the shore, the intensity of waves, the nature of coastal currents, and whether the coast is stable, sinking, or rising. Features that owe their origin primarily to the work of erosion are called erosional features, whereas deposits of sediment produce depositional features.

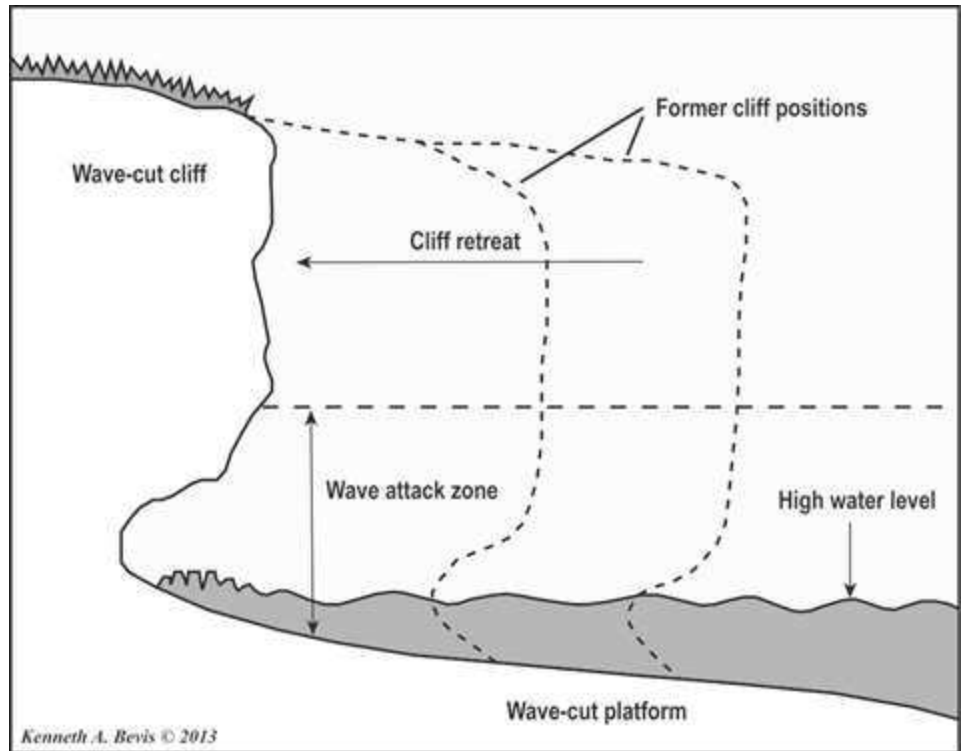
Erosional Features

Wave-cut cliffs:

Originate due to the cutting action of the surf against the base of coastal land.

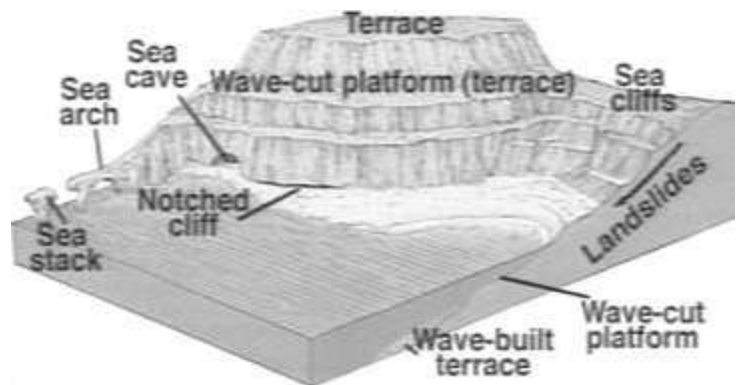
Wave-cut platform:

As erosion progresses, rocks overhanging the notch at the base of the cliff crumble into the surf and the cliff retreats. A relatively flat, bench like surface, called a wave-cut platform, is left behind by the receding cliff. The platform broadens as wave

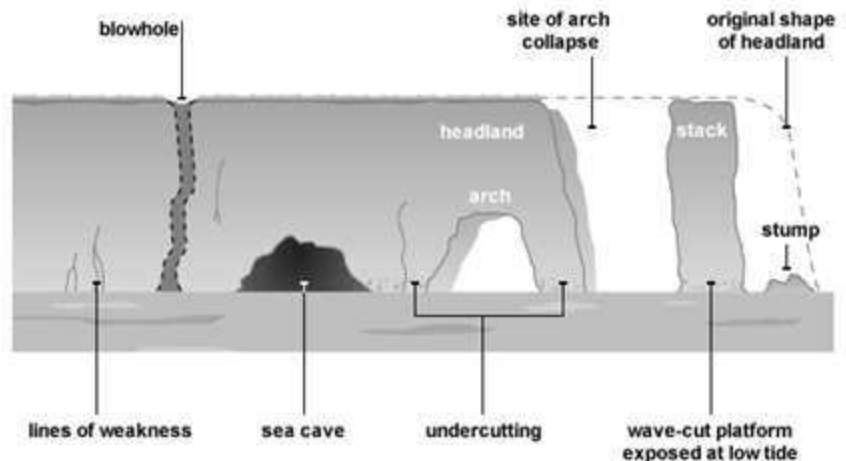


attack continues. Some debris produced by the breaking waves may remain along the water's edge as sediment on the beach, while the remainder is transported farther seaward.

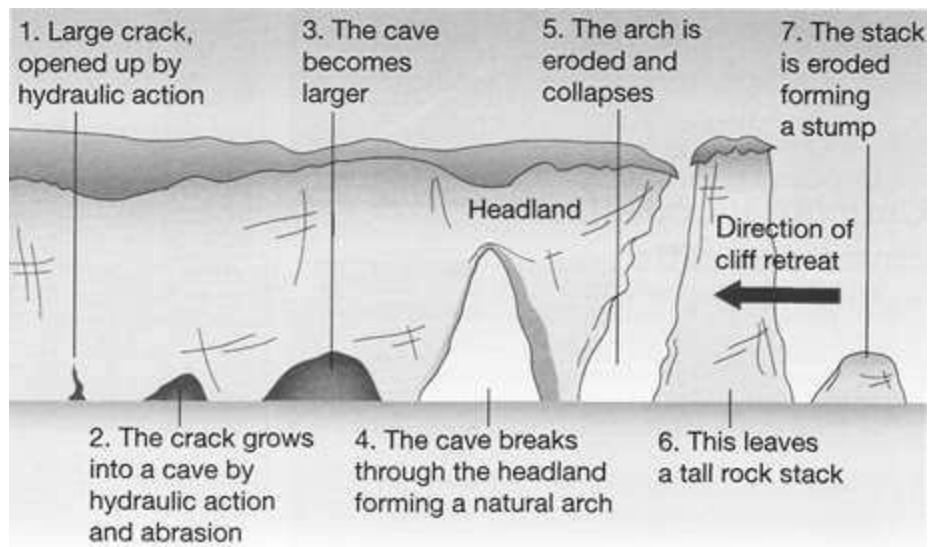
Marine Terrace: If a wave-cut platform is uplifted above sea level by tectonic forces, it becomes a marine terrace (Figure). Marine terraces are easily recognized by their gentle seaward-sloping shape and are often desirable sites for coastal roads, buildings, or agriculture.



Sea cave & Sea arch: Headlands that extend into the sea are vigorously attacked by waves because of refraction. The surf erodes the rock selectively, wearing away the softer or more highly fractured rock at the fastest rate. At first, sea caves may form. When caves on opposite sides of a headland unite, a sea arch results.



Sea Stack: When the arch falls in, leave an isolated remnant, or sea stack, on the wave-cut platform (Fig). In time, it too will be consumed by the action of the waves.



Tide pools, or rock pools: Rocky pools on the sea shore which are filled with seawater. Many of these pools exist as separate pools only at low tide. Tidal pools exist in the intertidal zones. These zones are submerged by the sea at high tides and during storms, and may receive spray from wave action. Tide pools provide a home for hardy organisms such as starfish, mussels.



Blowhole: Formed as sea caves grow landwards and upwards into vertical shafts and expose themselves towards the surface, which can result in blasts of water from the top of the blowhole. Blowholes are likely to occur in areas where there are crevices. As powerful waves hit the coast, water rushes into these crevices and bursts out in a high pressured release. It is often accompanied by a loud noise and wide spray.



Depositional Features

Beaches: Beaches are the most significant accumulations of sediments along coasts. They form in the zone where wave processes affect coastal sediments. In composition, they consist of a range of organic and inorganic particles, mostly sands or shingle or pebbles.



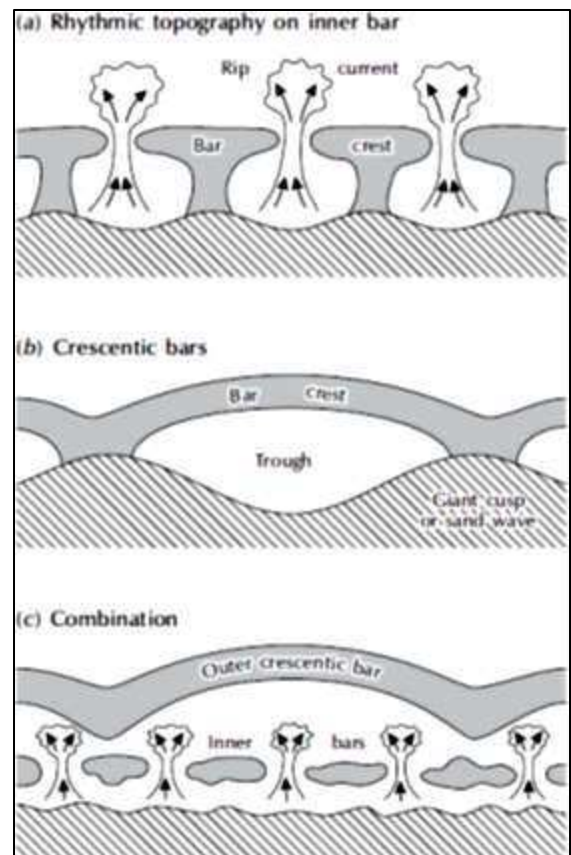
Pebble beaches are more common at middle and high latitudes, where pebbles are supplied by coarse glacial and periglacial debris. **Sand beaches** are prevalent along tropical coasts, probably because rivers carry predominantly fine sediments and cliff erosion donates little to littoral deposits in the tropics. In the tropics, beach sediments may form **beachrock** through the precipitation of calcium carbonate.

The most inland point of the beach, especially a storm beach, is the **berm**, which marks the landward limit of wave swash.

The beach profile changes as wave properties run through an annual cycle.

Beach cusps: In the aerial view, beaches possess several distinctive curved plan-forms that show a series of regularly spaced secondary curved features. The primary and secondary features range in size from metres to more than 100 km. **Beach cusps** are crescent-shaped scallops lying parallel to the shore on the upper beach face and along the seaward margins of the berm with a spacing of less than about 25 m. They form when waves approach at right-angles to the shore, although some scientists think that oblique waves cause them.

Inner and outer crescentic bars: Wavelengths of the majority are somewhere between 200 and 500 m. Inner bars are short-lived and associated with rip currents. Their horns often extend across surf-zone shoals into very large shoreline cusps



known as sand waves, which lie parallel to the shore. Outer crescentic bars may be detached from the shore and are more stable than inner crescentic bars.

Accumulation landforms occur where the deposition of sediment is favoured. Suitable sites include places where obstructions interrupt longshore flow, where the coast abruptly changes direction, and in sheltered zones ('wave shadows') between islands and the mainland.

May be simply classified by their degree of attachment to the land.

Form	Name	Comment
<i>Beaches attached to land at one end</i>		
Length greater than width	Barrier spit	A continuation of the original coast or running parallel to the coast ^a
	Comet-tail spit	Stretch from the leeward side of an island
Length less than width	Arrow	Stretch from the coast at high angles ^b
	Foreland (cusped spit)	—
<i>Beaches attached to land at two ends</i>		
Looped forms stretching out from the coast	Looped barriers	Stretch from the leeward side of an island
	Looped spit	A spit curving back on to the land
Connecting islands with islands or islands with the mainland (tombolos)	Double-fringing spit	Two joined spits or tombolos
	Tombolo	Single form
	Y-tombolo	Single beach looped at one end
	Double tombolo	Two beaches
Closing off a bay or estuary (barrier beaches)	Baymouth barrier	At the mouth (front) of a bay
	Midbay barrier	Between the head and mouth of a bay
	Bayhead barrier	At the head (back) of a bay
<i>Forms detached from the land</i>		
A discrete, elongated segment	Barrier island	No connection with the land. Runs parallel to the coast. Often recurved at both ends and backed by a lagoon or swamp

Barrier spits: often form at the mouths of estuaries and other places where the coast suddenly changes direction. Sediment moving along the shore is laid down and tends to extend along the original line of the coast. Some spits project into the ocean and then curve round to run parallel to the coast.

Recurved spits have their ends curving sharply away from incoming waves towards the land, and **compound recurved spits** have a series of landward-turning recurved sections along their inner side.

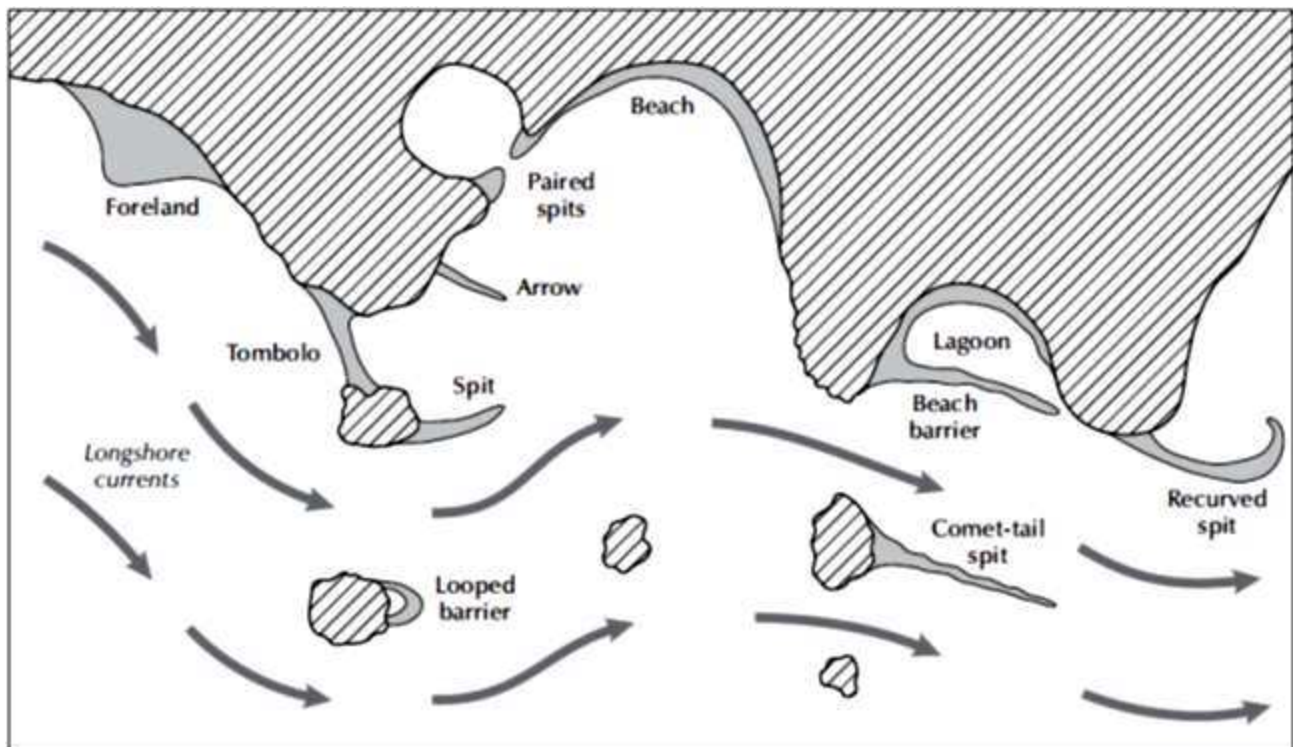
Sometimes spits grow towards one another - such **paired spits** are found at the entrance to Poole Harbour, in Dorset, England, where the northern spit, the Sandbanks peninsula, has grown towards the southern spit, the South Haven peninsula.

Forelands or cusped spits: tend to be less protuberant than spits. They grow out from coasts, making them more irregular.

Tombolos: **Tombolos** are wave-built ridges of beach material connecting islands to the mainland or islands to islands. They come in single and double varieties.

Tombolos tend to grow in the lee of islands, where a protection is afforded from strong wave action and where waves are refracted and convergent.

A **tombolino** or **tie-bar** is a tombolo that is partly or completely submerged by the sea at high tide.



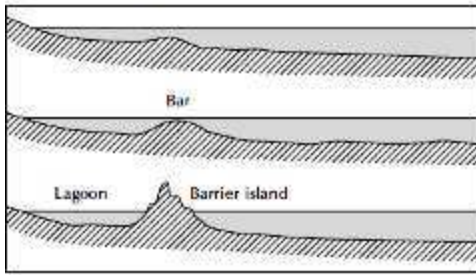
Coastal barriers and barrier islands

Formed on beach material deposited offshore, or across the mouths of inlets and embayments. They extend above the level of the highest tides, and enclose lagoons or swamps. They differ from bars, which are submerged during at least part of the tidal cycle.

Coastal barriers: Built of sand or gravel. Looped barriers and cusped barriers result from growing spits touching an opposite shore, another spit, or an island.

Barrier beaches seal off or almost seal off the fronts, middles, or heads of bays and inlets. Product of single spits growing across bays or from pairs of converging spits built out by opposing longshore currents. They may also possibly form by sediment carried into bays by wave action independently of longshore movement.

(a) Submarine bar

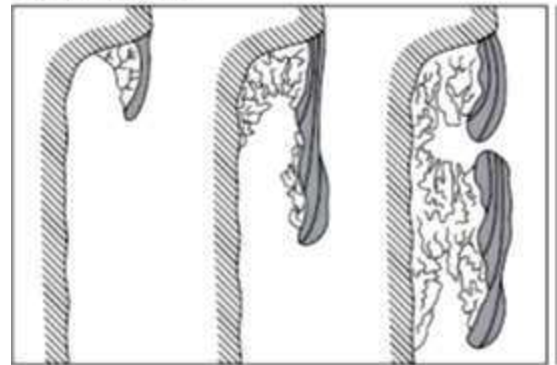


Barrier islands: Elongated offshore ridges of sand paralleling the mainland coast and separated for almost their entire length by lagoons, swamps, or other shallow-

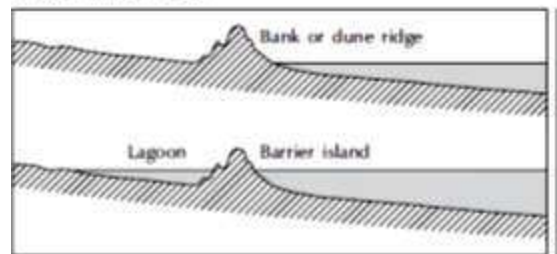
water bodies, which are connected to the sea by channels or tidal inlets between islands. Also called **barrier beaches**, **barrier bars**, and **offshore bars**. Sections of long barrier-island chains may be large spits or barrier beaches still attached to land at one end.

They may have been formed by the rising sea levels over the last 10,000 years and perhaps have grown on former dunes, storm ridges, and berms. Lagoons formed as the land behind the old beaches was flooded. Barrier beaches may also have formed by the accumulation of sediment carried landwards by wave action as sea level rose.

(b) Spit elongation



(c) Rise in sea level



Beach Ridges: Sandy **beach ridges** mark the position of former shorelines, forming where sand or shingle have been stacked up by wave action along a prograding coast. They may be tens of metres wide, a few metres high, and several kilometres long.

Coastal dunes: Heaps of windblown sediment deposited at the edge of large lakes and seas. Generally, they are made from sediment blown off a beach to accumulate in areas sheltered from the action of waves and currents. They shield the land from extreme waves and tides and are stores of sediment that may replenish beaches during and after storms. Dunes may also occur on cliff tops.

Coastal dunes are mainly composed of medium-sized to fine quartz grains that are well to very well sorted. Calcium carbonate is common in warm tropical and Mediterranean regions.

Blowouts: Shallow, saucer-shaped depressions or deep and elongated troughs occurring in dune fields. They are begun by wave erosion, a lack of aeolian deposition, or deflation of vegetation or poorly vegetated areas. Once started, they are enlarged by wind scour and slumping, and avalanching on the sidewalls.