Title
Nearshore Processes

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Nearshore processes

Processes that shape the shore features of coastlines and begin the mixing, sorting, and transportation of sediments and runoff from land. In particular, the processes include those interactions among waves, winds, tides, currents, and land that relate to the waters, sediments, and organisms of the nearshore portions of the continental shelf. The nearshore extends from the landward limit of storm-wave influence, seaward to depths where wave shoaling begins. *See* COASTAL LANDFORMS.

The energy for nearshore processes comes from the sea and is produced by the force of winds blowing over the ocean, by the gravitational attraction of Moon and Sun acting on the mass of the ocean, and by various impulsive disturbances at the atmospheric and terrestrial boundaries of the ocean. These forces produce waves and currents that transport energy toward the coast. The configuration of the landmass and adjacent shelves modifies and focuses the flow of energy and determines the intensity of wave and current action in coastal waters. Rivers and winds transport erosion products from the land to the coast, where they are sorted and dispersed by waves and currents.

In temperate latitudes, the dispersive mechanisms operative in the nearshore waters of oceans, bays, and lakes are all quite similar, differing only in intensity and scale, and are determined primarily by the nature of the wave action and the dimensions of the surfzone. The most important mechanisms are the orbital motion of the waves, the basic mechanism by which wave energy is expended on the shallow sea bottom, and the currents of the nearshore circulation system that produce a continuous interchange of water between the surfzone and offshore areas. The dispersion of water and sediments near the coast and the formation and erosion of sandy beaches are some of the common manifestations of nearshore processes.

Erosional and depositional nearshore processes play an important role in determining the configuration of coastlines. Whether deposition or erosion will be predominant in any particular place depends upon a number of interrelated factors: the amount of available beach sand and the location of its source; the configuration of the coastline and of the adjoining ocean floor; and the effects of wave, current, wind, and tidal action. The establishment and persistence of natural sand beaches are often the result of a delicate balance among a number of these factors, and any changes, natural or anthropogenic, tend to upset this equilibrium. *See* DEPOSITIONAL SYSTEMS AND ENVIRONMENTS; EROSION.

Waves. Waves and the currents that they generate are the most important factors in the transportation and deposition of nearshore sediments. Waves are effective in moving material along the bottom and in placing it in suspension for weaker currents to transport. In the absence of beaches, the direct force of the breaking waves erodes cliffs and sea walls.

Wave action along most coasts is seasonal, responding to changing wind systems over the waters where the waves are generated. The height and period of the waves depend on the speed and duration of the winds generating them, and the fetch, or distance, over which the wind blows. Consequently, the nature and intensity of wave attack against coastlines vary with the size of the water body, as well as with latitude and exposure. Waves generated by winter storms in the Southern Hemisphere of the Pacific Ocean may travel 10,000 km (6000 mi) before breaking on the shores of California, where they are common summer waves for the Northern Hemisphere.

The profiles of ocean waves in deep water are long and low, approaching a sinusoidal form. As the waves enter shallow water, the propagation speed and wavelength decrease, the wave steepens, and the wave height increases until the wave train consists of peaked crests separated by flat troughs. Near the breaker zone, the process of steepening is accelerated so that the breaking wave usually attains a height greater than the deep-water wave. This transformation is particularly pronounced for long-period waves from a distant storm. However, the profiles of local storm waves and the waves generated over small water bodies, such as lakes, show considerable steepness even in deep water.

Wave shoaling, that is, the shallow-water transformation of waves, commences at the depth where the waves “feel bottom.” This depth is about one-half the deep-water wavelength, where the wavelength is the horizontal distance from wave crest to crest. Upon entering shallow water, waves are also subjected to refraction, a process in which the wave crests tend to parallel the depth contours, and to wave diffraction, which causes a flow of energy along the wave crest. For straight coasts with parallel contours, refraction decreases the angle between the approaching wave and the coast, and causes a spreading of the energy along the crests. The wave height is decreased by this process, but the effect is uniform along the coast (**Fig. 1**). The amount of wave refraction and diffraction and the consequent change in wave height and direction at any point along the coast is a function of wave period, direction of approach, and the configuration of the bottom topography. *See* OCEAN WAVES; WAVE MOTION IN LIQUIDS.

Nearshore circulation. When waves break so that there is an angle between the crest of the breaking wave and the beach, the momentum of the breaking wave has a component along the beach in the direction of wave propagation. This results in the generation of longshore currents that flow parallel to the beach inside the breaker zone (**Fig. 2*a***). After flowing parallel to the beach as longshore currents, the water returns seaward along relatively narrow zones as rip currents. The net onshore transport of water by wave action in the breaker zone, the lateral transport inside the breaker zone by longshore currents, the seaward return of the flow through the surfzone by rip currents, and the longshore movement in the

Fig. 1. Longshore currents, generated when waves approach the beach at an angle. At Oceanside, California, the longshore current is flowing toward the observer. (*Department of Engineering, University of California, Berkeley*)

expanding head of the rip current together constitute the nearshore circulation system. The pattern that results from this circulation commonly takes the form of an eddy or cell with a vertical axis. The dimensions of the cell are related to the width of the surfzone and the spacing between rip currents. The spacing between rip currents is usually two to eight times the width of the surfzone.

When waves break with their crests parallel to a straight beach, the flow pattern of the nearshore circulation cell becomes symmetrical (Fig. 2*b*). Longshore currents occur within each cell, but there is little longshore exchange of water or sediment from cell to cell.

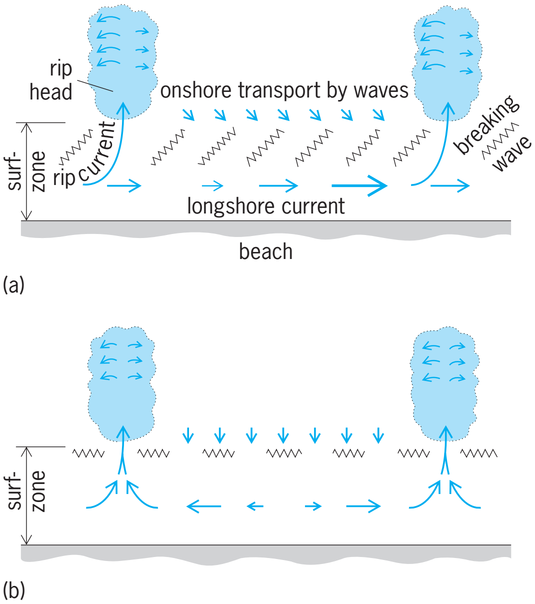
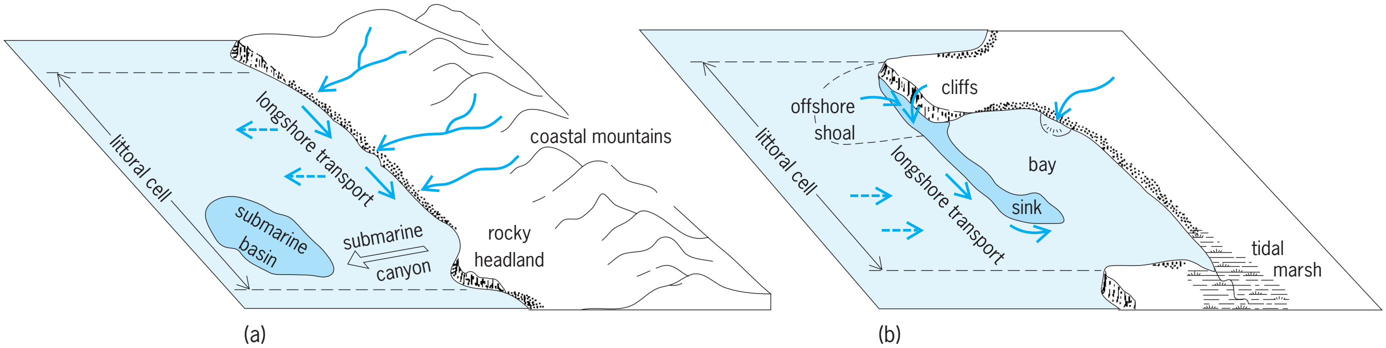


Fig. 2. Definition sketches for nearshore circulation cells. (*a*) Asymmetrical cell for breakers oblique to the shore. (*b*) Symmetrical cell for breakers parallel to the shore.

The nearshore cirulation system produces a continuous interchange between the waters of the surf and offshore zones, acting as a distributing mechanism for nutrients and as a dispersing mechanism for land runoff. Offshore water is transported into the surfzone by breaking waves, and particulate matter is filtered out on the sands of the beach face. Runoff from land and pollutants introduced into the surfzone are carried along the shore and mixed with the offshore waters by the seaward-flowing rip currents. These currents are a danger to swimmers who may be unexpectedly carried seaward. Longshore currents may attain velocities in excess of 2.5 m/s (8 ft/s), while rip current velocities in excess of 1.5 m/s (5ft/s) have been measured. Periodicity or fluctuation of current velocity and direction is a characteristic of flow in the nearshore system. This variability is primarily due to the grouping of high waves followed by low waves, a phenomenon called surf beat that gives rise to a pulsation of water level in the surfzone.

Formation of circulation cells. Nearshore circulation cells result from differences in mean water level in the surfzone associated with changes in breaker height along the beach. Waves transmit momentum in the direction of their travel, and their passage through water produces second-order pressure fields that change the mean water level near the shore. Near the breakpoint, the presence of the pressure field produces a decrease in mean water level (wave setdown) that is proportional to the square of the wave height and, for waves near the surfzone, has a maximum value that is about one-sixteenth that of the breaker height. Shoreward of the breakpoint, the onshore flow of momentum against the beach produces a rise in mean water level over the beach face, called setup.

If the wave height varies along a beach, the setup will also vary, causing a longshore gradient in mean water level within the surfzone. Longshore currents flow from regions of high water to regions of low water, and thus flow away from zones of high waves. The longshore currents flow seaward as rip currents where the breakers are lower. Pronounced changes in breaker height along beaches usually result from wave refraction over irregular offshore topography. However, on a smaller scale, uniformly spaced zones of high and low breakers occur along straight beaches with parallel offshore contours. It has been shown that these alternate zones of high and low waves are due to the interaction of the incident waves traveling toward the beach from deep water with one of the many possible modes of oscillation of the nearshore zone known as edge waves. Edge waves are trapped modes of oscillation that travel along the shore. Circulation in the nearshore cell is enhanced by edge waves having the period of the incident waves, or that of their surf beat, because these interactions produce alternate zones of high and low



(a)

(b)

Fig. 3. Typical (*a*) collision and (*b*) trailing-edge coasts and their littoral cells. Solid arrows show sediment transport paths; dotted arrows indicate occasional onshore and offshore transport modes. (*After D. L. Inman, Types of coastal zones: Similarities and differences, in National Research Council, Environmental Science in the Coastal Zone, National Academy Press, 1994*)

breakers whose positions are stationary along the beach. It appears that the edge waves can be standing or progressive. In either case, the spacing between zones of high waves (and hence between rip currents) is related to the wavelength of the edge wave.

Headlands, breakwaters, and piers influence the circulation pattern and alter the direction of the currents flowing along the shore. In general, these obstructions determine the position of one side of the circulation cell. In places where a relatively straight beach is terminated on the down-current side by points or other obstructions, a pronounced rip current extends seaward. During periods of large waves having a diagonal approach, these rip currents can be traced seaward for distances of 1.6 km (1 mi) or more.

Types of coasts. The geologic setting and the exposure to waves are the two most significant factors in determining nearshore processes. The large-scale features of a coast are associated with its position relative to the edges of the Earth's moving tectonic plates. Accordingly, plate tectonics provides a convenient basis for the first-order classification of coasts, with longshore dimensions of about 1000 km (600 mi). Tectonic classification leads to the definition of three general types: collision coasts, trailing-edge coasts, and marginal seacoasts. *See* PLATE TECTONICS.

Collision coasts. These coasts occur along active plate margins, where the two plates are in collision or impinging upon each other (**Fig. 3*a***). This area is one of crustal compression and consumption. These coasts are characterized by narrow continental shelves bordered by deep basins and ocean trenches. Submarine canyons cut across the narrow shelves and enter deep water. The shore is often rugged and backed by seacliffs and coastal mountain ranges; earthquakes and volcanism are common. The coastal mountains often contain elevated wave-cut platforms and sea terraces representing former relations between the level of the sea and the land. The west coasts of the Americas are typical examples of collision coasts. *See* SUBMARINE CANYON.

Trailing-edge coasts. These occur on the trailing edge of a landmass that moves with the plate (Fig. 3*b*). They are thus situated upon passive continental margins that form the stable portion of the plate, well away from the plate boundaries. The east coasts of North and South America are examples of mature, trailing-edge coasts. These coasts typically have broad continental shelves that slope into deeper water without a bordering trench. The coastal plain is also typically wide and low-lying and usually contains lagoons and barrier islands, as on the eastern coasts of the Americas. *See* BARRIER ISLANDS; COASTAL PLAIN; CONTINENTAL MARGIN.

Marginal seacoasts. These coasts develop along the shores of seas enclosed by continents and island arcs. These coasts are typically bordered by wide shelves and shallow seas. The coastal plains of marginal seacoasts vary in width and may be bordered by hills and low mountains. Rivers entering the sea along marginal seacoasts often develop extensive deltas because of the reduced intensity of wave action associated with small bodies of water. Typical marginal seacoasts border the South China and East China seas, the Sea of Okhotsk, the Mediterranean Sea, and the Gulf of Mexico. *See* BASIN; DELTA.

Other types. A complete classification would also include coasts formed by other agents, such as glacial scour, ice-push, and reef-building organisms, adding two other types of coast: cryogenic and biogenic. Common examples of these two coastal types are arctic coasts and coral reef coasts.

Beaches. Beaches consist of transient clastic material (unconsolidated fragments) that reposes near the interface between the land and the sea and is subject to wave action. The material is in dynamic repose rather than in a stable deposit, and thus the width and thickness of beaches is subject to rapid fluctuations, depending upon the amount and rigor of erosion and transportation of beach material. Beaches along collision coasts are essentially long rivers of sand that are moved by waves and currents and are derived from the material eroded from the coast and brought to the sea by streams. The coast may be cliffed (Fig. 3*a*), or it may contain a ridge of windblown sand dunes

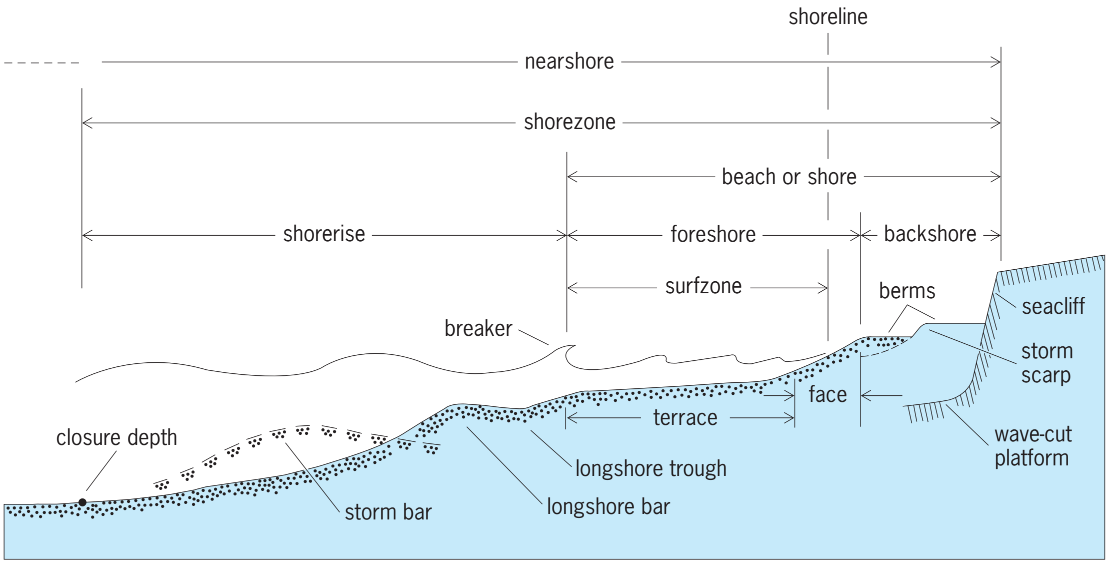


Fig. 4. Beach profile, showing characteristic features.

and be backed by marshes and water (Fig. 3*b*). Along many low sandy coasts, such as the east and Gulf coasts of the United States, the beach is separated from the mainland by water or by a natural coastal canal. Such beaches are called barrier islands. Barrier beaches are "braided" forms of the "river of sand" with transgressive rollover caused by sea-level rise and washover processes. A beach that extends from land and terminates in open water is referred to as a spit, while a beach that connects an island or rock to the mainland or another island is a tombolo.

Beach nomenclature. While differing in detail, beaches worldwide have certain characteristic features which allow application of a general terminology to their profile (**Fig. 4**). The beach or shore extends landward from the breakpoint bar to the effective limit of attack by storm waves. The region seaward is termed the shorerise; that landward is the coast. The coast is part of the coastal zone, which includes the continental shelf and the coast. The beach includes a backshore and foreshore. The backshore is the highest portion and is acted upon by waves only during storms. The foreshore extends from the crest of the berm to the breakpoint bar and is the active portion of the beach traversed by the broken waves and the uprush and backwash of the swash on the beach face. The foreshore consists of a steep seaward-dipping face, related to the size of the beach material and the rigor of the uprush, and of a more gentle seaward terrace, sometimes referred to as the low-tide terrace, over which the waves break and surge. In most localities the foreshore face and terrace merge into one continuous curve; in others there is a discontinuity at the toe of the beach face. The former condition is characteristic of fine sand beaches and of coasts where the wave height is equal to or greater than the tidal range. The latter is typical of coastlines where the tidal range is large compared with the wave height, as along the Patagonian coast of South America and portions of the Gulf of California. The foreshore frequently contains one or more bars and troughs that parallel the beach; these are referred to as longshore bars and longshore troughs. Longshore bars commonly form at the plunge point of the wave, and their position is thus influenced by the breaker height and the nature of the tidal fluctuation. *See* TIDE.

The shorerise is the transition between the continental shelf and the beach, and is marked by the increase in slope leading from the gently sloping shelf up to the beach proper. The shorerise extends seaward from the breakpoint bar to the closure depth that marks the seaward extent of depth changes between winter (storm) and summer beach profiles (Fig. 4). Together, the shorerise, foreshore, and backshore comprise the shorezone, which is the zone of active transport of beach material and the resulting areas of beach accretion and erosion.

Beach cycles. Waves are effective in causing sand to be transported laterally along the beach by longshore currents and in causing movements of sand from the beach to the shorerise and back again to the beach. Although these two types of transport are interrelated, for convenience longshore movement of sand is discussed separately.

Along most coasts, there is a seasonal migration of sand between the beaches and the shorerise in response to the changes in the character and direction of approach of the waves. In general, the beach face builds seaward during the small waves of summer and is cut back by high storm waves in winter. There are also shorter cycles of cut-and-fill associated with spring and neap tides and with nonseasonal waves and storms. Bottom surveys indicate that most offshore-onshore interchange of sand occurs in depths of 10–15 m (33-45 ft) but that some effects may extend to depths of 30 m (100 ft) or more.

A typical summer beach is built seaward by low waves (Fig. 4). During stormy seasons, the beach face is eroded, sometimes forming a beach scarp. Subsequent low waves build the beach face seaward again. The beach face is a depositional feature, and its highest point, the berm crest, represents the maximum height of the runup of water on the beach. The height of wave runup above still-water level is about equal to the height of the breaking wave. Since the height of the berm depends on wave height, the higher berm, if it is present, is sometimes referred to as the winter or storm berm, and the lower berm as the summer berm. The entire beach may be cut back to the underlying country rock during severe storms. Under such conditions, the waves erode the coast and form seacliffs and wave-cut platforms. These features and their terrace deposits are frequently preserved in the geologic record and serve as markers for the past relations between the levels of the sea and the land.

Mechanics of beach formation. Beaches form wherever there are waves and an adequate supply of sand or coarser material. Even anthropogenic fills and structures are effectively eroded and reformed by the waves. The initial event in the formation of a new beach from a heterogeneous sediment is the sorting of the material, with coarse material remaining on the beach and fine material being carried away. Concurrent with the sorting action, the material is rearranged, some being piled high above the water level by the runup of the waves to form the beach berm, some carried back down the face to form the foreshore terrace. In a relatively short time, the beach assumes a profile that is in equilibrium with the forces generating it.

The beach face is frequently characterized by laminations (closely spaced layers) that show slight differences in the size, shape, or density of the sand grains. The laminations parallel the beach face and represent shear sorting within the granular load as it is transported by the swash and backwash of the waves over the beach face. Detailed examination shows that each lamina of fine-grained minerals delineates the plane of shear between moving and residual sand. The mechanism concentrating the heavy fine grains at the shear plane is partly the effect of gravity acting during shearing, causing the small grains to work their way down through the interstices between larger grains, and partly the dependence of the normal dispersive pressure upon grain size. When grains are sheared, the normal dispersive pressure between grains, which varies as the square of the grain diameter, causes large grains to drift toward the zone of least shear strain, that is, the free surface, and the smaller grains toward the zone of greatest shear strain, that is, the shear plane.

Equilibrium profile. The action of waves on a sloping beach eventually produces a profile that achieves equilibrium with the energy dissipation associated with the oscillatory motion of the waves over the sand bottom. The slope of the beach face is related to the dissipation of energy by the swash and backwash over the beach face. Percolation of the swash into a permeable beach reduces the amount of flow in the backwash and is thus conducive to deposition of the sand transported by the swash. If in addition the beach is dry, this action is accentuated. Coarse sands are more permeable and consequently more conducive to deposition and the formation of steep beach faces. Large waves elevate the water table in the beach. When the beach is saturated, the backwash has a higher velocity, a condition conducive to erosion. From the foregoing it follows that the slope of the beach foreshore increases with increasing sediment size and with decreasing wave height. If an artificial slope exceeds the natural equilibrium slope, an offshore transport of sand will result from the gravity component of the sand load until the slope reaches equilibrium. Conversely, if an artificial slope is less than the natural equilibrium slope, a shoreward transport of sand by waves and currents will result, and the beach slope will steepen. An equilibrium slope is attained when the up-slope and down-slope transports are equal.

Beaches respond to wave-forcing by adjusting their form to an equilibrium or constant shape attributable to a given type of incident wave. The seasonal changes in beach profile in response to the high waves of winter and the lower waves of summer are expressions of the beach form tending toward a seasonal equilibrium with the changing character of the prevailing waves. Field studies show that the equilibrium beach consists of two conjoined parabolic curves that intersect at the breakpoint bar, one curve for the shorerise that extends from the closure depth to the breakpoint bar, and another for the foreshore that extends from the bar to the berm (Fig. 4). The principal differences between seasonal profiles are that in winter (higher waves) the breakpoint bar is deeper and farther offshore, while the berm crest is displaced landward. Thus, the changes in seasonal equilibria are manifest by simple, self-similar displacements of the bar-berm and shorerise curves. Also, since the equilibrium profile is parabolic, for any given sand size, the slope increases from the bar to the berm.

Longshore movement of sand. The movement of sand along the shore occurs in the form of bed load (material rolled and dragged along the bottom) and suspended load (material stirred up and carried with the current). Suspended-load transportation occurs primarily in the surfzone, where the turbulence and vertical mixing of water are most effective in placing sand in suspension and where the longshore currents that transport the sediment-laden waters have the highest velocity. The longshore transport rate of sand is directly proportional to the longshore component of wave power. Thus, the longshore transport rate of sand can be estimated from a knowledge of the wave climate, that is, the budget of wave energy incident upon the beach.

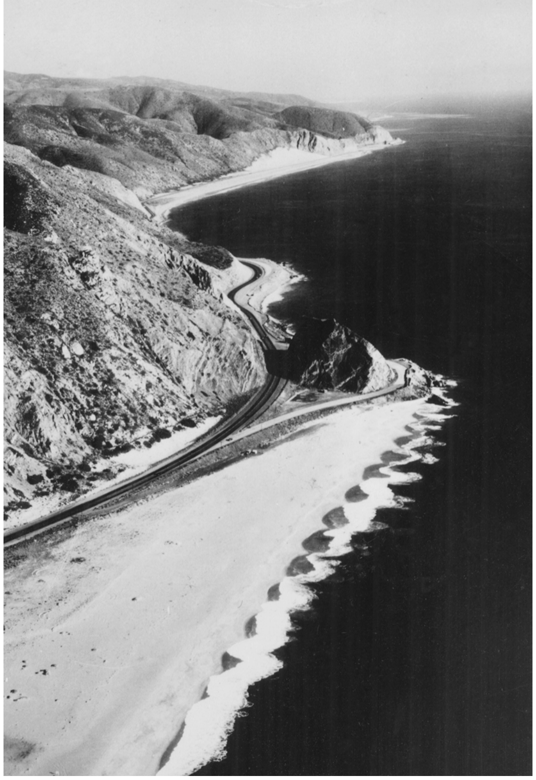


Fig. 5. Effect of headlands on the accretion of beach sand at Point Mugu, California. The point forms a natural obstruction that interrupts the longshore transport of sand, causing accretion and a wide beach to form (foreground). The regularly spaced scallops are swash cusps on the beach face. (*Department of Engineering, University of California, Berkeley*)

The volume of littoral transport along oceanic coasts is usually estimated from the observed rates of erosion or accretion, most often in the vicinity of natural obstructions, such as headlands (**Fig. 5**), or of coastal engineering structures, such as groins or jetties. In general, beaches build seaward up-current from obstructions and are eroded on the current lee where the supply of sand is diminished. Such observations indicate that the transport rate varies from almost nothing to several million cubic meters per year, with average values of 150,000–600,000 m^3 (200,000–800,000 yd^3) per year. Along the shores of smaller bodies of water, such as the Great Lakes of the United States, the littoral transport rate can be expected to range about 7000–150,000 m^3 (9000–200,000 yd^3) per year.

The large quantity of sand moved along the shore and the pattern of accretion and erosion that occurs when the flow is interrupted pose serious problems for coastal engineers. The problem is particularly acute when jetties are constructed to stabilize and maintain deep navigation channels through sandy beaches. A common remedial procedure is to dredge sand periodically from the accretion on the up-current side of the obstruction and deposit it on the eroding beaches in the current lee. Another method is the installation of sand bypassing systems, which continually remove the accreting sand and transport it by hydraulic pipeline to the beaches in the lee of the obstruction. *See* COASTAL ENGINEERING; SEDIMENTOLOGY.

Sources and sinks of beach sediment. The principal sources of beach and nearshore sediments are the rivers that bring quantities of sand directly to the ocean; the seacliffs and blufflands of unconsolidated material that are eroded by waves; and material of biogenous origin (shell and coral fragments and skeletons of small marine animals). In places, sediment may be supplied by the erosion of unconsolidated deposits in shallow water (Fig. 3*b*). Beach sediments on the coasts of the Netherlands are derived in part from the shallow waters of the North Sea. Windblown sand may be a source of beach sediment, although winds are usually more effective in removing sand from beaches than in supplying it. In tropical latitudes, many beaches are composed entirely of grains of calcium carbonate of biogenous origin. Generally the material consists of fragments of shells, corals, and calcareous algae growing on or near fringing reefs. The material is carried to the beach by wave action over the reef. Some beaches are composed mainly of the tests (shells) of foraminifera that live on sandy bottom offshore from the reefs. *See* NORTH SEA; REEF.

Streams and rivers may be important sources of sand for beaches in temperate latitudes (Fig. 3*a*). Surprisingly, the contribution of sand by streams in arid climates is quite high (**Fig. 6**). Arid weathering produces sand-size material from areas with a minimum cover of vegetation, so that occasional flash floods may transport large volumes of sand. The maximum sediment yield occurs from drainage basins where the mean annual precipitation is about 30 cm (12 in.) per year.

There is a pronounced multidecadal variability in the amount of river-borne sediment transported to the beach. The variability is associated with global climate changes related to the El Niño/Southern Oscillation (ENSO) phenomena. ENSO drives large-scale events such as the Pacific/North American (PNA) patterns of atmospheric pressure that lead to wet and

Fig. 6. Sand delta at Rio de la Concepción on the arid coast of the Gulf of California. Such deltas are important sources of sand for beaches. (*Courtesy of D. L. Inman*)

dry climate along the Pacific coast of North America. The 20 coastal rivers of central and southern California had streamflow and sediment fluxes during the wet phase of PNA (1969–1998) that exceed those during the preceding dry phase (1944–1968) by factors of 3 and 5, respectively. The sediment flux during the three major El Niño events of the wet phase were on average 27 times greater than the annual sediment flux during the dry phase. Also, the wave climate in southern California changed with the shift from dry to wet phase of PNA. The prevailing northwesterly winter waves of the dry phase were replaced by high-energy waves approaching from the west or southwest during the wet phase. Wave climate along the east coast of North America responds to shifts in the atmospheric patterns of the North Atlantic Oscillation (NAO), which is generally out of phase with the west coast climate. *See* CLIMATIC PREDICTION; EL NIÑO; TROPICAL METEOROLOGY; WEATHER FORECASTING AND PREDICTION.

Wave erosion of rocky coasts is usually slow, even where the rocks are relatively soft shales. Therefore, cliff erosion usually does not account for more than about 10% of the material on most beaches. However, retreats greater than 1 m (3.3 ft) per year are not uncommon in unconsolidated seacliffs. The most dramatic modern example of coastal erosion is found along the delta of the Nile River in Egypt. The High Aswan Dam, constructed in 1964, has intercepted the sediment that was previously brought down the Nile to the coast. Lacking source material, the delta coast is eroding, and waves and currents may cause an entire city block of Ras El Bar to be lost to the sea in one year.

The sand carried along the coast by waves and longshore currents may be deposited in continental embayments, or it may be diverted to deeper water by submarine canyons which traverse the continental shelf and effectively tap the supply of sand (Fig. 3*a*). Most of the deep sediments on the abyssal plains along a 400-km (250-mi) section of the California coastline are probably derived from two submarine canyons, Delgada Submarine Canyon in northern California and Monterey Submarine Canyon in central California. *See* MARINE SEDIMENTS.

Littoral cells and the budget of sediment. The budget of sediment for a region is obtained by assessing the sedimentary contributions and losses to the region and their relation to the various sediment sources and transport mechanisms. Determination of the budget of sediment is not a simple matter, since it requires knowledge of the rates of erosion and deposition as well as understanding of the capacity of various transport agents. Studies of the budget of sediment show that coastal areas can be divided into a series of discrete sedimentation compartments called littoral cells. Each cell contains a complete cycle of littoral transportation and sedimentation, including transport paths and sources and sinks of sediment. Littoral cells take a variety of forms, but there are two basic types. One is characteristic of collision coasts with submarine canyons (Fig. 3*a*), while the other is more typical of trailing-edge coasts where rivers empty into large estuaries (Fig. 3*b*). The concept of a littoral cell (or a subcell) with its budget of sediment and transport paths provides objective criteria for making choices among various coastal conservation methods. *See* ESTUARINE OCEANOGRAPHY.

Biological effects. The rigor of wave action and the continually shifting substrate make the sand beach a unique biological environment. Because few large plants can survive, the beach is occupied mostly by animals and microscopic plants. Much of the food supply for the animals consists of particulate matter that is brought to the beach by the nearshore circulation system and is trapped in the sand. The beach acts as a giant sand filter straining out particulate matter from the water that percolates through the beach face.

Since the beach-forming processes and the trapping of material by currents and sand are much the same everywhere, the animals found on sand beaches throughout the world are similar in aspects and habits, although different species are present in different localities. In addition, since the slopes and other physical properties of beaches are closely related to elevation, the sea animals also exhibit a marked horizontal zonation. Organisms on the active portion of the beach face tend to be of two general types insofar as the procurement of food is concerned: those that burrow into the sand, using it for refuge while they filter particulate matter from the water through siphons or other appendages that protrude above the sandy bottom, and those that remove organic material from the surface of the sand grains by ingesting them or by "licking." There are usually few species, which may be very abundant.

In tropical seas, the entire shore may be composed of the cemented and interlocking skeletons of reef-building corals and calcareous algae. When this occurs, the nearshore current system is controlled by the configuration of the reefs. Where there are fringing reefs, breaking waves carry water over the edge of the reef, generating currents that flow along the shore inside of the reef and then flow back to sea through deep channels between reefs. Under such conditions, beaches are usually restricted to a berm and foreshore face bordering the shoreward edge of the reef.

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