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ABSTRACT

The study of beaches and their capacity as an interface between land, air, and water is presented. Students investigate shore phenomena to better understand the beach's history and possible future. Also discussed is the interaction between man and the beach, from weather effects to pollution. Laboratory investigations of samples collected from the beach and of observations made at the beach are suggested. (Author/RE)

field guide to BEACHES

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It is natural to think of beaches as vacation playgrounds, but this interface between land, sea, and air is a fascinating subject for study. In this guide the student investigates the waves and shore in order to discover the beach's history and possible future. The pamphlet also discusses the interaction between man and beach—from hurricanes to pollution.

Dr. John H. Hoyt is Associate Professor of Geology at the University of Georgia Marine Institute, Sapelo Island, Georgia. His research is concerned principally with the deposition and erosion of sediments near the shore. Particularly exciting studies include the search for diamonds in the shallow water along the southwest African coast and the method of formation of barrier islands.

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FIELD GUIDE TO

Beaches

John H. Hoyt

Series Editor: Robert E. Boyer
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Contents

Beaches

INTRODUCTION

April 1, 1946, began like other mornings on the Hawaiian island of Oahu, but this was to be no ordinary April Fools' Day. During the previous night there had been an earthquake south of the Aleutian Islands, 3700 kilometers to the north, causing a major sea-floor disturbance and sending waves racing across the Pacific Ocean at speeds up to 750 kilometers per hour. In the open ocean the height of the waves was characteristically small, but the wavelength was very great. As they entered the shallow water along the Hawaiian shores, however, the waves increased in height and roared ashore as devastating *tsunamis*, or seismic sea waves.

Tsunamis, sometimes incorrectly called tidal waves, are caused by sub-sea earthquakes and volcanoes and are particularly destructive along the shores and islands of the Pacific Ocean. Although not common events, tsunamis occur frequently enough to be a constant threat to life and property. Several hundred islanders died in the early-morning disaster on Oahu as waves reached 15 meters and more above normal level.

Since the early 1950's a tsunami warning system has been in service along the Pacific coast. Ten *seismograph*, or earthquake recorder, stations were installed at critical locations and equipped with automatic alarm systems to indicate major earthquakes. When an earthquake occurs, its location can be quickly computed from the times the shock arrives at the different stations. If the location of the earthquake is under the ocean, the tide-measuring station nearest the earthquake is asked to report any unusual wave activity; if any occurs, a warning is sent to endangered coasts with an estimate for the arrival time of possible tsunamis. This system has been effective in reducing the loss of life, but, of course, little can be done about damage to shore property.

Although tsunamis are rare, they dramatize the constant and endless struggle between land and sea. The sea combines the relentless power of waves and currents to tear at the land, while the land resists by building a "fortress" at its edge to absorb the sea's fury. The battle between land and sea takes place on part of this fortress, one of the most

Figure 1. (A) Eroding beach at high tide, St. Catherines Island, Ga. (B) Sand beach, Brittany, France.

beautiful, and sometimes most peaceful, areas of the earth—the beach.

A *beach* is that part of the fortress along the edges of oceans, lakes, and rivers which can be moved, shifted, rolled, or disturbed (Figure 1). It is difficult to determine the seaward limit of the beach. Large ocean waves move sediment on the sea floor to depths as great as ten meters. Because there is a direct relationship between the size of waves and to what water depth the sea floor is disturbed, the outer edge of the beach will vary from area to area. In a lake or bay with small waves the beach will not extend as far from shore as a beach along the ocean. The landward limit is commonly marked by a row of sand ridges, or *dunes*, or a cliff which shows the normal extent of wave activity. During hurricanes or tsunamis the area affected by the waves is much greater, but these infrequent disturbances generally are not included in setting limits to the beach. In addition to length and width, beaches have a third dimension—thickness. The largest changes in thickness take place seasonally, and measurements at different times of the year often indicate major

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Figure 1 (C) Boulder beach, Brittany, France (D) Surf on a beach in Hawaii

differences in the thickness of beach material, due mainly to changes in wave sizes.

Most beaches are composed of pieces of rock; these pieces may range in size from huge boulders to mud. Usually the rocks are sand size, with a diameter between 1/16 millimeter and two millimeters. Waves easily break rocks into sand size, but cannot as easily knock the sand grains together hard enough to break the rock further. The waves also *sort* rock fragments; because any chips smaller than sand size are more easily carried away, the sand-size material is left behind. In a few places beaches consist of pieces of seashells or coral.

A large part of the population of the United States lives near the coast and can visit an ocean beach. Even inland cities such as Chicago and Detroit are near lovely beaches along the Great Lakes. Beaches are natural recreation areas that serve people from crowded cities as places to picnic, swim, fish, and play. Great tourist centers such as Atlantic City, New Jersey, and Miami Beach, Flor-


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ida, have been constructed to help people enjoy the beach.

Beaches provide not only recreation and protection from the sea. They also provide food such as clams, crabs, shrimp, turtles, and fish caught along the shore. Beaches are the breeding and nesting grounds of many kinds of animals, including seals, turtles, birds, and certain fish. Many different animals live *in* the beach, and it is exciting to collect and study them. Birds along beaches are numerous and interesting to watch and identify. Many plants grow exclusively along the beach. In some areas valuable minerals can be mined from beaches. The beach is an excellent place to study the first steps in the formation of sedimentary rocks and to study the motion of waves as they enter shallow water.

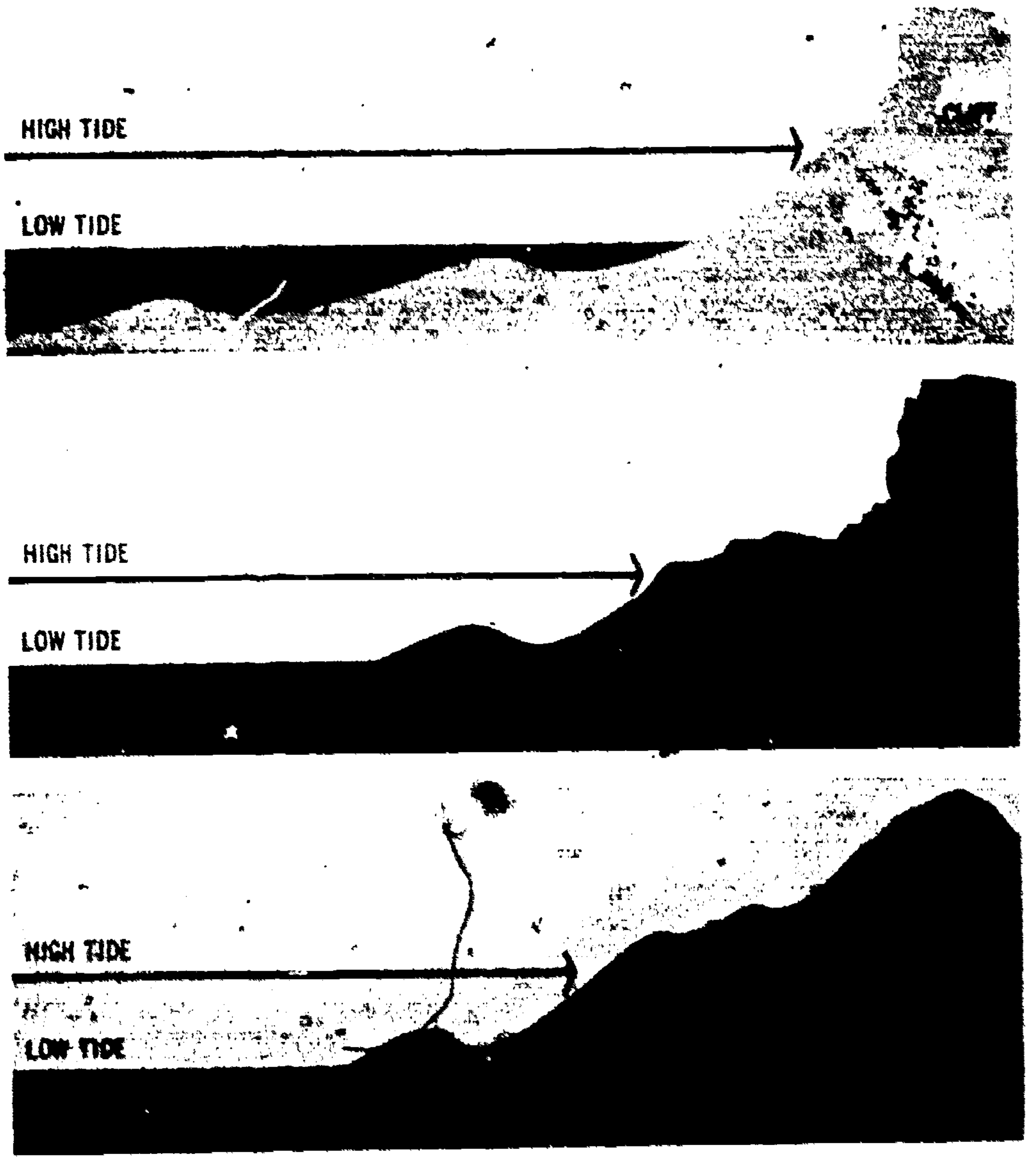
A beach is unique because it is the meeting place of land, sea, and air. The power stored in waves that formed hundreds or thousands of kilometers away in the open ocean is dissipated on the beach. Winds that have blown across many kilometers of water first meet land at the beach. The bulges of water formed in the ocean by attraction of the moon, the tides, are blocked by the beach.

BEACHES AND WAVES

Parts of a Beach

A beach is the collection, along the edge of an ocean, lake, or river, of rock or shell fragments that are moved by the waves and currents. The beach includes the area between the outer breaking waves and the highest point on land to which waves move rock fragments.

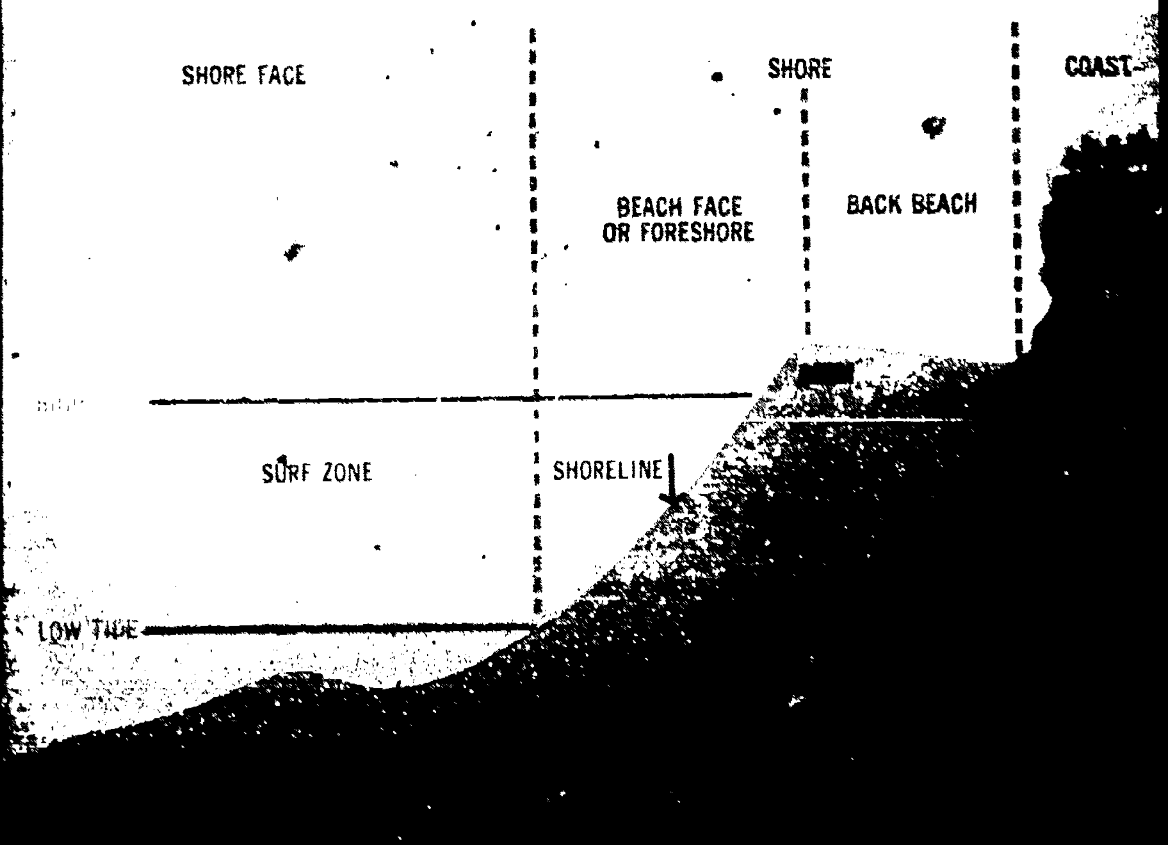
Figure 2 Characteristic beach profiles



The shape of the beach surface along a line called the *beach profile* (Figure 2) is usually steep near land and more gently sloping offshore. This shape results from the balance between waves bringing sand to the beach and currents carrying sand away. Because the size of the waves is constantly changing, the shape of the beach is always changing also.

The beach consists of a *beach face* or *foreshore* which slopes down to the water and includes all the area between the high- and low-tide shorelines (Figure 3). One or more *berms* or sand ridges are commonly present landward of the foreshore in a zone of variable width called the *back beach*. The back beach is usually widest on low coasts attacked by large waves and may be very narrow or entirely absent in areas of small waves or on a narrow beach at the base of a sea cliff. The beach seaward of the foreshore to the limit of breaking waves is called the *shore face*.

Figure 3 Parts of a beach



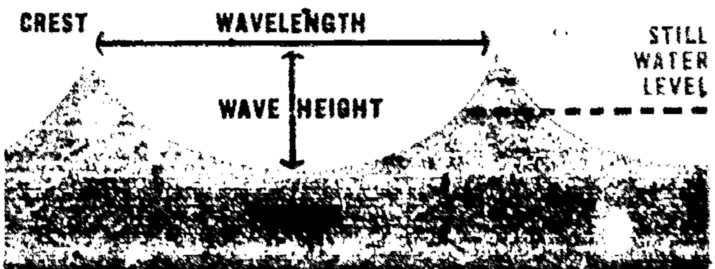
The foreshore is an area of active change caused by the erosion (removal) and deposition (addition) of sand as water from the breaking waves surges up the beach. These surges of water are called *swash*, and the return flow rolling down the beach face after each swash is called *backwash*. At times of very high tide and storm waves, the swash may sweep over the foreshore and berms and invade the back beach. Swash, in fact, forms the berms by dumping sand high on the beach. The highest berm is formed from the swash of large waves associated with a storm or unusually high tides. Any lower berms that are present result from smaller waves and lower tides, and are commonly at or near the normal high-tide level.

The *surf zone* is the area from the swash zone seaward to the farthest line of breaking waves. It is the equivalent of the shore face, and, like the shore face, its width is directly related to the size of the waves. Small waves breaking almost at the water's edge may create a surf zone only a few meters wide. In contrast, large waves breaking in deep water may create a surf zone as much as several hundred meters wide.

Waves

When you look at the ocean, what you probably see first are the *waves*, the ridges or swells moving along the water's surface. Usually there are *sets*, or "trains," of waves with parallel crests moving

Figure 4 Wave characteristics



in the same direction. Clearly, waves are complex and irregular, and several sets of waves may move in different directions at the same time. The waves in different sets commonly vary in size, and their interaction produces the irregularities seen in *breakers*, waves that crest or break into foam along the beach.

Although waves form in many different ways, most waves in the ocean and on lakes are caused by the wind. It is not surprising that the stronger the wind, the larger the waves. Waves may travel great distances. Many large waves that strike the coast of southern California are formed over 8000 kilometers away in the south Pacific Ocean. Apparently friction between the wind and water initiates wave formation. Once started, waves are pushed and pulled along in a manner that makes them grow larger. The distance the wind blows over the water, known as the *fetch*, also determines wave size. In the ocean the fetch may be very long so that quite large waves can develop. In lakes and bays the short fetch will limit the size of the waves, even if the wind is very strong.

Waves have relatively narrow, steep *crests*, or tops, and broad *troughs*, or bases (Figure 4). *Wave height* is the vertical distance from the lowest point of the trough to the highest point of the crest. *Wavelength* is the distance between successive crests, and the *period* of the wave is the time required for one wavelength to pass a fixed point.

The speed of a wave moving in deep water is usually determined by its length and period; the longer the wave and the shorter its period, the faster the wave moves. As a wave passes in deep water, the actual motion of a water particle in the wave is almost circular. Water particles near the surface make larger circles than deeper particles (Figure 5). As the wave moves into shallow water, the circular paths of water particles in the wave become flattened into ellipses, and near the sea floor very close to shore the water simply moves back and forth as

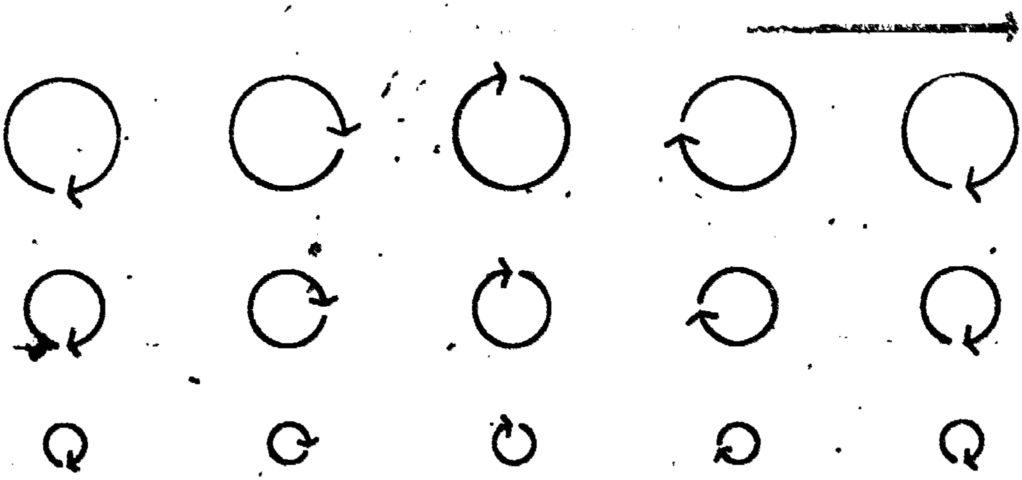


Figure 5. Water particles move in circular paths and rise one after the other to become the crest of an advancing wave.

the wave passes. The part of the wave near the bottom in shallow water is slowed down by friction with the sea floor, so that the wave moves toward shore faster at the surface than at the bottom. The surface part of the wave keeps getting ahead of its lower part, until there is no water supporting the top of the wave, and it tumbles forward as a *breaking wave*.

Tides

When you go to an ocean beach, build a sand castle near the water when the tide is out, and then wait. As the tide comes in, how does the destruction of your castle take place? The rhythmic rise and fall of the water level across the beach is called the *tide*. When the water level is rising, the tide is said to be coming in or flooding; when the water level is falling, the tide is going out or ebbing. The vertical distance between high and low tide is the *tidal range*; this varies from 20 meters in the Bay of Fundy in Canada to as little as 30 centimeters along much of the Gulf of Mexico.

What causes the tides? The answer to this question has two parts. First, the gravitational pull of the moon on the earth causes the water on the side of the earth facing the moon to be drawn toward the moon and to form a bulge. As the earth rotates on its axis, it moves beneath this bulge of water. If this were the complete answer, the result would be one high tide each day at any particular beach on the earth as that point passed beneath the moon. However, a second bulge of water is also produced on the side of the earth away from the moon. Authorities do not agree on the cause of this second bulge; a possible explanation is that the center of gravity of the earth-moon system is not at the center of the earth, but 4,640 kilometers from it toward the moon. As the earth-moon system rotates monthly around this center of gravity, the water is forced out into a bulge on the side of the earth opposite the moon (Figure 6).

Swash, Backwash, and Longshore Current

If the waves are not exactly perpendicular to the beach, the swash moves diagonally up the beach in about the same direction as incoming waves. The driving force of the swash is the breaking wave, so the direction of wave approach is also the logical path for the swash. In contrast, the backwash moves down the beach in response to gravity and

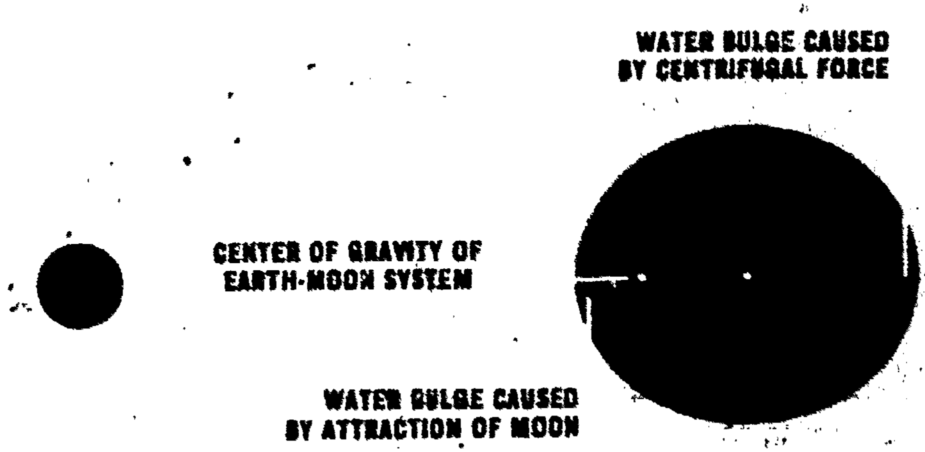


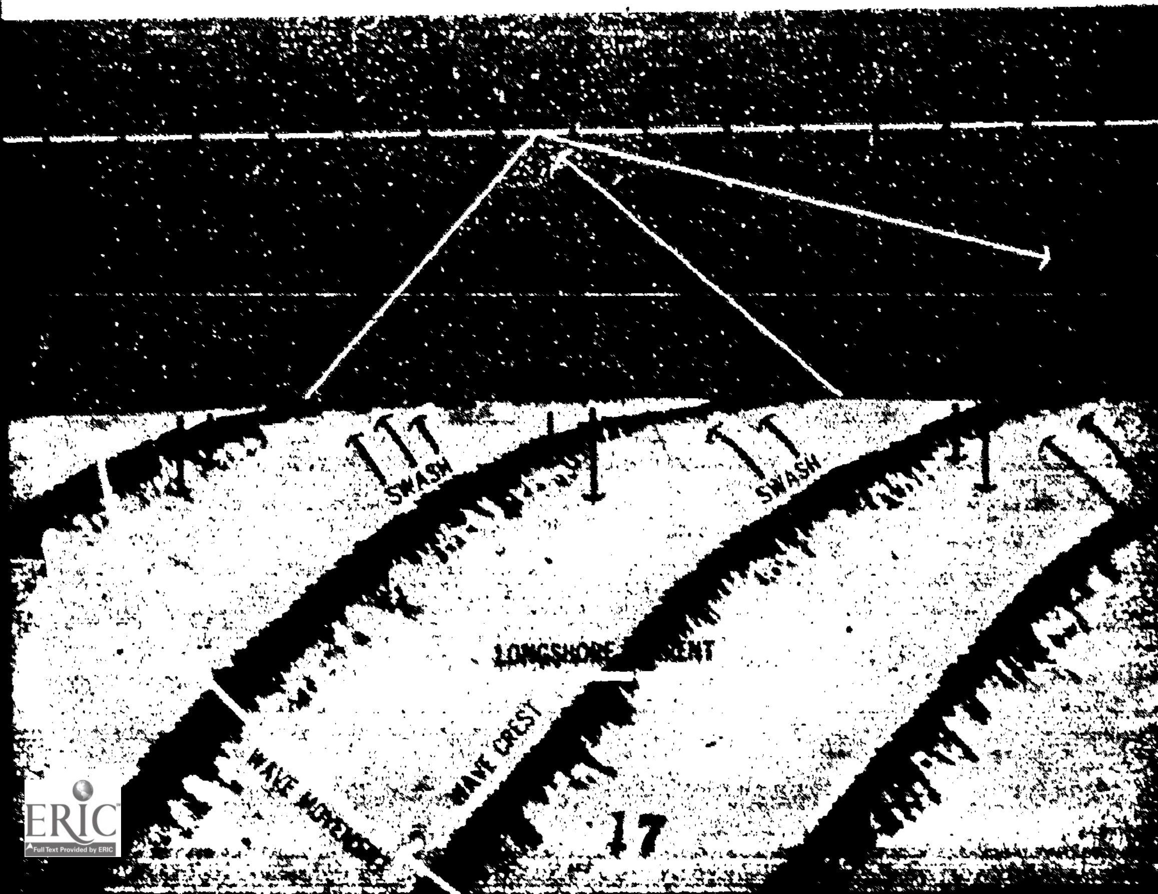
Figure 6. The forces that produce tides.

thus flows straight down the shore slope. The swash and backwash, therefore, often result in a zigzag motion of the water and the sand carried by the water (Figure 7).

Suppose that you dropped something, like your sunglasses, in the backwash. The water would be too foamy and turbid for you to reach down and pick them up, and the receding backwash would carry the dropped article with it. But your knowledge of swash and backwash would enable you to predict where the next swash would come, and with luck your sunglasses would wash in on the next wave.

Just seaward of the swash zone, in the surf zone, water will also surge beachward in the direction the waves are moving. If this direction is at a slight angle to the beach, the water and the sand carried by the water will also move along the beach with a slight zigzag motion. The resulting flow of water along the beach is called a *longshore current.* Waves one-half meter to one meter high approach-

Figure 7 Swash, backwash, longshore current, and direction of wave movement



ing the shore at an angle can set up a current so strong that a bather may be unable to walk against it in water that is chest deep.

If a beach is composed of coarse sand or larger fragments, the backwash may be greatly reduced, or there may be no backwash at all, because the water that surges in quickly runs down between the coarse fragments and returns to the ocean beneath the beach surface. The swash also sinks into beach material consisting of medium-grained or fine-grained sand, but there is more backwash than with coarser fragments.

Rip Currents and Undertow

Although swimming, surfing, and playing in the ocean are enjoyable and good exercise, each year many people drown while swimming or boating, and many more are injured. It is impossible to keep accurate records, but offshore currents near and below the surface are probably responsible for a large share of the difficulties of swimmers. As waves break in the surf zone, there is a large surge of water toward the shore. After one wave passes and as the next one approaches, a strong flow of water rushes seaward toward the next incoming wave. This seaward flow is called an *undertow*.

A second type of flow results because, while most of the water from breaking wave returns seaward, the general movement of waves toward land causes an excess of water to pile up along the shore. This buildup of water along the shore is especially pronounced if there is a ridge of sand, called a *bar*, in the shallow water where the waves are breaking. The excess water piles up behind the bar, which restricts the seaward flow of water until the water finally finds a low place in the bar and flows seaward near the surface in a strong current, called a *rip current* (Figure 8). Because of its rapid flow, a rip current is a hazard to swimmers and is capable of carrying them into deep water. If a swimmer is not aware of rip currents, his first reaction is to try to swim directly back to shore. However, to escape the current he should not try to swim against it, but rather swim parallel to the shore. The rip current is not wide, and once out of the current a swimmer can easily return to shallow water. If there is a strong longshore current, swimming in the direction of this current will help the swimmer escape the rip current.

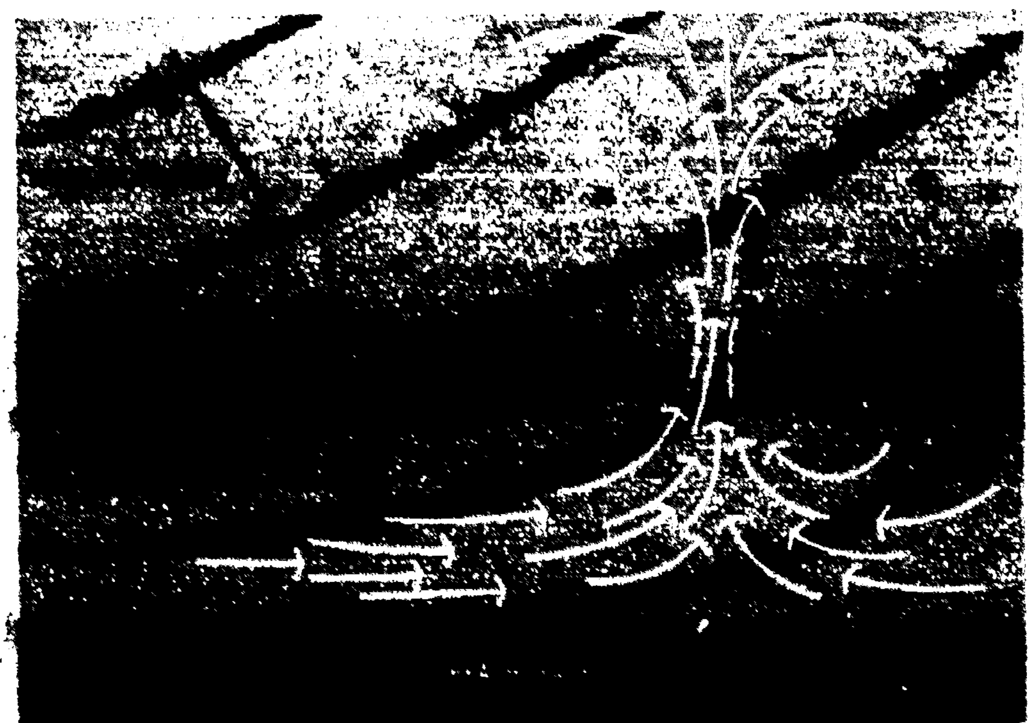


Figure 8. Rip currents.

Rip currents are important in moving beach sand into deeper water. Sometimes the currents can actually be seen because the sand they are carrying may make them appear browner than the surrounding water. As it moves through the bar, the current may erode a small channel. Reaching deeper water offshore, the rip current slows down and finally stops, dropping its load of sand.

Dunes

Most sand beaches are bordered on the landward side by one or more dunes. These sand ridges range in height from a few meters to over 100 meters. They may be almost unbroken ridges along the beach or just isolated piles of sand.

If you visit the beach on a windy day, you will quickly see that the wind is capable of moving large quantities of sand. When the tide is out, the beach surface dries rapidly, especially if the wind is blowing and the sun is out. The wind picks up sand grains and bounces them along. Since wind commonly blows toward land, the sand is blown to the upper beach where it may be trapped by driftwood, grass, or other objects. Sand is deposited on the downwind side of an object, where the air is moving more slowly, and a small dune starts to form. Once the dune starts, sand is blown to the top where some of it comes to rest, or to the landward side of the dune where the wind is less strong. In this way the dunes get bigger and bigger and finally form a ridge along the beach.

Storms, commonly accompanied by large waves and high tides, cause erosion on the seaward side of dunes. Part or much of the sand that has accumulated in the dunes is thus returned to the beach. When the storm subsides, the process of dune formation begins anew. The dunes serve a useful and important role in controlling the force of the waves and keeping them from washing over the land. Even though dunes may be partly destroyed by a storm, the material for their re-formation will be readily accessible elsewhere on the beach. In his eagerness to be near the sea, man foolishly bulldozes the dunes and constructs buildings. Then the waves produced by a storm tear down the unprotected buildings and the winds following the storm do not reconstruct buildings as they do the dunes.

Some dunes are covered with vegetation while others are bare. The extent of vegetation is an indication of the amount of sand movement on the dunes, because vegetation traps the sand and retards its movement. Because dunes protect adjacent land area, it is desirable to keep the dunes covered with as much vegetation as possible. Grasses and other plants are commonly encouraged to grow on the dunes in an effort to increase dune size. Dune vegetation is quite specialized, since it must tolerate salt spray, poor soil, and large variations in moisture. Observe sometime what sorts of plants grow on dunes. (See *Coastal Vegetation* in References.)

Barrier Islands

Most beaches of the Atlantic and Gulf coasts of the United States are along barrier islands, so called because they protect the mainland from the sea. There are numerous islands, usually long and narrow, and separated from the mainland by a *lagoon* (an enclosed area of salt water) or a salt marsh. A marsh is simply a lagoon that has become filled with sediment (loose rock material). Barrier islands are usually covered with dunes that form in rows along the beach. These islands are actually just a series of beaches stacked one in front of another, the beach on the landward side having formed first. But how did the first beach form so far from the mainland?

At some time in the past, during the last part of the Ice Age when sea level was still a few meters lower than it is now, dunes formed along the shoreline. With the melting of ice, sea level rose and water flooded the area landward of the dunes, which became islands. More beaches and dunes were added along the seaward side of the new islands, and additional flooding enlarged the lagoons. The islands continued to widen as long as sediment was brought to shore by the waves; however, as the water became deeper because of rising sea level, the waves did not bring as much sand to the beaches. Many islands are now eroding because the sand is being removed by the waves faster than it is being brought in.

BEACH STUDIES

To get the most out of a trip to the beach, some preparations are essential. Get good maps of the area you will visit. (See References.) Maps may also be available at a local library. See if the library has any old maps available of the area you are going to visit. The older the better, but maps only 40 or 50 years old can be useful, because they will enable you to check for changes in location of the beach over that length of time. The beach is continually changing its position, but the long-term changes are the most useful in predicting what will continue to happen there. When you get to the beach, ask local residents, especially those who have lived in the area for a long time, whether the beach has been advancing seaward because of deposition or retreating because of erosion.

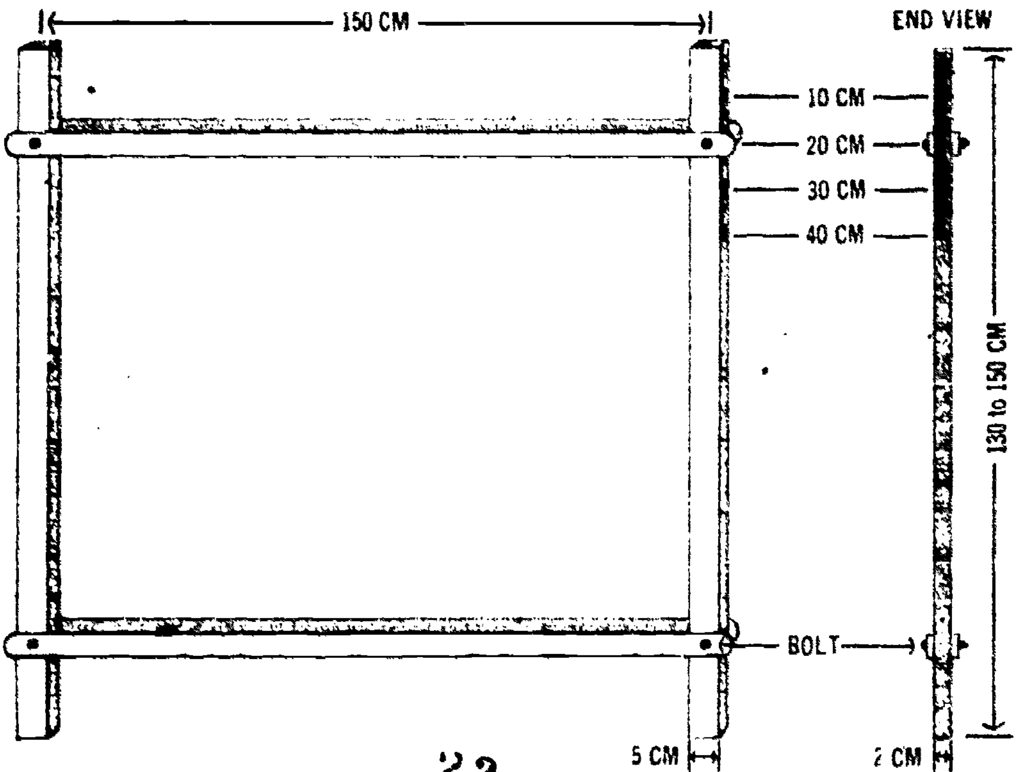
The following equipment will make it easier to study the beach:

- Long-handled shovel
- Cement trowel, wide-bladed machete, or knife (for example, a cake or palette knife)
- Small ice cream cartons or other containers such as plastic bags
- Rubbing alcohol
- Small jars with tight-fitting lids
- Felt-tipped marking pen
- Measuring tape
- Stick at least 2 meters long marked in centimeters
- Compass
- Stopwatch, or watch with second hand
- Notebook, ruler, protractor
- Old tennis balls, painted different colors if possible
- Plastic bottle with cap, such as an old bleach bottle
- Heavy twine about 3 meters long
- Surfcasting rod and reel, if you have one
- Spray can of clear plastic such as Krylon (available at most paint or art supply stores)

Pint of liquid latex (such as Cementex #600 latex cement, available from paint stores or from Cementex Company, Inc., 336 Canal Street, New York, New York)
Brush for applying liquid latex
Cheesecloth and small nails

To measure beach shape, make a "beach profiler" from sticks marked as described in Figure 9. The sticks should be between 130 and 150 centimeters long; while the exact length is not important, the two sticks should be precisely the same. Sticks about five centimeters wide and two centimeters thick will be the right strength. Start at the top end and using a felt- or nylon-tipped pen, mark off carefully a scale 40 centimeters long on the narrow edge of each stick. Make smaller marks at the one-half-centimeter positions. Number the scale at even centimeters from the top down. Join the sticks exactly 150 centimeters apart with two thin pieces of wood each about 160 centimeters long. Wood

Figure 9. Beach profiler.



lathing or similar material is fine. If the wood is too thin or too flexible, use four cross pieces instead of two. The thin pieces are used to join the marked sticks into a parallelogram (Figure 9). Drill a 1/4-inch hole five centimeters from the end of each of the joining sticks, making sure that the holes are exactly 150 centimeters apart. Drill a hole in each profiling stick 20 centimeters from the bottom and 20 centimeters from the top. Then fasten the profiling sticks to the joining sticks with 1/4-inch bolts. Leave the bolts slightly loose, so that the profiling sticks can be moved. The parallelogram can be taken apart for easy transportation.

If the weather is suitable and you plan to get wet, don't forget your bathing suit: old tennis shoes are best for walking along the beach and will protect your feet from sharp objects. If the sun is shining, guard against sunburn. Use suntan oil and stay covered if you burn easily.

Try to time your visit so that the tide is going out when you arrive. Then you will have maximum time to study the beach while it is exposed. Profiling, trenching or digging holes, shell collecting, and other observations are best done at low tide. The times of low and high tides are usually printed in newspapers published in coastal areas and are reported on radio and television broadcasts. Tide tables showing the predicted times of high and low tide for the east and west coasts of the United States can be purchased from the U.S. Coast and Geodetic Survey. (See References.)

Waves

Waves breaking on the beach are important for several reasons:

1) They move the beach sand and thus influence beach shape. The larger the waves, the more sand is moved.
2) The size of the waves determines whether sand is moved toward or carried away from the shore. This sand movement is quite complex,

because it depends on the height of the waves that have broken on the beach at previous times.

3) The direction at which waves approach the beach determines the direction of the longshore current and the direction that sand is carried along the beach.

You can measure several things about waves that will help describe them. If the waves are small and you can safely wade in the water, measure the height of the waves in the breaker zone and beyond. Use the two-meter stick marked in centimeters. Note the water height in the wave trough and the height at the crest. Make several measurements to get an average. The difference between the trough and crest heights is the wave height (Figure 4). If the waves are too large to measure in this way, perhaps you can find some pilings out in the water and note the height of the wave troughs and the wave crests on a piling as the waves pass.

Using a face mask and breathing through a snorkel or breathing tube, observe the motion of the sand in the area seaward of the breaking wave. Again, attempt this only if the waves are small enough so that you can safely wade into water beyond which the waves are breaking. How does the sand move?

Observe the sand movement in the area of breaking waves. How much turbulence or tumbling motion is there in this area? How much sand is in the water, and where in the water is most of the sand?

The breaker height can be estimated from shore by lining up the top of the breaker with the *horizon*, that is, the boundary line between ocean and sky, and then measuring the height of your eye above the water surface (Figure 10). This is done by moving up or down the beach or stooping over at the water's edge until the highest part of the wave is just level with the horizon. Then you can measure the height of your eye above the water by placing the stick at the water's edge at the level the water

Measure the wave direction using a compass. First, determine magnetic north. Draw a line on the beach pointing north. Now, look just beyond the breakers and see if you can sight along the wave crests. If you stand on the upper part of the beach, perhaps even on a box or other object, it is easier to see over the breakers. If the waves are approaching the beach at an angle, draw a line on the beach parallel to the wave crests. Have this line intersect the line indicating magnetic north (Figure 7). Transfer the lines on the beach to a sheet of paper as accurately as you can. A line perpendicular to the wave-crest line is the direction of wave movement. Measure the angle between magnetic north and the direction of wave movement with a protractor to get the direction of wave movement in degrees from magnetic north. Note that wave movement is given as the direction from which the wave comes. Now, on the beach draw a line parallel to the shore, and transfer this line to the paper. Relate the direction of wave movement to the direction of the shoreline.

Longshore Current

The speed of the longshore current can be determined by putting floats, such as old tennis balls or ice cream cartons painted different colors, in the surf zone and timing their movement over a measured distance. Put them in the water at different distances from the shoreline to check the speed of the current. If the breakers are large, it will be necessary to throw the floats into the surf zone. If the surf is low enough so that you can wade, line the floats up perpendicular to the shore. Drive stakes in the beach in a row perpendicular to the shore to help you line the floats up. Four or five floats placed ten meters apart should give a good indication of current flow. Measure the time it takes them to move a distance of ten meters along the beach. Repeat the measurements several times to get a good average. If the current is moving rapidly, you

Measure the wave direction using a compass. First, determine magnetic north. Draw a line on the beach pointing north. Now, look just beyond the breakers and see if you can sight along the wave crests. If you stand on the upper part of the beach, perhaps even on a box or other object, it is easier to see over the breakers. If the waves are approaching the beach at an angle, draw a line on the beach parallel to the wave crests. Have this line intersect the line indicating magnetic north (Figure 7). Transfer the lines on the beach to a sheet of paper as accurately as you can. A line perpendicular to the wave-crest line is the direction of wave movement. Measure the angle between magnetic north and the direction of wave movement with a protractor to get the direction of wave movement in degrees from magnetic north. Note that wave movement is given as the direction from which the wave comes. Now, on the beach draw a line parallel to the shore, and transfer this line to the paper. Relate the direction of wave movement to the direction of the shoreline.

Longshore Current

The speed of the longshore current can be determined by putting floats, such as old tennis balls or ice cream cartons painted different colors, in the surf zone and timing their movement over a measured distance. Put them in the water at different distances from the shoreline to check the speed of the current. If the breakers are large, it will be necessary to throw the floats into the surf zone. If the surf is low enough so that you can wade, line the floats up perpendicular to the shore. Drive stakes in the beach in a row perpendicular to the shore to help you line the floats up. Four or five floats placed ten meters apart should give a good indication of current flow. Measure the time it takes them to move a distance of ten meters along the beach. Repeat the measurements several times to get a good average. If the current is moving rapidly, you may have to use a distance of 20 or 30 meters along the beach to get good results. If the wind is strong, put a small amount of sand in the floats to keep them from floating too high. If the waves move the floats inshore, put them back at the original distance from shore.

When you have consistent results, make a bar graph of the current speed versus the distance from shore, with the length of the bars proportional to the speed of the current. Determine where the current is moving fastest in relation to the surf zone. Is the fastest movement outside the surf zone, in the surf zone, or shoreward of the surf zone? If you can make measurements on different days, relate current motion to wave height and direction of wave movement.

Tides

Tidal measurements are difficult to make along a beach unless the waves are small or there is some quiet water in a small bay or behind a pier. If such conditions exist, measure down to the water level from some fixed reference mark on a dock, piling, pier, or other structure every half hour for four or five hours. Or you can drive a small stake in the beach at the water's edge every half hour as the tide goes out. Then measure the vertical distance between the stakes with the beach profiler. This method will be described in the next section, Beach Profiles. When the tide comes in, note what time the water reaches each of the stakes. Then plot the height of the water against time. The height of the last high tide can be estimated from the position of the line of beach drift consisting of such materials as seaweed, grass, cans, bottles, or wood.

Note the position of the surf zone at several tide levels. As the tide goes in and out, the turbulence that accompanies breaking waves becomes concentrated on different sections of the beach. Think for a moment what would happen if the tide continued to rise above the normal high-tide level. This

Figure 11. Height of water table in a beach. Height varies with the tide.

rise sometimes takes place during severe storms such as hurricanes when the water level may reach three or four meters above high-tide level. The surf zone then moves over the dunes and shore and may destroy any buildings that are too close to the beach. More damage is commonly done by abnormally high tide and accompanying waves than by hurricane winds.

Find how the height of the *water table*, the level of water-saturated sand, varies with the tide (Figure 11). At high tide, dig a hole in the upper part of the beach. You dig first through a layer of fairly dry loose sand, then through a damp zone, and finally, at a depth of approximately 30 to 70 centimeters, you will encounter water-saturated sand. When water flows into the hole, it means that you have dug below the water table. Now dig another hole lower on the beach and note the depth of the water table there. Dig two or three more holes in a line farther down the beach and measure the depth of the water table below the beach surface for each one. Dig the last hole right at the edge of the water. Where is the water table there? What is the relationship of the water table to the surface as you dig holes across the beach (Figure 11)? As the level of the ocean rises and falls with the tide, the water table also rises and falls, but more slowly, because the water has to seep through small openings and spaces between sand grains. When the tide falls, water gradually flows out of the beach to the ocean.

Beach Profiles

Begin your determination of the beach profile at some easily relocated fixed mark near the beach. You can use a telephone pole, distinctive rock, piling, or other structure as a permanent reference that you can find on subsequent visits. Note a vertical position as well as a horizontal position, because elevation changes of the beach are as important as horizontal changes.

The beach profile can be determined rapidly and accurately using the beach profiler you made. Because you have joined the sticks together as a parallelogram, they can be worked by one person, assisted by a recorder.

Start your profile determination at the permanent reference mark and place the rear stick, the one toward land, upright at the reference in such a way that you can replace it in that exact position at a later time if you want. At the same time, direct the front stick toward the water so that the beach profiler is at right angles to the shoreline (Figure 12). It may be useful to scratch a line on the beach from your reference mark to the water to follow as you progress across the beach. Since the sticks are in a parallelogram, the distance between them is already determined as 150 centimeters, or 1.5 meters. Always hold both sticks as nearly vertical as possible. Stand behind the rear stick and sight seaward, lining up the top of the front stick with the horizon. There must be good visibility so you can determine the boundary between water and sky. With the horizon lined up with the top of the front stick, determine the intersection of the horizon with the rear stick and have the recorder write this measurement in a notebook. With practice and good conditions

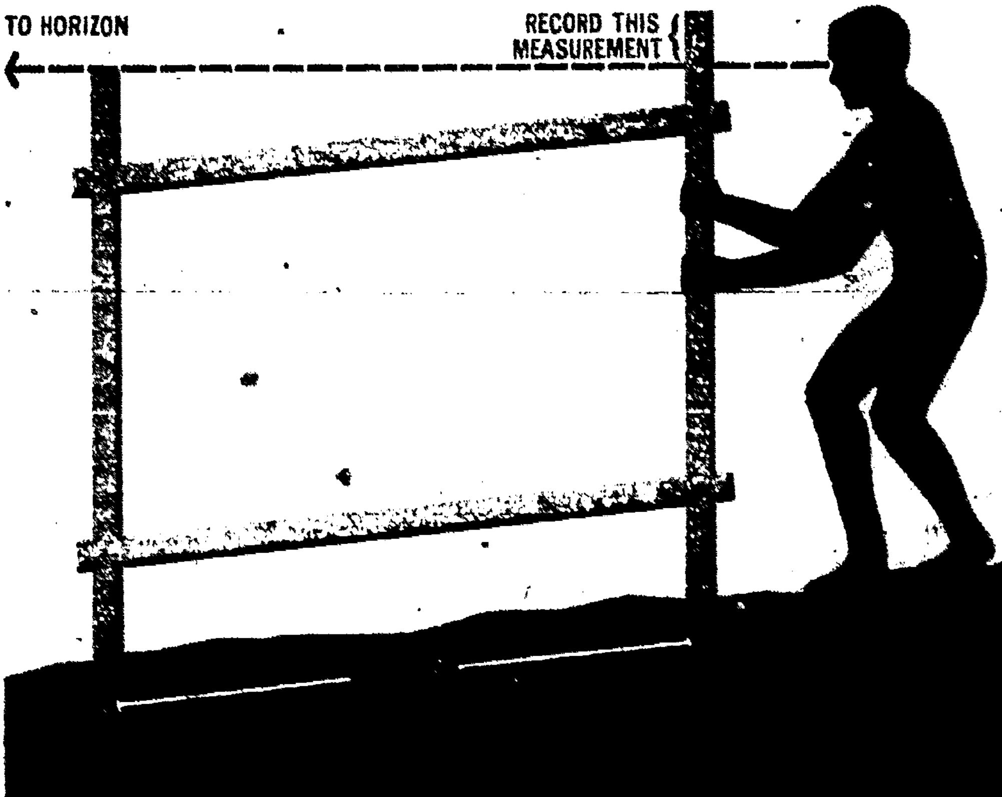


Figure 12. Beach profiling

you can estimate the position of the horizon to the nearest one-half centimeter. If the front stick is higher than the rear stick, line the top of the rear stick up with the horizon and note the position of the horizon on the front stick. Record the reading as a minus number to signify that the front stick is higher.

Now move both sticks seaward, with the rear stick occupying the exact location vacated by the front stick. Don't push the stick into the sand, for this will cause an error in the reading. Again line up the sticks with the horizon and note the difference in elevation. If the reading is zero, be sure to record it. Move the sticks forward again and continue this process across the beach. Don't stop at the water's edge, but continue profiling as long as you can make measurements. It is difficult to move the sticks the correct distance when their base is in the water, but with a helper and by carefully using your feet as markers, the correct movement can be achieved.

Now determine the vertical distance between the stakes you put in the beach as the tide was going out (page 23). Start at the position of the last high tide, determined by the concentration of seaweed and other debris, and profile down to the base of the first stake. Continue profiling to the second stake and so on, determining each elevation relative to the high-tide position.

If time permits or if you have a number of people, several profiles may be made at different points on the beach. Try to select locations where there is a noticeable difference in slope, or where a trough or low area is found on the beach. Remember to note carefully the location of the starting point because, if possible, the profiles should be surveyed again at a later time. Try to resurvey the area two months later to note any changes in the beach profile. In general, beaches are constantly changing, and the detailed profiling you have done is the best way of showing the changes. Storms, of course, cause rapid changes, but small changes in wave size that continue for some time also affect the shape of the beach. In many areas the changes through the year or over a period of years do not result in any large net change in the location of the beach. In other areas there may be a net advance or net retreat of the beach position. In planning the use of a beach, it is important to know what changes can normally be expected.

Beach Sediments

If you could travel to beaches all over the world, you would find that they consist of a great many different kinds of material. Some beaches are made of broken volcanic lava and are jet black; some are made of coral and shell fragments and are dazzlingly white; others are covered with garnet, small red mineral grains, and are red or pink; some consist of huge boulders and others are made of mud. The type of sediment or fragments is determined by what is available in the area or what the waves bring to the beach. For instance, the beaches of an *atoll*, a ringlike coral island, may have no material other than coral and shell fragments broken up by the waves.

There are many documented cases of huge rocks being moved by storm waves. Many of the stories concern lighthouses, because lighthouses are commonly built on rocks to warn ships of the presence of these rocks. The lighthouse on Tillamook Rock along the northwestern Oregon coast experiences many violent storms. Tillamook Rock has nearly vertical sides rising more than 25 meters above the ocean, and the top of the lighthouse is 42 meters above water level. The entire rock shakes from the impact of the big, powerful waves, and large stones are often thrown to the top of the rock. On one occasion a rock weighing 60 kilograms was thrown to the top of the lighthouse and smashed through the lightkeeper's house. The glass in front of the light at the top of the lighthouse was broken many times until a shield was installed below it to deflect the rocks. Another time a half-ton rock was tumbled across the surface of Tillamook Rock at the base of the lighthouse.

Considering the force of the waves, it is not surprising that the sea can reduce rocks to the size of sand. If you can visit a beach with rock fragments the size of gravel, observe the shape of the rocks. Usually they will be rounded and smooth, indicating the grinding and chipping action of the waves as they churn the rocks about. You can even hear the rocks being bumped together. Rocks are made up of a variety of mineral grains. The softer minerals are more easily broken than others and are destroyed first. The strongest and most resistent of the abundant minerals is quartz, so most sand beaches of the world are composed largely of quartz. The sand particles may be of different sizes on different beaches, depending on the size of the waves and the size to which mineral grains can be reduced.

The characteristics of beach sediments can be determined by collecting samples of the beach for later laboratory study. Collect four to six samples about equally spaced along the surveyed profile line. Note the location of each sample in your notebook so that you can show its position when you plot the profile on graph paper. Put each sample in a separate ice cream carton, plastic bag, or other container, and carefully number or label it so that you can identify it later. About a handful will be enough for each sample. Take only the top centimeter of the beach surface so that all the sand in each sample will have been deposited under the same wave conditions.

On beaches consisting of gravel and boulders, grain size is determined by direct measurement of the particles. At several locations along the surveyed profile, find the average diameter of each of 100 stones taken from the surface of a small area. This is done by averaging the longest and the shortest dimension of the stone. Use a ruler or meter stick for your measurements. It will help to have a recorder quickly write down measurements as they are determined. After each stone is measured, it should be tossed aside so it will not be recounted, but save a few that seem about average size and composition as representative of the sample.

Beach Layering

Dig a series of trenches along the surveyed profile lines to study beach layering or stratification. Each trench should be about two meters long and one meter wide and should be dug as deep as the water table will permit. On the upper foreshore the depth may be as much as 30 to 70 centimeters (page 24), but lower on the beach it will be less. Dig one wall of the trench as vertically as possible and carefully scrape it with your machete, cake knife, or cement trowel so the layers of sediment can be seen (Figure 13). Some layers will be parallel to the surface of the beach; some may slope; and some layers may intersect. Layers commonly vary in thickness as they run up or down the beach, or they may show a wavy pattern. All of these features reveal something about the recent history of the beach. In your notebook, sketch the appearance of the layers in the smoothed wall of the trench.

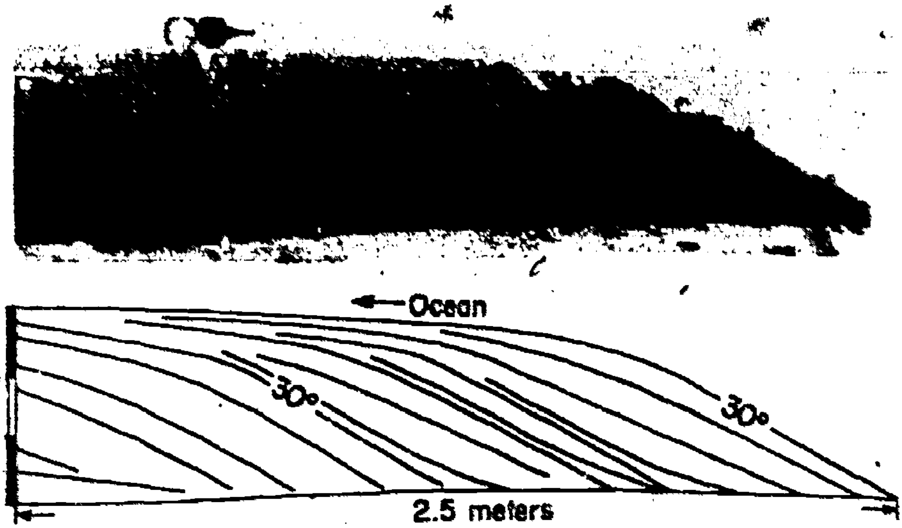


Figure 13 Beach stratification on the steep side of a small bar, Sapelo Island, Georgia.

Changes in layering usually indicate changes in wave height or wave direction that result in slightly different conditions for erosion and deposition. The layers may be distinguished by differences in grain size or grain composition. As the tide goes out, coarse sand deposited in the surf zone is covered by finer sand deposited by the backwash. On some beaches the layers are well marked by thin bands of darker grains. These may be mineral grains denser than quartz that settle out of the water faster than the less dense particles of similar size. Carefully collect samples from different layers for further study in the laboratory.

The landward end of the trench should also be dug as vertically as possible and smoothed to reveal the layering in the direction *parallel* to the shore.

When you have finished digging trenches in the beach, you might dig some in the dunes, if there are any along the beach you are studying, to compare dune layering with beach layering. Find a steep slope on the landward side of a dune and dig a trench perpendicular to that slope. Try not to disturb vegetation. You will find that you can dig deeper trenches in the dunes than on the beach without reaching the water table. *Do not dig the trench deeper than one meter*, otherwise the side of the trench may cave in on top of you. You will notice the steeper slope of some layers, numerous changes in slope direction, and the irregularity in layer thickness. Dig more trenches in the dunes, some on gentle slopes and others on flat areas. You will see more different angles and directions of slope in dune layers than you saw in the beach.

It is possible to take part of the wall of a trench home with you by making a "peel." Trim the trench wall carefully with the machete or cake knife until it is smooth. Then spray a section of the wall with three or four coats of clear plastic. Next brush on liquid latex, keeping the amount of brushing to a minimum. A pint will do several small peels. For areas more than 20 centimeters on a side the peel should be strengthened by pinning cheesecloth to the wall with small nails before the latex is brushed on through the cloth. Apply three or four layers and allow each to dry 30 to 45 minutes, depending on temperature and humidity, before taking the peel from the trench wall. Lay the peel on a board to finish drying.

Other Beach Features

A great many other interesting structures and objects can also be found on beaches. One common structure is *ripple marks*, ridges produced on sand by water action. These you will see in all shapes

Figure 14. Rhomboid ripple marks. Current flowed from right to left. Length of ripples (long diagonal) about ten centimeters.

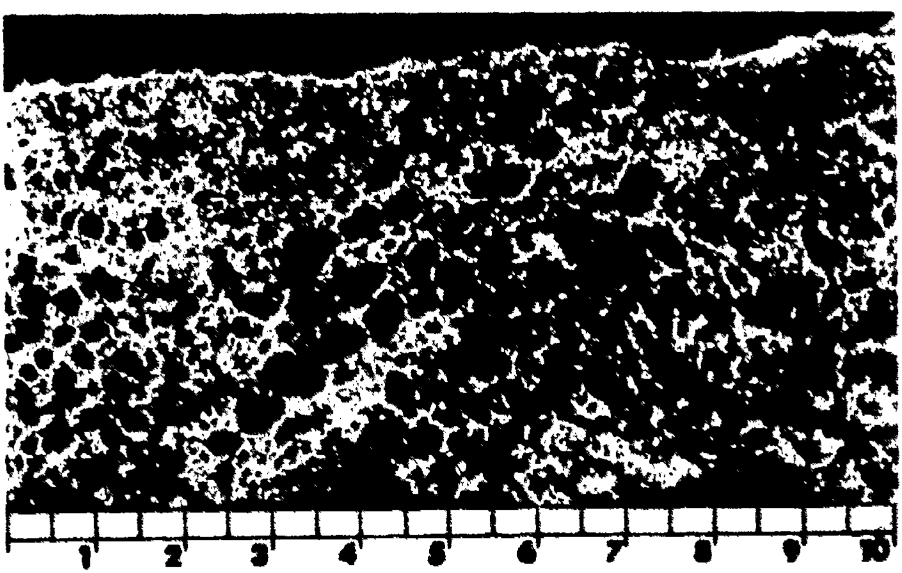
and sizes. Find a small channel where water is flowing out of a trough. As the water flows along, you will see ripple marks form and re-form on the bottom of the shallow channel. Ripple marks on the bottom of the shallow trough are shaped differently from those in the channel. This is because the ripple marks in the channel are formed by the rapidly moving water, whereas those of the trough are formed by small waves. Ripple marks may show a rhomboid or diamond shape (Figure 14). You can see these form in water two to three centimeters deep as the backwash runs off the beach. Their shape is not a perfect diamond but is slightly curved in one direction.

During a rising tide, the swash moves up over dry sand. This rapid wetting traps air beneath the water-soaked surface sand. As the swash retreats, air may rise through the wet sand and form small blow holes. As the air rushes out, the sand may actually bubble, or if the air cannot get through the surface layer, a small layer of the sand may arch into a slight dome about ten centimeters across and one to two centimeters high. Sometimes, if the sand is very fine-grained, the air will be trapped in the sand and will puff it up like a sponge (Figure 15). The sand will be soft where this happens and you can see the bubbled texture by carefully breaking the sand.

You may find more than one line of beach drift along the upper beach. The lowest one is the location of the last high tide. Higher ones indicate the position of higher tides or even storm tides. These may be partly buried by sand, but they will show you how high the tide can be.

Another common feature of beaches are beach *cusps*, low scalloped or crescent-shaped mounds separated by troughs spaced at more or less regular intervals along the beach. The points of the cusps are directed seaward and may be either angular or rounded. The distance between the points varies from a few meters to as much as 20 meters, and the

Figure 15 Soft bubbled sand, Sapelo Island, Georgia. Scale is in centimeters.



elevation difference between the center of the cusp and the points varies from less than ten centimeters to more than one meter. Sometimes the points of the beach cusps are composed of sand coarser than the sand in the center of the troughs. The waves make the cusps, and large waves make the larger cusps, but why cusps are found in some places and not in others, and exactly how the cusps are formed are still unknown. Dig a trench across the points of a cusp. Look for any difference in layering or in grain size. Collect samples of the sediment for study in the laboratory.

Shells are some of the most beautiful and interesting objects you will find on the beach. They occur in many shapes and sizes and are fun to collect and identify and even to make into displays. When you go to the beach, spend some time collecting different kinds. Save the ones that are unbroken. You may want to have several of one kind to show the variations in size and color. Shell collecting is usually best after a storm or strong wind when new material has washed ashore. After you have taken them home, identify the shells. Several good books that will help you are listed in the References.

Many different kinds of animals burrow in beaches. As they burrow, the animals disrupt the sand and may destroy part of the layering. Some burrows may be distinctive enough for you to identify the animal from its traces. Dig into the beach with a small knife or a shovel near a suspected burrow opening and work carefully over to the opening. Measure the length and width of any burrows found and some of their characteristics, such as the smoothness of the burrow and whether it is lined with material other than beach sediment. Try to find the animal that is making the burrow, and put it in an ice cream carton for identification in the laboratory. If there will be some delay before you can identify the animals, preserve them in a small jar filled with rubbing alcohol. See the References for books to help you identify them.

LABORATORY STUDIES

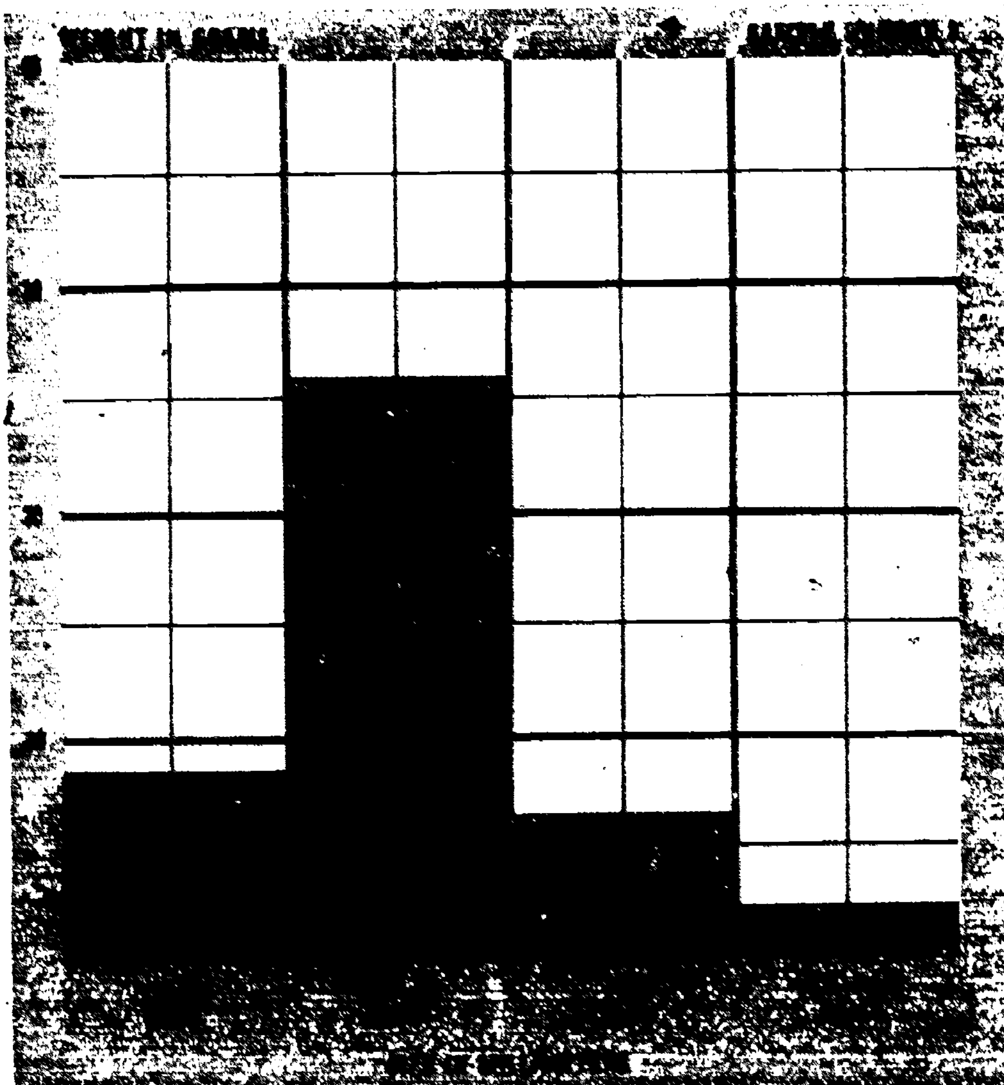
The sand samples collected at the beach can be dried by spreading them out on separate sheets of paper in the sun. Label the sheets to avoid confusing the samples. Then shake each dried sample through a series of sieves of three or more different sizes. The screen gratings should range from about window-screen size to some much smaller. Hold the sieve with the largest openings over a large sheet of paper and pour the sand through the sieve. The coarser sand grains will not pass through the screen and should be placed in a bottle labeled to show the sample number and the sieve used. Now pour the sand through the next smaller sieve, again saving the portion that will not pass through. Continue doing this with each sieve. Weigh the sand in each size class of each sample, or pour the sand of each size into a narrow bottle and measure its height. For each sample, record the weights or the heights and set up a bar graph as shown in Figure 16. Estimate the actual size of a few grains in each size class; this can be done best with a microscope or a hand lens and a ruler with fine markings (one millimeter or smaller). Record the largest and smallest sizes in each size class.

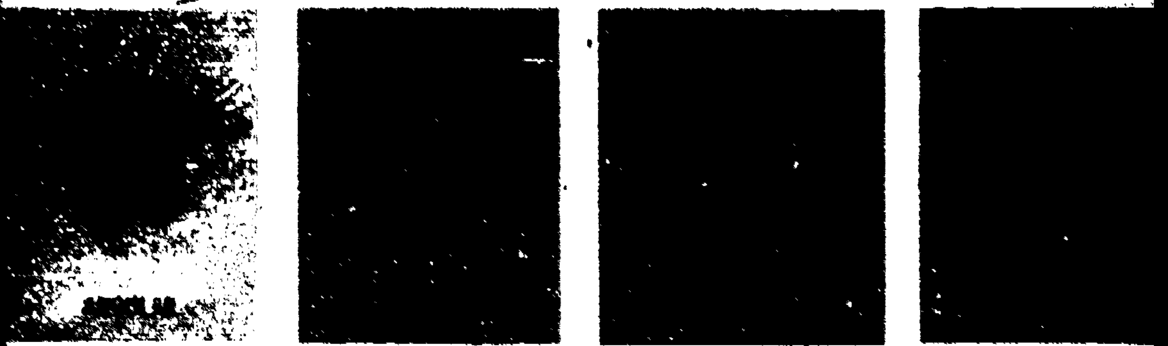
Compare the size of sand from different places on the beach, from the dunes, and from different layers. If there was a difference in wave height along the beach, you can relate the grain size to the waves. Also, if you go back two months later and take more samples, you can compare them with the earlier samples and relate any changes in size to possible changes in wave conditions. Grain size is important because to some extent it determines how rapidly the beach can be eroded. The small grains are easier for the waves and wind to carry away.

Using a microscope or magnifying glass, examine the individual sand grains for shape, roundness, and color. "Shape" refers to whether a grain is flat, spherical, or elongated; "roundness" refers to the sharpness of its corners (Figure 17). Small biological remains may also be found, such as small shells, sharks' teeth, spines from sand dollars and sea urchins, and sharp pieces of skeletons from sponges.

Plot the measurements you recorded as you made your beach profile on graph paper (Figure 18). It is important to choose proper scales so that the profile fits on the paper. Note that the horizontal and vertical scales do not have to be the same. The

Figure 16 Graph showing size distribution of sand in a beach sample

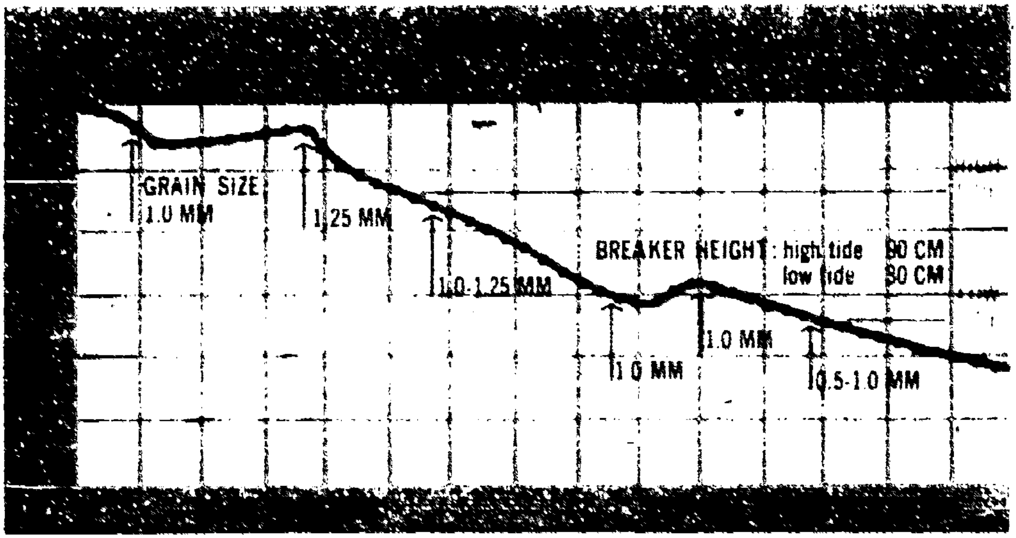




vertical scale is often exaggerated to emphasize the shape of the beach, so that a short distance on the vertical scale equals a large distance on the horizontal scale. If each division of the graph paper equals one meter on the vertical scale but ten meters on the horizontal scale, the exaggeration is ten to one. When you resurvey the profile lines, plot the new data on the same graph as your first survey, but in a different color. By starting at the same point and elevation you can see any changes that have occurred in the beach shape. Note the grain size at the sample points along the profile and also record the wave conditions on the graphs so that all the essential information is available (Figure 18).

Figure 17 Chart for estimating roundness.

Figure 18 Graph of beach profile Vertical exaggeration is 10 1



The shape of the beach is important because of its relation to wave characteristics and to the grain size of the beach material. Changes in the beach profile may indicate problems of erosion or deposition, or they may be only seasonal or related to storm activity. Long-term observation is usually required to determine major alteration in beach position.

MAN AND THE BEACH

Beaches are important to mankind, and our concern for the beach increases as more and more people come to enjoy relaxation and recreation along the shores. As both population and leisure time increase, the value to society of prime recreational areas is apparent. Unfortunately, in his eagerness to enjoy the beach, man is capable of destroying it. Miami Beach, Florida, is an example of what can happen. Millions of dollars have been spent to build hotels near the beach. In an effort to retain the sand, hotels have built metal or stone walls out from the shore in front of the hotels. Such walls are supposed to block partially the longshore current, thus trapping sand and limiting its movement, and to reduce the effectiveness of waves in picking up and moving the sand. However, more than one wall has the opposite effect, and soon there is no sand to trap and what is left are unsightly and dangerous walls reaching like giant fingers into the sea.

The solution is clear: Let the sea and the land have their battleground to advance and retreat. Since man is not capable of controlling the sea, he must learn to construct his homes and hotels a safe distance from the beach; in most cases 100 to 200 meters is sufficient unless the shore has an unusual history of rapid retreat. Moving the buildings back leaves a natural area between the beach and man where dunes can form and re-form to absorb the power of the waves.

Although man loves the beach, if he continues many of his present activities, he will make our coastal areas unfit for use. Dumping of sewage and chemical wastes into coastal waters has too often made beaches unfit for swimming and bathing, as well as making poisonous those fish and shellfish that live in the contaminated waters. Our expanding population and economy are compounding the problem just when we need our beaches most. We cannot think of the ocean as a gigantic sewer.

Beaches are just one part of the coastal environment, others include bays, marshes, lagoons, and river mouths. All these areas are used for transportation, food production, flood control, wildlife refuge, and recreation. They also serve as natural treatment plants for the purification of waste carried to the coast by rivers and thus aid in keeping the beaches usable. Filling of bays and marshes with trash or debris to provide building sites reduces the area available for such useful purposes. With proper planning and control, man can continue to use and enjoy his beaches and coastal areas, but he must act quickly. It is far easier to prevent the damage than to correct it.

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Glossary

atoll—a coral island or islands that encircle or nearly encircle a body of water.

backwash—the seaward return of water down the beach following the uprush of the swash.

bar—an elongate, slightly submerged sedimentary deposit.

barrier island—an elongate island parallel to the coast generally composed of sand or gravel. It is separated from the mainland by a relatively narrow body of water or salt marsh.

beach—a sedimentary deposit, generally sand or gravel, formed by waves.

beach profile—the shape of the beach measured along a line perpendicular to the shoreline.

breaker—a wave that moves into shallow water along a beach, increasing in height and steepness until it tumbles forward, or breaks.

cusp—a crescent-shaped depression hollowed out toward the water. Cusps form on the upper beach due to wave action along the shore of a body of water.

dune—a sedimentary deposit, generally a low hill or ridge, formed by windblown sand.

fetch—the extent of open water over which the wind blows to develop waves.

lagoon—an elongate body of water roughly parallel to the coast, separated from the ocean by a barrier island or reef.

longshore current—the inshore current moving essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline.

rip current—a seaward-flowing current of water that originates near the shoreline and continues offshore into or through the breaker zone.

ripple marks—an undulating surface produced in sediment by the wind, water currents, and waves.

seismograph—an instrument for recording seismic (earthquake) movements.

shore face—the part of the beach seaward of the foreshore extending offshore to the limit of ordinary surf action.

surf zone—the area from the outermost breaking waves to the swash zone.

swash—the uprush of water onto the beach following the breaking of a wave.

tide—the periodic rise and fall of the sea, caused principally by the attraction of the moon and sun for the earth.

tsunami—a large and potentially dangerous wave formed by an undersea earthquake or volcano.

undertow—the seaward flow of water in the surf zone that follows the passing of a breaking wave and precedes the approach of the next wave.

wave period—the time it takes a wave to move a distance equal to one wavelength.

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