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ABSTRACT

To dive safely, it is suggested that the diver have a working knowledge of waves, tides, currents, and water quality. Lack of understanding and respect for ocean currents and surf can be of serious consequence to the diver. This paper on the diving environment is designed to provide the diver with a general understanding of the physical characteristics common to lakes and oceans. The descriptions of diving techniques are included to give the diver a better understanding of how to safely handle himself/herself under various conditions. The discussions include: (1) waves at sea; (2) waves in shallow water; (3) surf; (4) currents; (5) sandy beach entry; (6) rocky shore entry; (7) tides and tidal currents; (8) wind currents; (9) seiches; (10) diving in currents; and (11) weather. The document concludes that good physical condition, basic knowledge, common sense, and good judgment can be very important for safe underwater exploration. (CW)

DIVER EDUCATION SERIES

Oceanography for Divers
Waves, Tides, and Currents

Lee H. Somers

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OCEANOGRAPHY FOR DIVERS

WAVES, TIDES, AND CURRENTS

Lee H. Somers, Ph.D.

To dive safely, the diver must have a working knowledge of waves, tides, currents, and water quality. Lack of understanding and respect for ocean currents and surf can be of serious consequence to the diver.

Unfortunately, inland divers are unable to receive proper training in ocean diving techniques during their basic courses. Safe diving in ocean currents and executing proper surf entries/exits require special instruction. Consequently, the inland diver, whether novice or experienced, must acquire special instruction upon making the first trip to the ocean. Furthermore, a diver who learns the proper techniques for diving in the currents of the Florida Keys must still acquire additional ocean training when he travels to the surf beaches of the Pacific, the oil rigs of the Gulf, or the wrecks off the New England coast.

This paper on the diving environment is designed to provide the diver with a general understanding of the physical characteristics common to lakes and oceans. The descriptions of diving techniques are included to give the diver a better understanding of how to safely handle himself/herself under various conditions.

These written descriptions, however, are **not sufficient in themselves** to prepare the inland diver for an ocean experience. The diver must acquire special instruction and dive under the supervision of an instructor or experienced ocean diver when desiring to advance his/her qualifications to include ocean diving. Proper training, common sense, good judgment, and **physical fitness** are prerequisites for ocean diving.

WAVES AT SEA

Waves are a series of undulations generally propagated on the water's surface by the force of the wind. Ocean waves are usually measured in terms of their length, height, and period. **Wave length** is the horizontal distance between successive crests, **height** is the vertical distance between crest and trough, and **period** is the time required for the movement of two successive crests (or troughs) past a given reference point (Figure 1).

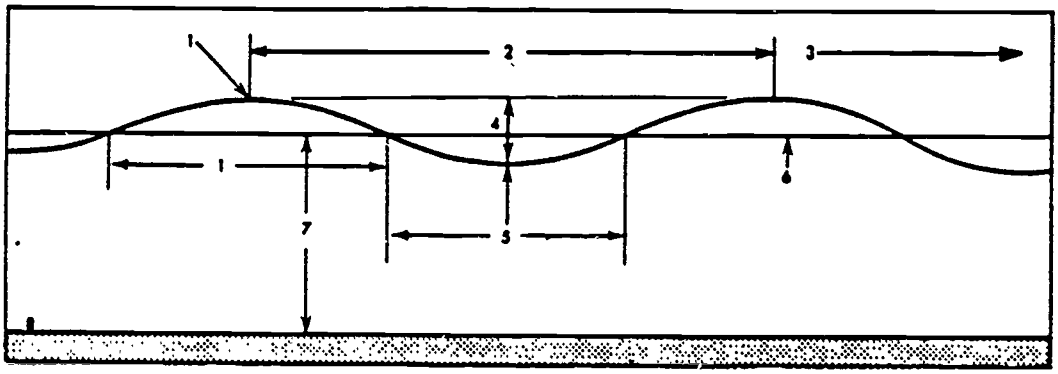


Figure 1. Wave Characteristics: (1) Wave Crest; (2) Wave Length; (3) Direction of Wave Travel; (4) Height; (5) Wave Trough; (6) Still-Water Level; (7) Depth; (8) Ocean Bottom [1]

Waves are moving **forms**, a transferral of energy from water particle to water particle, with very little mass transport of the water. The volume of water transported by the passing wave form is negligible for waves of little steepness (under normal conditions) and can be disregarded for all practical purposes. The water particles within a wave move in an orbital motion (Figure 2). The surface particles move in a circular orbit exactly equal to wave height; below the surface, the orbits become smaller and, in an ideal deepwater wave, the diameters diminish with increasing depth.

Common water waves develop under the influence of newly formed winds (Figure 3). The air pressure changes on the surface and the frictional drag of the moving air of these winds develop ripples on the water surface which evolve into waves whose dimensions tend to increase with the wind velocity, duration, and **fetch** (the length of the area over which the wind is blowing). Energy is transferred directly from the atmosphere to the water. The waves grow in height and steepness (height/length ratio) until, in some cases, the wave breaks at a steepness of about 1:7 to form whitecaps. In a steady wind, waves of various dimensions develop with progressively increasing heights and periods until a steady state is reached in which the sea is fully developed for the prevailing wind speed. This steady state is maintained as long as the wind remains constant. These waves, generated locally by a continuing wind, are known as **sea**. Although this local sea originated in a single wind system, it is a combination of many different superimposed wave trains with various heights and directions. This gives the appearance of a rapidly changing ocean surface.

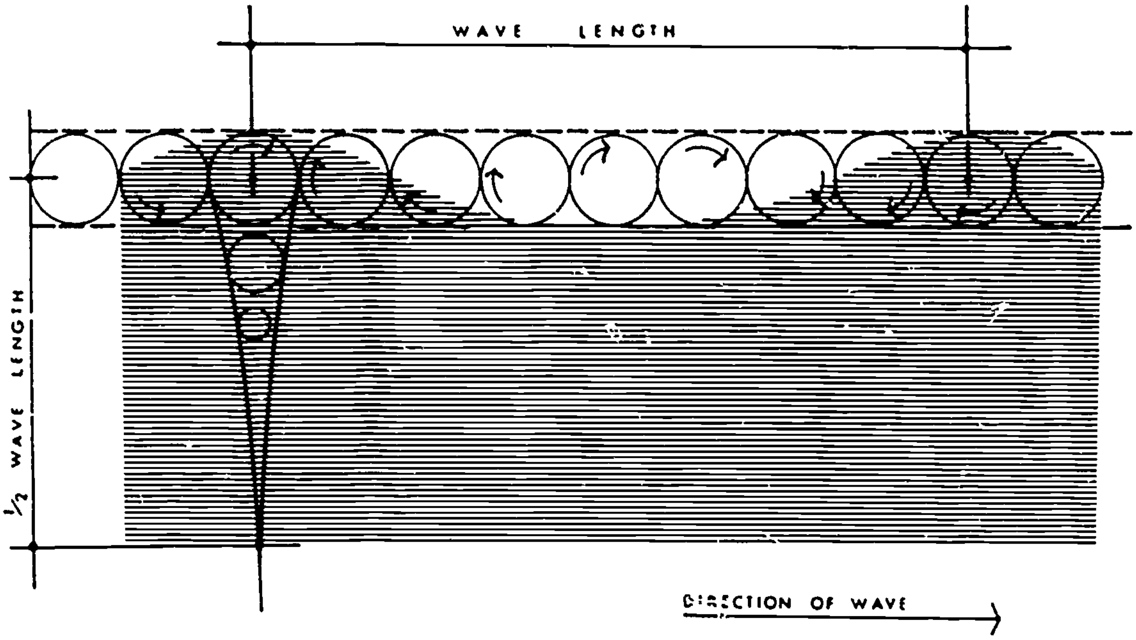


Figure 2. Cross-Section of Wave (Traveling from Left to Right): Circles Represent Water Particles in the Wave

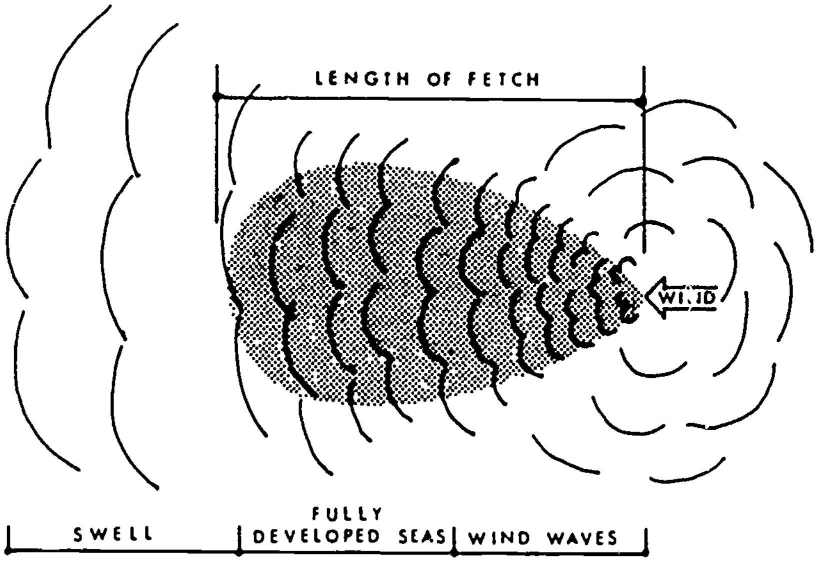


Figure 3. Diagram of Wave Development

Sea persists only in the fetch area and for the duration of the generating wind. When the wind velocity decreases or the wave leaves the fetch area, it is called a **swell wave.** Swell waves are characterized by long, rounded crests and decreased wave heights relative to sea waves, and they are more regular in height, period, and direction. As a swell wave progresses, in absence of a sustaining wind, its height decreases, with a consequent reduction in wave steepness. This change in wave form is known as **wave decay.** One cause of wave decay is a loss of energy from the wave that is brought about by internal friction, wind resistance, current action, and the effects of solid objects (ice, seaweed, land masses, etc.) in the path of the wave.

WAVES IN SHALLOW WATER

As the wave forms approach shore and move across shallow bottoms, they are reflected, diffracted, and refracted. When a wave encounters a vertical wall, such as a steep rocky cliff rising from deep water or a seawall, it is **reflected** back upon itself with little loss of energy (Figure 4). If the period of the approaching wave train is regular, a pattern of standing waves may be established in which the orbits of the approaching and reflected waves modify each other in such a way that there is only vertical water motion against the cliff and only horizontal motion at a distance out of one-fourth wave length. Submerged barriers, e.g., as a coral reef, will also cause reflections.

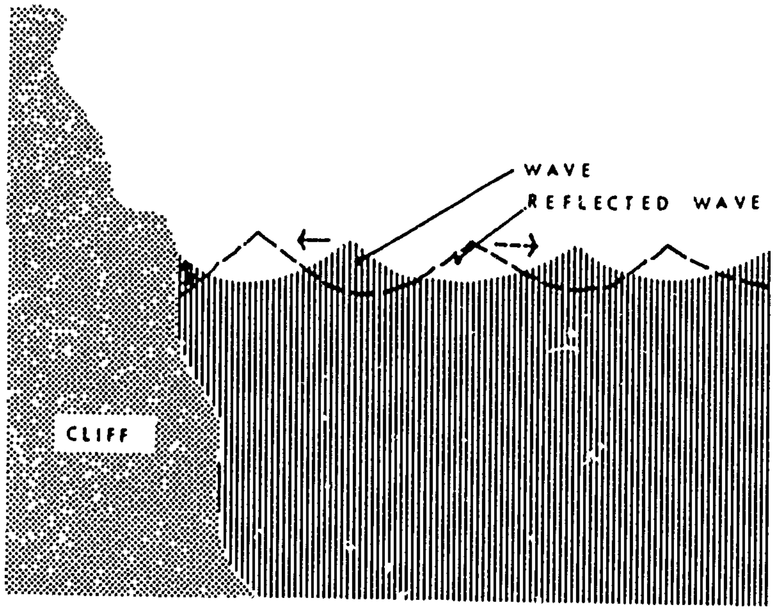


Figure 4. Wave Reflection

When a wave encounters an obstruction, the wave motion is **diffracted** around it (Figure 5). As the waves pass the obstruction, some of their energy is propagated sideways due to friction with the obstruction, and the wave crest bends into the apparently sheltered area.

As the wave train moves into shallow water, the friction on the bottom causes it to slow. Since different segments of the wave front are moving in different depths of water, the crest bend and the wave direction constantly change. This is called **refraction** (Figure 6). Essentially the wave crest or front parallels the contours of the bottom. A simple example of refraction is that of a set of waves approaching a straight shoreline at an angle. The part of each wave nearest shore is moving in shallower water and, consequently, is moving slower than the part in deeper water. Thus the wave fronts tend to become parallel to the shoreline and the observer on the beach will see larger waves coming directly toward him. On an uneven shoreline the effect of refraction is to concentrate the wave energy on points of land and disperse the wave energy in coves or embayments. Submarine depressions, i.e., canyons, also cause the waves to react in a similar fashion. The waves dissipate over the canyon and increase in intensity on the perimeter of the canyon. Any irregularities in bottom topography in **shallow** waters will cause refraction to some degree.

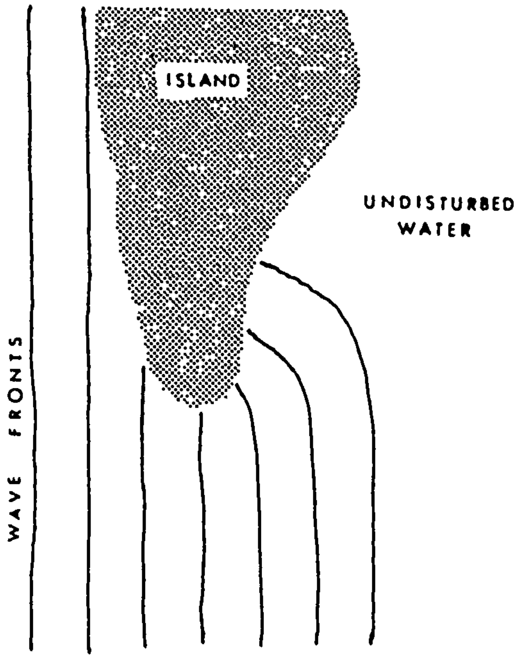


Figure 5. Wave Diffraction

A knowledge of the behavior of waves as they enter shallow water is of considerable significance to scuba divers when planning entries from shore. By observing wave patterns and by studying the shoreline configuration and bottom topography, the diver can select the locations where wave energy and, consequently, height is least. This will aid entry and nearshore work.

SURF

As swell, the waves traverse vast expanses of ocean with little modification or loss of energy. However, as the waves enter shallow water, the motion of the water particles beneath the surface is altered. When the wave enters water of depth equal to or less than one-half the wavelength, it is said to

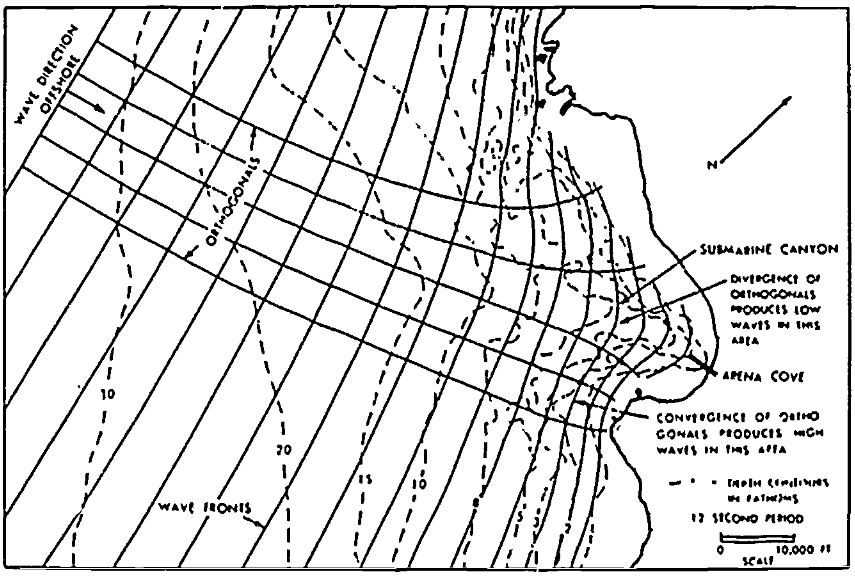


Figure 6. Wave Refraction [1]

"feel bottom." The circular orbital motion of the water particles becomes elliptical, flattening with depth. Along the bottom, the particles oscillate in a straight line parallel to the direction of wave travel.

As the wave "feels bottom," its wave length decreases and steepness increases. Furthermore, as the wave crest moves into water where the depth is about twice that of the wave height, the crest changes from rounded to a higher, more pointed mass of water. The orbital velocity of the water particles at the crest increases with increasing wave height. This sequence of changes is the prelude to the breaking of the wave. Finally, at a depth of approximately 1.3 times the wave height, when the steepest surface of the wave inclines more than 60 degrees from the horizontal, the wave becomes unstable and the top portion plunges forward. The wave has broken; this is **surf** (Figure 7). This zone of "white water," where the waves finally give up their energy and where systematic water motion gives way to violent turbulence, is the **surf zone**. The "white water" is a mass of water with bubbles of entrapped air.

Having broken into a mass of turbulent foam, the wave continues landward under its own momentum. Finally, at the beach face, this momentum carries it into an uprush or swash. At the uppermost limit, the wave's energy has diminished. The water transported landward in the uprush must now return seaward as a backrush, or current flowing back to the sea. This seaward movement of water is generally not evident beyond the surface zone or a depth of 2-3 ft. This backrush is **not** to be considered as an **undertow**. Undertow is one of the most ubiquitous myths of the seashore. These mysterious mythical currents are said to flow seaward from the beach along the bottom and "pull swimmers under." There are currents in the surf zone and other water movements which may cause trouble for swimmers, but not as just described. Such problems will be discussed later.

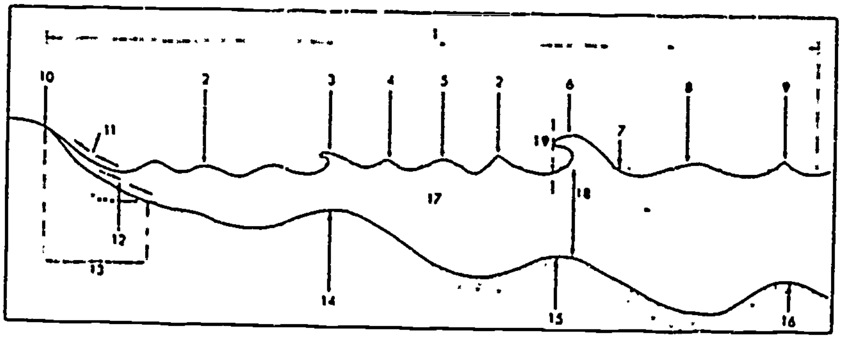


Figure 7. (1) Surf Zone; (2) Translatory Waves; (3) Inner Line of Breakers; (4) Peaked-up Wave; (5) Reformed Oscillatory Wave; (6) Outer Line of Breakers; (7) Still-Water Level; (8) Waves Flatten Again; (9) Waves Break Up but Do Not Break on This Bar at High Tide; (10) Limit of Uprush; (11) Uprush; (12) Backrush; (13) Beach Face; (14) Inner Bar; (15) Outer Bar (Inner Bar at Low Tide); (16) Deep Bar (Outer Bar at Low Tide); (17) Mean Lower Low Water (MLLW); (18) Breaker Depth, 1.3 Height; (19) Plunge Point [1]

Once the wave has broken, if the water deepens again, as it does where bars or reefs lie adjacent to shore, it may reorganize into a new wave with systematic orbital motion. The new wave is smaller than the original one and it will proceed into water equal to 1.3 times its height and also break. A diver may use the presence of waves breaking offshore as an indicator for the location of rocks, bars, etc. and plan his entry or approach to shore accordingly (Figure 8).

One characteristic of waves most evident to an observer standing on shore is the variability in the height of breakers. They generally approach in groups of three or four high waves, followed by another group of relatively small waves. This phenomena is frequently the result of the arrival of two sets of swells (from two different storms or sources), of nearly the same wave period, at the same time. When the crest of the two sets of swells coincide, they reinforce each other and produce waves higher than those of either set. When the crests of one set coincide with the troughs in the other set, a cancellation effect results in smaller waves. By studying the waves, the diver can determine the "surf beat," or frequency of the pattern (Figure 9), and time his entry (or exit) to coincide with the

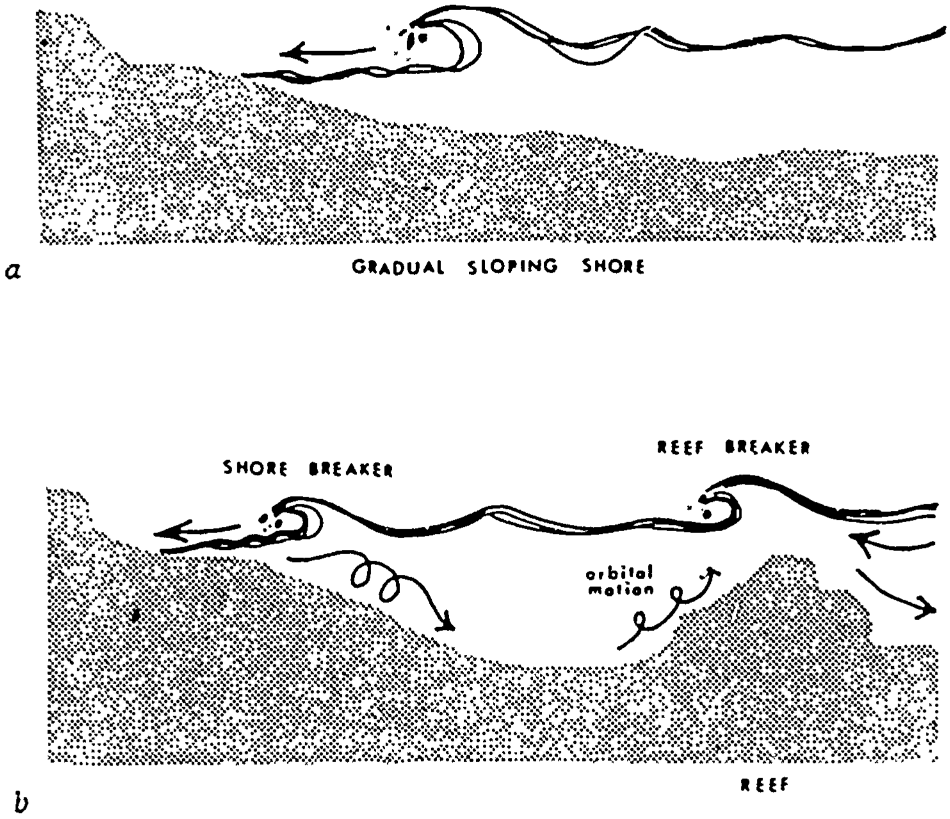


Figure 8. (a) No Bar or Reef Offshore; (b) Bar or Reef Offshore

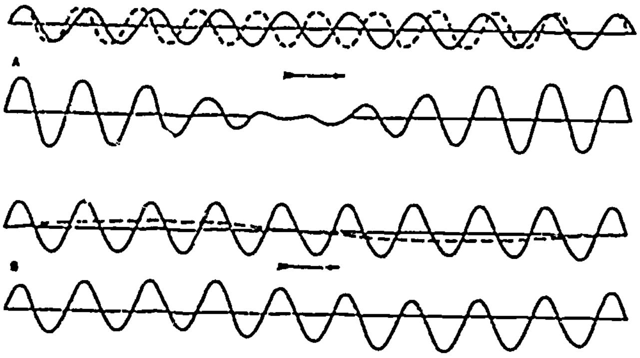


Figure 9. Wave Interference and Surf Beat: (A) Two Waves of Equal Height and Nearly Equal Length Traveling in the Same Direction, Shown with Resulting Wave Pattern; (B) Similar Information for Short Waves and Long Swell [2]

period of minimum wave height. Two groups of waves, each with a period of about 12 seconds, combine to cause an overall "surf beat" period of 2 minutes. Consequently, under such conditions, a period of minimum wave height can be expected every 2 minutes.

Currents

In and adjacent to the surf zone, **currents** are generated by waves approaching the bottom contours at an angle and by irregularities in the bottom. When waves approach the shore at an angle, a longshore current is generated which flows **parallel to the beach** within the surf zone. Longshore currents are most common along straight beaches. The speeds increase with breaker height, decreasing wave period, increasing angle of breaker line with the beach, and increasing beach slope. Speed seldom exceeds 1 knot. As previously discussed, wave fronts advancing over nonparallel bottom contours are refracted to cause convergence or divergence of the energy of the waves. Energy concentrations, in areas of convergence, form barriers to the returning backwash, which is deflected along the beach to areas of less resistance. These currents turn seaward in concentrations at locations where there are "weak points," extremely large water accumulations, gaps in the bar or reef, submarine depressions perpendicular to shore, etc. and form a **rip current** through the surf (Figure 10).

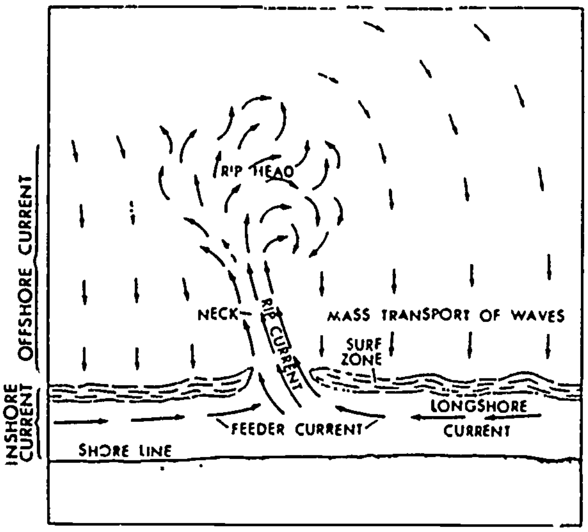
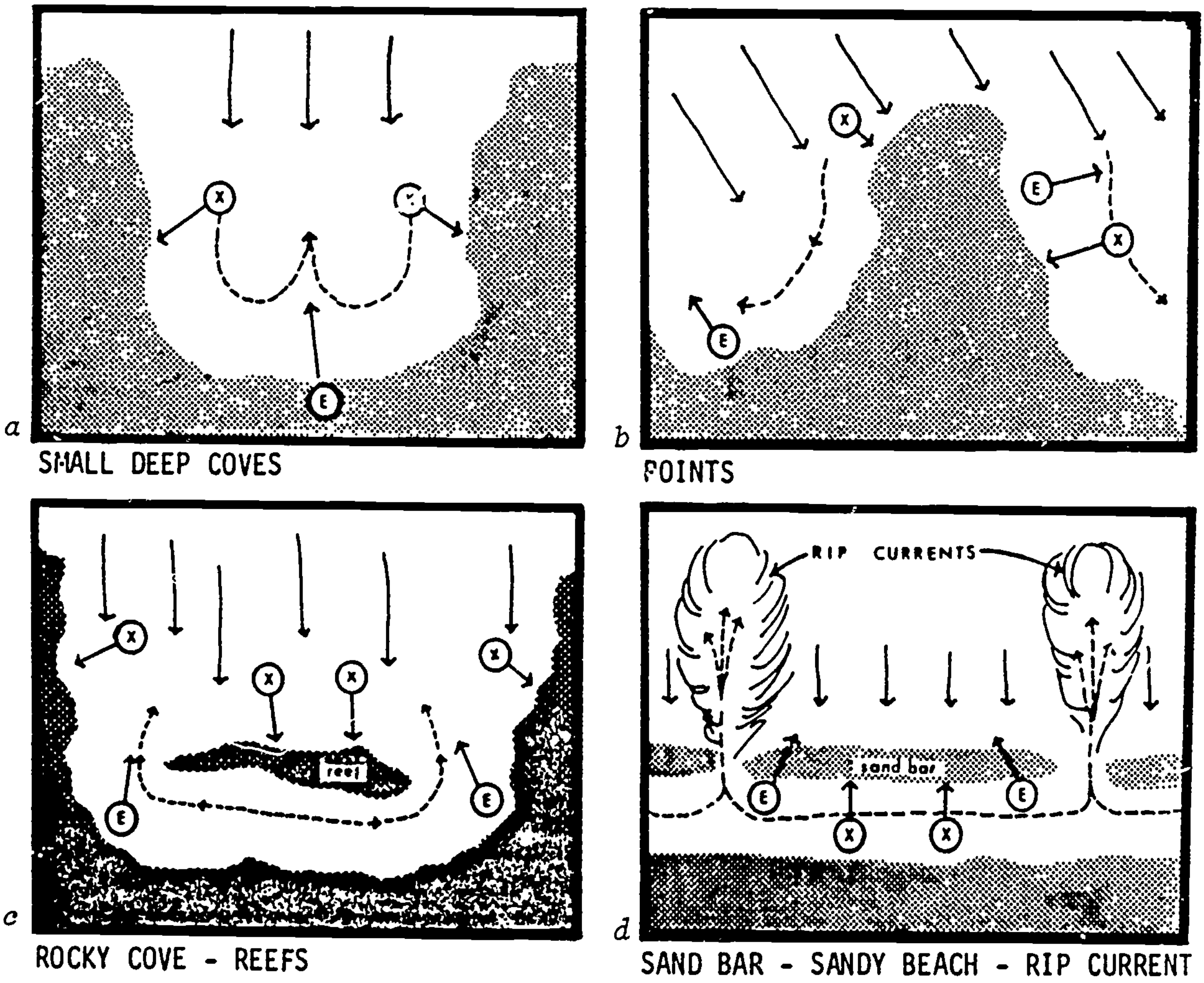


Figure 10. Nearshore Current System [1]

The large volume of returning water has a retarding effect upon the incoming waves. The waves adjacent to the rip current, having greater energy and not being retarded, advance faster and farther up the beach. This is one way to visually detect a rip current from shore. The rip may also be transporting large volumes of suspended material, creating a muddy appearance.

The knowledgeable diver will use modest rip currents to aid rapid seaward movement. An unsuspecting swimmer, when caught in a rip, should ride the current and swim to the side, not against the current. Outside the surf zone the current widens and slackens. He can then enter the beach at another location. The rip current dissipates a short distance from shore.

Most shorelines are not straight features. Irregularities in the form of coves, bays, points, etc. affect the incoming waves, tidal movements, and the resultant current patterns. When preparing for a dive where beach entries and exits are necessary, the diver must take wave approach, shoreline configuration, and currents into account. Entries and exits should be planned to avoid high waves, as on the windward side of points, and to take maximum advantage of current movements. Avoid dives that require swimming against the current. Never undertake a dive from an ocean beach without considering these factors. Hypothetical beach configuration, wave approach, and current diagrams are included in Figure 11 to aid the diver in the concepts of planning beach-entry dives.



SMALL DEEP COVES

POINTS

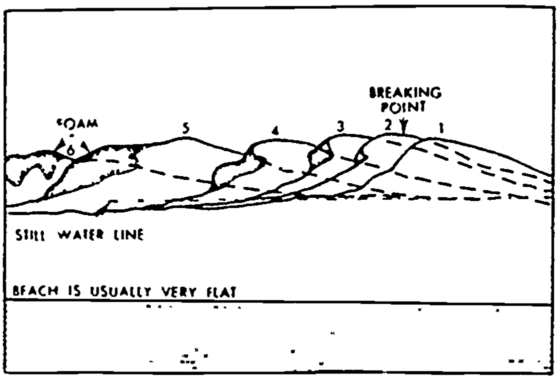
ROCKY COVE - REEFS

SAND BAR - SANDY BEACH - RIP CURRENT

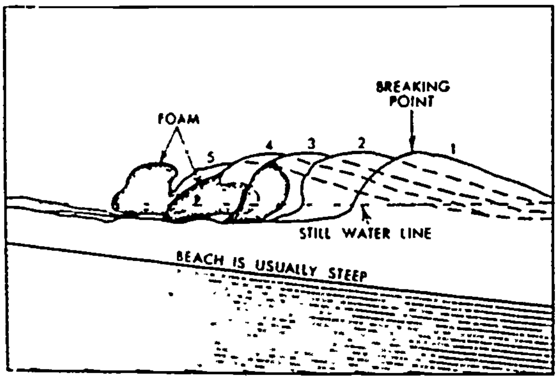
Figure 11. Shore Types and Currents: (a) Small, Deep Coves; (b) Points; (c) Rocky Cove, Reefs; (d) Sand Bar--Sandy Beach--Rip Current (E = Entry; X = Exit)

Sand Beach Entry

The width of surf zone and the severity of the breaking waves will be influenced significantly by the slope of the beach. On a **gradually sloping beach** the surf zone will be wide since the wave will break, re-form, and break again (Figure 12 a). The diver must observe the wave pattern and surf beat in order to time his movement into the surf zone. The best technique for entry is usually to get completely outfitted (including fins), select the best time (least wave height), and move into the zone backwards while watching the oncoming waves. As soon as the water is deep enough, the diver should start swimming. He must swim under the oncoming waves, not attempt to swim over them. A diver should not stand up and face an oncoming wave. If a float is used, it should be towed, not pushed into the waves.



a GENERAL CHARACTER OF SPILLING BREAKERS



b GENERAL CHARACTER OF PLUNGING BREAKERS

Figure 12. Breakers: (a) Spilling; (b) Plunging [1]

The weight of the equipment, the shift of the normal center of gravity, the restriction of the diving suit, the cumbersome fins, and the fogginess of the mask are all factors which complicate entries through surf. A diver can compensate for the shift in center of gravity and the weight of the tank by moving with his knees slightly bent, feet apart, and leaning slightly forward. When moving, the diver should slide his feet along the bottom and not attempt to take big steps. If a diver falls or is knocked down, even in shallow water, he should not attempt to stand and regain his footing. He should conserve his energy and swim or crawl to deeper water (or back to shore).

A high surf on a **steeply sloping beach** is extremely dangerous for a diver in full equipment. The waves will break violently directly on the beach, with a very narrow surf zone (only a few feet wide) (Figure 12 b). A diver wearing fins may be up-ended by the force of the water running down the steep slope after a wave has broken. The diver must evaluate both the shoreline and the surf conditions to determine if safe entry is possible. Under severe conditions, the best judgment may be to abort the dive. To make the entry, the diver should move as close to the water's edge as possible, select the proper time (smallest wave), and move into the water and under the oncoming wave **as soon as possible.**

On steeply sloping beaches in Hawaii, divers sometimes elect to carry their fins through the surf instead of wearing them. This method allows rapid entry and better footing while entering the surf. Otherwise the diver may be up-ended by the backrush of water acting on his fins. Once beyond the surf zone, the diver dons his fins. Prior to entry, the diver using this method must inflate his buoyancy compensater (or lifejacket) in order to be slightly **positive buoyant** when he gets beyond the surf zone so he can put on his fins. However, an entry **without fins is not recommended.** If local conditions are such that an entry with fins is not possible, then the entry without fins must be made **with considerable discretion** and a great deal of caution. A fully equipped scuba diver overweighted and caught in the surf zone without fins is virtually helpless. The diver should select another entry location rather than attempt entries through surf without fins.

When exiting through surf, the diver should stop just seaward of the surf zone and evaluate wave conditions. The exit should be timed so that the diver rides the back of the last large wave of a series as far up the beach as possible. At a point where the diver can stand, he should turn his back toward the beach, face the oncoming waves, and move toward the beach with his body positioned to retain his balance. If the oncoming waves are still at chest level or higher, the diver should dive head first into the wave and stand up as soon as possible when the breaking part of the wave has passed. If the wave is below chest level, the diver should simply lie on top of the wave, keep his feet under him, and ride the wave toward shore. A fatigued diver should not attempt to regain his footing, but ride the wave as high up the beach as possible and crawl out on his hands and knees. On exits through the surf, the float should be pushed in front of the diver and released if necessary to avoid injury or entanglement.

Rocky Shore Entry

When entering surf from a **rocky shore**, the diver should not attempt to stand or walk. A fall can be extremely hazardous. The diver should evaluate the wave conditions, select the backwash of the last large wave of a series, and crawl into the water. The backwash will generally carry the diver through the rocks. Once the diver is moving, he should not attempt to stop or slow down. If the diver retains a prone swimming position and faces the next oncoming wave, he can grasp a rock or kick to keep from being carried back toward the shore. He can then kick seaward after the wave passes. Floats should be towed behind the diver.

When exiting on a rocky shoreline, the diver must stop outside the surf zone and evaluate the wave conditions. Exit toward the beach is made on the backside of the last large wave of a series. As he loses momentum, he should grasp a rock or kick in order to avoid being carried seaward by backwash. The diver should maintain position, catch the next wave, and move shoreward. The diver will finally find it necessary to crawl from the water. When exiting through surf, the diver should always look back in order to avoid a surprise condition.

TIDES AND TIDAL CURRENTS

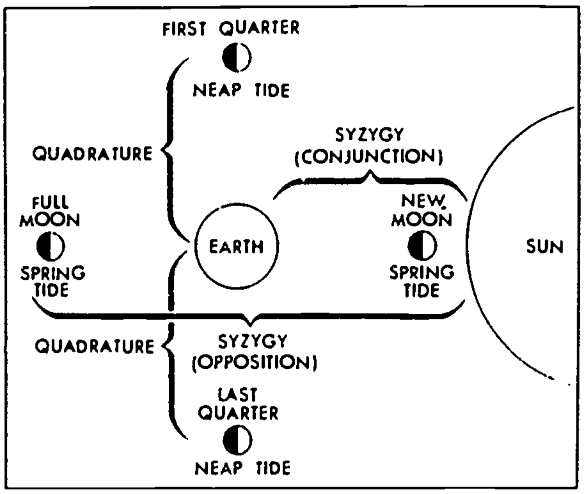


Figure 13. Tide Cycle [1]

The **tidal phenomenon** is the periodic motion of the ocean waters in response to the variations in attractive forces of various celestial bodies, principally the moon and sun, upon different parts of the rotating earth (Figure 13). On the seacoasts this motion is evidenced by a rhythmic, vertical rise and fall of the water surface called the **tide** and horizontal movements of the water called **tidal currents.** Essentially, tides are long-period waves having a period of 12 hours and 25 minutes and a wave length equal to one-half the circumference of the earth. The tidal cycle is

24 hours and 50 minutes. The force of the earth's gravity acts approximately toward the earth's center, and tends to hold the earth in the shape of a sphere. Although the sun is larger in mass than the moon, the moon's effect on the earth is much greater because of its proximity to the earth. The moon appears to revolve about the earth, but actually the moon and earth revolve about a common center of mass (the sun). The two bodies are held together by gravitational attraction and pulled apart by an equal and opposite centrifugal force. In this earth-moon system, the tide-producing force on the earth's hemisphere nearest the moon is in the direction of the moon's attraction (toward the moon). On the hemisphere opposite the moon, the tide-producing force is in the direction of the centrifugal force (away from the moon). The resulting effect on the oceans is that two bulges of water are formed on opposite sides of the earth's surface. The earth rotates on its axis once each day, and one can visualize that it rotates constantly inside a fluid veneer (the oceans). This concept considers the tidal "wave" as standing motionless while the ocean basin turns beneath it. Ideally, most points on the earth should experience two high tides and two low tides daily. However, due to changes in the moon's declination (position) relative to the equator, there is introduced a diural (daily) inequality in the pattern of the tidal forces at many places.

There are similar forces due to the sun, and the total tide-producing force is the result of both the sun and the moon, with minute effects caused by other celestial bodies. The sun tides increase or reduce the lunar tides. The two most important situations are when the earth, sun, and moon are aligned (in phase) and when the three form a right angle (out of phase). When they are in phase, the solar tide reinforces or amplifies the lunar tide to cause **spring (highest) tides.** Spring tides occur at new and full moon. **Neap (lowest) tides** occur when the sun and moon oppose each other (out of phase). The tidal range is further influenced by the intensity of the tide-producing forces (Figure 14). When the moon is in its orbit nearest the earth (at **perigee**), higher perigean tides occur; when the moon is farthest from the earth (at **apogee**), the smaller, apogean tides occur. When new or full moon and perigee coincide, the great perigean spring tides (highest tides of the year) occur. When first quarter or third quarter moon and apogee coincide, the small apogean neap tides occur. A slight delay or lag may be

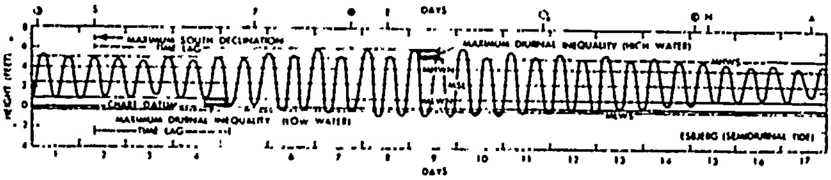


Figure 14. Typical Tide Curve [1]

noted between a particular astronomic cause and the resultant tide.

Although the tide-producing forces are distributed over the earth in a regular manner, the sizes and shapes of the ocean basins and the interference of the land masses prevent the tides from assuming a simple, regular pattern. The position of the tide relative to the moon is somewhat altered by the friction of the earth as it rotates beneath the water. This friction tends to drag the tidal bulge, while the gravitational effect of the moon tends to hold the bulge beneath it. The two forces establish an equilibrium and, in consequence, a point on the earth passes beneath the moon before the corresponding high tide.

A body of water has a natural period of oscillation that depends on its dimensions. The oceans of the earth's surface appear to be comprised of a number of oscillating basins, rather than a single oscillating body. The response of the basin of water to tide-producing forces is classified as semidiurnal, diurnal, or mixed (Figure 15). In a **semidiurnal** type of tide, typical to the Atlantic coast of the United States, there are two high and two low waters each tidal day, with relatively small inequalities in the high- and low-water heights. The **diurnal** type of tide of the northern shore of the Gulf of Mexico has a single high and single low water each tidal day. In the **mixed** type of tide, the diurnal and semidiurnal oscillations are both important factors and the tide is characterized by a large inequality in high-water heights, low-water heights, or in both. Such tides are prevalent along the Pacific coast of the United States.

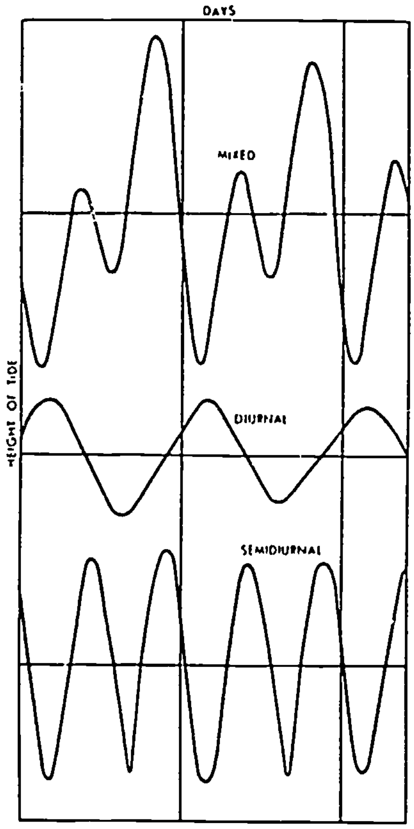


Figure 15. Types of Tide Curves [1]

The tidal range will vary considerably, depending on the configuration of the shoreline, time of month, time of year, wind conditions, etc. On small oceanic islands, the range may be a foot or less. However, along the coasts of major continents, the tidal range is exaggerated at the shore. Estuaries with wide funnel-shaped openings into the ocean tend to amplify the tide range even more. The width of the tidal wave that enters the mouth of the estuary is restricted as the channel narrows; this constriction concentrates the energy and increases the height of the wave. The frictional effects of the sides and bottom of the channel tend to reduce the energy and height. The classic example of this phenomenon is the Bay of Fundy, where the tidal range exceeds 40 feet. Only a few hundred miles away, Nantucket Island has a tidal range of about 1 foot.

Tidal current, the periodic horizontal flow of water accompanying the rise and fall of the tide, is of considerable significance to the diver who must work in restricted bay-mouth areas, channels, etc. Offshore, where the direction of flow is not restricted by any barriers, the tidal current flows continuously, with the direction changing through all points of the compass during the tidal period. In rivers or straits, or where the direction of flow is more or less restricted to certain channels, the current reverses with the rise and fall of the tides. In many locations there is a definite relationship between times of current and times of high and low water. However, in some localities it is very difficult to predict this relationship. Along channels or waterways the relationship will change as the water progresses upstream.

At each reversal of current, a short period of little or no current exists, called **slack water**. During flow in each direction, the speed will vary from zero at the time of slack water to a maximum, called **strength of flood** or **ebb**, about midway between the slack periods. These tidal movements are represented graphically in Figure 16. The current direction or set is the direction toward which the current flows. The term "velocity" is frequently used as the equivalent of "speed" when referring to current; however, in proper terminology "velocity" implies direction as well as speed. Tidal current movement toward shore or upstream is the **flood**; the movement away from shore or downstream is the **ebb**.

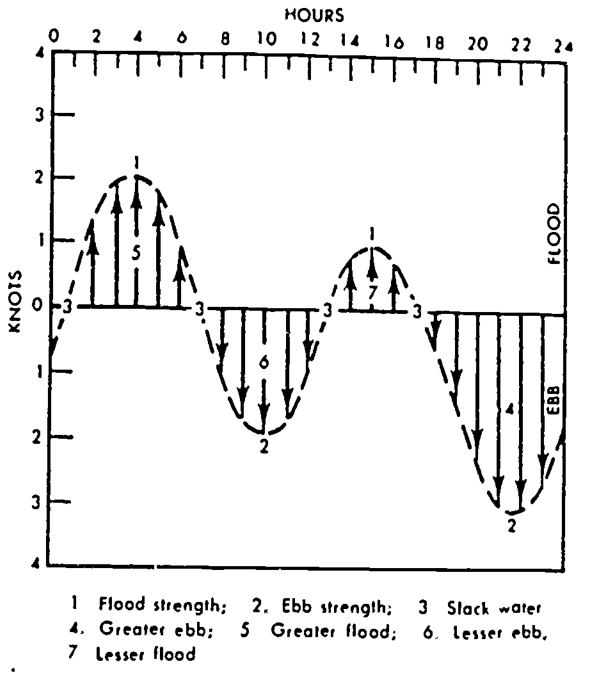


Figure 16. Tidal Current Curve [1]

Divers are encouraged to consult local tide tables, confer with local authorities, and make personal evaluations of the water movements in order to determine time of slack water and, consequently, the best time to dive. Tide tables and specific information are contained in various forms in many navigational publications. Tidal current tables, issued annually, list daily predictions of flood and ebb tides, and of the times of intervening slacks.

In some channels or straits the diver will be limited to 10-20 minutes of safe diving at time of slack water (Figure 17). Specific precautions must be taken when working in these areas. Dives must be planned and timed precisely. Scuba diving may be least desirable. Surface-supplied diving equipment, with heavy weighted shoes, may be required for the diver to work in the currents. The diver should not attempt to swim against the tidal current. If he is caught in a current, he should surface, inflate his lifejacket and swim perpendicular to the current toward shore or signal for pick up by the safety boat.

WIND CURRENTS

The stress of wind blowing across the sea causes the surface layer of water to move. This motion is transmitted to succeeding layers below the surface; however, due to internal friction within the water mass, the rate of motion generally decreases with depth. Although there are many variables, generally a steady wind for about 12 hours is required to establish such a current. A seasonal current has large changes in direction or speed due to seasonal winds.

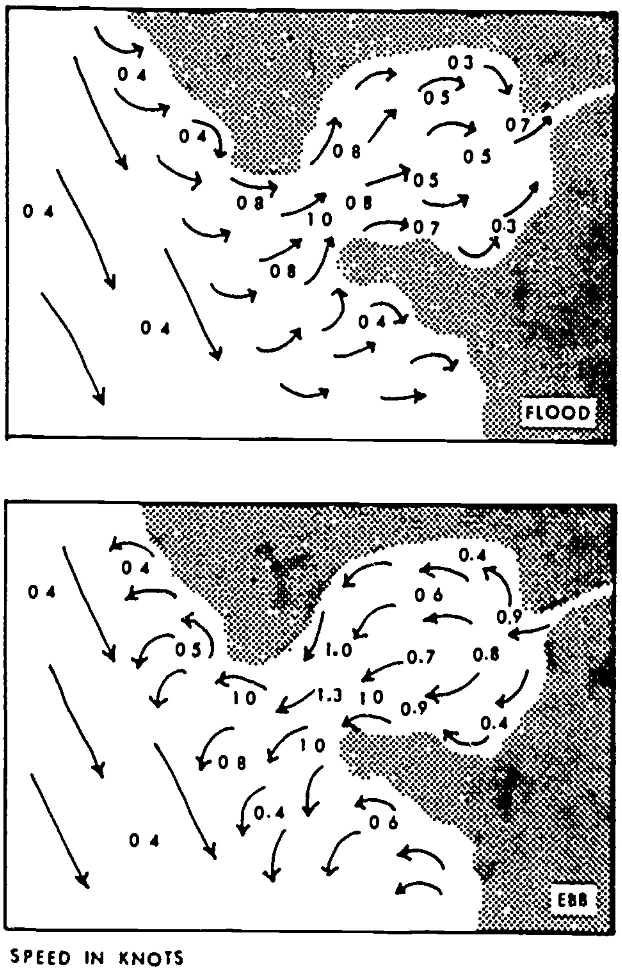


Figure 17. Flood and Ebb

A wind current does not flow in the direction of the wind due to the effects of the rotation of the earth, or Coriolis force. Deflection by Coriolis force is to the right in the northern hemisphere, and toward the left in the southern hemisphere. This force is greater in higher latitudes and more effective in deep water. Current direction varies from about 15 degrees relative to wind direction along shallow coastal areas to a maximum of 45 degrees relative to wind direction in deep ocean. The angle increases with depth, and at greater depths the current may flow in the opposite direction to the surface current.

The speed of the wind-derived current depends on the speed of the wind, its constancy, the length of time it blows, and other factors. In general, about 2 percent or less of the wind speed is a good average for deep water where the wind has been blowing steadily for at least 12 hours.

A number of ocean currents continue with relatively little change throughout the year. These large-scale currents are primarily the result of the interaction between the general circulation of the atmosphere and the ocean water.

The primary generating force of currents is the wind, and the chief secondary force is the density differences in the water. In addition, such factors as water depth, underwater topography, shape of the ocean basin, land configuration, and the earth's rotation affect oceanic circulation.

SEICHES

When the surface of a large, partially enclosed body of water, such as one of the Great Lakes or a bay, is disturbed, long waves may be set up which will rhythmically oscillate as they reflect off opposite ends of the basin. These waves, called **seiches**, have a period that depends on the size and depth of the basin. The seiche is a rather common phenomenon not frequently observed by laymen because of the very low wave height and extremely long wavelength. A seiche can be regarded as a standing wave pattern.

In the Great Lakes, seiches are induced by differential barometric pressure changes and, most frequently, winds. For example, a strong wind blowing for several hours along the axis of Lake Erie will drive the surface water toward the leeward end of the lake, raising the water surface there as much as 8.4 ft, and lowering the level at the windward end of the lake. When the wind ceases or shifts, the lake surface will start to oscillate, alternately rising and falling at each end of the lake. This oscillation, which diminishes rapidly in amplitude, has a period of 14-16 hours [3]. Lake Erie is particularly subject to seiches because the lake is shallow, nearly parallel with the prevailing winds, and has a basin of fairly regular and simple shape.

In 1954 a severe seiche in Lake Michigan, resulting from both wind and barometric pressure changes, caused an abrupt increase in water level to 10 feet above normal in the vicinity of Chicago. At least seven lives were lost [4,5].

In bays that open to the ocean, seiching is almost always caused by the arrival of a long-period wave train. Once the water is set in motion by the initial wave, seiching continues at the natural period for that harbor or bay. Bascom discusses the phenomenon of seiching in ocean bays [6].

DIVING IN CURRENTS

Currents are caused primarily by the influence of surface winds, changing tides, and rotation of the earth. They are essentially flowing masses of water within a body of water. Divers must always take currents into account in planning and executing a dive, particularly a scuba dive. Large ocean currents such as the Gulf Stream of the Atlantic and Japan current of the Pacific flow continuously, although there may be local variations in magnitude and location. Local wind-derived currents are common throughout the oceans and on large lakes.

The current velocity may exceed 2-3 knots. Attempts to swim against this type of current may result in severe fatigue. Sometimes in the Gulf of Mexico, as well as other portions of the ocean, there may be no noticeable current at the surface with a 1- to 2-knot current at a depth of 10-20 ft, or there may be a current at the surface and no current at 10-20 ft down. The following precautions should be observed to minimize the hazards to the diver:

- The diver should always wear a personal flotation device.
- The diver should be in good physical condition when working in currents.
- A safety line at least 200 ft long with a float should be trailed over the stern of the boat during diving operations when anchored in a current. Upon entering the water, a diver who is swept away from the boat by the current can use this line to keep from being carried far down current.
- Descent should be made down a weighted line placed at the stern, or, if unavailable, down the anchor line. Free swimming descents in currents should be avoided. If the diver stops to equalize pressure, he may be swept far down current. Furthermore, if a diver has to fight a current all the way to the bottom, he'll be fatigued, a hazardous situation underwater. Ascent should also be made up a line.
- When a bottom current is encountered at the start of the dive, the diver should always swim into the current, not with it. This will facilitate easy return to the boat at the end of the dive. He should stay close to the bottom and use rocks if necessary to pull himself along in order to avoid overexertion. If the diver wants to maintain position, he should grasp a rock or stop behind a rock, not attempt to swim. The same technique should be used by a fatigued diver to rest.

* A qualified assistant should stay on the boat at all times. This will facilitate rescue of a diver swept down current.

WEATHER

Weather is always a factor to consider when planning offshore diving operations in large lakes or the ocean. Divers must be familiar with local weather conditions and monitor weather forecasts. Different areas may have unique weather conditions and the diver must consult with local authorities regarding weather conditions and changes. In some areas, offshore operations from small boats are prohibited by weather and, consequently, wave conditions during certain portions of the year.

When diving offshore, abrupt wind and sea condition changes can transform a pleasant day into a nightmare. The diver should not venture too far from shore or from his diving craft when he is aware of the possibility of weather changes. High winds and rough seas can defeat even the strongest swimmer. It is therefore wise to surface periodically and evaluate the weather situation. In the Florida Keys, a squall can sometimes appear seemingly out of nowhere on an otherwise perfect day.

A squall line which appears to be some distance away should be observed for direction of movement, greater development, increased wind velocity, water spouts, etc. If the approaching storm looks severe and is approaching from open ocean, it may be wise to abort the operation and return to shore if you are working from a small boat. In the Florida Keys, however, these squalls approach quickly and are generally of short duration. If the squall overtakes the fleeing boat, navigation in poor visibility will be very hazardous.

Under these circumstances it may be wiser to anchor the boat securely and ride the storm out. If the skipper decides to anchor, he must face his boat into the oncoming waves and let out plenty of anchor line; a taut line can snap and the boat will be set adrift.

Following a heavy rain squall, there may be high winds, and the skipper must exercise caution while getting underway again. Choppy seas and murky water may make it difficult to avoid shallow reefs, floating objects, lobster trap lines, etc.

The diver must remember that a wind blowing from land to sea can be very deceiving. What may appear as calm water from shore may be a raging sea at the outer reef. Returning to shore into the waves will be difficult.

Serious storms and severe wave conditions can be expected on the Great Lakes in September, October, November, and December as a result of local weather phenomena. This period of instability relates to the energy system established when cold atmospheric air encounters the air heated by the warmer lake water. The result is sudden storms and high seas. Again the diver is encouraged to consult with local authorities and monitor weather forecasts before diving offshore. Divers are also encouraged to acquire instruction in boat handling and seamanship. Courses are available from the US Coast Guard Auxiliary, sportsman groups, etc.

CONCLUSIONS

Since the beginning of time, the waters of our planet have stimulated the imagination of man. Under these waters lies an exciting world of beauty and challenge. The underwater explorer and researcher can now, as never before, venture to greater depths and to the most remote corners of the ocean. However, he/she must be equipped with a basic working knowledge of waves, tides, and currents. When divers visit unfamiliar areas, they must consult with local divers and authorities to gain information on particular environmental conditions.

The diver must develop a "sixth sense" in the evaluation of environmental conditions in order to plan dives safely and efficiently. Most divers get into trouble at one time or another by underestimating the potential hazards associated with the underwater environment or by overestimating their physical capabilities and diving skills in coping with adverse currents, waves, etc. Good physical condition, basic knowledge, common sense, and good judgment are prerequisites for **safe** underwater exploration.

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