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SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION ALEXANDRIA, VIRGINIA

CLASSIFICATION CHANGED
TO: UNCLASSIFIED
FROM: CONFIDENTIAL
AUTHORITY:
OPNAV INST 5510.1E
Sec. 1-603(2), 23 Aug 73,
Per USNOO ltr, 14 Sep 77

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Application of Oceanography to Mine Warfare

U. S. NAVY HYDROGRAPHIC OFFICE
H. O. PUB. NO. 768

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Frontispiece—Aerial view of mineable water showing effects of such oceanographic variables as transparency, currents, and waves (Photo from ONI files)

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H. O. PUB. NO. 765

APPLICATION OF OCEANOGRAPHY
TO
MINE WARFARE

First Edition
1957

Published by the Hydrographic Office under the authority of the
Secretary of the Navy

U. S. Navy Hydrographic Office
Washington, D. C.

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FOREWORD

At the direction of the Chief of Naval Operations, the Hydrographic Office has undertaken the responsibility to prepare a mine manual. It is intended to satisfy the present urgent need for a publication especially designed for the effective use of environmental intelligence in the mine operations of the Fleet.

In an attempt to improve this publication and in order to expedite its maintenance, users are requested to submit pertinent material which may be useful.

H. C. Daniel,
Rear Admiral, U. S. Navy
Hydrographer.

PREFACE

The judicious use of environmental intelligence can often spell the difference between success and failure of a mining operation. This requires the application of basic oceanographic principles to specific situations in the ocean. This publication, while not dealing in specific situations, is intended to furnish the mine warfare officers with some of the elementary principles of the interaction of environmental factors with mines and mine countermeasures. It is hoped that this manual will further the understanding of the oceanographic environment, so that maximum use may be made of such information.

The comments submitted by the various Technical Bureaus, ONR contractors, and personnel of the operating forces contributed immeasurably to the preparation of this manual. The service of Dr. S. Q. Duntley, who assisted in preparing the section on Visibility, is gratefully acknowledged.

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INTRODUCTION

1.1 HISTORY

One of the earliest uses of gunpowder in warfare, even before the invention of the gun, was to tunnel beneath an enemy and detonate a stationary charge. This item of ordnance was exploded before the enemy knew where it was. To describe it, the term *mine* was borrowed from metallurgical mining where similar digging techniques were employed, and the term later became generic for any fixed explosive charge. Underwater mines were first called *torpedoes*, after a kind of fish, but when the Whitehead self-propelled torpedo was developed, shortly after the American Civil War, the term *torpedo* was restricted to such self-propelled charges, and the fixed or drifting underwater charges became known as *mines*.

During the American Revolution, Bushnell, the inventor of the submarine, failed in an attempt to attach a 150-pound mine to the bottom of a British man-of-war. Bushnell also launched mines, consisting of kegs of gunpowder equipped with contact fuzes, which drifted with currents into the paths of British ships. However, Bushnell's drift mines proved to be no more successful than his earlier limpet-mining attempts.

Experiments with contact mines continued; Russia, during the Crimean War, and the Confederacy, during the American Civil War, developed controlled and contact mines. In the latter case, mines became sufficiently perfected so as to sink several ships. Mines were also used widely in the Russo-Japanese War.

The prototypes of most modern mines were developed before World War I. During that war the Germans laid numerous minefields around the British Isles. The British and American navies countered by laying a broad belt of mines 230 miles long across the North Sea. During World War II, mines again proved important. The main developments were the techniques of air-dropping mines and the invention of complicated firing mechanisms. The Allies and Germans fought a continuous battle of wits, each side trying to surprise the other by introducing new features into the firing mechanisms for the purpose of making the mines more difficult to sweep. These new features have developed to the point where minesweeping alone cannot counter a mining attack.

As mines became more sensitive and complex, the effect of the environment became increasingly important. The following statement by CINCNELM (Ellis, 1956) illustrates the significance of hydrographic and oceanographic information in mine warfare.

> "The mine is the perfect weapon for a nation with inferior sea power. By restricting or slowing the movement of a fleet, that nation using mines wrests control of the sea from the superior naval power. The United States, the greatest sea power of modern times, temporarily lost control, locally, at Wonsan and Chinnampo, Korea at a very crucial stage, preventing the landing of our troops and permitting the escape of the enemy.
>
> "Had the North Koreans possessed a larger variety of mine types, and had they not been ignorant of the environmental factors involved, we probably would not have been able to use these harbors at all. Knowledge of the hydrography and oceanography of places to be mined plus an understanding of how mines are thereby affected is absolutely essential to the accomplishment of an efficient mining campaign, or of countermeasures to such a campaign."

1.2 EFFECTS OF THE ENVIRONMENT

Mines utilize the ocean and the sea floor for concealment, as a medium for transmission of the signals of an approaching target, and as a medium for transmitting their destructive energy to the target when exploded. The effectiveness of mine countermeasures is critically dependent upon the ability of equipment to penetrate this medium to sweep or locate and neutralize mines.

A mine detects a target by measuring the disturbances in the environment produced by the approach or proximity of that target. Physical disturbances may be actual contact between the target and the mine. Acoustic, magnetic, pressure, and other environmental characteristics of the target produce influence fields in the water and sea bottom. The mine may be tuned to fire on a disturbance of the environment which results from being within the target's field of influence. The mine environment is subjected continually to other disturbances, natural and manmade, against which the mine must discriminate. These disturbances are collectively termed *background noise* and are always present in some degree. The passage of surface waves causes continuous pressure fluctuations at the bottom. Noise created by marine animal life, ocean waves, or industrial activity is always present. Natural fluctuations in the earth's magnetic field associated with the occurrence of magnetic storms are especially intense at certain magnetic latitudes. Earth currents may be induced near metropolitan areas by industrial activity, especially electric street car or subway facilities (Hunter, 1956). Theoretically, these disturbances may cause mines to fire prematurely.

For the purpose of decreasing the probability of firing on background noise and to make sweeping more difficult, many mines employ a combination of several distinct types of influence firing mechanisms. The frequency with which the separate influence firing mechanisms are satisfied by the background is a factor which deserves consideration in sweeping a minefield. For instance, when waves produce background pressure sufficient to cause continuous pressure looks, sweeping schedules and techniques may be modified to take advantage of the background.

The ability of the water and bottom media to transmit the influence fields of ships and of minesweeping gear depends upon depth, bottom type, gradients of temperature and salinity, sea state, and many other environmental factors, which will be described in the following sections.

1.3 OCEANOGRAPHIC INTELLIGENCE

The sources of local oceanographic intelligence may be of two types—on-the-spot observations and published intelligence surveys, such as Hydrographic-Oceanographic Data Sheets (Air Target Materials Program), National Intelligence Surveys, and Harbor Defense Atlases, compiled well in advance of the operation. The degree of reliability of each type of data depends upon the particular variable of interest. In general, for the rapidly changing features of the environment such as thermal structure and water transparency, on-the-spot observations are essential, and the long-term statistical picture obtained from intelligence surveys may be of little value. On the other hand, for relatively stable features such as bottom sediment type or regional current patterns, intelligence surveys are generally reliable since they have the advantage of a large number of observations not possible by superficial reconnaissance. In some areas intelligence data will not be available, and reconnaissance must be relied upon to provide the necessary advance information required by operations. Local on-the-spot observations or short-term reconnaissance may provide much valuable information of an original or supplementary nature and may be obtained visually, photographically, or by instrumental techniques. Hydrographic information such as location of shoreline, shoal or reef areas, and obstructions may be obtained visually and photographically. Bathythermograms (thermal structure) may be taken by reconnaissance boat or helicopter. Meteorological observations made in the area will enable sea, swell, surf, and weather conditions to be forecast. Current meters may be used in obtaining surface and subsurface currents. Bottom sampling provides a means of establishing or confirming bottom sediment type. Acoustic or electrical methods may be utilized in examining the structure of the bottom.

1.4 NEARSHORE OCEANOGRAPHY

Bathymetry

The shallow marine terraces which border the continents are called *continental shelves.* These shelves are in many places a continuation of the adjacent lands. Like adjacent coastal areas, they have many irregularities, most of them of a rather small size. They are cut by shallow valleys and deep canyons, and they have ridges and basin depressions. The shelf is ordinarily less than 100 fathoms deep. However, the gentle sloping shelf may extend down to 200 or 300 fathoms, the outer extremity being established as the point at which the somewhat steeper *continental slope* begins its descent to the abyssal depth (Fig. 1.1).

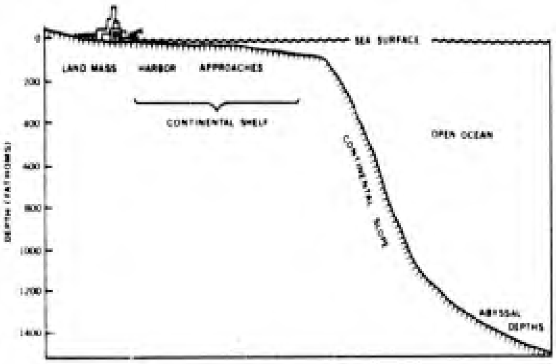

Figure 1.1.—Cross section through a typical harbor and offshore area.

The margin of the shelf may extend many miles offshore, or it may lie in close proximity to the coast. The continental shelf has a worldwide average width of 42 miles and an average slope of 0° 07′, being somewhat steeper in the inner half.

The platforms surrounding oceanic islands are called *insular shelves* in contrast to continental shelves which surround the continents. These are usually quite narrow. Exceptions are some coral islands which have broad shelves. Some coral banks in the southwest Pacific are 100 miles or more in width. These coral insular shelves are seldom deeper than 30 fathoms. Around noncoralline island shelves, depths are in general comparable to those found on the narrow continental shelves. Some islands lack appreciable insular shelves. Among these are islands made up of active volcanic mountains. The island of Hawaii, having active and recently extinct volcanoes, shows no shelf along most of its coast.

Near shore, the grosser features of the bottom topography are related to the general geologic structure of the shelf as produced by horizontal and vertical forces warping the bedrock into folds and faults. Submarine terraces over the shelf may be due to vertical faulting or may be the result of erosion at previous water levels during the geologic history of the area. Similarly, submarine valleys and canyons which extend at right angles to the general trend of the shore may be related to fault zones, or to submarine erosion channels. Various topographic features, such as basins or ridges, may result from bending of the earth's crust, or may have been dug by glaciers.

The shelf topography also is formed by the processes of sedimentation. This process may be slow or rapid, depending upon the volume of water runoff from the land and the volume of rock debris carried by the water.

Near shore, this rock debris, now called bottom sediments, is frequently shifted about by current and wave forces. As the sediments are shifted about so will the bottom topography be accordingly modified, and the depth of water may change. In tropical waters, reef-building coral and associated biological organisms are the main causes of bottom irregularity in the nearshore bathymetry. Steep slopes and soundings that change rapidly both with time and with distance are characteristic of coralline waters.

In some cases the nearshore bathymetry can be identified with adjacent coastal land.

Shelves off Glaciated Areas.—The distinctive glaciated nearshore bathymetry can be found along the coast of Alaska, New England, and Canada. The glaciated shelves of Europe (especially Norway) and South America (especially southern Chile) have the same characteristics.

The trough-shaped valleys of these glaciated shelves can be traced in many places from long, straight-sided estuaries or fjords, out across the entire shelf where they may terminate or, in a few cases, continue as submarine canyons. The valleys differ from typical submarine canyons in their great width, their relatively straight sides, and their great basin depressions. The depths of the troughs and basins are commonly in excess of 100 fathoms. Banks and shoals are more common on these types of shelves than most other types. Glaciated shelf widths are usually greater than the world average, such as the Grand Banks of Newfoundland.

Shelves off Large Rivers.—Some of the widest shelves in the world are found off large rivers, examples being the shelves of the Yellow Sea, the Gulf of Siam, and the Alaskan side of the Bering Sea. Nearly every wide shelf of the world is either off a glaciated coast or off the mouth of a large river. But not all large rivers empty over wide shelves. The delta of the Mississippi River, for example, slopes continuously into the deep basin of the Gulf.

Broad, level terraces frequently occur off large rivers at various depths, being especially common between 5 and 18 fathoms, although occuring at depths up to 55 fathoms. These terraces are decidedly shoaler than the terraces not related to large rivers.

Shelves in Areas of Active Coral Growth.—The shelves where coral is growing are always shoal. Numerous irregular shoals and reefs are found scattered over these areas. Abruptly shoaling bottoms, scattered coral heads, and extensive rough-surfaced coral flats are typical features.

The largest example of this type of shelf is the Great Barrier Reef along the Northeast coast of Australia. Shelf depths associated with coral growths are usually less than 20 fathoms.

Shelves off Young Mountain Ranges.—Bordering much of the Pacific Ocean are young mountain ranges. Along these ranges the continental shelves are either narrow or lacking. Where present, they average 10 miles in width. Narrow shelves are found off the coast in the vicinity of the Atlas Range in North Africa, the Maritime Alps, and the Spanish Pyrenees. These narrow shelves are steeper than average, particularly near shore.

Such shelves may not slope continuously into the *continental slope*, but they frequently have terraces.

Deeps and Shoals at Bay Entrances.—With the exception of deeps associated with glaciated coasts, the most remarkable submarine topography on inner continental shelves is found at narrow entrances to bays. Wherever sizeable bays are cut off from the ocean by narrow straits, deep holes exist either in the narrows or directly adjacent to them. In the entrance to San Francisco Bay the bottom attains a depth of 64 fathoms, with two sills in the approaches, one at a depth of 10 fathoms and one at 25 fathoms. Pronounced bottom depressions are found at the Pacific entrance to the Inland Sea of Japan. The narrow entrance to Rio de Janeiro has a depression with a depth of 26 fathoms and a sill of 8 fathoms. All these localities are associated with the scouring action of strong tidal currents.

Outside the Golden Gate a crescent-shaped sand bar rises to within 5 fathoms of the surface. Bars of this type, concave landward, exist off numerous narrow bay entrances. They appear to be a good indication of the depression within the narrows.

Bottom Sediments

The bottom may be composed of bare outcrops of bedrock, deposits of lava, or masses of coral rock, but usually such solid material is covered by a layer of unconsolidated particles of sediment, ranging in thickness from a few inches to several hundred feet. Bottom sediments can be divided into types according to the grain size. Grain sizes range from boulders to clay (Wentworth Scale, Glossary). All sediment types are found on the Continental Shelf and in harbor areas. In general, sand is the most common of the nearshore sediments. Exposed rock is the least common, but may occur adjacent to the coast off headlands or far out at the edge of the shelf. Where strong bottom currents tend to occur, they maintain the finer materials in suspension so that only the coarser type bottoms or exposed rock will prevail; however, fine grained sediments may remain from previous environmental conditions. Shell and coral fragments are often mixed with the inorganic mineral grain deposits. Various debris, due to natural causes or jettisoned from passing vessels, may constitute an appreciable quantity of the bottom deposits in the vicinity of harbors. Generally, bars and reefs will be characterized by the sands and coarser sediments. Basins or depressions, and relatively protected embayments are the typical environments for deposition of the finer grained sands, silts, or clays.

The physical properties of the sediments vary, depending upon porosity, water content, compaction, and plasticity. The greater variations of the physical properties within a given sediment type are found within the finer grained categories and particularly among the clays. In general, the mineral composition of the clays determines the plasticity characteristics. Grain size is the primary determinant of the porosity and water content. The mechanical behavior of nearshore sediments depends upon the properties inherent in each sediment type. In considering the effect of sediments upon naval weapons, careful study of physical properties and areal distribution of the sediments should be made.

Vertical variations in sediment types also may be expected where long-term environmental changes have occurred. Sands may grade vertically into silts or clays before bedrock is reached. The thickness of each layer may vary considerably.

Currents

The speed and direction of currents near shore are primarily due to the tides and winds. However, they are also influenced by the circulation in the open ocean. There current patterns have fallen into equilibrium with prevailing winds and density structure. The shoreline configuration and topography of the bottom are factors in determining the current patterns over the Continental Shelf. Offshoots from the main oceanic currents encroach upon the Continental Shelf. With respect to the circulation pattern, the density of the water is of lesser consequence over the shelf than in the deep ocean.

Longshore currents and *rip currents* develop along the coast. Irregular nearshore topography is a major factor in the formation and orientation of longshore currents. Along straight beaches, rip currents flow seaward and are a result of the breaker-induced shoreward mass transport of water, which must return seaward. They often may be identified by their color contrast to the surrounding water.

A distinction needs to be drawn between surface and subsurface currents. Nearshore water may be in layers. Each layer will have different properties. The layers tend to flow at varying speeds and in varying directions. The wind stress strongly influences the surface currents. At depths other causes may prevail in determining the current direction and velocity. Extreme variation of current with depth normally may be expected off estuaries and river mouths where differing water types are in close contact and may form sharply contrasting layers.

The strength of tidal currents, which accompany the rise and fall of tidal waters, is modified by the nontidal currents. Nontidal currents may increase or lessen the strength of tidal currents as well as change their direction. Abnormal tide levels also may be associated with unusual tidal currents, which may result from meteorological causes.

The path that a floating object will take depends upon the force imposed on the immersed and exposed parts of the object. These forces are the current and the wind, respectively.

In narrow channels and waterways, reversing tidal currents are characteristic. The direction of the tidal current is either ebb or flood, parallel to the axis of the channel. Minor topographic irregularities of the bottom will cause a deflection of the current stream pattern. The greatest tidal current velocities are attained within the confines of restricted channels, such as straits, narrows, and passes where speeds over 12 knots have been recorded. Rotating tidal currents, clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere, are typical of the open shelf waters. Near the bottom, all currents may be somewhat less than at the surface owing to the friction induced by the flow over the bottom. The degree of reduction is dependent upon the roughness of the bottom.

Tides

Tides are most noticeable near shore because of the restrictions imposed by the shore and bottom upon the flow of water. The range of water level is generally greater along indented coasts where the bottom slope is gradual. Along steeply sloping exposed coasts the tide range generally is less. Gradually sloping nearshore bottoms will lie exposed after an ebbing tide, leaving widespread areas of tidal flats which may consist of mud, sand, or rock. As the moon is not the sole determinant of the tide, local topographic features and weather conditions must be considered to establish the tidal characteristics of a given area. Onshore winds will tend to increase the height of water, whereas offshore winds will drive the water away from shore, thereby decreasing the water level.

Physical Properties

Sea water temperatures vary horizontally and vertically, the vertical gradient being much greater. The primary source of heat in the sea is radiation from the sun. Owing to the relatively high heat capacity of water, the sea is capable of transporting heat energy great distances. In tropical and temperate zones the temperature of the surface water will be greater than that of the subsurface water. The converse is true in polar regions in winter due to the low air temperatures which tend to cool the surface waters below the temperature of the deeper waters. Convective currents and turbulent mixing processes will tend to reduce or eliminate vertical temperature changes so that a more homogeneous water mass results. Near shore, the horizontal as well as the vertical water temperature range may be considerable over short distances. Temperature variation with depth may be detected by use of the bathythermograph (BT). In the higher latitudes, fresh water, flowing from stream outlets and estuaries, will be colder than the salt water of the shelf into which it is discharged. In the lower latitudes, river runoff may be warmer than the shelf water. The less dense river discharge will spread over the more dense sea water.

Salinity of the nearshore waters varies somewhat similarly to the temperature. Generally, the least saline water will lie close to shore and in the vicinity of stream outlets. Water masses containing nearly constant salinity may be found in horizontal layers. Water of high salinity tends to accumulate in deeper parts of the shelf basins, whereas the water of lower salinity spreads horizontally over the surface. As a result of the distributing processes, wedge-shaped water masses having similar properties are developed over the shelf. They will vary somewhat in shape, size, and position.

Salinity, temperature, and pressure combine to determine the water density, or specific gravity. Low temperatures and high salinities yield high density values, whereas the higher temperatures and lower salinities are characteristic of the lower densities. Off estuaries, the lower densities are due to the extremely low values of salinity. Turbulence due to high sea states, tidal flow, and advection from converging currents, will tend to destroy the identities of the mixing waters.

Electrical conductivity of sea water is dependent upon the salinity and temperature of the water. The conductivity varies directly with the salinity and temperature (Fig. 1.2).

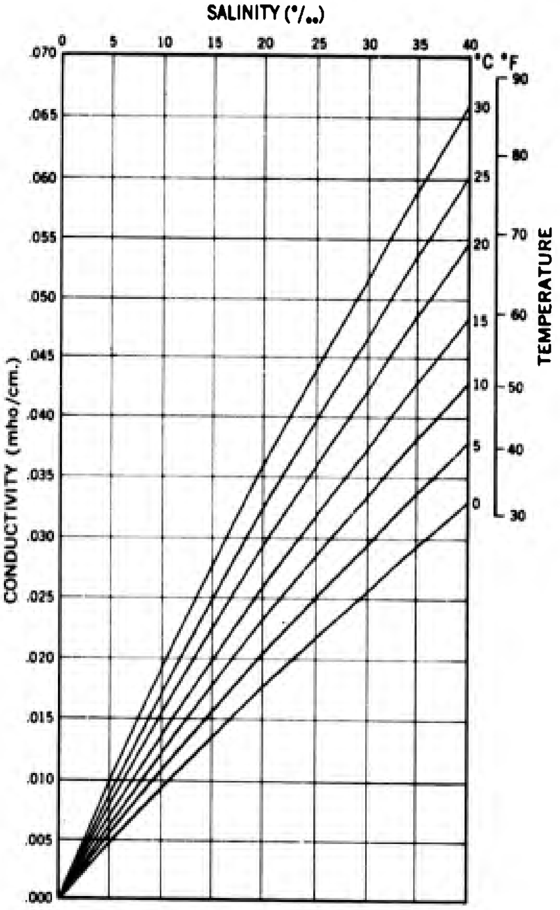

Figure 1.2.—Specific conductance of sea water for various temperatures and salinities.

Electrical conductivity values of nearshore waters are likely to vary considerably, not only geographically but seasonally as well, owing to changes in both water temperature and salinity.

The transparency of nearshore waters depends upon the amount of suspended matter. Additional factors controlling the degree of visibility of submerged objects will be the amount of glitter due to the rippling of the sea surface, the angle of incidence of the sun's rays, and the amount of available light. The bottom, against which submerged objects must be detected, must provide a requisite degree of contrast. Rocks covered with seaweed and dark colored sediments impart a dark color to the nearshore bottom, making the presence of dark foreign objects difficult to detect. Seasonal distribution of suspended material and floating organisms will cause a cyclic change in the visibility of nearshore waters.

Sea and Swell

Winds blowing over sea waters generate waves which vary in height and period according to certain laws. The wave height is dependent upon the duration and fetch, or over-water distance, of the wind. Wave height is also dependent to some degree upon the water depth, since the longer and higher waves are incapable of being generated in the shoaler waters. Waves slow down as they reach shallow water. This is followed by a decrease in wave length and an increase in wave height. The process of wave refraction, or bending, is particularly noticeable as the swells approach the coast. These wave fronts tend to parallel the bottom contours as they near the shore.

Nearshore bottom pressure fluctuations are related to the passage of the waves as they progress over the shelf. Generally, the higher recorded pressures are related to the wave crests and the lower pressures to the wave troughs. Owing to the irregular nature of sea waves, an exact relationship between the geometrical wave profiles and wave-induced pressure fluctuations is difficult to establish.

Ambient noise in the sea is due to a number of factors. Nonbiological noise is partly related to the sea state. The higher waves are related to the higher noise levels. Two types of breaking waves occur. In deep water the wind will drive spray off the crests of the bigger waves. Nearshore breakers are formed by the upper part of the water wave traveling faster than the lower part, which is slowed by friction between the water and the bottom. Ambient noise will result from either type of breaking noise. The lower frequencies (below 15 kc.) are the most representative of sea state noise. The higher frequency (above 15 kc.) components may be present also but are characterized by much lower intensity levels. Some difficulty may exist in dissociating ambient noise due to sea state from other causes such as rainfall, earth movements, or noises of biological origin. Biological noises include noises produced by snapping shrimp, fish, sea mammals, and myriads of other organisms.

Ice

The occurrence and concentration of nearshore ice will vary with the climate and the prevailing wind and current regime. Ice will form in the sea in accordance with the relationships of temperature and salinity (Fig. 1.3). The higher the salinity, the lower the freezing point of sea water. Near shore and in the vicinity of stream outlets, ice formation will be fostered by the presence of less saline water and the colder air temperatures that occur. Older sea ice is less saline than newly formed

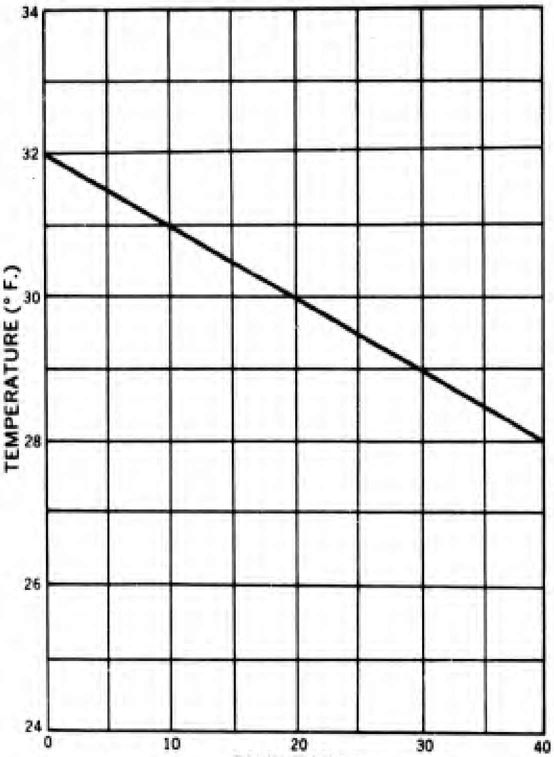

FIGURE 1.3.—Relationship between freezing point of sea water and salinity (H. O. Pub. No. 551, 1950).

due to the downward seepage of the entrapped brine. Sea ice floes may be concentrated or dispersed, depending upon the causal forces of current or wind.

River ice, formed from fresh water, may find its way into coastal waters where the formation of sea ice has not occurred. Much of the ice found in harbors may be of stream origin. Ice of either sea or stream origin may be shorefast or drifting, depending upon the forces causing concentration or dispersion.

Glaciers are the source of the massive icebergs that endanger shipping. When a berg has broken away from the glacier, it floats away. Both currents and winds contribute to the direction and speed of the drifting berg. Their drift into shoal water is limited by the relationship between water depth and the draft of the berg.

Nearshore Weather

Weather phenomena occurring over the Continental Shelf are associated with both continental and oceanic weather conditions.

Weather forecasting methods in use today have developed from methods pioneered by the Norwegian school of meteorologists. The primary thesis of the method is that warm air overruns cold air and is lifted when air masses of different temperature meet. Another forecasting thesis is that weather in the temperate zones moves from west to east.

When cool air moves equatorward it forms a wedge under the warmer mass, thus forcing it forward and upward. Because of cooling resulting from vertical motion, moisture is condensed in the form of clouds or precipitation. When warm air advances ahead of cold air, the zone of separation of the air masses is called a cold front.

When warm air flows up over a cooler air mass moving in the same general direction the zone of separation of the air masses is called a warm front. As in the case of a cold front the warm air will be lifted and cooled with cloudiness and precipitation likely (Fig. 1.4).

When a cold front overtakes a warm front it underruns the cool mass ahead of the warm front and forms an *occlusion*.

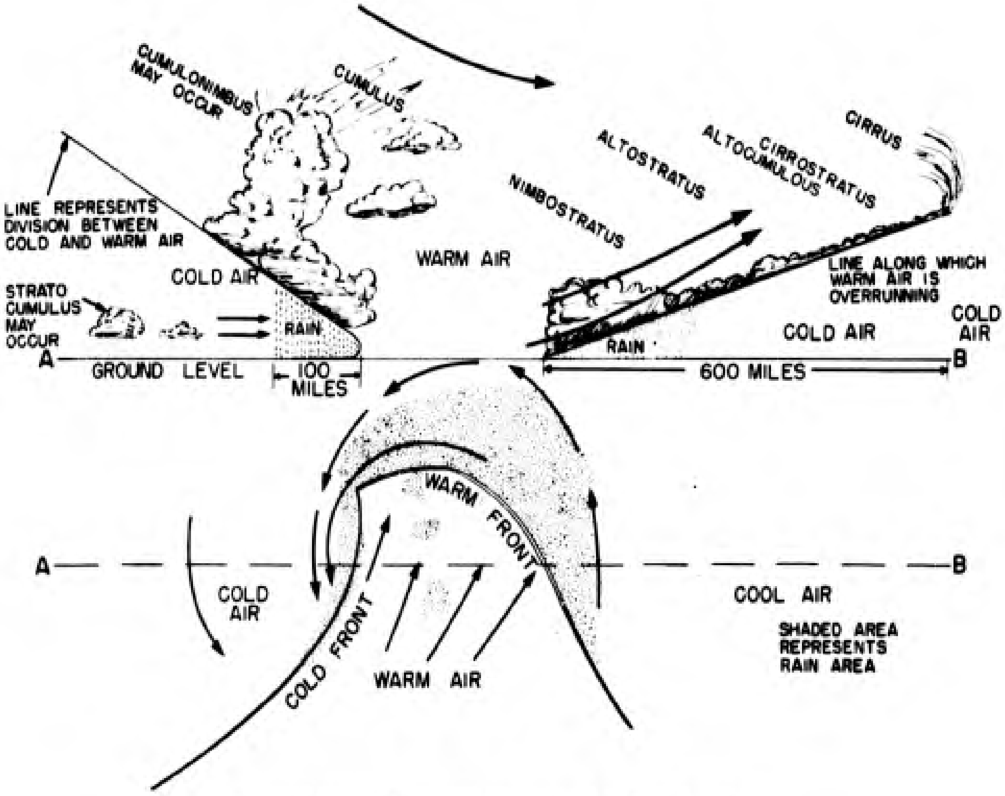

FIGURE 1.4.—Schematic diagram of a frontal system.

The greatest heating takes place at the equator. The air rises thus creating a zone of low pressure of about 10 degrees each side of the thermal equator, known as the doldrums. As the air rises from the doldrums the resultant expansion due to reducing pressures aloft causes the air to cool. These conditions are favorable for heavy daily rains in the central doldrums. This risen air cannot sink immediately to the surface because of the converging surface trade winds from the northeast and southeast. Thus the risen air spirals poleward while it remains aloft. The rotation of the earth deviates these antitrades from a straight path into a spiral, so that a partial damming effect impedes the poleward flow. Cooling and the damming effect combine to produce the high pressure belts known as the horse latitudes. The belts are about 10 degrees in width and are located about 35° N and 30° S of the thermal equator.

Surface winds on the equatorward side of the high pressure belts are called the trade winds while those on the poleward side are the so-called westerlies. Due to the rotation of the earth these winds are deflected to the right of the path of motion in the Northern Hemisphere and to the left of the path of motion in the Southern Hemisphere.

Some of the upper winds continue from the doldrums beyond the horse latitudes and spiral poleward. In subsiding they create a polar high-pressure area. Easterly winds blow out from both poles. At about 60° latitude the polar winds encounter the winds of the prevailing westerlies. Since the polar easterlies are cold winds, they do not rise over the westerlies. Instead they are dammed up and, when a sufficient quantity of air collects, the entire mass pours over into the temperate latitudes. This spilling over of cold polar air into lower latitudes is important in creating temperate zone weather. Figure 1.5 is a schematic diagram of the circulation of the world.

In addition to the primary circulation of the atmosphere, many variations are set up in the primary wind system due to local effects. Such effects include thermal, topographical, and pressure differences. Local variations in the primary wind system constitute what is known as the secondary circulation.

FIGURE 1.5.—General wind patterns of the world.

The regions most favorable to the development of monsoons are in the middle latitudes. The term refers to certain winds which blow with great persistence and regularity at definite seasons of the year. In the summer the land will heat up more quickly and to higher temperatures than the sea, generating thermal currents. This results in low pressure over land. The nearby ocean represents a relative high pressure area, and the prevailing winds are onshore. During the winter when the reverse of these conditions occur, the prevailing winds are offshore.

The general description of the origin of land and sea breezes is the same as for the monsoon. The difference is that the change in wind direction occurs daily rather than seasonally. During the day the cooler and denser air overlying the shelf waters blows onshore where the warmer, less dense air rises by convection. At night a seaward breeze results from the rapid cooling of the land. Land and sea breezes usually occur in the middle latitudes during the summer months. They may occur during any season in the tropics, although they will not be as pronounced as in a temperate climate.

Traveling pressure systems of great size originate along the polar front. These pressure systems carry with them their own wind systems. In the Northern Hemisphere winds blow out of high pressure systems in a clockwise direction. In low pressure systems the winds converge, blowing towards the low pressure center in a counterclockwise direction in the Northern Hemisphere. In the Southern Hemisphere the winds about low and high pressure systems blow in the opposite direction.

The basic physical processes leading to fog formation are evaporation and cooling. The most logical method of classification is on the basis of fog-producing processes.

Along both warm and cold fronts, warm air is lifted over the frontal discontinuity surface above the cold air. When precipitation takes place, the raindrops formed will be warmer than the air through which they fall. The cold air is unsaturated and evaporation of the raindrops takes place. The cold air quickly becomes saturated, but evaporation continues. The moisture, evaporated after saturation has taken place, condenses forming visible clouds. If this process is progressive and turbulence is at a minimum, the cloud layer will build downward to the ground or water surface and fog will be the result.

When cold dry stable air overflows a water surface several degrees warmer than the air, steam fogs are formed. In regions where ice and open water occur, conditions for the formation of steam fog are good. The ice cools the air by coming in contact with it, and the cool air flows out over the warmer water causing steam fog. Generally this occurs in winter months in arctic regions.

Air, upon rising, will cool. If the air has a high relative humidity very little upward movement may bring about condensation. The convergence of nearby saturated air adjacent to slowly moving fronts may thus bring about the formation of fog by cooling. These types of fogs are classified as being the result of adiabatic processes.

In some parts of the world cold ocean currents upwell along the coasts. As the land heats during the day, an onshore wind occurs. If relatively warm moist air blows shoreward over the cold coastal water, fog may result. This is called a monsoon fog. It never occurs in very low nor very high latitudes.

During the summer months, warm moist air may be carried out over the relatively cool sea surface, where condensation may occur. The resulting fog may be carried shoreward during the afternoon by the returning sea breeze. This is termed land-and-sea-breeze fog. It is a coastal phenomena.

When warm moist air passes over cold ocean currents, condensation results and sea fogs occur. Sea fogs are often carried inland. It is not merely a coastal-type fog, but may be found anywhere over the sea.

As tropical air moves to higher latitudes, it gradually cools. Tropical air fog may result. This fog type will form more readily in winter than in summer.

Tropical cyclones occur in many parts of the world. They are known by various names, depending upon the area. They are a vast whirl of rapidly moving air currents circulating around a center of very low pressure. Zones of tropical storms, such as nearshore waters along the western margins of the oceans, are commonly affected by storm tides. Any strong wind of appreciable duration that has onshore components will tend to raise the water level to a greater than normal height. Stronger than normal currents may be associated with storm tides.

Biology

The Continental Shelf waters are particularly rich in the nutrients, which are necessary for the growth of marine plant or animal life. Prevailing current patterns concentrate the nutrients near shore. The quantity of the nutrients varies with the season. Seasonal variation is more characteristic of the mid-latitude and northerly waters. Wide ranges in the quantity of organic life may be expected where seasonal fluctuations in nutrients occur.

Both plant and animal forms constitute major fouling agents in shallow waters; however, animal forms are dominant in the deeper waters. The fouling agents consist of marine plants, such as the sea weeds and encrusting algal growths, and marine animals of which barnacles, tubeworms, hydroids, bryozoa, and molluscs are representative.

Coral growths are widespread and may be found at most depths. However, the reef-building corals are tropical by nature and are only found in shallow water. The reefs usually consist of both algal and animal growths. They may occur as fringing reefs adjacent to the shore or as barrier reefs at some distance from the beach, thereby forming lagoons. Coralline atolls are situated atop submerged volcanic platforms and may be circular or semicircular in outline, forming lagoons which, in some cases, may attain a diameter of 30 miles or more.

In nearshore as well as offshore waters, bioluminescent organic life may be a common occurrence. Plankton, free floating and nonswimming plant and animal forms, are the prime source of bioluminescence (phosphorescence) in the sea. Their concentration may become greater over the Continental Shelf where nutrients are abundant. Tropical waters generally are well populated by these organisms, although more northerly waters may exhibit bioluminescence whenever the oceanographic conditions of temperature, salinity, and nutrients are conducive to plankton growth.

The distribution and concentration of noise-producing organisms in the sea are controlled by the same processes as those previously mentioned. The larger forms of sea life, such as the fishes and sea mammals, are the leading producers of marine noise. Snapping shrimp, primarily subtropical in distribution, are generally found over rock or coral bottoms and are characterized by noises of higher frequency than the larger animal forms.

Seismicity

Earthquakes may affect mines in various ways. Earthquake energy passes through the ground in a series of energy waves. One type is called a *P* wave. It is an acoustic-type wave. Frequencies up to 50 cycles per second in air and up to 100 cycles per second in rock have been reported. The following estimates of *P* wave frequency have been made for distances from an earthquake epicenter.

500 miles----	3 to 5 c. p. s.	highest frequency
10–50 miles--	10 c. p. s.	highest frequency
less than 10 miles	50 c. p. s.	highest frequency

These indicated distances are for distances within the earth. The acoustic coupling between water and the earth is better than between the earth and the air. Audible sounds originating in the earth are likely to be communicated to the water, resulting in loud underwater sounds. They appear to occur in both the audio and subaudio ranges. Sound travels more rapidly and with much less absorption of energy through water than through air.

This evidence indicates both as to frequency range and possible underwater intensity that sufficient sound energy is present during nearby earthquakes to actuate certain acoustic type mine mechanisms.

Shaking and displacement of the ground frequently occurs in the vicinity of earthquakes. The amount depends upon the size and depth of focus of the shock and the type of bedrock. The disturbance of the ground varies from just perceivable to a displacement of several feet in extreme cases. This type of shock disturbance may satisfy a magnetic or pressure type mine actuation device.

Another earthquake phenomenon is the seismic sea wave, sometimes called *tsunami*. The tsunami is a rare type of sea wave which accompanies some large submarine earthquakes and explosive volcanic eruptions. These waves may be far larger than any wind wave. They occur in a series of up to 5 or 6 large crests. They can travel for thousands of miles at speeds approaching 500 knots and retain enough energy to raise the sea level a score or more feet along an unprotected coast facing the direction of wave approach and to set up seiche oscillations in any suitable basin. This phenomenon itself may not satisfy the pressure requirements of a mine directly, but secondary series of waves, called *seiches*, are often induced in confined bodies of water along shelf areas by tsunamis. These seiches may persist for several hours or even days, and their period-height characteristics frequently satisfy the requirements of a mine mechanism for a pressure look.

Continental shelves frequently are areas of earthquake activity. The frequency of earthquakes varies greatly from one area to another, the greatest activity being noticed in those areas where oceanic deeps lie adjacent to mountainous land masses. Areas of frequent quake activity are grouped into belts. The principal

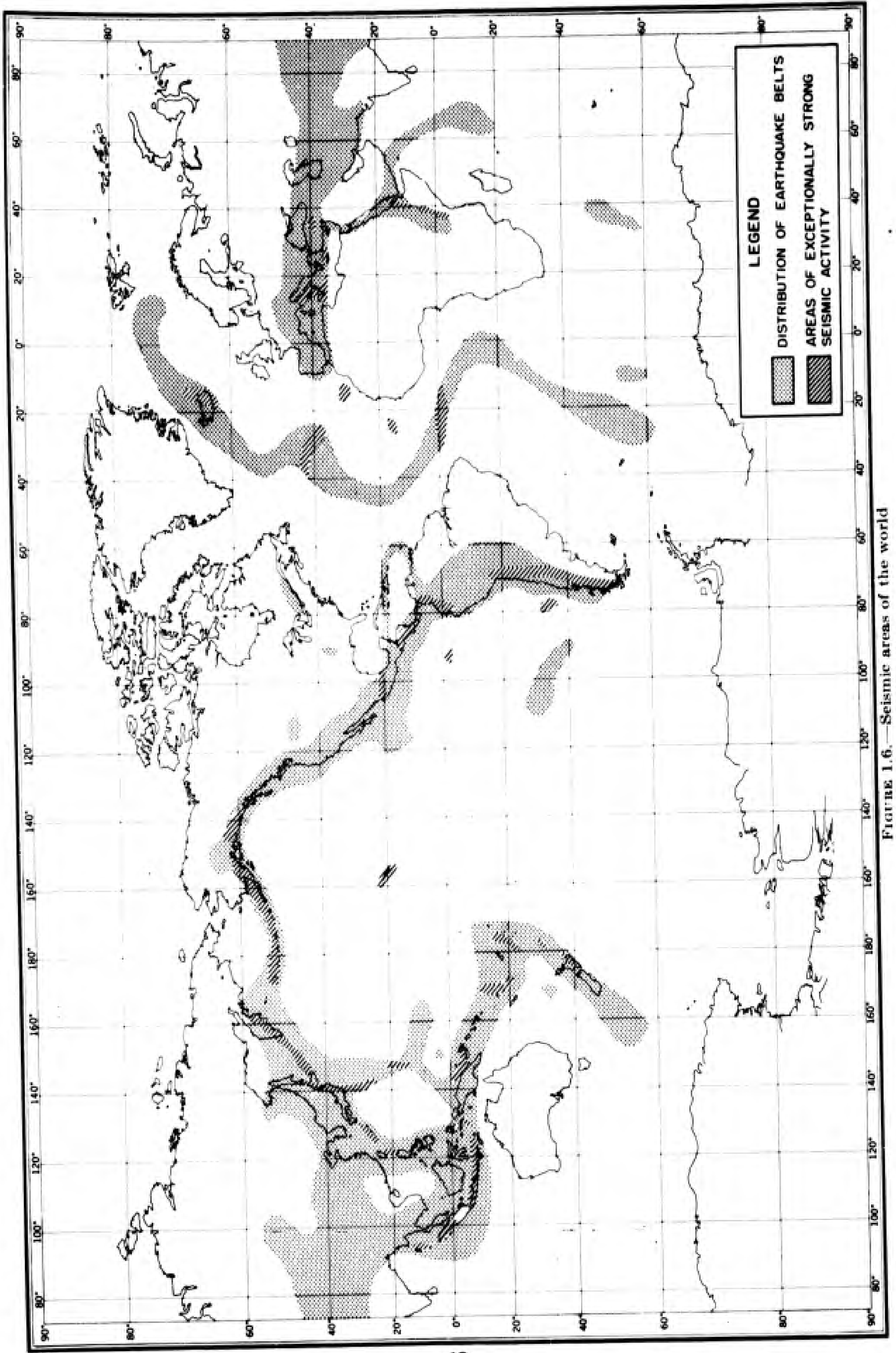

FIGURE 1.6.—Seismic areas of the world

geographical division is the Circumpacific Belt. This belt of high shock activity includes the Aleutian Islands, the coast of California and Oregon, the Pacific coast of Central and South America, the coast of New Zealand, the vicinity of Samoa, Fiji, Tonga, and Kermadec Island groups, New Hebrides, Solomon Islands, Caroline Islands, Marianas Islands, New Guinea, Japan and adjacent areas, Formosa, the Philippines, Celebes Island, the Moluccas Islands, the Banda Sea and the Sunda Arc. The Caribbean loop of high seismic activity extends from Yucatan and Honduras around the arc of the West Indies returning through Venezuela and Colombia to join the Andes Mountains. The other area of major seismic activity extends from Burma westward across Asia, through the Alpine structures of Mediterranean Europe, and into the Atlantic as far as the Azores. The Caucasus and Crimea are included. Besides these areas numerous other areas of minor seismic activity, such as the Saint Lawrence Valley, occur. Numerous inactive areas lie between seismically active zones. Moreover, many shelf areas do not adjoin seismic belts (Fig. 1.6).

Sound in the Sea

Sound energy is reduced, or attenuated, in the sea when it is transmitted from the sound source to the receiver. The difference in sound intensity between the source and the receiver, represents the amount of sound energy lost and is termed the *transmission loss*. This difference becomes greater as the distance between the sound source and receiver increases. Transmission ranges result from a variability in the factors affecting sound transmission in water. Sound intensity losses are caused by *spreading*, *absorption*, *refraction*, *scattering*, and *directivity* or *beam pattern* (Fig. 1.7).

As the sound energy radiates from a point source, it spreads over an increasingly larger area. Thus, if the spreading is spherical in nature, the sound passing through one square yard at A is spread thin over 16 square yards at B (Fig. 1.8).

Since sound intensity is defined as the acoustic power passing through a unit area, the intensity decreases rapidly as the range increases. This decrease of intensity is described

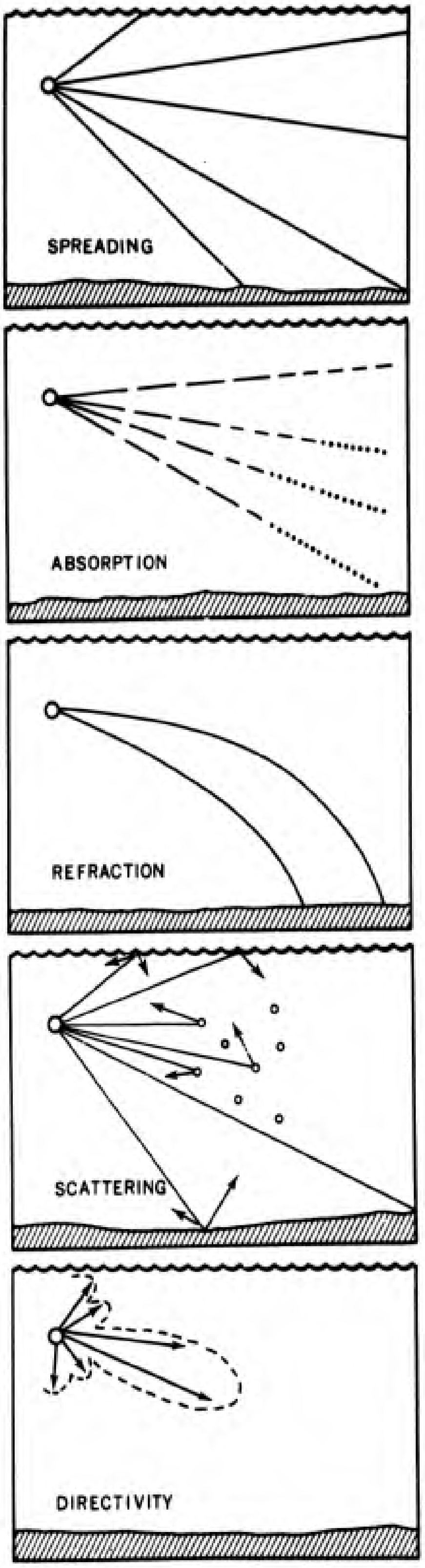

FIGURE 1.7.—Factors affecting attenuation of sound.

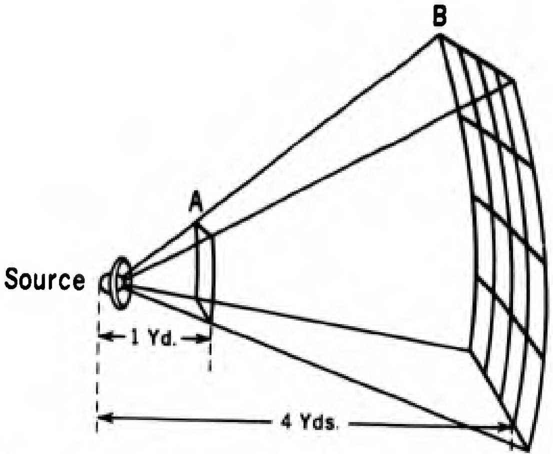

Figure 1.8.—Loss of sound energy caused by spherical spreading.

by the inverse square law, which states that the intensity of the sound is inversely proportional to the square of the range. Thus, the intensity of sound at 10 yards is $1/10^2$ or 1/100th that of the sound one yard from the transducer.

Energy loss of sound along a given path is caused by *absorption*. Owing to the friction of the vibrating water molecules, the energy of transmission is converted into heat. The higher the frequency of the transmitted sound the greater is the loss due to absorption.

Refraction is the result of changes in the velocity of sound in the water. Sound would not be refracted if the sea were homogeneous in temperature and salinity and if pressure did not increase with depth. The effect of temperature, salinity, and pressure on the speed of sound in water is shown in Figure 1.9. Sound velocity increases as either the temperature, salinity, or pressure increase. If the water is warmest at the surface but becomes steadily colder with depth, sound will travel faster at the surface than it will at greater depths. If a beam of sound is projected horizontally into such a sea, the top of the beam is traveling through water in which the sound velocity is high; the bottom of the beam is traveling through water in which the sound velocity is low. Consequently, the resulting beam is refracted, or bent, downward (Fig. 1.10). Generally, temperature decreases with depth, especially during calm sea conditions, but during rough conditions, that is, high sea states, mixing of the upper layers results in uniform temperatures to a depth dependent upon the extent of mixing. This resulting layer of uniform temperature is said to be *isothermal*, thus, no refraction due to temperature will occur (Fig. 1.11).

In nearshore environments both the temperature and salinity structure of the water are likely to vary considerably in space and time. Typical nearshore and open ocean salinity curves are shown in Figure 1.12. Fresh-water runoff from the land may have seasonal characteristics so that static conditions do not prevail. Layering of less dense water of lower salinity upon denser water will cause sharp changes in the vertical sound velocity gradients. Horizontal salinity gradi-

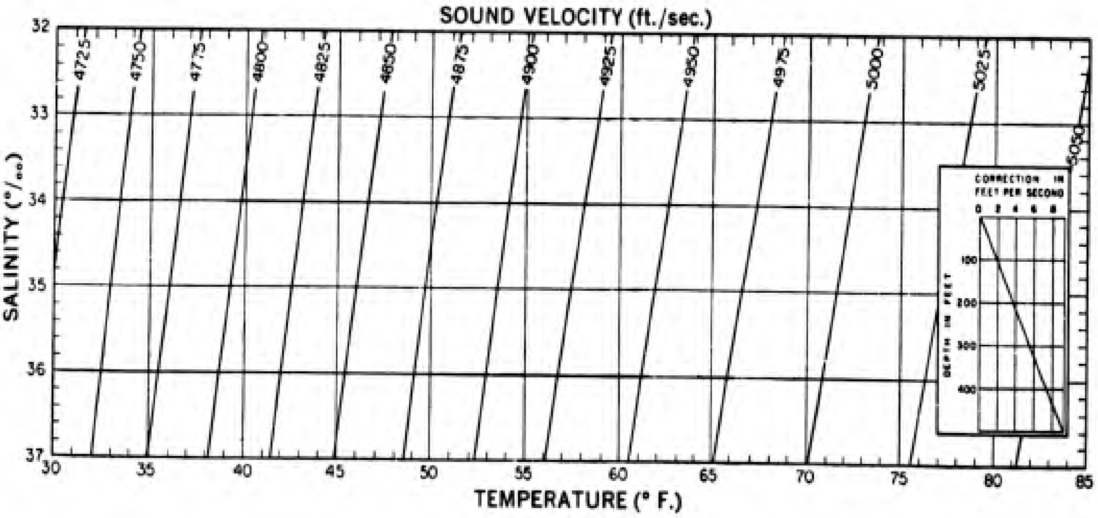

Figure 1.9.—The effect of temperature, salinity, and pressure on the velocity of sound in sea water. (Application of Oceanography to Subsurface Warfare NRC-CUW, 1946).

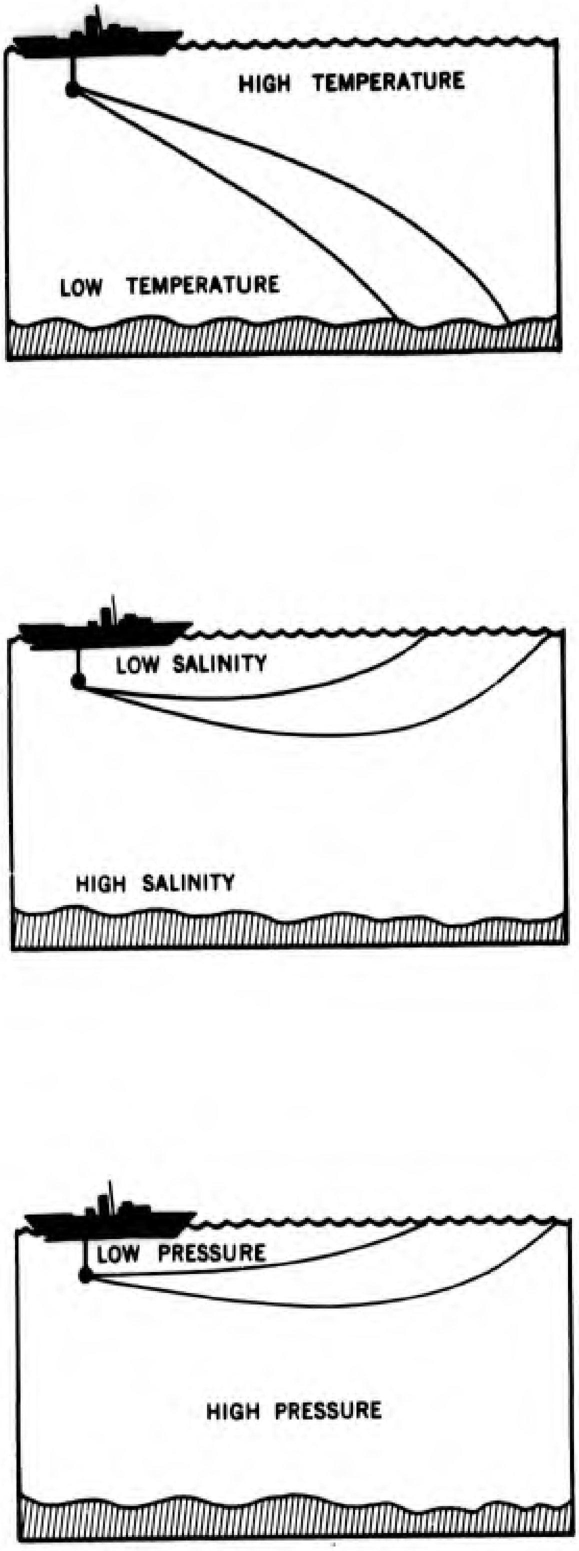

FIGURE 1.10.—Refraction of sound beams caused by differences in temperature, salinity, and pressure.

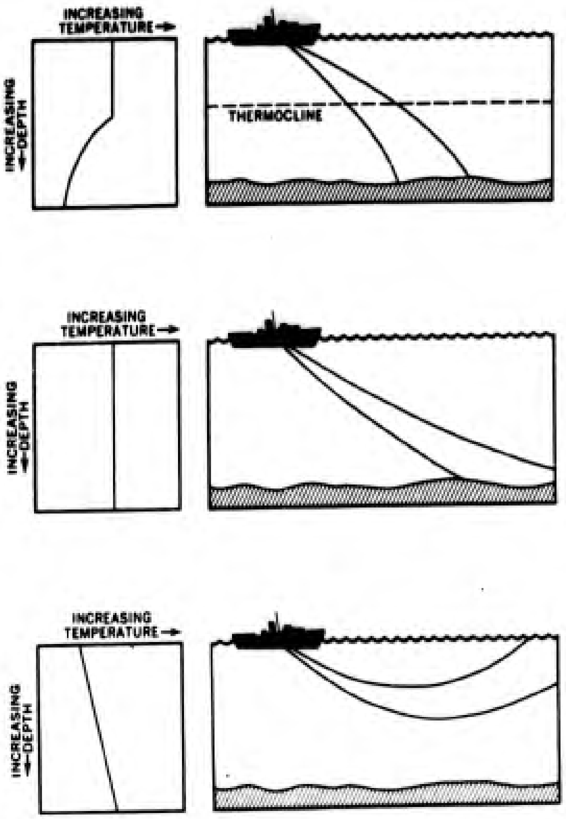

FIGURE 1.11.—Refraction of sound beams caused by variations in temperature with depth.

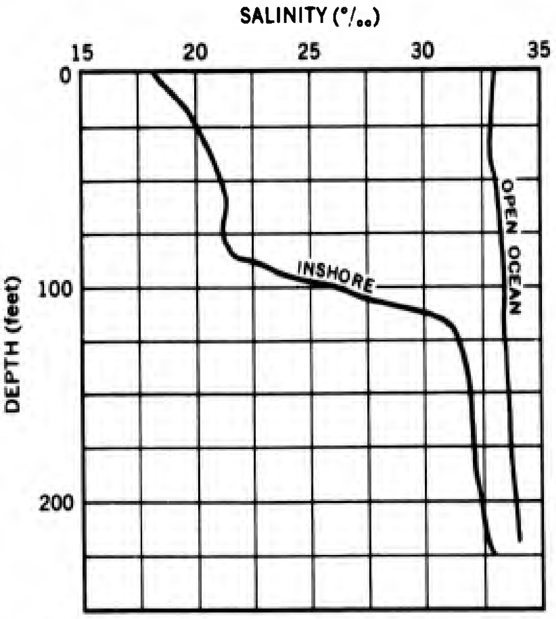

FIGURE 1.12.—Typical inshore and open ocean salinity structures.

ents may also be expected progressively away from river mouths and estuaries. Density of water increases directly with the salinity but inversely with the temperature. Thus stratification of nearshore waters due to relative density will be accompanied by wide variations in the salinity and temperature gradients. The densest water adjacent to the bottom is usually more saline even though it may be warmer than the overlying water that is contributed in the form of fresh-water runoff. Increasing, or positive, salinity gradients are expected in nearshore environments, but the temperature gradients may be either positive or negative. Positive salinity and temperature gradients cause upward refraction so that little, if any, horizontally projected sound energy is capable of reaching the bottom. In the event that strong negative temperature gradients are found in shallow water, the downward refracted sound energy will result in strong bottom reverberations. Changes of temperature or salinity within a few feet are referred to as *microstructure* and may cause a variability in the distribution of the sound field. In nearshore areas a wide variety of sound conditions is likely to exist due to stratification and microstructure present in the waters (Fig. 1.13).

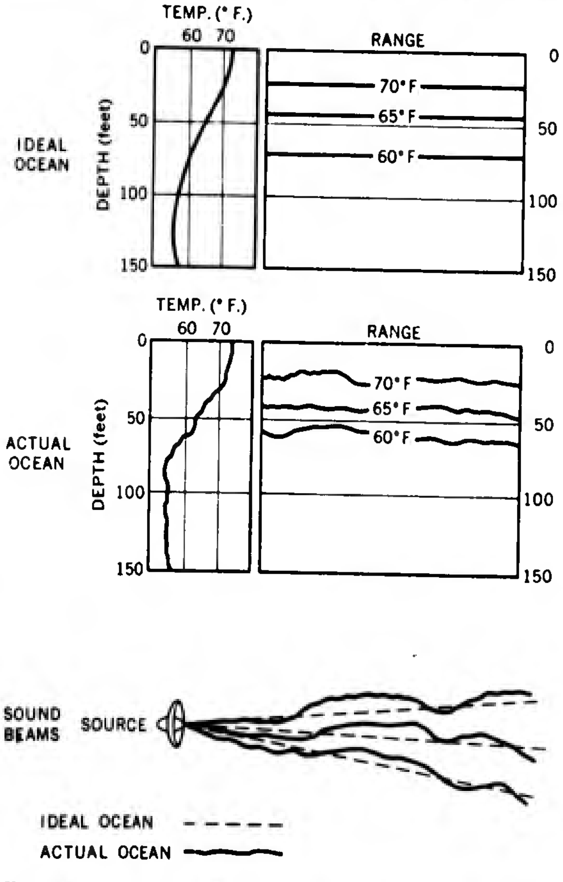

FIGURE 1.13.—Temperature distribution in an ideal and actual ocean and resulting distortion of sound beams. (Physics of Sound in the Sea NRC–CUW 1946).

The imperfect reflection of sound waves from objects or surfaces having dimensions of less than a wave length causes a general *scattering* of sound energy. Scattering is caused by small particles and irregularities in the water volume, such as fish, air bubbles, and suspended materials. Surface scattering is caused by waves and ripples, and bottom scattering is caused by debris and other irregularities on the bottom, such as ripple marks on sand. As the wave length of sound is reduced to the dimensions of these irregularities (by increasing the frequency), scattering becomes more pronounced. Experimental data indicate no significant dependence of bottom reverberation upon the transmitted frequency; however, one might reasonably assume that as the frequency is increased, that is, the wave length shortened, the smaller bottom irregularities would tend to return a greater degree of the sound energy to the receiver. Inhomogeneities or nonuniformities in the water volume, such as temperature microstructure and turbulence, are further causes of scattering of sound energy. Ship wakes cause extensive bubble formation. The effect of back-scattering is increased by longer pulse durations because of the increase in the volume insonified at a given instant. Shorter sound pulse durations will reduce back-scattering.

The sea surface and sea bottom act as reflecting surfaces. The effectiveness of the reflecting surface depends upon the difference in the sound velocity between the water medium and air, in the case of surface reflection, or the bottom sediment, in the case of bottom reflection. The physical characteristics of the bottom will determine the quality of the reflections resulting from sound-wave incidence upon the bottom. Texture, water content, compaction, and uniformity of the bottom are qualities that require consideration in order to determine the reflective quality. The angle with which the sound waves strike the reflecting surface is also a factor in determining the efficiency of reflection.

The bearing resolution or *directivity* of sound equipment depends upon the concentration of the acoustic energy along the wave path or ray. For a transducer of given dimensions, equipment operating at the higher frequencies has better directivity because of the greater ratio of transducer diameter to wavelength. The diameter of an echo-ranging transducer or projector must be at least several wavelengths across if the sound is to be sharply directional. Figure 1.14 shows the directivity pattern of a typical transducer. Good transducer design concentrates the available sound energy into a narrow beam. This increases bearing resolution and source level so that the range of useful transmission is increased. Low frequency projectors that have the same directivity as the short wavelength high frequency projectors are difficult to design. Theoretically, sound of low frequency and long wavelength could also be made directional, but only with equipment so large and so heavy as to be impractical for Navy use. Projectors must be designed to compromise between the good directivity of higher frequencies and the good transmission ranges of lower frequencies.

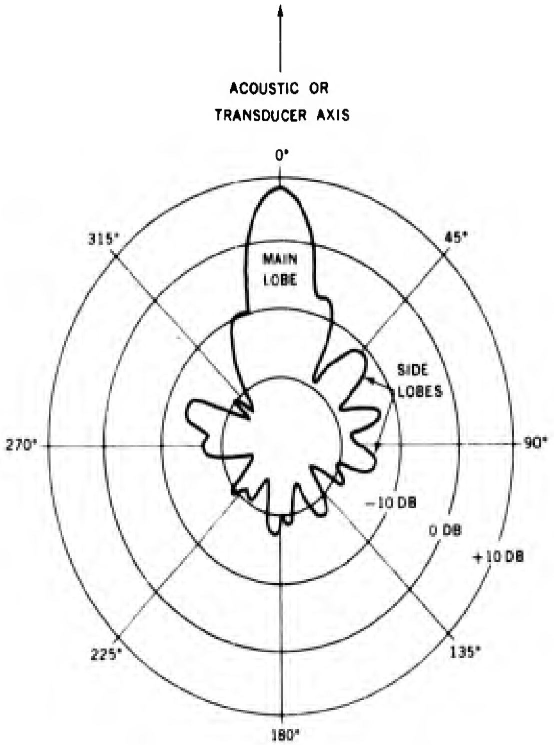

Figure 1.14.—Typical transducer directivity pattern.

Of all the factors affecting attenuation, refraction is probably the most variable with time. Consequently, temperature and salinity structure, from which the sound velocity structure can be determined, must be known before any attempt at predicting echo ranging performance can be made. Surface scattering is another important time variable since it depends upon the state of the sea.

Apart from the factors that vary with time, bottom scattering, depending upon bottom characteristics, will vary with location. The variability of scatterers in the water from time to time and place to place will also be significant in the performance of acoustic detection equipment.

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CHAPTER 2

EFFECT OF OCEAN ENVIRONMENT ON PHYSICAL BEHAVIOR OF MINES

When a mine is launched, it immediately comes under the influence of its environment. The influence that the environment will impose upon the mine depends upon the mine type. Each environment will vary geographically and will have various dominant oceanographic factors which contribute to the physical behavior of the mine. This chapter describes the effects of the oceanographic factors upon the various mine types.

2.1 MOVEMENT OF BOTTOM MINES

A bottom mine upon impact with the bottom may come to rest without any penetration, or partial or complete burial may occur. After initial impact, the mine may remain in position, or penetration may occur, or it may roll. The factors governing mine movement are so numerous that the amount of initial penetration, subsequent penetration, or roll of bottom mines can be predicted only within wide limits.

Initial Penetration

The penetration of bottom mines into sediments should properly be divided into two stages, penetration resulting from initial impact and subsequent penetration, which may take place over a period of days, weeks, or months.

In general, no initial penetration of a mine will occur on a rock, gravel, sand-gravel, or sand bottom (Fig. 2.1). Rock bottoms are found off rocky promontories, along coasts, off rocky sea cliffs, and in areas of swift currents. Initial penetration will depend upon whether or not the bottom can resist the impact force of the mine. Rock or gravel bottom will successfully resist the impact force. Experiments have shown that sand-and-gravel and sand bottoms also are very resistant to initial penetration. A mine hitting such a bottom may gouge into it, cutting a furrow across the bottom, but, in general, no initial penetration will result. Sand bottoms are found in harbors and along the Continental Shelf off sand beaches and points, and on banks off glaciated areas.

A surface- or submarine-laid mine generally will not be damaged by impact on the bottom. However, an aircraft-laid mine may be damaged by impact on rock, gravel, sand-and-gravel, or sand bottom if its entry velocity is so great that the water depth is insufficient to slow it down to a safe impact velocity.

Initial penetration into a mixture of fine-grained sand, silt, and clay will vary widely according to many variables. Partial burial can be expected in most cases (Fig. 2.1). In fine-grained sediments, such as mixtures of clay, silt, and sand, commonly referred to as mud, a certain amount of penetration can be expected. Penetration will vary from none to complete burial depending upon the physical properties of the bottom sediments as well as the velocity and angle of impact of the mine with the bottom.

Probably the most significant factor contributing to the depth of initial penetration is grain size of the sediments. In general, the resistance of the bottom to penetration by a mine decreases with decrease in grain size. In other words, with increase in silt and clay content of the bottom sediments the bearing capacity of the bottom decreases.

Penetration depends not only on the surface sediments but also on those found in the underlying layers. This allows an infinite variation in bearing capacity. For example, bottom sediments can be found in layers, with each layer having its own degree of bearing capacity, which will be due to variation in grain size, wet density, clay types, water content, organic material, sequence and thickness of the layers, and depth below the surface of the particular layer. These facts are interrelated and each affects the bearing capacity of the bottom. Figure 2.2 shows grain-size analysis of two bottom sediment cores which were taken close

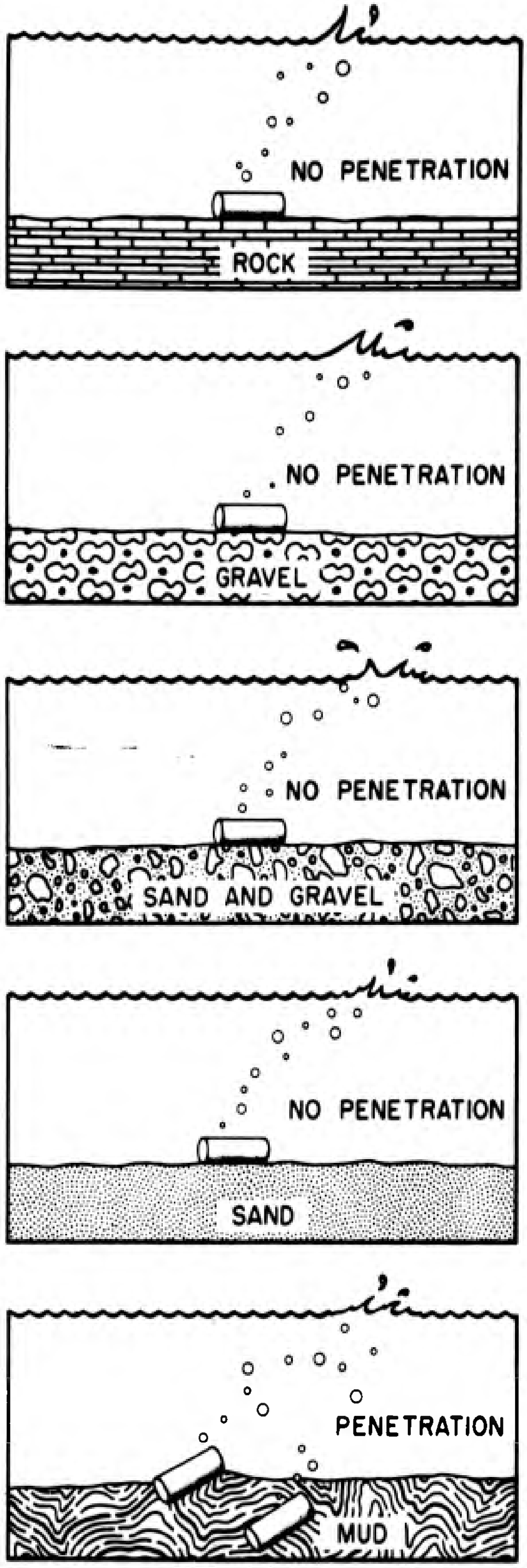


FIGURE 2.1.—Initial penetration of mines into various sediment types.

together. Considerable grain-size variation, both between cores and vertically within each core, can be noted.

The distinction between a normally deposited fine-grained sediment and a flocculent deposit or precipitate should be made. A normally deposited fine-grained sediment, which usually has a single-grained or mixed-grain structure, will be resistant in varying degrees to penetration. A fine-grained flocculent deposit has little resistance and allows rapid penetration to the depth of the deposit. Such deposits may be found at river mouths where clay-size particles are carried from fresh water into salt water. Detailed information on sediment structure types can be found in Krumbein and Pettijohn (1938).

Aircraft-laid nonparachute mines dropped in fine-grained sediments may completely bury, but ship-laid, submarine-laid, and parachute mines will be less likely to bury completely. Data from Operation MUD indicate that a Mk-39 aircraft-laid mine (nonparachute) will consistently have greater initial penetration than other mines, since this mine has a higher terminal velocity in water. Data from Operation MUD and Hydrographic Office Surveys also indicated that if samples from a bottom sediment core feel gritty when rubbed between the fingers, complete burial is not likely regardless of the other variables. In such sediments, the nonparachute mine may bury over one-half of its surface area, but other mines will seldom bury this much.

If a bottom sample feels greasy when rubbed between the fingers, air-dropped nonparachute mines will probably bury completely. Other mines probably will bury over one-half of their diameter. If a small quantity of pebbles, shell, or granular, coarse sand is present in a predominantly silt-clay bottom, initial burial usually will be less than one-half the diameter regardless of the mine type or how laid.

Initial penetration of a mine into fine-grained sediment will depend upon the impact velocity and angle of impact of the mine into the bottom, as well as the physical properties of the bottom (Fig. 2.3). The impact velocity will depend upon the mine (weight and shape), mine-laying vehicle (aircraft, ship, or submarine), and depth of water. Each mine type

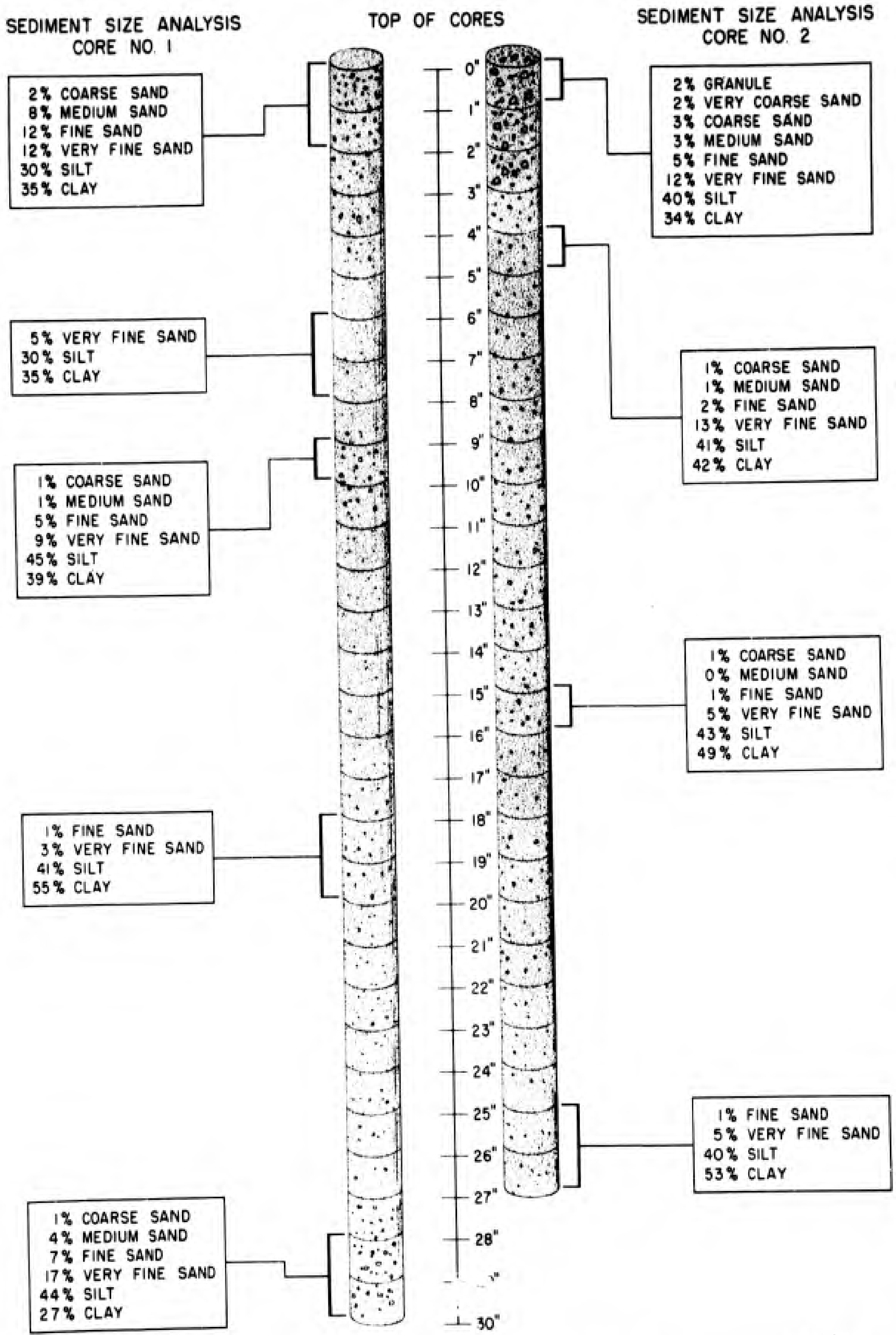


FIGURE 2.2.—Examples of variations in bottom sediments with depth, analyzed from actual core samples.

will have its own ballistic characteristics, and these characteristics determine the depth of water through which the mine must travel before it slows to its terminal velocity.

Terminal velocity is the falling velocity that a mine will reach when the force of gravity is balanced by the frictional resistance of the medium, that is, the vector sum of all forces acting upon it is zero. Since water is much more resistant than air, terminal velocities in water are much lower than terminal velocities in air. The depth of water will not have much influence on the depth of penetration when the mine is laid by submarine or surface vessel. This is true because water terminal velocity is reached within approximately 25 to 35 feet of vertical water penetration (Figs. 2.4 and 2.5). At water depths greater than terminal velocity depth, the penetration will be constant assuming the other variables remain constant.

In the case of aircraft-laid mines equipped with parachutes, the altitude and speed of the aircraft will influence the velocity and angle of entry into the water and into the bottom only if the mine is dropped from below a 200-foot altitude. An aircraft-laid mine equipped with a parachute will reach its terminal velocity in air in 200 to 500 feet of fall after the opening of the parachute. The parachute will contribute variation in speed and angle of entry into the water. Parachute mines will strike the water at various angles and continue downward. The angle at which the mine hits the water will influence the depth at which the mine slows down to water terminal velocity. Available data indicate that parachute mines reach terminal velocity in 35 to 50 feet of water (Figs. 2.6 and 2.7).

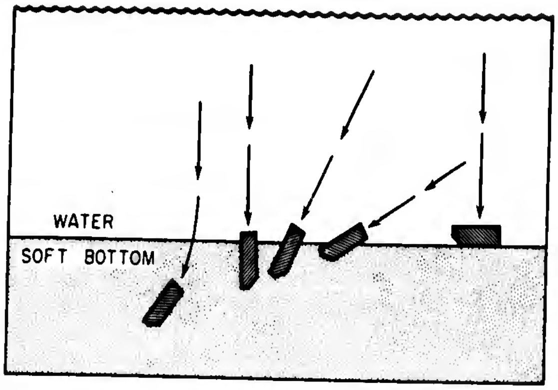


Figure 2.3.—Typical resting attitudes of air-dropped mines in a mud bottom. (Data from Operation MUD).

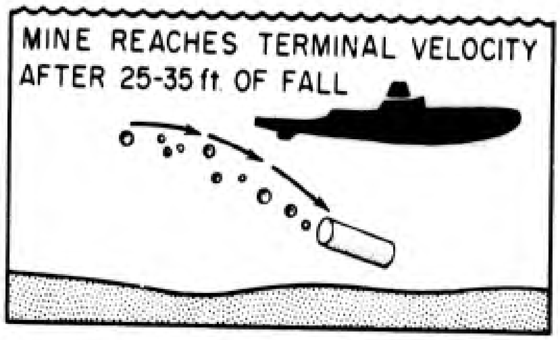


Figure 2.4.—Depth at which terminal velocity is reached by a submarine-launched mine.

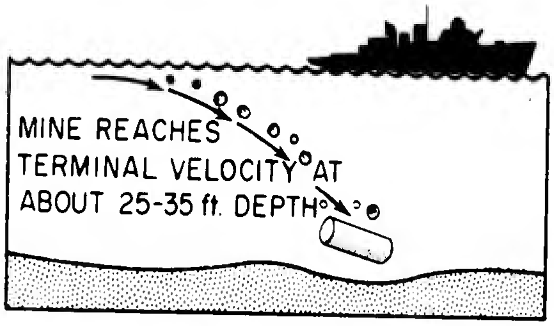


Figure 2.5.—Depth at which terminal velocity is reached by surface-launched mine.

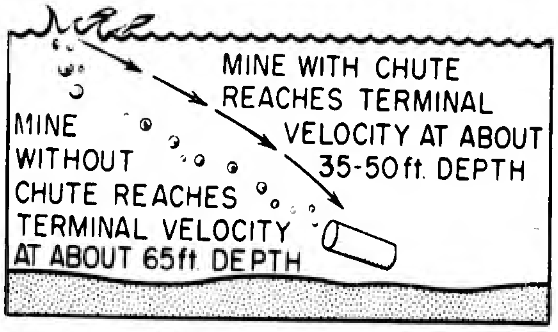


Figure 2.6.—Depth at which terminal velocity is reached by aircraft-launched mine.

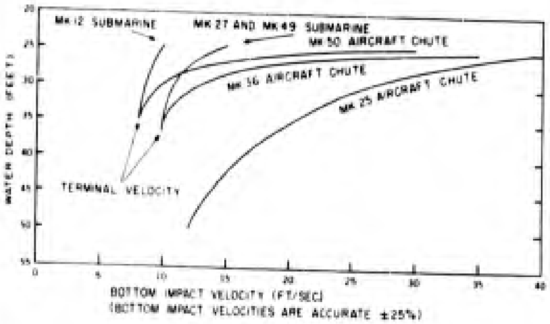


Figure 2.7.—Bottom impact velocity of various mines versus water depth.

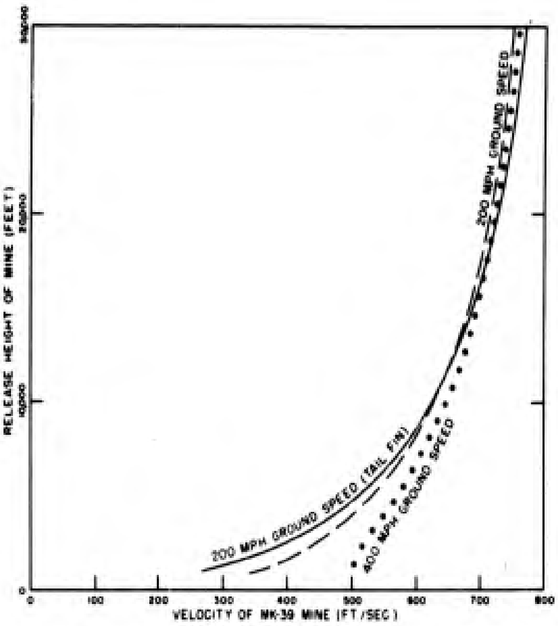


Figure 2.8.—Water entrance velocities for mines released at various altitudes.

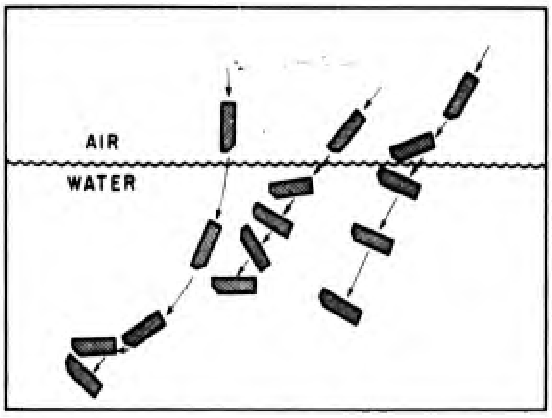


Figure 2.9.—Angle of impact into the water with possible resulting trajectories in water.

The altitude and speed of an aircraft-laid mine without parachute are important variables. Increase in one or both of these variables will increase the velocity with which a mine hits the water. Above 15,000 feet the speed of the plane is not an important factor. Although nonparachute mines never reach their air terminal velocity regardless of drop altitude and plane speed above 25,000 feet, for all practical purposes, the air terminal velocity of approximately 750 ft/sec. is reached (Fig. 2.8). The trajectory in the water depends upon the angle at which the mine strikes the water surface (Fig. 2.9). Usually, the mine will strike the water and continue downward, yet some mines have been observed to hit the water with the long axis nearly horizontal and then skip along the surface before entering the water. The mine will slow down to its water terminal velocity at 65 feet (±25%), if traveling at its air terminal velocity when it hits the water (Fig. 2.10). If the mine is not falling at its air terminal velocity, it will slow down to its water terminal velocity in less than 65 feet. If the other variables are constant, a mine's penetration into the bottom will decrease with increasing depth of water. (At depths greater than 65 feet, the penetration will no longer depend upon water depth.)

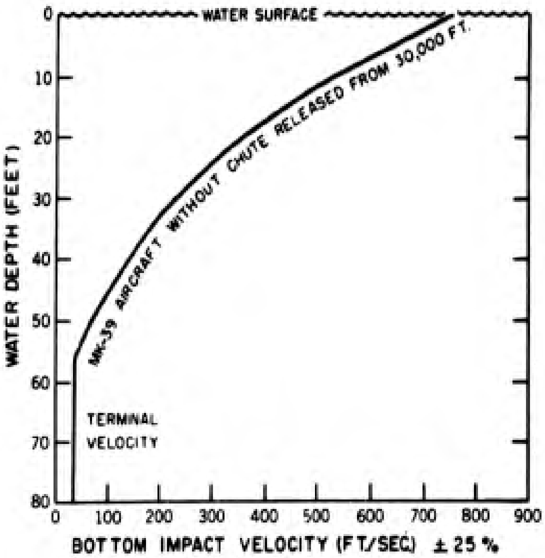


Figure 2.10.—Bottom impact velocity of a Mk-39 mine versus water depth.

The heavier the mine in water, the greater will be its penetration into a soft bottom. For example, the Mk-27-0, being a heavier type mine, will penetrate further into soft sediments than lighter submarine-laid mines. The weight in water and the terminal velocity in water of the Mk-39 are considerably greater than any parachute mine; therefore, the initial penetration can be expected to be greater.

The depth of penetration also depends upon the impact angle. The more nearly perpendicular the mine upon impact with the bottom, the greater the expected penetration. The radially asymmetrical or slant nose found on many mine types will contribute random variation to the underwater trajectory, and the angle of impact with the bottom will be a random function. Narragansett Marine Laboratory experiments show considerable variation in initial penetration of Mk-36 mines into a mud bottom. Figure 2.11 shows variation in depth of penetration even though the mines were dropped on the same bottom within a few feet of each other. In this case, the only variables would be the random functions of velocity and angle of impact of the mine with the bottom.

Actual observations show that the angle at impact of a Mk-39 will vary from vertical to horizontal even to having the tail sticking into the mud (Burt and others, 1952). Limited experiments carried out on a fine-grained sandy-clayey-silt showed that 26% of the Mk-36 mines were more than 50% buried, but none were completely buried. Yet 61% of the Mk-39 mines were observed to be over 50% buried and 28% were completely buried. The average penetration of the Mk-36 mines into the silt bottom was 21 inches, and the average penetration of the Mk-39 mines was 36 inches.

Summary of Variables Controlling Initial Penetration

MECHANICAL FACTORS

Mine weight and shape (mine type).
Angle of impact (a random function).

Impact velocity:
- *Submarine*
  - Terminal velocity reached after 25 to 35 feet of free fall in water.
- *Ship*
  - Terminal velocity reached after 25 to 35 feet of free fall in water.
- *Aircraft (parachute)*
  - Terminal velocity reached after 35 to 50 feet of free fall in water.
- *Aircraft (nonparachute)*
  - Terminal velocity reached after 65 feet of free fall in water.

(Depths accurate to ±25%.)

ENVIRONMENTAL FACTORS

Physical properties of the bottom sediments
- *porosity*
- *wet density*
- *organic material*
- *grain size*
- *clay types*
- *natural water content*
- *other miscellaneous physical and chemical properties of the bottom sediments.* (See Burt and others, 1952, for complete list.)

Vertical distribution of the sediments (Fig. 2.2).

Subsequent Penetration

Subsequent penetration results from plastic flow or scour and deposition. Plastic flow is a phenomenon whereby the sediments, under pressure of the mine's weight, flow out from under the mine, allowing partial or complete burial. Scour is defined as the removal of sediment particles from around objects on the bottom. It results from an increase in water speed as the water flows around the object. The load-carrying ability of the water increases, and sediment, which would normally be at rest, is set into motion and scour results.

No subsequent penetration of a mine upon a rock bottom will occur. The ability of rock bottoms to support loads is high, and scouring and deposition will be slight (Fig. 2.12).

A mine on a gravel or sand-and-gravel bottom will have none to slight subsequent penetration. Plastic flow of the sediment about the mine is nonexistent, and scouring and deposition will be slight.

For scouring to take place about a mine on a gravel bottom, a considerable bottom current will be necessary to move the gravel-size sediments. Strong currents, such as those which accompany the wave action of intense storms, conceivably will scour and partially bury mines on gravel sediments. On a sand-and-gravel bottom under the influence of moderate to strong wave oscillation or a moderate to strong current, the sand-size grains will scour. Burial from this scouring is improbable; however, the inclination of the mine may change (Donohue and Garrison, 1954). Ordinary wave action will affect scouring only to approximately 30 to 40 feet of water depth. However, storm

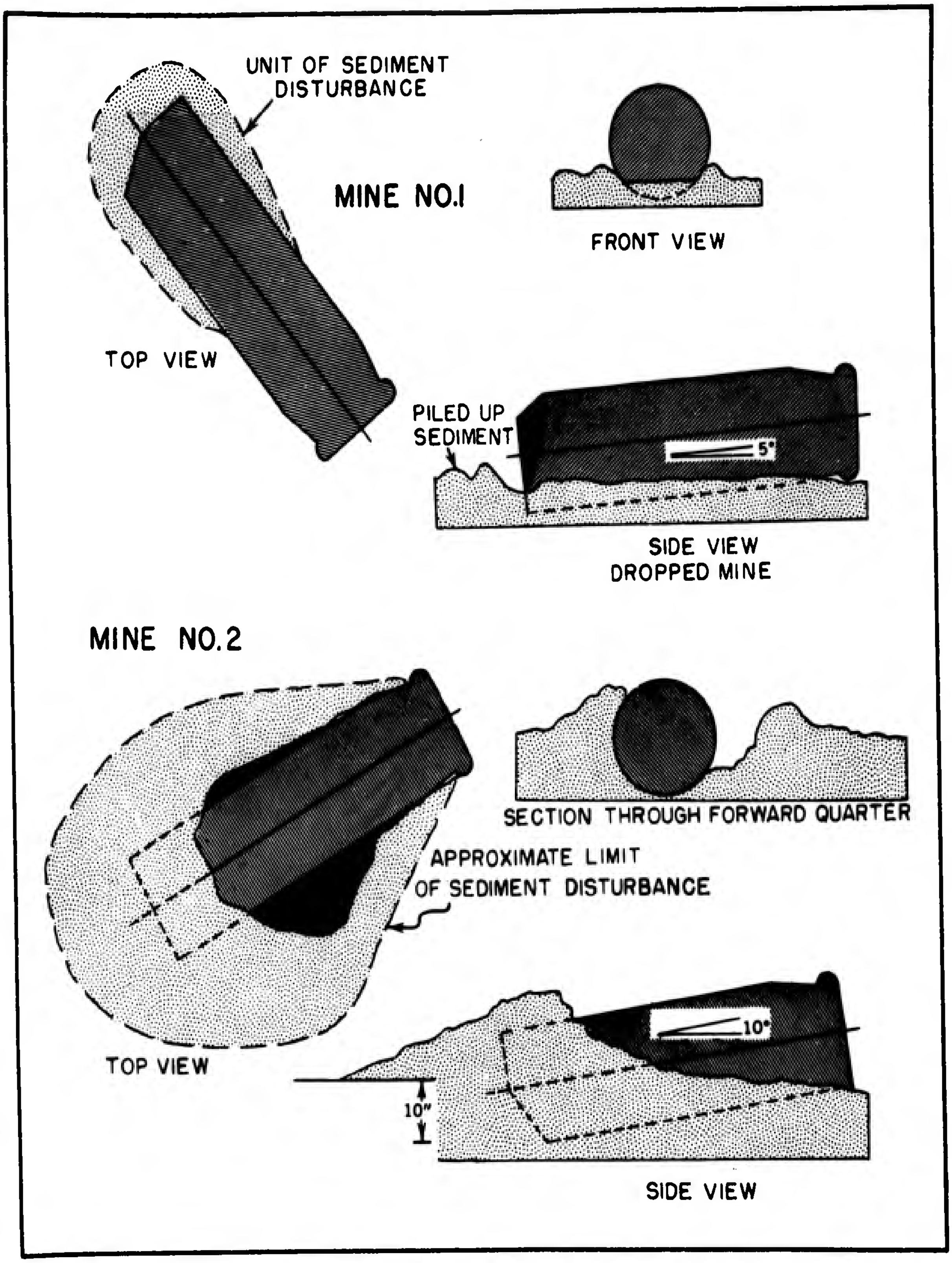


FIGURE 2.11.—Mine dropped on a mud bottom by a surface vessel.

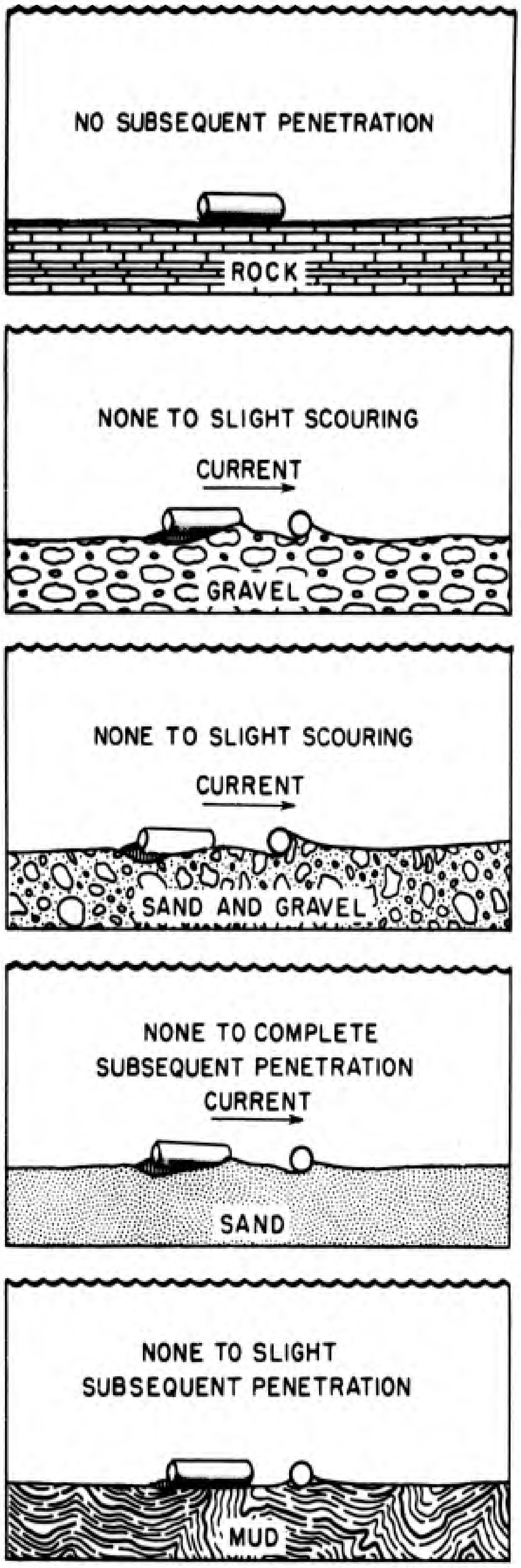


FIGURE 2.12.—Subsequent penetration of mines into various sediment types.

waves will influence scouring to a much greater depth. With a moderate to slight current speed, scour will progress, if at all, at a very slow rate.

Subsequent penetration of a mine on a sand bottom will be the result of a scour and deposition process resulting from current and wave action.

No subsequent penetration on a sand bottom will be caused by plastic flow. However, scouring and/or deposition may be carried on about a mine lying on a sand bottom when under the influence of wave and current action.

Wave action alone cannot move sediments any great distance. However, in shallow water the wave action is believed to set up sufficient turbulence to get particles off the bottom where a slight current can transport the sediment. Scour of sediments depends upon several variables. The rapid fluctuations in velocity and direction of water flow is the most important. Secondary factors are the velocity gradients, the amount of silt or clay carried in suspension in the water, and the physical characteristics of the water and particles of sediment.

As a result of recent investigations on sediment erosion, Hjulstrom (1955) has prepared a chart which shows the relations between the "average" velocity across a transverse profile of a river and size particles for the three states—erosion, transportation, and deposition (Fig. 2.13). This chart is based on several assumptions: (1) average water velocity is used, not fluctuations in water velocity, (2) uniformly sorted sediments, not sediments of varying size distribution, and (3) the curves apply to river currents, not ocean bottom currents. Until more data are available, improved curves cannot be made. However, the Hjulstrom curves give an approximate bottom current velocity necessary to scour and transport various size sediments.

When particles are in motion, they will remain in motion as long as the water velocity is maintained at the same or a somewhat lower level. For gravel, evidently the scour velocity can be decreased about 30% before deposition begins. For given velocities and particles ranging between 2 and 30 millimeters in diameter, the particles that can be transported are double the diameter of those that can be eroded. Additional information on transportation of detritus by moving water can be found in Hjulstrom (1955).

Limited data (Stetson, 1955) indicate that bottom tidal currents on the continental shelf do not exceed 0.2 knot. Current velocity of this magnitude by itself is indicated to have little effect on sediments (Hjulstrom, 1955). Such a current alone might keep silt and clay sizes in transit to deeper water but could not move larger sediments. However, in the vicinity of mines the water current velocity will increase to such an extent that scour may occur. Locally, wave-generated currents will move quantities of sediment, but data are not available on the velocities of such currents. However, maximum horizontal oscillatory velocities at the bottom resulting from waves have been computed theoretically (Fig. 2.14).

If water depth, wave period, and wave height are known, Figure 2.14 can be used to compute maximum orbital velocity at the bottom. Knowing this velocity, Hjulstrom curve number one can be used to determine whether or not the wave action could stir and lift the bottom sediments, causing scour. Then currents of low velocity (tidal or wave-generated) might move them, at least for short distances.

Bascom and Fry (1953) have computed theoretically that currents below a velocity of 1.6 knots will move sand in such a way as to excavate a trench on one side and build a ridge on the other side of a mine. A shift in the current direction, such as during a tidal cycle, may roll a mine into the excavation, and with alternate shifts complete burial ultimately can take place (Fig. 2.15).

Strong wave oscillations may cause complete burial in shallow water on an actively moving beach in just a few days (Bascom and Fry, 1953). When a mine is in more than 30 feet of water it may still bury, but the burial process will be slower. The rate of burial will depend on the wave characteristics, grain size, mine shape, and depth of water. Under the influence of relatively weak waves, a mine probably will be nearly stable or only slight scour will take place. During seasons of large waves in shallow water, large volumes of sand will be shifted about, and the burial rate will increase. During storms, sand movement caused by wave action may extend to a depth of 100 to 150 feet.

In many nearshore areas, large volumes of sand are being shifted about constantly by wave and current forces. Thus, erosion of the nearshore sands goes on continuously the year round in one area, alternating erosion and deposition goes on in another, deposition goes on continuously in a third area. Some beaches are nearly in equilibrium with little deposition or erosion.

Mines may bury completely on a sandy bottom if subjected to strong variable currents. After several months complete burial may take place under the influence of moderate bottom currents (0.5 to 1.0) knot and wave action. The following incidents have been recorded on the subject.

> Several Mk-39 mines were dropped into the Gulf of Mexico near Pensacola Bay in 28 to 40 feet of water. No initial penetration into the hard sand bottom occurred. Yet when recovered, the mines had buried up to 75% of the mine case in 8 weeks. The partial burial was attributed to fairly rapid tidal currents in this area (Lubnow, 1952).
>
> A mine placed on the fine sand bottom of Nantucket Sound partially buried due to moderate wave oscillations and slight tidal currents in 54 days in approximately 37 feet of water (Fig. 2.16). After 54 days the mine was in a trough having a total vertical displacement of 13 inches. Maximum observed waves were 1.6 feet in height and 406 feet in length (McMaster, Garrison, and Hicks, 1954).
>
> Tests of mines on a fine sand beach in 14 feet of water showed that under influence of 4-foot waves having 10 second periods complete burial took place in as little as 8 days. The sand on this beach was continually being shifted about (Bascom and Fry, 1953).
>
> Tests off a sandy beach in 27 feet and 70 feet of water found that mines were buried and lost in about 30 days (Bascom and Fry, 1953).

Complete burial in less than 30 days on a sand bottom is concluded to be quite unusual.

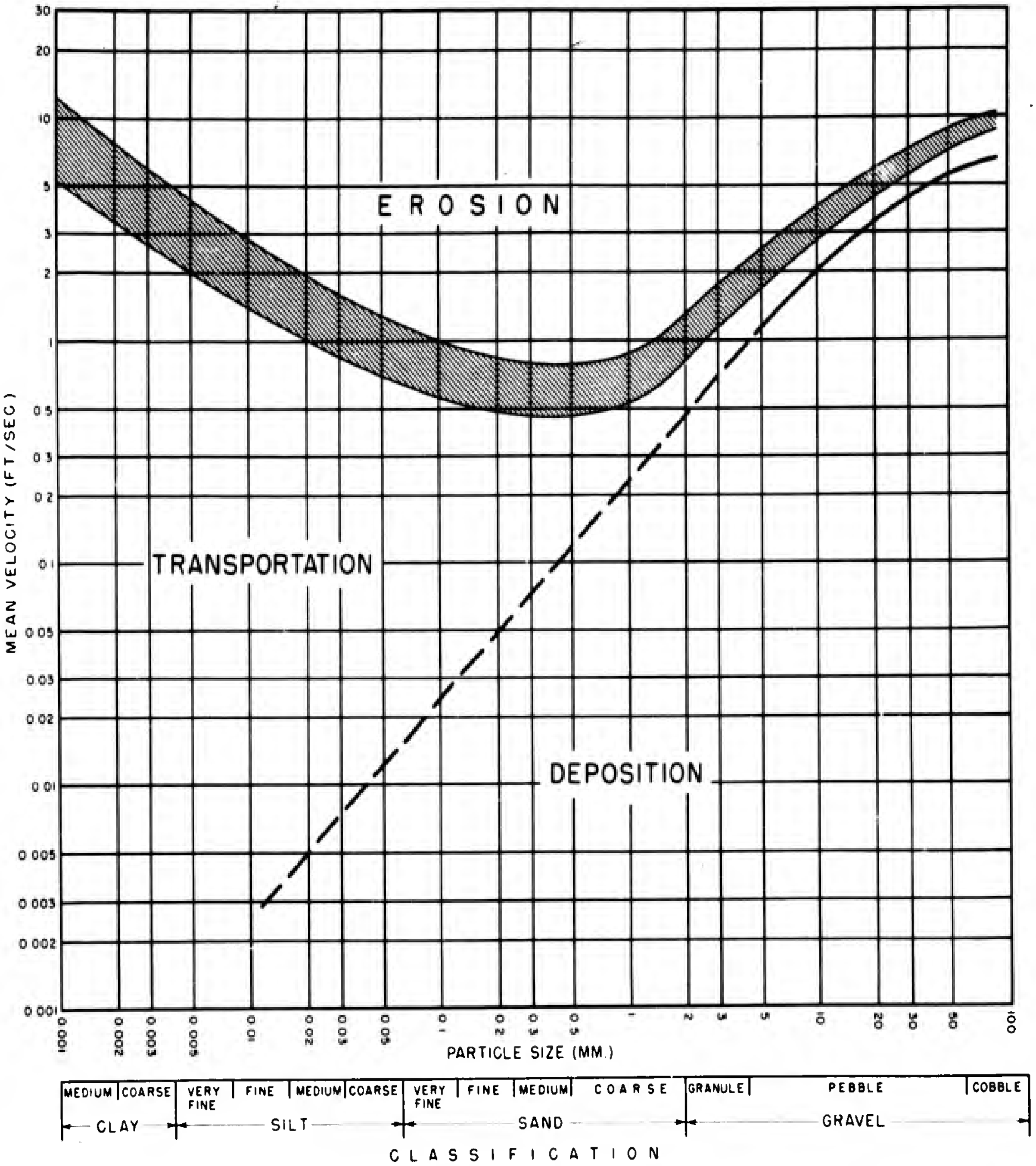


FIGURE 2.13.—Relationship between average current velocity in a river and sediment particle size showing velocities necessary for erosion, transportation, or deposition.

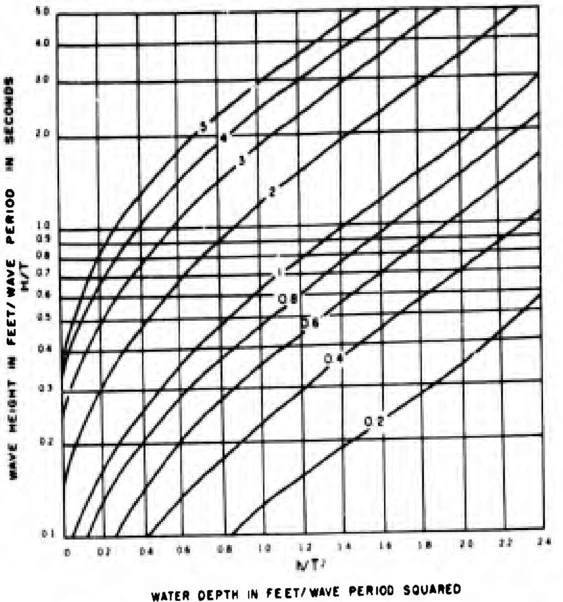


FIGURE 2.14.—Maximum horizontal orbital velocities at bottom resulting from waves.

Subsequent penetration of a mine into mixtures of fine-grained sand-silt-clay sediments, probably will be considerably less than the initial penetration. In most cases it probably will be limited to a few inches (Fig. 2.13).

The depth to which a mine will bury subsequent to initial penetration on a fine-grained sediment (mud) is very difficult to predict. Subsequent penetration appears to be the result of a flow phenomenon (plastic flow). This penetration depends not only on the surface layer of the bottom sediments, but also on the variation of the sediment characteristics in the deeper layers.

Few observational data are available as to subsequent penetration of a mine in mud. Published results by Narragansett Marine Laboratory mention one Mk-36 that had penetrated 5 inches in 3 days subsequent to initial penetration, another Mk-36 penetrated 4 inches in 3 days, but had no additional penetration in 27 days. The bottom was predominantly silt with about 15% fine-grained sand. These examples should not be taken as indicative of all subsequent penetration in a fine-grained sediment.

Scouring about a mine resting on fine-grained sediments probably will be slight, and limited to smoothing of the sediments disturbed by the initial impact.

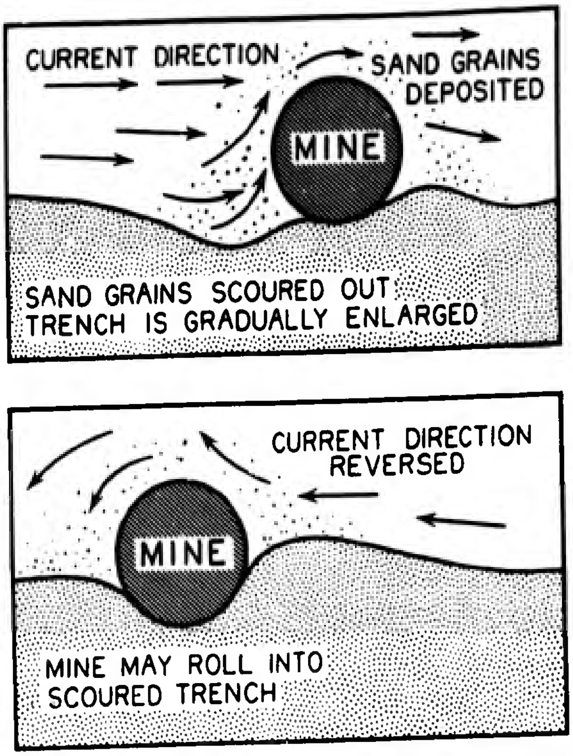


FIGURE 2.15.—Scouring about a mine.

Experiments carried out by Narragansett Marine Laboratory indicate that on a sand-clay-silt bottom in 25 to 30 feet of water scouring will be negligible if the tidal currents are weak (less than 0.5 knots) and the area is sheltered from high waves. NML reported that this mine was undisturbed by hurricane forces. Maximum bottom velocities were calculated to be 9.7 ft./sec. In addition, currents of a significant magnitude were present. Currents sufficiently strong to cause scour in areas of fine-grained sediments are unusual.

Results of Burial

Burial of a mine will have little or no influence upon a magnetic-actuated mechanism, but an acoustic signal may be attenuated by overlying sediments. The pressure-actuated mine mechanism may be affected by burial because the motion of the diaphragm may be impeded. Results of tests carried out by the Naval Ordnance Laboratory (McInteer, 1956) indicate that sand effectively blocks applied pressure signals by clogging the space between the rubber diaphragm and front cover plate, thereby preventing movement of the diaphragm in

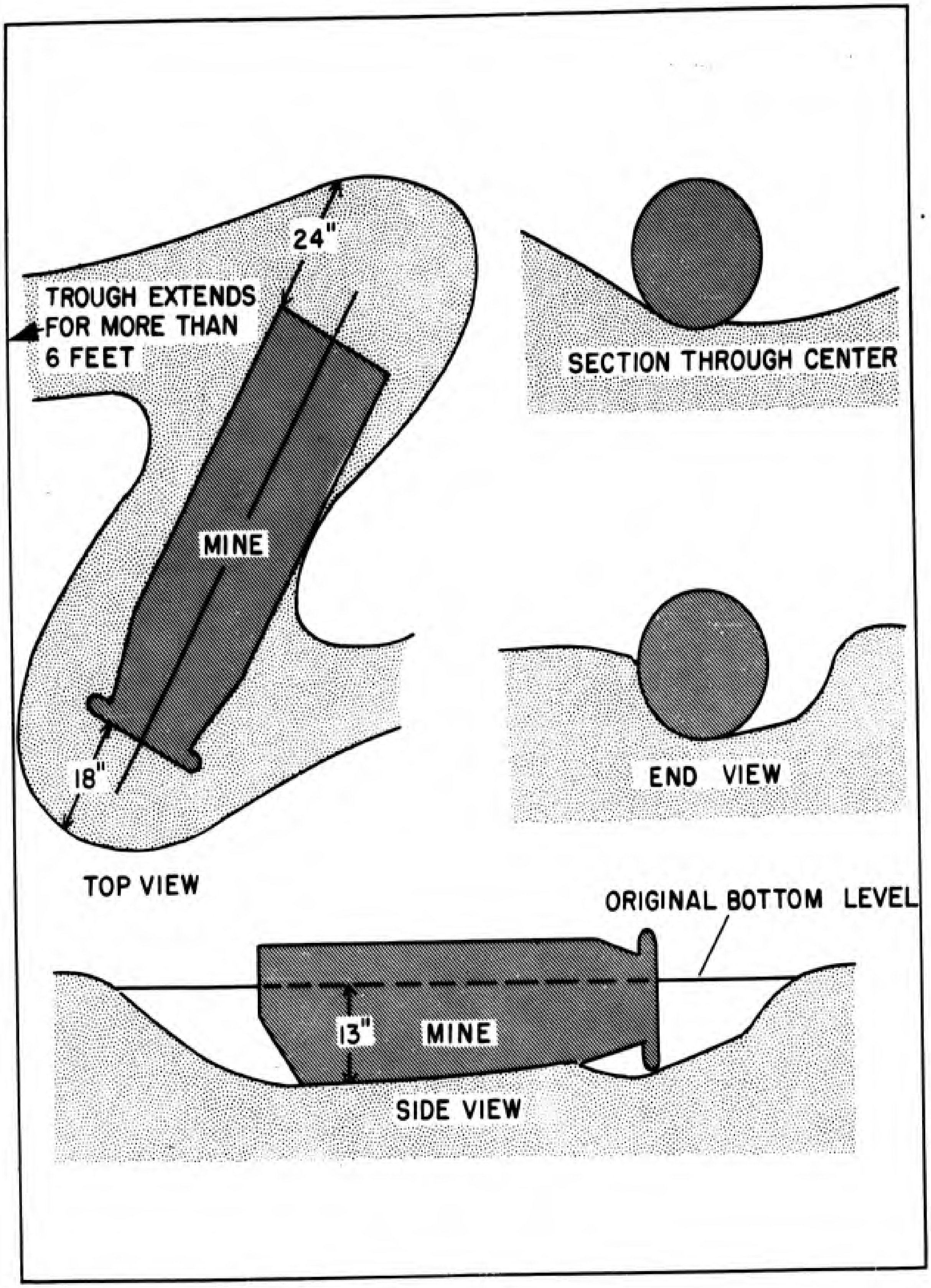


FIGURE 2.16.—Erosion about a Mk-36 mine on a fine sand bottom.

response to pressure signals. Only the first few inches of sand contribute to the observed effect. The extent of this blocking increases with increased hydrostatic pressure. Soft muds have a much smaller effect than sand under most of the conditions observed.

In cases where soluble washers are used in extender mechanisms, strong currents which cause water to circulate around the washers will decrease their dissolving time, while washers imbedded in silt or mud may take as much as 10 times their normal period to dissolve.

No data are available regarding firing widths of influence mines as a function of depth of burial and sediment type. Possibly, the firing width of some influence mines will be reduced by burial (Murphy, 1955).

Mine-hunting operations can be impaired by partial or complete burial of a mine in bottom sediments. Mine-hunting teams are composed of ships equipped with sonar and supported by divers. Crumpton (1956) reports that reverberation from a sand bottom tends to mask target echo. Partial or complete burial on a sand bottom will tend to decrease to zero the target echo. Reverberation levels on a mud bottom will be less, but the rate of absorption will be greater. If the mud contains shell or other similar fragments, scattering and attenuation will occur, decreasing the effectiveness of sonar.

Rolling

The tendency for a mine to roll will depend on the bottom topography, the bottom currents, and the bottom sediments (Fig. 2.17). However, in most mineable waters rolling is believed to be relatively uncommon.

No data are available as to the bottom current speed necessary to roll a mine on a flat or graded rock bottom. If the rock bottom is rough, a rolling mine will soon become wedged and be unable to roll regardless of the current. A current of ¾ to 1 knot is estimated as necessary to roll a mine on a smooth rock bottom. However, smooth rock bottoms are rarely found in nature. Less current speed is necessary to roll a mine down a slope. Wave oscillations may help a mine overcome inertia and start to roll.

In general, mines will not roll on a level gravel or sand-and-gravel bottom (Fig. 2.17).

Incidents have been recorded in which mines have rotated and rolled under the influence of strong wave action.

A mine which rested with only slight apparent movement on a gravel bottom in 35 feet of water for 2 months rolled a minimum distance of 2 feet. About 6 weeks later during a hurricane it again moved a minimum distance of about 2 feet; however, the total movement may have been as much as 20 to 30 feet. The inclination of the mine varied about 3° (McMaster, Garrison, and Hicks, 1954).

Under normal conditions a mine will not roll on a sandy bottom. Normal bottom currents are of such a velocity that scouring and current ripples will develop at much lower velocities than those required to roll a mine, and these irregularities tend to prevent rolling.

If a mine remains in sand in the same location without rolling for one tidal cycle and is subject to current action, it probably will never roll. Scouring action will build a ridge and trough and cause partial or complete burial, which will tend to prevent rolling. As the mine sinks into the bottom, it will have a tendency to tilt its long axis and slowly sink into the gradually deepening scour depression. However, storm waves may upset this equilibrium.

No data are available as to minimum current velocity necessary to cause a mine to roll over a flat sandy bottom. Maximum surface tidal currents of over 10 knots have been recorded in certain restricted areas. Although the associated bottom current will be much less, it may be sufficient to cause a mine to roll.

In general, a mine will not roll on a bottom made up of various mixtures of fine-grained sand, silt, and clay (Fig. 2.17).

Currents are usually weak over such bottoms, and initial penetration into the bottom will prevent subsequent rolling. However, this is not always true. Mines might roll over hard fine-grained bottoms provided rapid bottom currents are present.

Results of Rolling

Very little information is available on the effect of rolling on mine-actuating mechanisms.

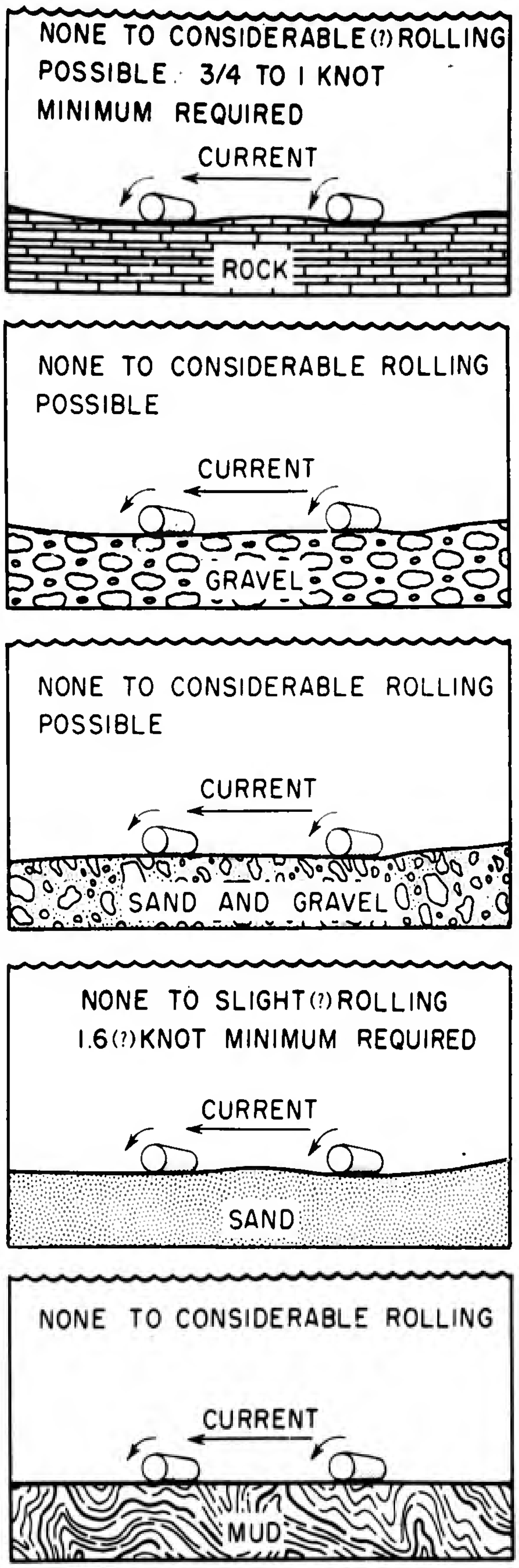


FIGURE 2.17.—Rolling of mines over bottoms of various sediment types.

The following statements are based primarily on conjecture.

The jarring action of the mine rolling or tilting on the bottom may result in a magnetic look for a search-coil or dip-needle magnetic mine, an acoustic look for an acoustic-actuated mine, or a pressure look for a pressure-actuated mine.

A search coil in a rolling or rocking mine might cut the lines of flux of the earth's magnetic field, inducing a voltage that causes a look.

Rolling may generate a noise that would result in a look for an acoustic mine. A rolling pressure mine will experience hydrostatic pressure changes as the pressure diaphragm rotates about the axis of the mine. The period of these changes is dependent upon the rate of roll, which may well be within the range required to fire the mine. In most mineable waters, rolling is thought to be relatively uncommon. Most rolling upon a sand bottom will occur within 24 hours of planting. However, a mine laid upon a gravel or rock bottom may roll about any time a storm passes. Mines laid in water greater than 100 feet in depth will not be affected by storms. A delay arming device will eliminate most mine loss due to rolling.

Figure 2.18 is a summary of mine behavior on various types of bottoms.

Estimation of mine behavior

As little is known about bearing capacity of marine sediments and about vertical distribution of the sediments, accurate estimates of depth of penetration of a mine in a given area can only be determined by actual field tests. This is a difficult, expensive, time consuming, and frequently an impossible task.

However, bottom sediment charts, and some standard navigation charts and smooth sheets show bottom sediment notations, and qualitative estimates of mine penetration depth can be made. Bottom sediment and navigation charts have been prepared and published by the Coast and Geodetic Survey and the Hydrographic Office. Notable are the Hydrographic-Oceanographic Data Sheets (HODS), prepared by the Hydrographic Office, which contain bottom sediment data of many important harbors of the world.

MINE BEHAVIOR \ BOTTOM TYPE[3]	ROCK (Rk, Co, Rky, hrd, Bld)	GRAVEL (P, G, crs, hrd)	SAND AND GRAVEL	SAND (S)	COMBINATIONS OF SILT, CLAY, SAND, AND GRAVEL[1] (M, stf, Cl, stk, sft, hrd)
INITIAL PENETRATION	NONE	NONE	NONE	NONE	SLIGHT TO COMPLETE
SUBSEQUENT[2] PENETRATION	NONE	NONE TO SLIGHT	NONE TO SLIGHT	NONE TO COMPLETE	NONE TO SLIGHT
ROLL	NONE TO CONSIDERABLE	NONE TO CONSIDERABLE (?)	NONE TO CONSIDERABLE (?)	NONE TO SLIGHT (?)	NONE TO CONSIDERABLE

1. Examples are silty clay, clayey silt, fine grained sandy clayey silt, fine grained sandy silty clay, and clayey silt with a small percent of gravel. Such sediments are commonly referred to as mud. In the above examples the last sediment named predominates. Thus a silty clay contains over 50% clay.
2. Subsequent penetration includes plastic failure of the sediment caused by the weight of the mine on the sediment. Also included is scouring and deposition as a cause of subsequent penetration. Scour is due to the wave and current action of picking up sediment particles and moving them and depositing the particles in a different location (deposition).
3. Bottom type abbreviations are found on navigation and survey smooth sheets.

FIGURE 2.18.—Summary of mine behavior on various types of bottoms.

Standard navigation charts cover nearly all commonly navigated coastal waters and harbors of the world. Smooth sheets of actual hydrographic surveys carried out by the Hydrographic Office and the Coast and Geodetic Survey are on file at these offices. Both types of charts give some bottom sediment notations, the smooth sheets giving more complete notations. Where notations indicate rock (Rk or Rky), coral (Co), shell (Sh), boulders (Bld), hard (hrd), gravel (G), pebbles (P), stiff (stf), coarse (crs), or sand (S) no initial penetration should be expected. However, mines can be expected to bury to some extent in mud (M), sticky (stk), soft (sft), or clay (Cl) bottoms. Complete burial might occur in these latter types of sediments.

2.2 MOVEMENT OF MOORED MINES

The effectiveness of a moored mine is largely dependent upon its environment. Forces in the ocean may cause movements of the minecase or entire mine assemblage. These movements are generally undesirable to the mine planters; however, if the causes and effects of these movements are properly evaluated, they may be used to advantage in mine evasion or mine countermeasures. The two types of movement of major concern are the vertical displacement of the minecase relative to the surface and horizontal movement of the entire mine assemblage. Vertical movements may result in the mine surfacing or in becoming deeper than the drafts of the ships it is intended to destroy. Horizontal movements of the mine to shallower or deeper water will result in similar effects. Horizontal movements may also result in the mines' moving out of the intended mined area.

Dip

Dip of the moored mine is its increase in depth due to displacement from the normal vertical position above the mooring point. It is caused by variation in drag action on the minecase and cable. Drag action depends upon the size and shape of the minecase, the diameter of the mooring cable, and the magnitude of the oceanographic variables involved.

Dip, rise or fall of the sea level, and settling of the mine anchor all will vary the depth of a moored mine. The extent of the depth variation is determined by any one or a combination of currents, tides, biological fouling, waves, bottom sediments, bottom topography, and sea water density.

Current action is the most important oceanographic variable affecting dip. It tends to pull the mine case and cable away from its normal vertical position thereby increasing the distance from the mine case to the sea surface. The force of the current against underwater objects is proportional to the square of the current speed. Consequently, dip can be expected to increase considerably with faster currents. At a given current speed, dip is greater the longer and/or thicker the mooring cable. It decreases with the additional buoyancy of the mine (Fig. 2.19).

Figures 2.19, 2.20, and 2.21 are based on the assumption of constant current velocity with depth. In most cases currents decrease in velocity with depth. For this reason, estimates of dip from these graphs will, in general, be high. Likewise, all ordnance publications which incorporate the assumption of constant current velocity with depth should be used with reservation. The variations of current velocities with depth depend on the locality of the mine planting and in most instances cannot be estimated without prior knowledge of the actual current profile. Complete mathematical procedures for computing mine dip are not treated in this publication but may be found in McMahon (1956). An example of a calculated mine dip curve is shown in Figure 2.22. This figure shows the tide curve, the tidal and nontidal rotary current vectors, and the calculated mine dip on the assumption of constant current velocity with depth.

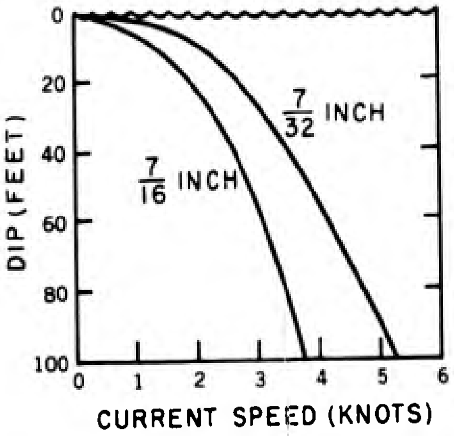


Figure 2.19.—Dip as a function of current and cable diameter for a Mk-6 mine with a net buoyancy of 283 pounds and a cable length of 200 feet.

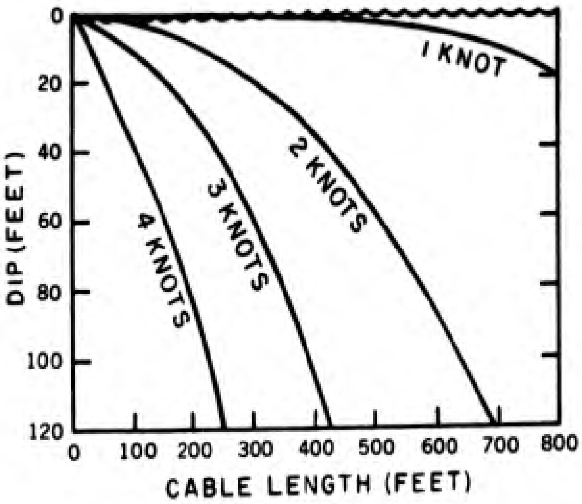


Figure 2.20.—Dip as a function of current and cable length for a Mk-6 mine with a net buoyancy of 283 pounds and a cable diameter of 7/16 inch.

The effective dimensions of the minecase and the effective diameter of the mooring cable may be modified by biological fouling. Fouling of mines, cables, and antenna floats by oysters, coral, barnacles, mussels, seaweed, and other marine fouling organisms may cause considerable dip by the combined effect of weight and increased area resistance to current action (drag). As marine fouling increases, offering greater resistance to current action, mine dip also increases, in some instances increasing depth below the surface to the extent of rendering the mine ineffective (Fig. 2.23).

Variations due to changes in sea level are one of the primary causes of depth variation of the moored mine. Tides vary as to location and time, and increase or decrease minecase depth accordingly.

Settling of the mine anchor, causing subsequent increase in the depth of the minecase, is dependent upon consistency of the ocean bottom and current action. Settling will occur if the bottom is mud, thus allowing penetration by the mine anchor. Current action on the mine anchor may hasten the settling process by scouring if the bottom is sand. Settling subsequent to the initial penetration of the anchor on the bottom generally will be small and negligible.

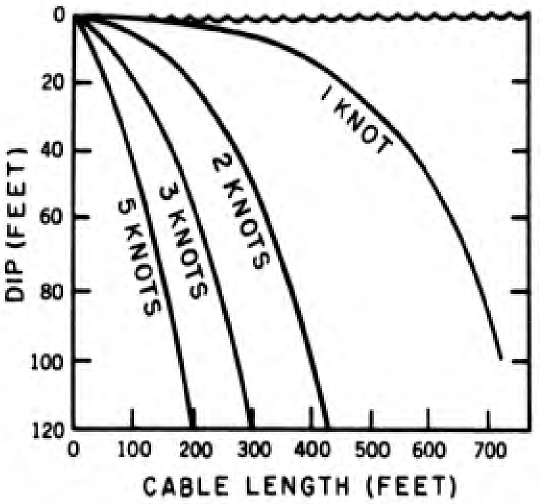


FIGURE 2.21.—Dip as a function of current and cable length for a Mk-6 mine with a net buoyancy of 283 pounds and a cable diameter of 7/32 inch.

Density change in sea water possibly may change the relative buoyancy of the minecase. However, even under the most extreme density changes experienced in the ocean, a change in relative buoyancy would amount to only a few pounds and can be considered negligible in estimating dip.

Variations in wind velocity and atmospheric pressure may also indirectly increase and decrease the depth of the minecase. Combinations of stormy onshore winds, a barometric low, and flooding tide may cause an increase in sea level several feet greater than that normally increased by the tide.

Tides will cause depth variations of the moored mine and may cause the mine to surface. If the mine has been planted where the tide range is greater than the set depth of the mine, the mine may surface at low tide.

Wave action also may cause temporary surfacing of moored mines, but for a much shorter period of time than that caused by tides. Surfacing of moored mines due to wave action will be a function of wave height.

The role that currents play in the surfacing of moored mines is dependent upon the type of mechanism employed for establishing the depth of the minecase below the sea surface.

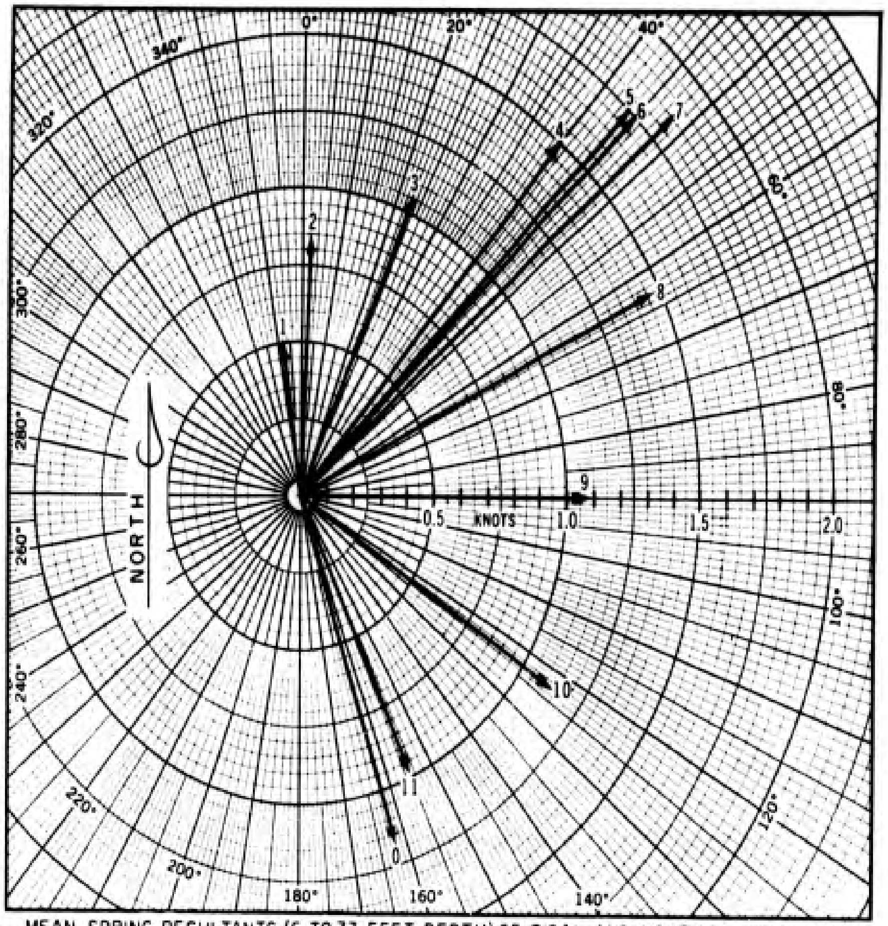
At the present time, two types of depth setting mechanisms for moored mines are in use: the hydrostatic type and the plummet type. If the hydrostatic depth setting mechanism is used and mine cable is released in a tideway at a time other than slack water, more cable will be released than would be necessary to establish the set depth of the minecase, and it will cause the minecase to float near the surface, possibly surfacing at slack water when no longer subject to current action (Figs. 2.24 and 2.25). The plummet type depth setting mechanism may be set at any stage of the tide, since the effect of currents upon the depth setting mechanism is small.

Walking

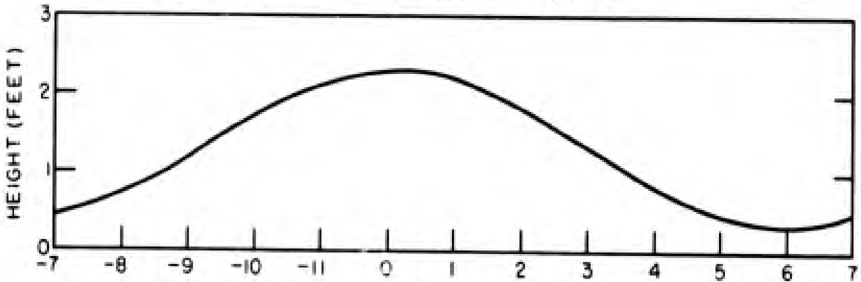
Moored mines are designed to remain where planted, and in the vast majority of cases no appreciable horizontal movement will occur. Many reports of mine field movements can be explained by faulty navigation. In some instances, however, the moored mine may drag its anchor across the ocean bottom to a new location. This movement, termed *walking*, is dependent upon one or a combination of currents, bottom sediments, bottom topography, and wave action. The primary oceanographic variable causing walking is current action. When a current is of sufficient strength, its force upon minecase, cable, and anchor will tend to walk the mine in the direction of the current.

A moored mine subject to current is more likely to walk across a smooth hard bottom of rock than a comparatively soft bottom of mud. In all probability a smooth bottom will offer less resistance to walking than will a rough bottom. Such irregularities as coral heads, depressions, and rocky outcrops are likely to trap a mine anchor and lessen the probability of walking. A moored mine planted on a slope will have the additional assistance or hindrance of the angle of slope in walking, the rate and extent of walking being dependent upon the degree and length of slope and motivating oceanographic variables.

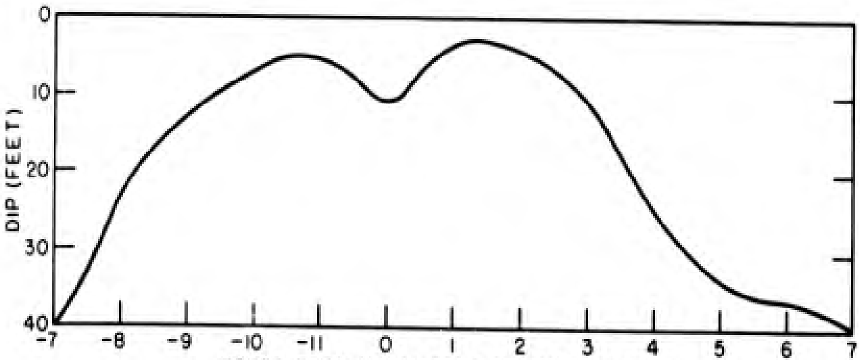
Also, wave action must be considered in the walking of a moored mine. Increasing wave height will increase the tendency of the mine to walk, and the additional lift imparted to the minecase by wave action makes it more susceptible to current flow (Fig. 2.26). However, the current force will almost always remain the dominant factor in causing the moored mine to walk.



A MEAN SPRING RESULTANTS (6 TO 33 FEET DEPTH) OF TIDAL AND NONTIDAL CURRENTS AT 70° 34' N., 58° 24' E. THE NUMBERS NEAR ARROWHEAD REPRESENT NUMBER OF HOURS AFTER HIGH WATER AT KAMENKA GUBA, PROLIV KARSKIYE VOROTA. DIRECTION OF ARROW IS THE SAME AS DIRECTION OF RESULTANT CURRENT.



B TIDE CURVE (KAMENKA GUBA)



C. CALCULATED DIP AS THE RESULT OF CURRENTS ON A MK-6 MINE MOORED ON 280 FEET OF 7/16-INCH CABLE.

FIGURE 2.22.—Example of tide curve, the tidal and nontidal rotary current vectors, and the calculated mine dip.

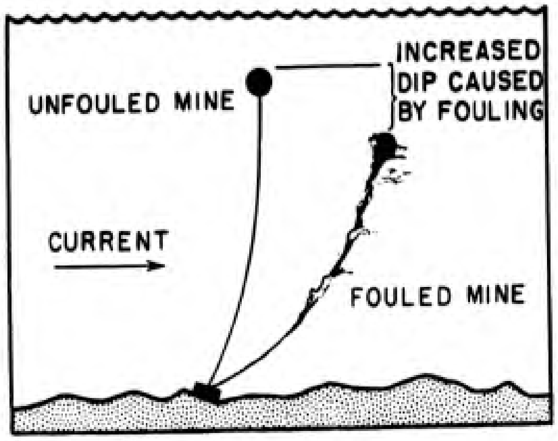


FIGURE 2.23.—Schematic drawing comparing the dip of a fouled mine with that of an unfouled mine in a constant current.

Oscillation of the moored mine is caused by the motion of water particles set up by the motion of surface waves (Fig. 2.27). This water particle motion is dependent mainly upon the type of wave action on the surface and the depth of the water.

Oscillation of moored mines can produce a number of problems. In dip-needle mines the rapid motion may conceivably cause an inertial drag on the mechanism which may fire the mine prematurely. Another important factor is fatigue (progressive fracture) of the cable caused by the continuous oscillation of the minecase. Either of these factors may limit appreciably the endurance of a moored mine.

Our present knowledge of mine dip and walking is incomplete; consequently dip and walking estimates should be used with caution. Several possible applications of these phenomena should be considered:

1. Periods of maximum currents are also periods of maximum dip and as such are probably the best times to penetrate a moored minefield. Lead sweepers have best protection during these periods.
2. Periods of slack water are the best times for visual detection of moored mines.
3. In areas where walking is likely to occur, mines may move out of the original mined area; conversely, moored mines might be planted in such an area where currents will replenish a minefield by moving mines into a shipping channel.

2.3 BIOLOGICAL EFFECTS

Growth of the Fouling Layer

Fouling may be defined as the process by which certain marine animals and plants attach and grow on submerged objects. Fouling may have a detrimental effect on underwater ordnance and harbor defense installations. Antifouling paints may be used to prevent fouling, but the life of protective coatings is measured in months. Thus, ordnance on the bottom will become overgrown within a few months in spite of the type of paint used.

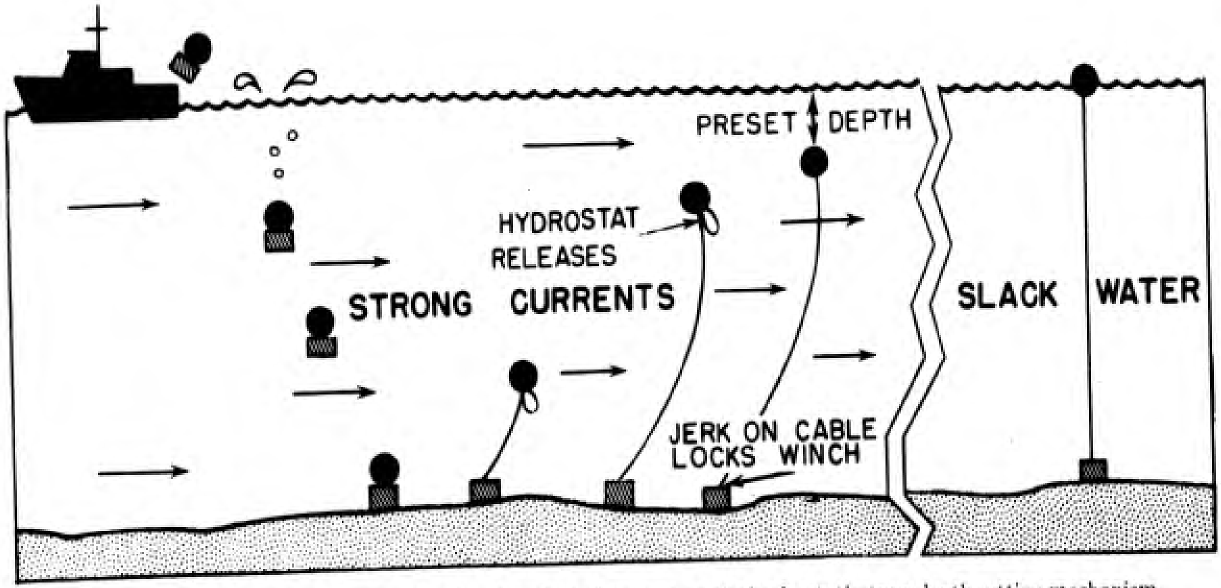


FIGURE 2.24.—Schematic drawing showing the effect of current on the hydrostatic-type depth setting mechanism.

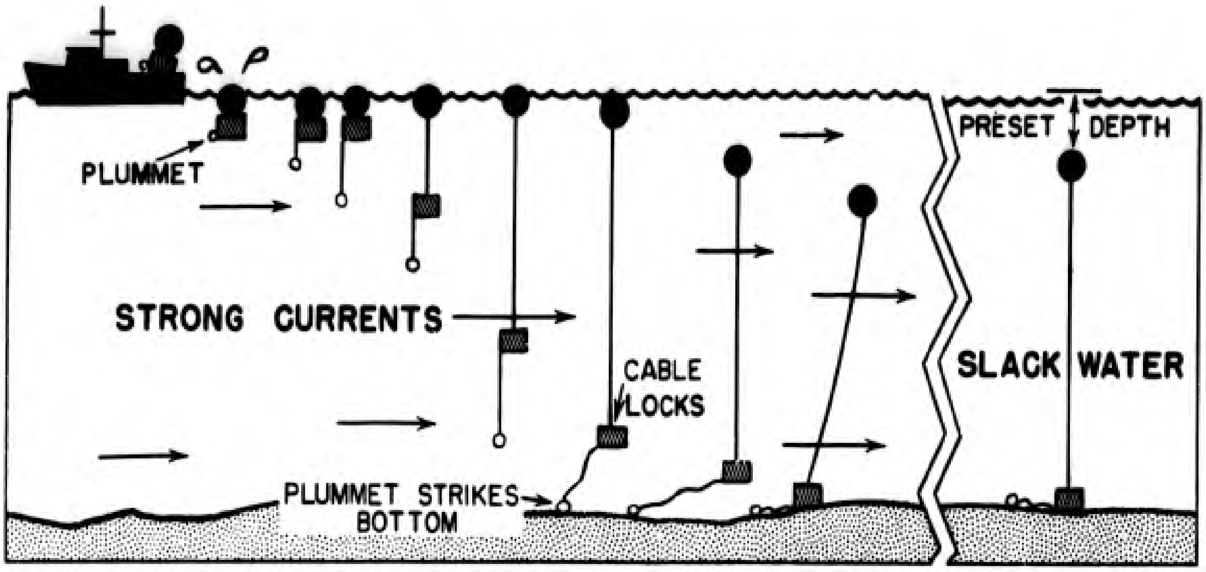


FIGURE 2.25.—Schematic drawing showing the effect of current on the plummet-type depth setting mechanism.

Fouling animals, such as mussels, consume small plants, animals, and organic debris suspended in ocean waters. Therefore, the rate of growth of such fouling animals depends on the food supply. The speed of growth is also affected by water temperature, the food being more quickly converted to body substance at higher temperatures. The microscopic plants consume certain nutrients of sea water, phosphate and nitrate nutrients being in greatest demand. These nutrients are liberated upon decomposition of organic materials that have sunk from the surface layers of the sea. The nutrients are returned to the surface by turbulence and upwelling. The rate at which this occurs determines the abundance of plant and animal food supply. Nutrients must be brought close to the surface because they are converted to food only in the presence of sunlight. The depth at which sufficient sunlight is available for this conversion ranges from about 30 feet in turbid inshore waters to 300 feet in oceanic waters. Attached plants or seaweeds are similar to the microscopic plants in their need of phosphates, nitrates, and sunlight (Fig. 2–28).

Turbulence, upwelling, temperature, and sunlight are seasonal variables. Thus, the intensity of biological fouling on objects submerged less than a year is not simply a function

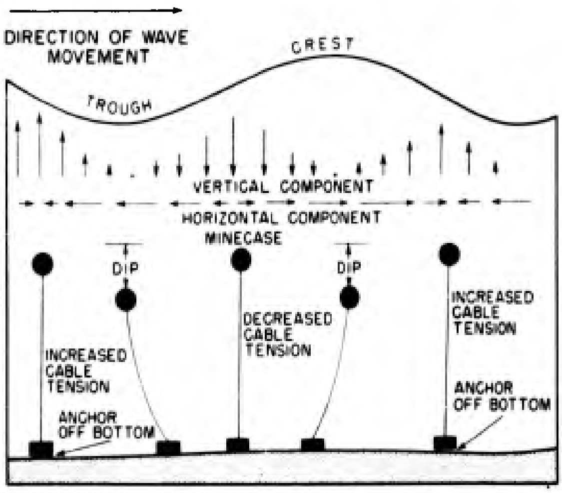


FIGURE 2.26.—Schematic drawing showing direction of forces associated with waves and their effect on a moored mine.

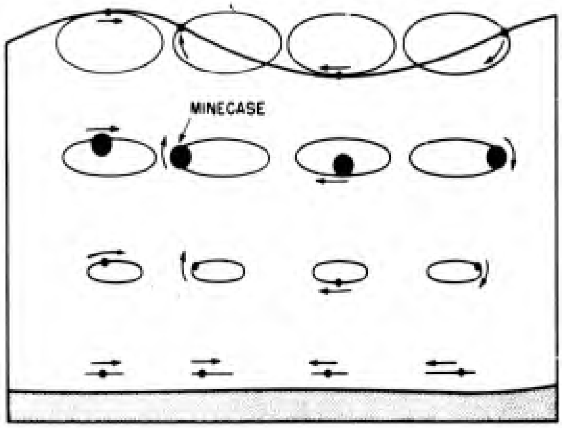


FIGURE 2.27.—Water particle motion caused by waves.

of the length of time exposed but primarily dependent upon the season and geographic location. Most fouling organisms are capable of reaching a new surface for only a brief period after they hatch from the egg, and likewise spawning (egg production) is limited in many cases to a season of only a few weeks in each year. Thus initial fouling is usually heavily dependent on season, and a fresh surface exposed after the major season of attachment may show much less fouling in the subsequent 10 months than another surface exposed two months earlier. Figure 2.29 illustrates the seasons of attachment of fouling organisms in the eastern Mediterranean. Figure 2.30 shows an Mk–39 mine that has been on the bottom in 60 feet of water for five months in the vicinity of Key West.

In colder water the rate of fouling generally is less than in warmer waters. Along the coast of Maine, attachment and accumulation occur from late spring to early fall. The annual increment in thickness on fixed installations is estimated at one inch and will be attained primarily during the summer. Farther south, between Cape Cod and Cape Hatteras where the summer temperatures are much higher, attachment and accumulation are still most pronounced during the warmer period of the year. In the southern portion of the region between Cape Cod and Cape Hatteras, the annual increment in thickness of fouling is estimated at 2 inches. Proceeding southward on the Atlantic Coast, the length of the growth season increases until monthly equality of growth is found at the southern tip of Florida. In the tropics, most of the annual increment is attained in the first 2 to 3 months of submergence.

Poor growth conditions induced by winter temperatures in temperate waters limit growth to the same degree as the poor growth conditions brought about by smaller quantities of suspended organic matter in tropical waters. Thus, in one year fixed installations from Cape Cod to southern Florida collect about five pounds per square foot of fouling. The dominant fouling organisms between Cape Cod and Cape Hatteras are mussels, while barnacles are the most important fouling organisms in southern Florida. For temperate and more northerly regions, the weight of fouling in pounds per square foot may be roughly computed by multiplying the average temperature of the water, $\overline{T}$, in excess of 32° F by 0.02 and this product by the number of months of exposure.

$$0.02\ (\overline{T}-32)\ (\text{number of months exposure}) = \text{pounds per square foot.}$$

The thickness in inches is 0.39 times the weight in pounds per square foot. At best, these equations are only approximations. Great variability in the accuracy of these equations will be found in different areas.

Large differences in biological fouling of mines result from differences in current speed. Observations on buoys showed that fouling is increased 2.3 times, on the average, as the mean tidal velocity increases from 0.25 knot to 1.50 knots, (Table 2–I). This is the result of an increased quantity of micro-organisms (suspended in the water) brought to the fouling organism per unit time.

As a crude approximation, the intensity of fouling in a given ocean area will resemble the intensity of production of other forms of marine life, such as fish or shrimp. Areas where rich fisheries exist can be expected to be areas of vigorous fouling; conversely, waters known to be poor in fishery resources are likely also to have a lower intensity of fouling. Areas of upwelling will have greater fouling than adjacent areas with no upwelling. In tropical waters where nutrients are very low in surface waters, land drainage from the mouth of a harbor or bay increases the nutrient concentration and resultant fouling markedly.

Although mussels, barnacles, bryozoa, and seaweeds are the principal fouling organisms, other kinds of organisms occasionally cover the mine surface. Types without shells are much lighter than shelled organisms. Animals, without shells such as tunicates (commonly called sea squirts, sea pork, etc.), have a density close to that of sea water, while mussels have a density 50% greater than that of sea water. Seaweeds, such as kelps, may be dominant foulers in very northern regions (for example, north of Cape Cod). Kelps grow from 2 to 5

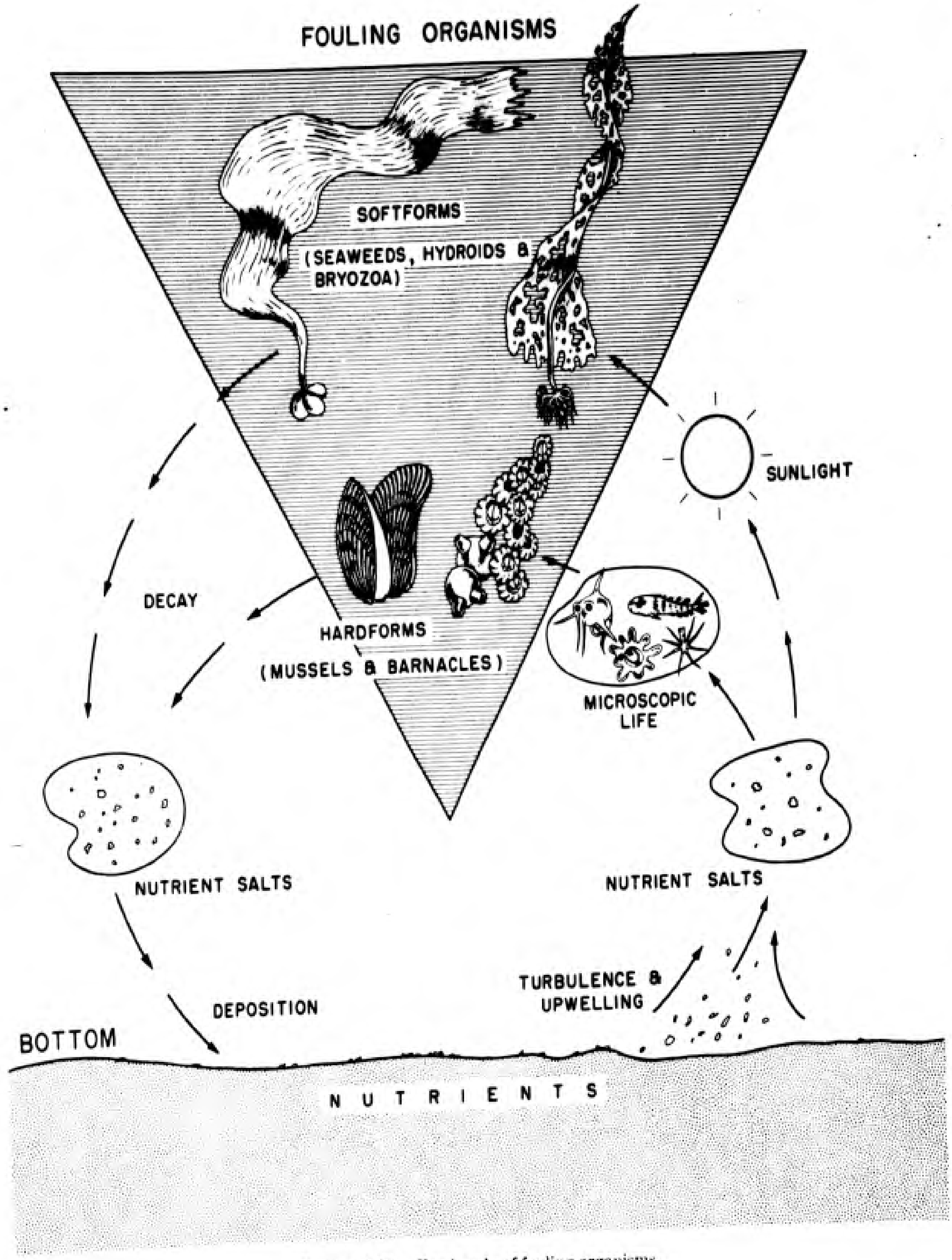


FIGURE 2.28.—Food cycle of fouling organisms.

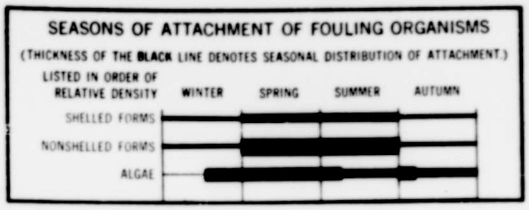


Figure 2.29.—Seasons of attachment of fouling organisms.

yards in length in 1 to 2 years and usually possess flat blades of 6 to 24 inches in width.

The Effect of Fouling on Dip

Fouling has distinct effects on mine behavior. Increase in dip of a moored mine will occur as the weight is increased and the cross-sectional area of the mine and its mooring wire normal to current direction is increased by fouling. A spherical mine 3 feet in diameter with a mooring line ¼-inch in diameter and 100 feet long have together a projected cross-sectional area of 7 square feet. Theoretically, the area of the assemblage is enormously increased by fouling. For example, a fouling layer 3.5 inches in thickness is to be expected at the end of a year in a 1-knot current where the mean yearly temperature is 58° F (as off the coast of Delaware). The area normal to current flow would then be 60 square feet. The dip to be expected at various current speeds with a year's thickness of fouling having the same density as sea water is compared in Figure 2.31 with the dip of the clean mine. This figure shows that dip is accentuated drastically at higher current speeds, since fouling grows to greater thickness at higher current speeds. Fouled mine assemblages with shorter mooring cables would have much less dip, since the increase in area of the cable due to fouling is primarily responsible for the area increase of the whole assemblage.

The weight of fouling by shelled organisms increases the dip by reducing the buoyancy of

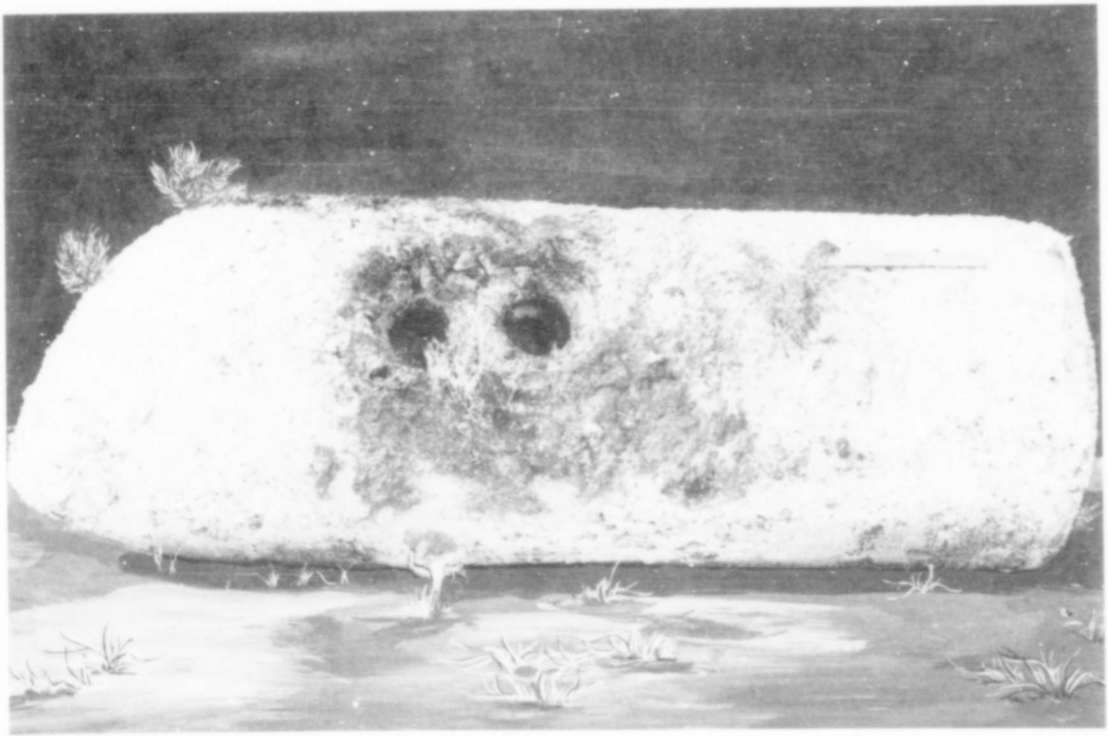


Figure 2.30.—Mk-39 in 60 feet of water for five months near Key West, Florida. (Photo by OPDEVFOR MINEVDET).

the mine. Six and one-half pounds per square foot are estimated to grow in one year on a 3-foot-diameter mine and 100-foot cable in 0.5-knot current at 58° F temperature. If this fouling were entirely composed of mussels, 165 pounds of weight in water (negative buoyancy) would be added to the assemblage. The dip due to area of mine and cable, to the added area of fouling, and to the loss in buoyancy caused by mussel weight is shown in Figure 2.31 by the dashed line. In areas of current speeds greater than 0.7 knots the negative buoyancy of the mussels may become greater than the positive buoyancy of the mine in one year. Fouled mine assemblages with a mooring cable shorter than 100 feet would have much less loss of buoyancy by mussel fouling. In fact, as greater thicknesses of mussels grow, more and more of the cable would lie on the bottom and reduce the negative buoyancy caused by mussels to equal the positive buoyancy of the mine. Thus, the mine would occupy progressively deeper positions in the water. If fouling was sloughed off from the slender mooring cable of a mine, the estimates of dip given in Figure 2.31 would be too large.

Tracing Mine Movements

The identification by a qualified biologist of important fouling species can be used to locate the geographical origin of moored mines which have drifted north or south along the margins of the ocean basins. Since overlapping of range of species occurs, combinations of several species should be used. The fouling organisms found along the east coast of the United States are a good example. North of Cape Cod, the mussel *Mytilus edulis* and the barnacles *Balanus crenatus* and *Balanus balanoides* are the dominant forms; from Cape Hatteras *Mytilus edulis*, *Balanus eburneus*, and *Balanus improvisus* are dominant. Between Cape Hatteras and Cape Canaveral (northern Florida) *Balanus eburneus* and *Balanus improvisus* are found together with *Balanus amhitrite* and rock oysters, such as *Pteria colymbus*. From Cape Canaveral to Key West and in the Bahamas *Balanus tintinnabulum* and coralline algae are among the more conspicuous species. Thus, mines adrift with these combinations of species would betray the portion of the coastline where they were originally laid. Rare species as well as dominant species can be used to determine the origin of moored mines.

Age Determination of Mines

If antifouling paints are used, the paint testing results can be consulted to determine the expected life of the paint before fouling would begin. Assuming that antifouling paints and similar applications are of negligible importance, the length of time a mine has been in the water can be inferred from the weight or

TABLE 2-I

RELATION OF AVERAGE CURRENT VELOCITY TO ANNUAL GROWTH OF FOULING

CURRENT VELOCITY	THICKNESS OF FOULING IN INCHES	
KNOTS	COAST OF DELAWARE MEAN YEARLY TEMP. OF 58°	COAST OF MAINE MEAN YEARLY TEMP. OF 45°
0.25	2.0	1.0
0.50	2.5	1.2
1.00	3.5	1.7
1.50	4.6	2.3

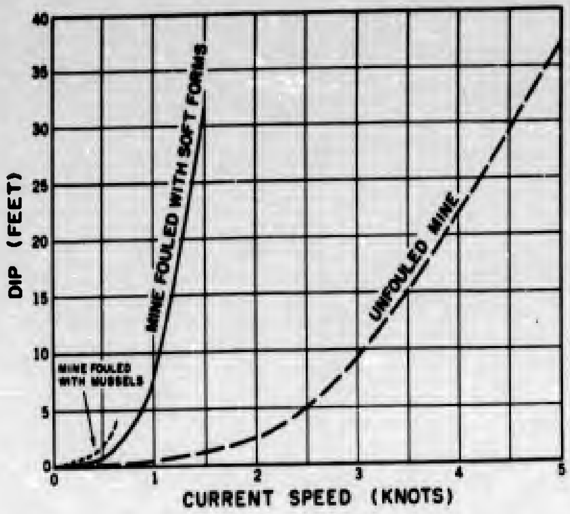


FIGURE 2.31.—Dip of a Mk–6 mine with 100 feet of ¼-inch cable as affected by fouling.

thickness of the fouling layer and from the size of individual species for which growth rates are known. For example, measurements of the length of mussels can be used. Along the coast of southern New England the mussel *Mytilus edulis* grows 2 to 3 millimeters per month between April and November, and in Southern California the mussel *Mytilus Californianus* grows 3 to 5 millimeters per month throughout the year. The total annual growth of these mussels averages 3 and 5 centimeters, respectively (Fig. 2.32).

Various species of barnacles growing on buoys reach their maximum size and adulthood in one year. Thus, if barnacles smaller than adult size are found on mines the mine probably has been in the water less than a year. Populations of some species may show very different growth characteristics. There are exceptions to every rule, however. The jingle shell *Anomia simplex* was found to be slightly smaller on older mines in one location—as if crowding had occurred. Succession of different species has been recorded from float bottoms and on rocky shorelines. Therefore, organisms such as hydroids, ascidians, and barnacles may cover the mine surface and ultimately be overgrown by mussels. Periods of ½ to 2 years have been observed to elapse before mussles began to appear. Mine age estimates would have to be made using all the layers of organisms. Thus, for a combination of barnacles overgrown by mussels on a submerged object, the size of both organisms should be considered to obtain an estimate as to the length of time the object has been in water.

Effect of Fouling and Other Organisms on Mine Actuation

Mine mechanisms may be completely covered by the fouling layer. Sonic devices under such conditions may be completely inactivated. The magnetic mine is not affected by fouling, and the pressure mine is unlikely to be affected by a nominal amount of fouling. Figure 2.33 shows fouling on an Mk–36 pressure mine. The mine was in 48 to 60 feet of water for 16 months in the vicinity of Key West, Florida.

Acoustic mines are sensitive in the range characteristic of shrimp sounds. However, at the lower frequency where these mines operate, shrimp sound is not a major contribution to the overall background level (Fig. 4.4). Sounds of some fish are in the range of the acoustic mine; whether or not their intensity is sufficient to actuate the mine is unknown. By way of example, Figure 2.34 is the sound spectrum emitted by the sea trout (Fish, 1954).

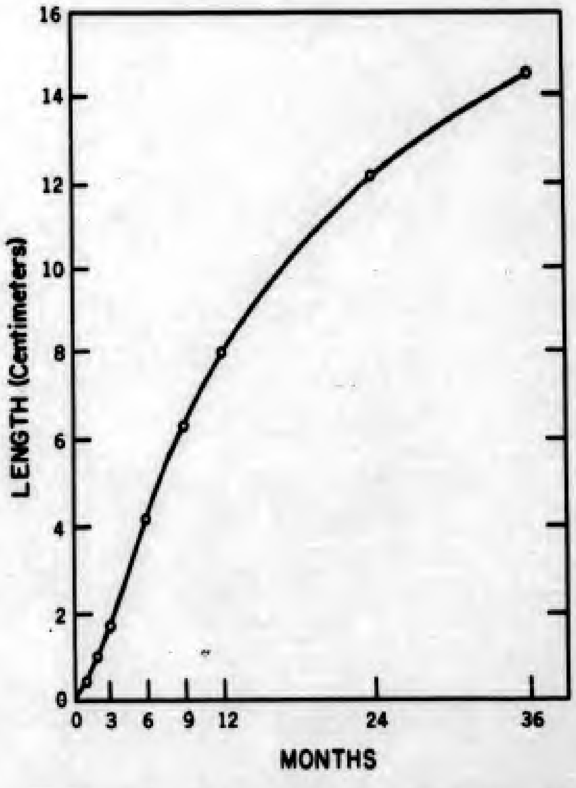


FIGURE 2.32.—Growth of *mytilus californianus* (sea mussel).

Detection of Mines by Sonar

Laboratory experiments show that reflection of sound from fouled metal surfaces is less than that from clean metal surfaces (Fig. 4.2). However, field observations of mine detection by sonar showed little impairment in detection when the mines were fouled. Thus, under conditions met at sea other disturbing factors appear to be more important in reducing the efficiency of detection by sonar than fouling on the mine surface.

Bioluminescence and Mines

Little is known of the bioluminescence (phosphorescence) associated with mines. Underwater objects may be illuminated by bioluminescent organisms, especially in the presence of currents or turbulence. The operational significance of bioluminescence on mine detection has not been established.

2.4 DRIFTING MINES

Free floating mines constitute a threat to both naval and merchant shipping. Such mines are subject to the moving forces of currents, waves, and wind. Characteristics of the floating minecase, such as the depth it rides in the water, will strongly influence the effect of the environmental factors on drift. An examination of each factor, individually and collectively, affecting mine drift, is necessary if a proper evaluation is to be made of the probable movements of free floating mines.

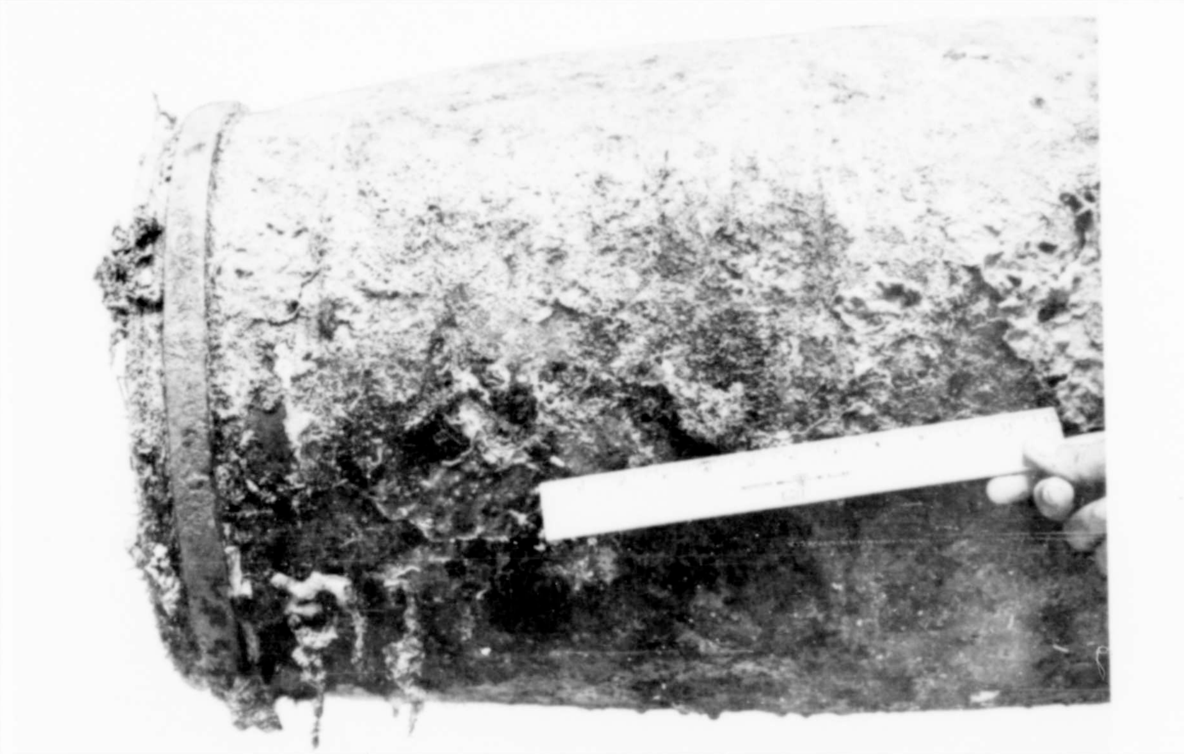


FIGURE 2.33.—Fouling on a Mk-36 mine in 48–60 feet of water for 16 months in the vicinity of Key West, Florida. (Photo by OPDEVFOR MINEVDET).

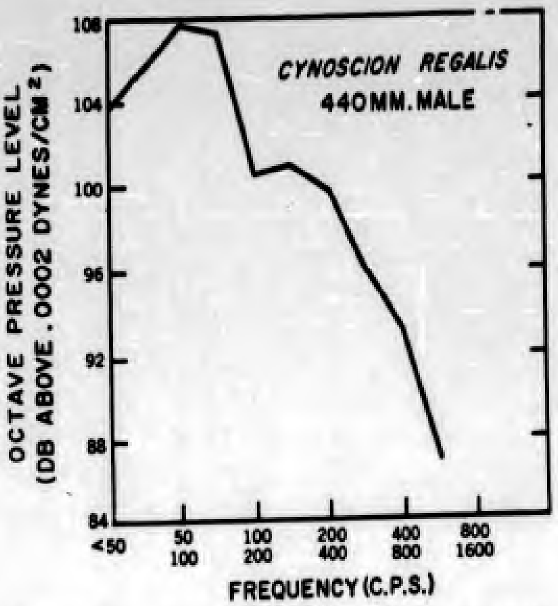


Figure 2.34.—Spectrum of spontaneous sound of a sea trout.

Factors Affecting Mine Drift

Permanent Currents.—The prevailing patterns of circulation in the sea are due to both the differences in water density resulting from variations in the salinity and the temperature of the water and to the stress of the wind upon the sea surface. In open water, well distant from land, the current flow patterns tend to be parallel to the water density contours. In the open ocean of the Northern Hemisphere less dense water is on the right hand side of an observer looking in the direction of the current. In the Southern Hemisphere the less dense water will be found on the left hand side. Local factors, such as restrictions of land masses, may modify this generalization so that no firm evaluation can be made by referring to the density distribution alone.

Wind-drift currents may develop in areas where a wind of fairly constant direction exists, such as in the low latitude trade wind belt or in the zone of prevailing westerlies of the midlatitudes. The current, caused by wind stress, tends to take a direction up to 30° to the right of the wind direction in the Northern Hemisphere north of 10° N, and to the left in the Southern Hemisphere south of 10° S. Between 10° N and 10° S, wind currents are generally downwind. In Table 2-II the interrelationships between the wind velocity and the wind-induced current are shown.

Table 2-II.—*Velocity of the Wind Current in miles per day*

Wind (Beaufort force)	*Wind Speed (knots)*	*Wind Current (miles per day)*
1	1-3	2
2	4-6	4
3	7-10	7
4	11-16	11
5	17-21	16
6	22-27	21
7	28-33	26

Submarine topography will tend to modify the flow pattern by deflecting the currents. Oscillations in the axis of oceanic currents will cause further variations in the flow pattern. The so called "permanent" currents are quite variable in nature and are capable of changing radically over a period of days or years. In many instances eddy currents from the main current flow may cause an apparent reversal of the general circulation. A comparison can be made between the major surface currents of the oceans and the prevailing oceanic wind regimes of the winter and summer seasons. Figures 2.35 and 2.36 show the prevailing winds and ocean currents of the world.

Tidal Currents.—Over the continental shelves, tidal currents are generally stronger and have a greater effect at depth than other currents. Tidal currents may be bidirectional in restricted waters, such as in channels, or may be rotary in more open waters, such as roadsteads, embayments, gulfs, or seas. Funnel-shaped bodies of water, such as estuaries, are characterized by strong tidal currents ranging to as much as 10 knots. Usually the ebb current is stronger than the flood current because of the added effect of land runoff. Little is known of the strength and nature of tidal currents in the open ocean due to the difficulties of measurement.

Longshore Currents.—Nearshore currents are attributable, in large part, to the effect of wave-induced flow. Although winddrift, tidal, and permanent currents also are present in various degrees of strength, currents off beaches, promontories, and nonestuarine embayments tend to flow parallel to the beach, the direction depending upon the approach angle of the coastal incident waves. At frequent intervals along the shore, seaward-flowing rip currents

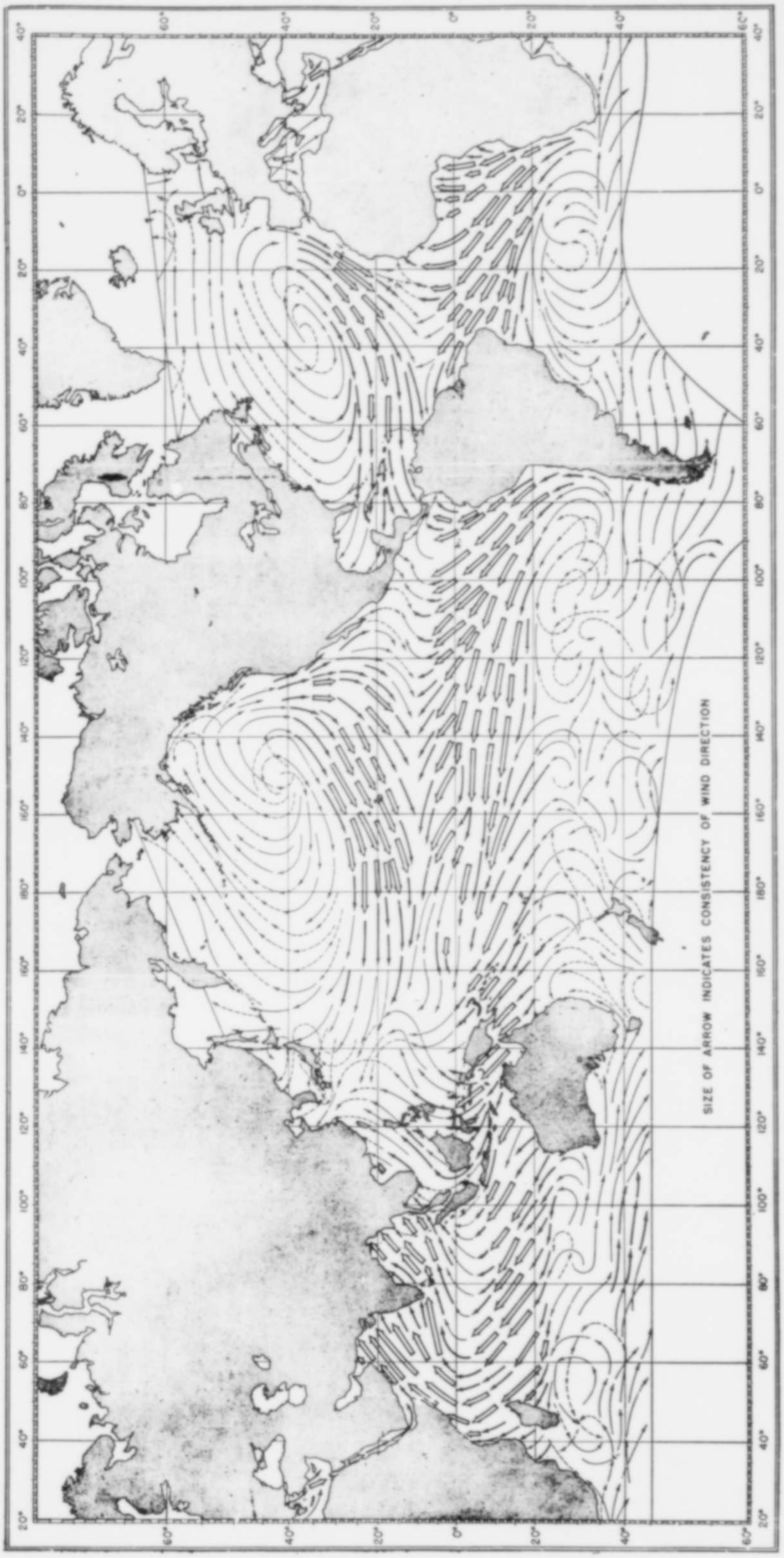


FIGURE 2.35.—Prevailing winds over the oceans of the world for February.

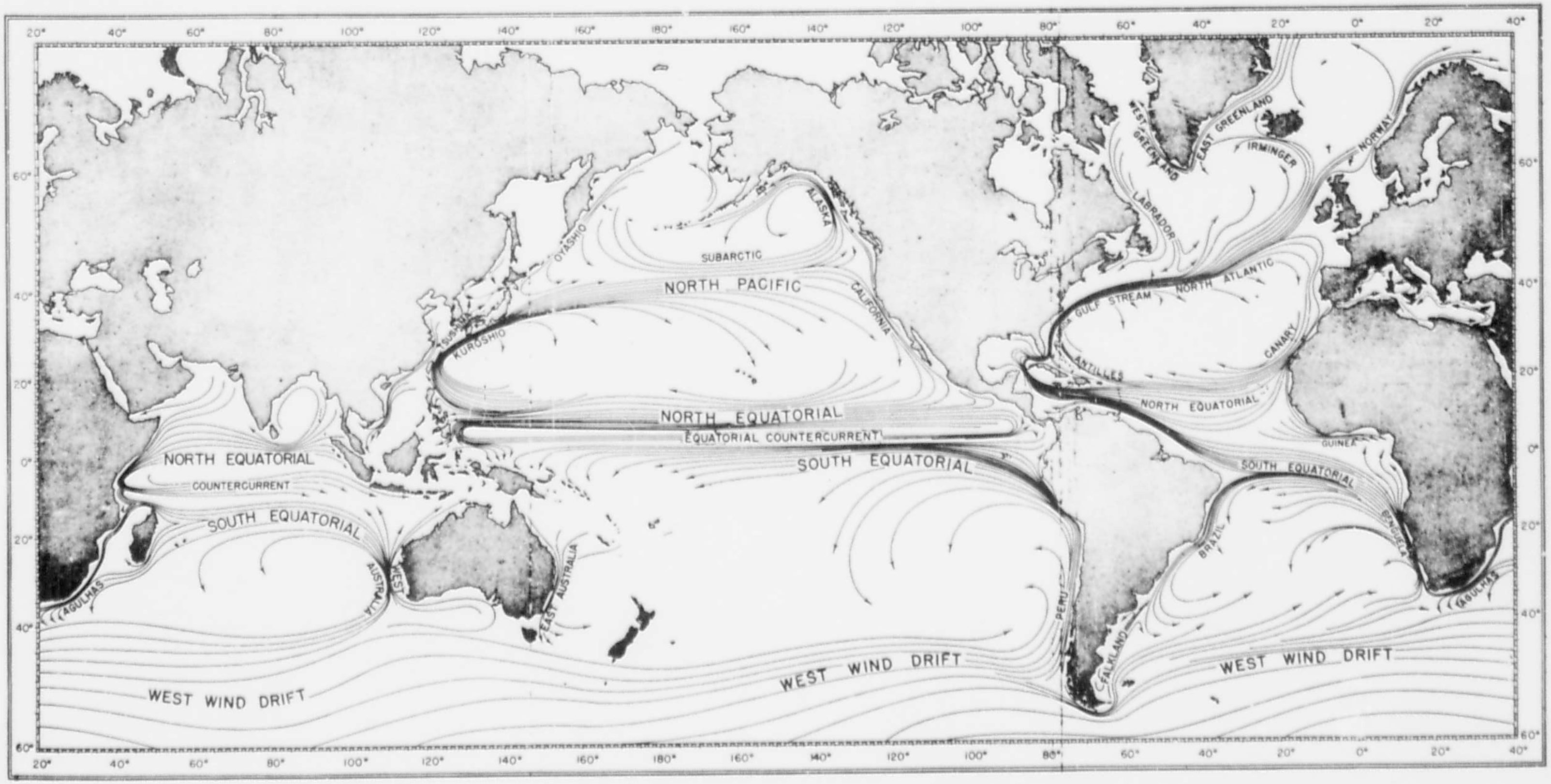


FIGURE 2.36.—The major ocean surface currents of the world.

develop, returning to the sea the water that was previously accumulated within the surf zone. Along irregular coastlines, longshore circulation patterns are well developed and have a considerable degree of permanency, whereas, off straight beaches and strands the angular incidence of the approaching waves is the primary determinant of the current regime.

Wind Currents.—The effect of wind stress upon the floating minecase depends upon the exposed surface area and the configurations of the surface. In still water, one-third of a spherical mine is exposed, whereas only one-fourth of a cylindrical mine is exposed (Fig. 2.37). Generally, a drifting mine will take a course up to 30° from the direction of the wind, to the right in the Northern Hemisphere and to the left in the Southern Hemisphere (Fig. 2.38). The stronger a wind blows, the more closely does the drift track of the mine correspond to the wind direction. The speed of the wind-induced current ranges from 1.5% to 2.5% of the wind speed. A 20-knot wind will drive a life raft at a speed of 1 knot, and a 4-knot breeze will drive a life raft at the speed of ½ knot, indicating the life raft is subject to both the current and wind influences. However, rafts have a greater sailing tendency than spherical- or cylindrical-shaped mines; consequently, an analogy between the drift responses of rafts and mines is rather poor. In general, when detailed information is unavailable, Figure 2.39 will give a rough estimate of mine drift.

Deviations of floating mines from the wind direction will vary with the shape of the mine case, the geographic latitude, the exposure of the mine case, and the wind velocity. Spherical-shaped mines have four times greater deviation than cylindrical mines. The deviation increases with increase in latitude (Coriolis force), and with the amount of surface area of the case exposed to the wind force. Bottom extensions from the minecase, such as cables and chains, will cause the mine drift to conform more nearly to the water current in both direction and speed. When a current is present but no wind, a mine will drift in the same direction and at the same speed as the current.

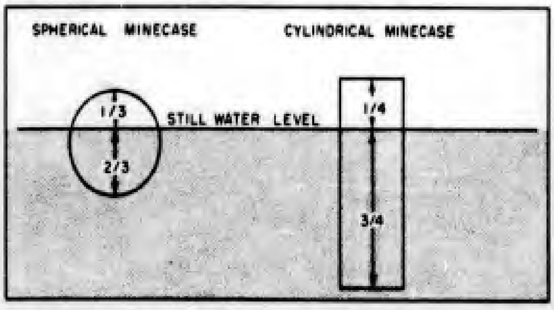


FIGURE 2.37.—Minecase flotation characteristics.

Waves.—Wave motion is oscillatory in the vertical plane and imparts a similar movement to floating mines. Little movement in the direction of advance of the wave may be expected in deep water unless the breaking action of the wave tends to push the mine. However, in shallow water a net forward movement occurs at the surface, and a pushing effect may be developed against the mine. The dissociation of the individual effects of wind stress, wind drift current, and surfing action of the breaking waves upon the minecase is extremely difficult if not impossible.

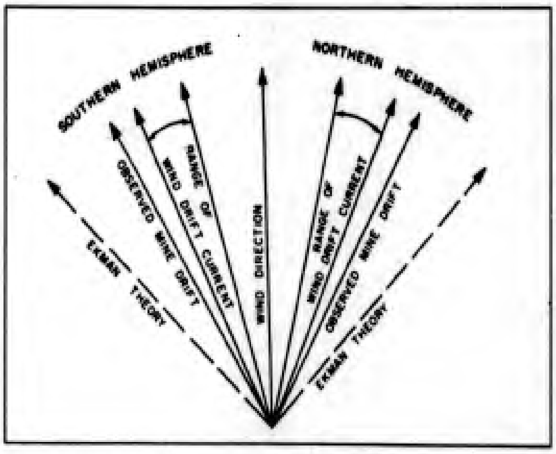


FIGURE 2.38.—Direction of wind-drift current and minecase drift relative to wind direction.

Applications of Current Data

Pilot Charts and Sailing Directions.—The primary sources of information on sea currents, both oceanic and local, are found in pilot charts, sailing directions, and various Hydrographic Office special studies, as well as various U. S. Coast and Geodetic Survey publications. Fairly detailed descriptions of local and nearshore currents may be found in the sailing directions; however, variability in such currents must be recognized in order to be applied

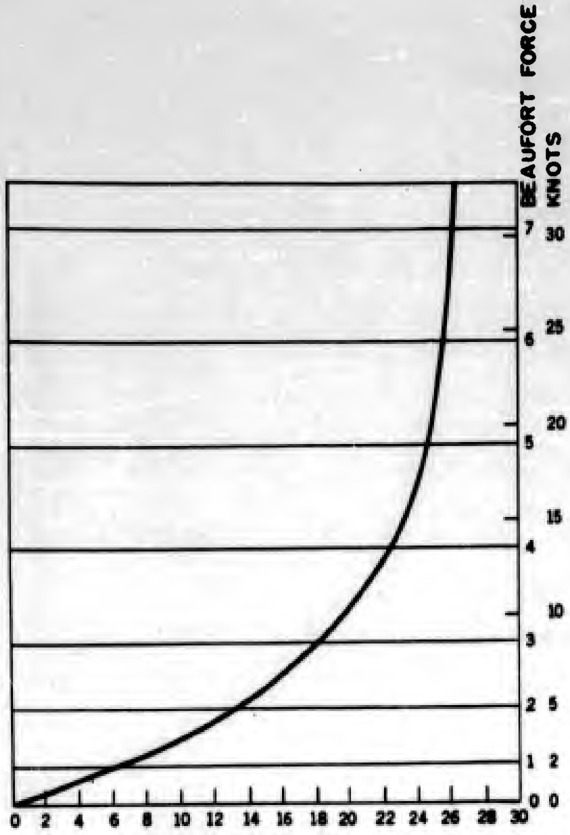


FIGURE 2.39.—Relationship between mine drift and wind speed.

to a given situation. Pilot chart information is not sufficiently detailed or refined for use, except in a very general manner. Along well traveled sea routes and thoroughly investigated areas the degree of refinement of the data may be increased and the information somewhat more reliable. Special oceanographic studies and reports will provide more detailed current information; however, relatively few areas of the world are covered in detail by such sources. Mine-drift information based upon current data should be applied with some reservation, inasmuch as the actual trajectories of individual drifting mines or other floating objects do not necessarily correspond to charted or tabulated data.

Ship-Drift Information.—The usual technique of determining sea currents by the navigational practice of frequent position fixing may lead to erroneous conclusions regarding the direction and strength of currents. The effect of the sea current upon the vessel will be complemented by the effect of the winds and waves, all of which may have differing effects upon a drifting mine. A large proportion of current data is based upon the drift of vessels during their normal courses of navigation, and much caution must be exercised in applying such information. If intelligently applied, current data based upon the drift of vessels may be useful in the determination of the drift track of floating mines, especially when more refined information is lacking.

Analogy to Other Drift Data

Drift Bottle Results.—Experiments conducted with drift bottles provide some measure of currents, which may be useful in determining the drift of floating mines. Contrasts in the configuration and the buoyancy characteristics between drift bottles and mine cases must be considered prior to the application of such current data to the drift performance of floating mines (Fig. 2.40).

Drift of Sea Ice, Bergs, and Debris.—The drift behavior of other floating masses also conforms with wind or current direction, depending upon the interaction between these forces which may be additive, opposing, or normal to each other. Water-logged debris may not be as subject to the wind force as masses of ice, such as bergs, which may have a greater sail effect contributing to a greater drift. Sea-ice drift may be applicable in some measure to the possible drift response of floating mines; however, the relationship cannot be fully established with the present state of knowledge.

Floating debris and seaweed are less subject to the wind than to the sea current. Observed drift patterns of well immersed material may give a truer indication of the actual water currents in a localized area than the drift of higher floating objects having appreciable positive buoyancy.

Duration and Distance of Mine Drift.—The problem of determining the length of time a floating mine has been drifting or establishing the point of its origin may involve reference to the existing current pattern. In addition to having fairly precise knowledge of the set, the current speed must be known within rather

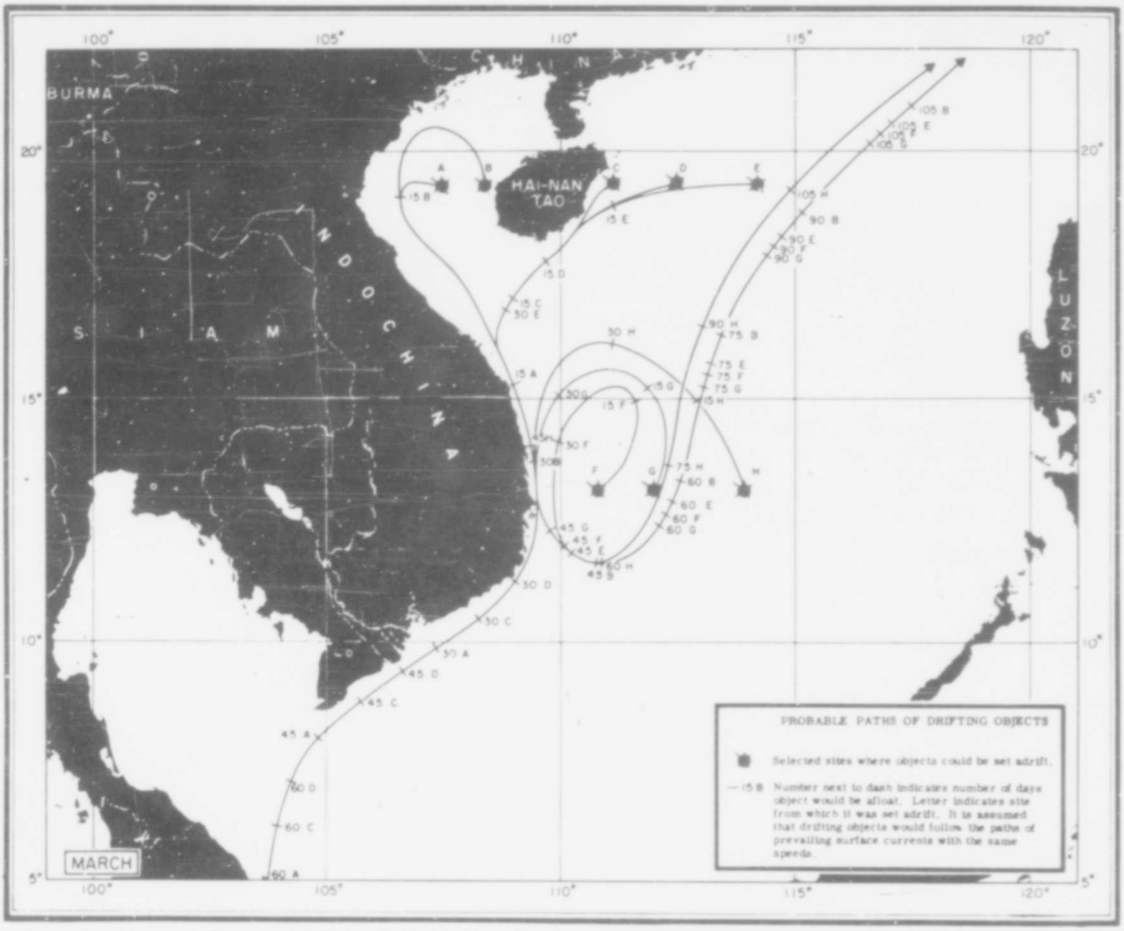


FIGURE 2.40.—Probable drift of bottles released during March 1932 in the South China Sea.

narrow limits in order to evaluate the distance floating mines may have drifted and the locale of their origin. Along well traveled coasts, where merchant shipping or fishing activity have been functioning for a length of time, available current information may be of sufficient accuracy to be utilized for backtracking drifting mines to their source. Generally, however, such precision is not obtainable for floating mines which have drifted over great distances. Eddy currents associated with the main current patterns will impart various degrees of error in determining mine drift. Published seasonal current charts provide a means of determining the average drift of floating mines; however, allowances must be made for wanderings caused by unusual conditions of current flow, influences of wind and storm, or factors pertaining to the response reactions of the individual minecase design.

Drag mines, which are more subject to the force of the sea current and less to that of the wind than free-floating mines, may be more readily related to the average current flow. Therefore, backtracking drag mines to their probable source is less subject to error. Although mathematical relationships have been developed for determining the drift of floating objects, such as mines, the difficulty of determining the extent and duration to which each factor may be operating at a given time results in various solutions.

Other methods for determining the time and distance of mine drift may be related to the degree of fouling and corrosion of the minecase. Environmental influences, however, are such that the intensity of fouling or corrosion does not provide a simple solution to the problem. Each marine area is characterized by unique factors of fouling and of corrosive tendencies which may change seasonally or over a period of years. The length of time a floating mine has been drifting, therefore, has no simple relationship to the degree to which it has been fouled or corroded.

Tactical Utilization of Currents

Knowledge of the current regime is useful in drift-mining operations. Waters that are relatively inaccessible to naval craft, due to shoal water or defense measures, may be entered by drift mines launched at safe distances by offensive mining forces. Roadsteads, heavily patrolled by enemy craft, offer opportunities for the exercise of drift mining operations by mining forces that otherwise cannot obtain entry to the area. Additional sites for the conduct of offensive drift mining campaigns are convoy forming areas, relatively deep and narrow channels through which flow swift currents preventing effective moored or bottom mining campaigns, repeatedly used rendezvous points, or estuarine waters where holding ground may be poor. Careful consideration must be exercised in utilizing currents for offensive drift mining purposes. Since drift mines draw no distinction between friendly or enemy targets, a reversal or a slight modification of the current pattern, such as may be produced by the tides or wind, provides an inherent element of danger to the mining forces or to other friendly forces during later stages of a campaign Investigations especially conducted for the purpose of determining the detailed characteristics of sea currents in selected areas, both at the surface and at various depths, may become the sources of information for future use in offensive drift mining operations. The accuracy of the findings is dependent ultimately upon the refinement of the current data utilized and the intelligence with which the information is applied. As experience is gained in the field of utilizing sea currents in drifting mine problems, confidence will be achieved in exercising such practices. The relative scarcity of precise information on sea currents in probable theaters of future naval operations may lead to only general conclusions regarding the drift performance of floating mines. As information on mine drift improves in both quality and quantity, increased accuracy in mine-drift predictions will result.

Drifting mines have been discussed from the oceanographic aspect and without regard to International Law on the subject.

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CHAPTER 3

EFFECT OF OCEAN ENVIRONMENT ON INFLUENCE MINES

Although the concepts of influence trigger mechanisms on mines were originated before World War I, they were not utilized on a large scale until World War II. Types of influence-firing mechanisms now in use include acoustic, magnetic, and pressure.

The propagation width of influence fields of ship and minesweeping gear may be critically dependent upon the characteristics of the oceanographic environment. For example, the rate of decay of low frequency sound varies greatly in shallow water and is dependent upon depth and bottom structure. Open loop magnetic sweep widths are dependent upon sea water and bottom resistivity.

Environmental disturbances may resemble the signatures of ships so closely that they may cause spurious actuation of the influence mechanism, or may effectively mask the signature of the ship the mine is intended to destroy.

3.1 EFFECT OF ENVRONIMENT ON ACOUSTIC INFLUENCE MINES

Acoustic mines are actuated by underwater sound produced by ships. The acoustic output of ships ranges from less than 1 cycle per second to more than 100 kilocycles. The frequency range depends upon the particular ship and its construction. The low frequencies are associated with hull vibrations augmented by ships' machinery, as well as engine and propeller noise, whereas high frequencies are produced principally by propeller cavitation. Acoustic mines, however, generally respond to a more restricted frequency range, chosen by the mine designer to suit his intended target and expected conditions. Usually, mine designers prefer the lower frequencies for several reasons. High-frequency cavitation noise is more dependent on ship speed than lower frequency machinery noise. Above a few hundred cycles per second, directional effects make the performance of a mine difficult to predict unless its design is additionally complicated to take care of random orientation. Very low frequencies are attractive, as they introduce difficulties in sweeping, since heavy and unwieldy devices are required to match ship noise output. Consequently, minesweeping effort has been concentrated at frequencies below 300 cycles per second, though devices have been designed which should be suitable at higher frequencies, if required. Acoustic mine sweeping gear must produce sufficient sound intensity at these frequencies to create the level of noise required to actuate the firing mechanism at as great a range as practicable for efficient sweeping performance. Figure 3.1 shows the general frequency range of ships, acoustic sweep gear, and acoustic mines.

The effectiveness of acoustic minesweeping gear and likewise the effectiveness of the mine is dependent upon:

(1) The frequency response (tuning and sensitivity) of the mine,

(2) The rate of change of intensity, intensity level, and frequency of the sound produced by the gear or ship, and

(3) The efficiency with which the sound is transmitted from the gear or ships to the mine.

Whereas the first two factors are dependent upon the design and the individual characteristics of the mine, sweep equipment, and vessels, the third factor is dependent upon the environment which is virtually uncontrollable. The purpose of this chapter is to discuss the environment so that its behavior relative to acoustic minelaying and minesweeping may be better understood and, to some degree, predicted.

As sound waves travel from a sound source through a medium that is homogeneous, nonabsorbing, and of infinite extent, the intensity decreases as the square of the distance from the source. This intensity loss is termed *spherical spreading* and is described by the inverse square law. For this reason the intensity is expected to be 16 times less at 4 yards than at one yard from the source. Since it is necessary to deal with large numbers, two sounds of different intensities are usually compared in terms of decibels.

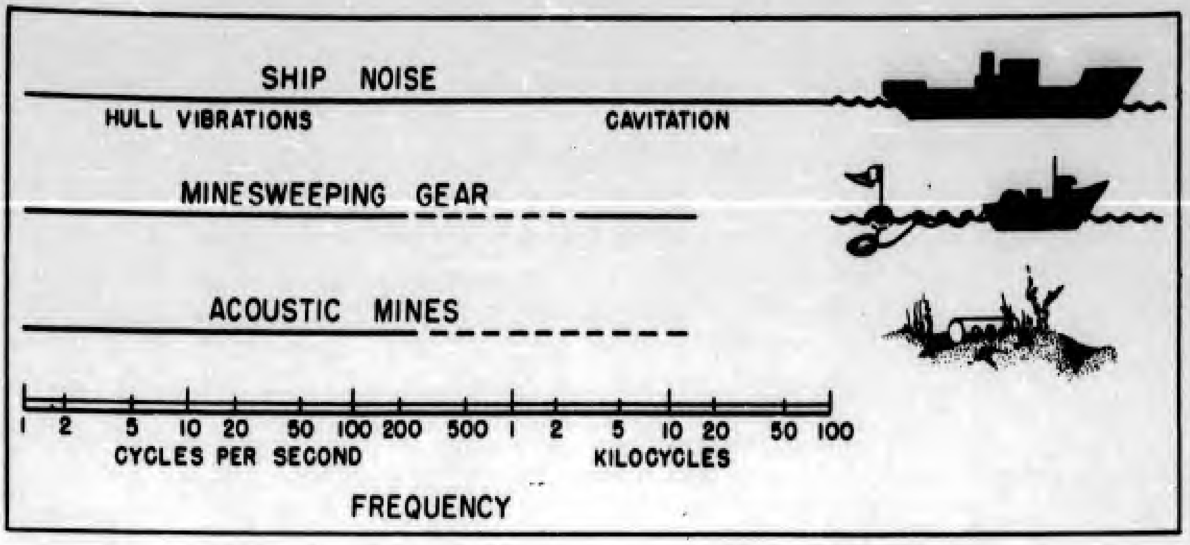

FIGURE 3.1.—Frequency range of ships, acoustic sweep gear, and acoustic mines.

The ocean is not an unbounded medium. The boundaries, namely, the surface and the bottom, have reflection characteristics which will vary with distance and with time as well as with the frequency of the incident sound energy. If both the surface and the bottom were reflecting perfectly, sound energy in a homogeneous medium would spread in only two dimensions, the sound intensity decreasing by an inverse first power law. Such a decay rate is termed *cylindrical spreading*. In reality the boundaries permit some of the sound to leak through so that the resulting rate of sound decay is dependent upon the physical characteristics of the surface and bottom.

A third type of spreading, known as *dipolar spreading*, may be described by the inverse fourth power law. Such a high rate of decay is due to destructive interference as the result of reflected waves arriving in phase opposition to the outgoing waves, causing cancellation. The spreading laws may be compared when plotted on the same graph (Fig. 3.2). In general, sound transmitted in the sea will experience combinations of the three types of spreading. Furthermore, the manner of spreading will change at different ranges from the sound source. Spreading is a function of the geometry of the medium and the wave length or frequency of the sound transmitted. Therefore, it is related to depth the of the water and to the depth of the sound source.

A typical transmission loss curve at 60 cycles per second in 35 feet of water with the sound source suspended 20 feet from the surface is shown in Figure 3.3, which displays the relative intensity as received at the bottom. Sound waves may travel in multiple paths. Besides the direct path, reflected paths from the sea surface and bottom exist, and waves may also be refracted through the bottom. A schematic of these various paths is shown in Figure 3.4.

Low sonic frequencies and subsonic frequencies (those below 20 cycles per second) are capable of effective transmission through low density sediments such as muds and muddy sands. As the density of bottom sediments generally increases with depth, owing to compaction, sound energy being transmitted through the bottom will be refracted or bent upward toward the overlying water volume (Fig. 3.4). Sub-bottom reflections will also occur with the incidence of sound energy on layers of hard sediment or rock within the bottom. Although the sea surface functions as a good, though irregular, reflector, the softer sediments will serve as refracting horizons, or layers. The transmitting medium for the lower frequencies therefore consists not only of the water volume, in which refraction or bending of the sound waves is produced, but also of the underlying sediment. The cutoff frequency is that sound frequency below which sustained transmissions are not possible. The cutoff frequency may also be described in terms of wave length, wherein the short vertical dimension of the transmitting medium is equivalent to one-half or less than the wave length of the propagated sound energy. For a hard bottom, the vertical dimension is equivalent to the water depth. Where the bottom consists of soft sediments, such as muds, permitting the penetration of sound energy, the vertical dimension may be considerably greater than the water depth.

Some fluctuations in the sound intensity level are due to interference of the direct sound waves with surface- and bottom-reflected waves. In-phase arrivals of sound energy will increase the sound level causing peaks in the transmission loss curve (Fig. 3.3). Out-of-phase arrivals decrease the sound level causing sharp dips in the sound intensity. Reflection characteristics of the surface and bottom vary. The higher sea states and rock bottoms cause a diffuse scattering of incident sound energy in all directions.

The net result of the intensity variations owing to interference at some distance from the sweep gear is that these variations tend to simulate ship signatures by building up at a certain rate, reaching a peak intensity, and falling off, somewhat in the same manner as ships passing directly over a mine. Mines that incorporate rate-of-change mechanisms will be actuated under these circumstances if the change in intensity is sufficiently great and at the required rate as well as by the normal method of modulating the sound source.

Increasing ship displacement results in a corresponding increase in the sound intensity level owing to the increase in the number and magnitude of the component sound radiating sources, such as ship plating, propellers and propeller shafts, struts and other hull extensions, and machinery. An actual frequency selection may occur for the level of sound energy penetrating the bottom to the hydrophone within a buried mine, so that energy of certain frequency bands of the spectrum are admitted into the bottom sediments, whereas the remainder of the spectrum energy is absorbed. Acoustic observations in specific areas will disclose the frequency selectivity, that is, characteristic of the bottom type. Since bottom sediments will vary considerably in their physical characteristics, intensity of the sound energy transmitted through the sediments will vary accordingly.

Sweep widths are related to the range of effectiveness of acoustic sweep devices in actuating the mines in the presence of background noise. The frequency spectrum must be suitably broad, and the output intensity of the acoustic sweep projector must be sufficiently variable to actuate, in the presence of ambient noise, the acoustic mine at reasonably safe distances. Proper adjustment of both frequency and the intensity modulation is re-

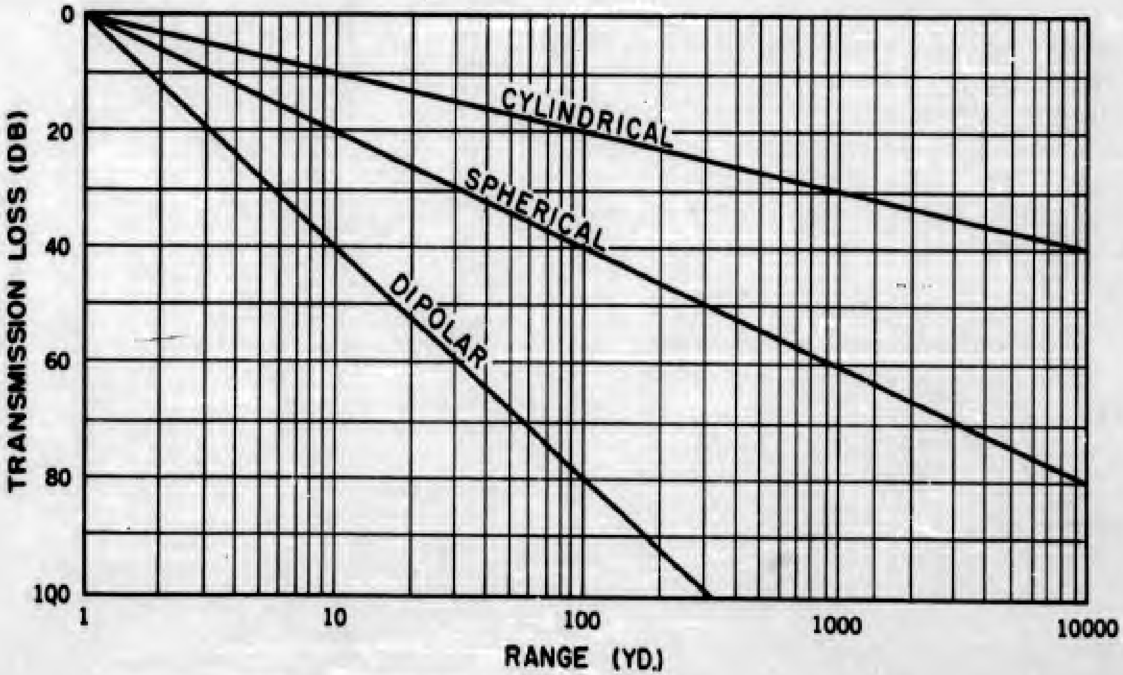

FIGURE 3.2.—Comparison of cylindrical, spherical, and dipolar spreading laws.

Figure 3.3. A typical transmission loss curve at 60 c. p. s. in 35 feet of water, with sound source suspended 20 feet from surface.

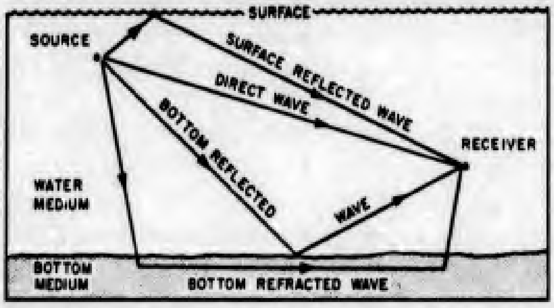

Figure 3.4.—Examples of direct, reflected, and bottom-refracted wave paths.

quired in order for acoustic sweep devices to have the required degree of reliability in actuating acoustic mines. Tables 3-I and 3-II show typical intensity levels of sea noises. Over wide geographic areas, variation in the characteristics of the ambient noise, composed of biological, industrial, water turbulence, and traffic noises, should be expected (Fig. 3.5).

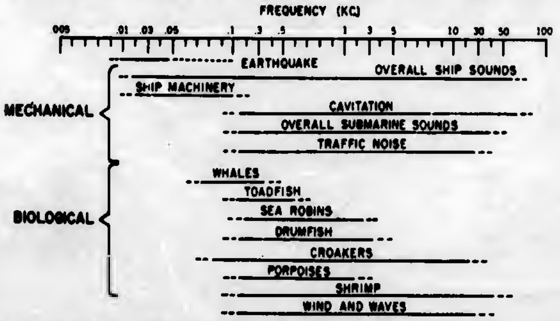

Figure 3.5.—Various sound prlducers which are known to generate sound in the frequency ranges denoted by solid lines.

Table 3-I.—*Typical Spectrum Levels of Amplified Noise at 24 kc. (Ref. 1 dyne/cm*^{2}*)*

	Decibels
Ambient noise: Sea noise	−74 to −54
Biological noise:	
Snapping shrimp	−39
Croakers	−20
Traffic noise (includes sea noise)	−55 to −50
Target noise (source levels):	
Submarine, 6 knot (periscope) depth, 12 knot (surface).	8
Battleship	27
Cruiser	20
Destroyer	15
Passenger	13
Corvette	8
Freighter	3

Table 3-II.—*Overall Levels of Amplified Noise From 0.1 to 10 kc. (Ref. 1 dyne/cm*^{2}*)*

	Decibels
Ambient noise: Sea noise:	
Deep sea	−5 to 6
Near surface	−17 to 9
Biological noise:	
Snapping shrimp	5 to 7.5
Croakers	36 (max)
Porpoises	40 (max)
Evening noise	8.5 (max)
Traffic noise: (includes sea noise)	0 to 22

(From: U. S. Office of Scientific Reasearch, N. D. R. C., 1946)

3.2 EFFECT OF ENVIRONMENT ON MAGNETIC INFLUENCE MINES

Terrestrial Magnetism

The earth is like a giant magnet and is surrounded by a magnetic field. The distribution of this field is such as would be created by a great bar magnet located near the earth's center and tilted slightly from the earth's geographic axis. Figure 3.6 is an idealized model of the earth's magnetic field. Actually, the field is neither uniform nor static. Its nonuniformity requires the navigator to make constant corrections to his compass for various parts of the world, its changes eventually affect radio transmission and may cause spurious firing of magnetic mines.

The two places on the earth's surface where the field is vertical are called the magnetic poles. In 1955 the location of the North Magnetic Pole was approximately 74° N., 101° W. The South Magnetic Pole is approximately 68° S., 145° E. The magnetic equator is an irregular line encircling the earth where the magnetic field is horizontal. It varies from 10° N. in Africa to 15° S. in South America.

Beside the displacement of the geomagnetic axis from the geographic axis, large irregularities or anomalies in the earth's magnetic field result from deposits of iron and other geological structures. As a result, magnetic compasses rarely point to the magnetic pole. The direction of the magnetic field may be determined at any point on the earth's surface by suspending a small balanced magnet, such as a compass needle, from a string. This magnet will orient itself parallel to the earth's magnetic field. At any given point on the earth's surface the horizontal angle between the magnetic field and true north is termed *declination*. A world chart of declination is given in Figure 3.7. Other values of the magnetic field at a point on the earth's surface are *dip*, the vertical angle between the field and the horizontal plane, and *intensity*, the strength of the field which is generally divided into horizontal and vertical components. Figure 3.8 shows the horizontal component of intensity over the world. It is taken from H. O. 1701, one of a series of charts showing the various components of the earth's magnetic field.

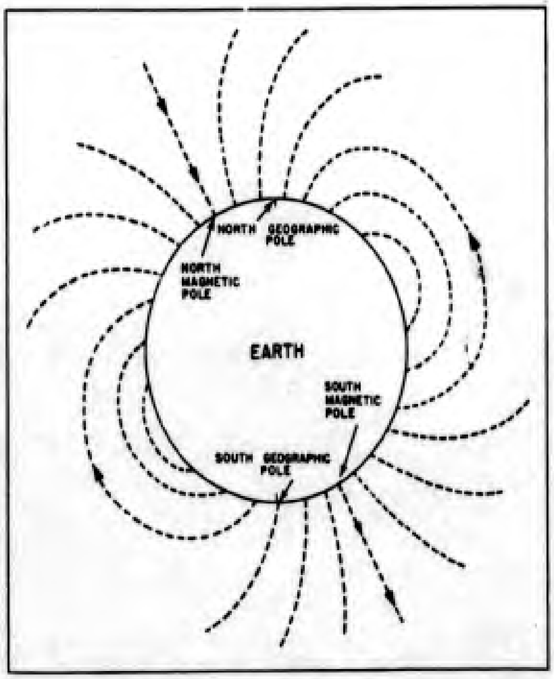

FIGURE 3.6.—The earth's magnetic field.

The variations in field strength that occur in the course of time include *secular variations* which have their origin deep within the earth. These variations are small and progressive and may amount to as much as a 17° change in declination in 100 years. Other variations in field strength are *annual changes* and *daily changes*. Geomagnetic fluctuations which are probably most important to mine warfare are the erratic short-period fluctuations and more or less unpredictable variations known as *magnetic storms*. These *storms* cause momentary fluctuations in the earth's field that may closely resemble the magnetic signature of a ship and may result in magnetic influence mines firing prematurely. The occurrence of these *storms* has been related to the 27-day rotation period of the sun and the 11-year sunspot cycle. *Storms* occur simultaneously over large areas of the world and are most violent and frequent in the vicinity of the Arctic Circle.

Ship's Magnetic Field

The earth's magnetic field at a given point may be distorted by the presence of another magnetic field. This field may be generated by either a bar magnet or a conductor through

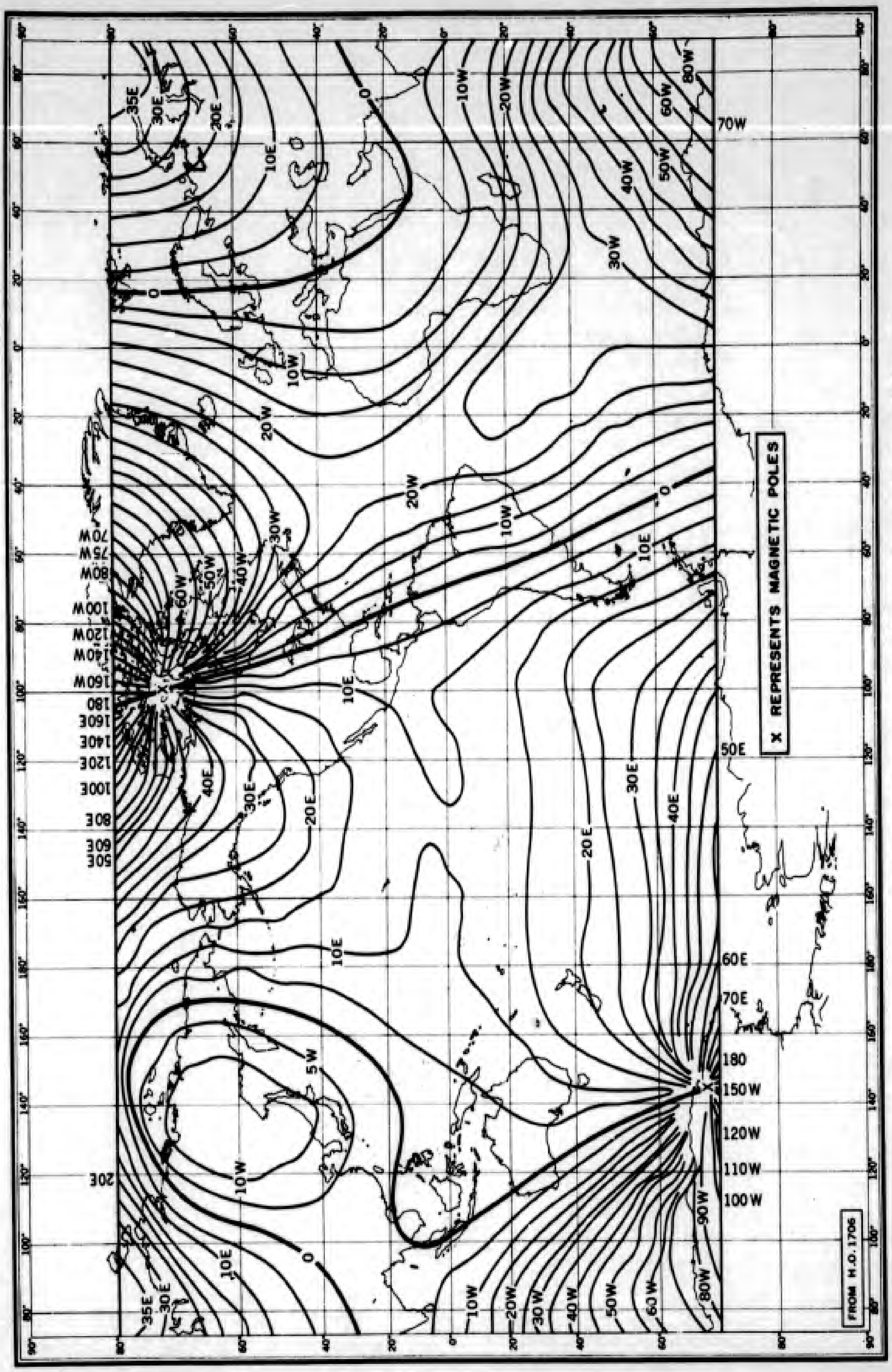

FIGURE 3.7.—The variation of the compass for the year 1955.

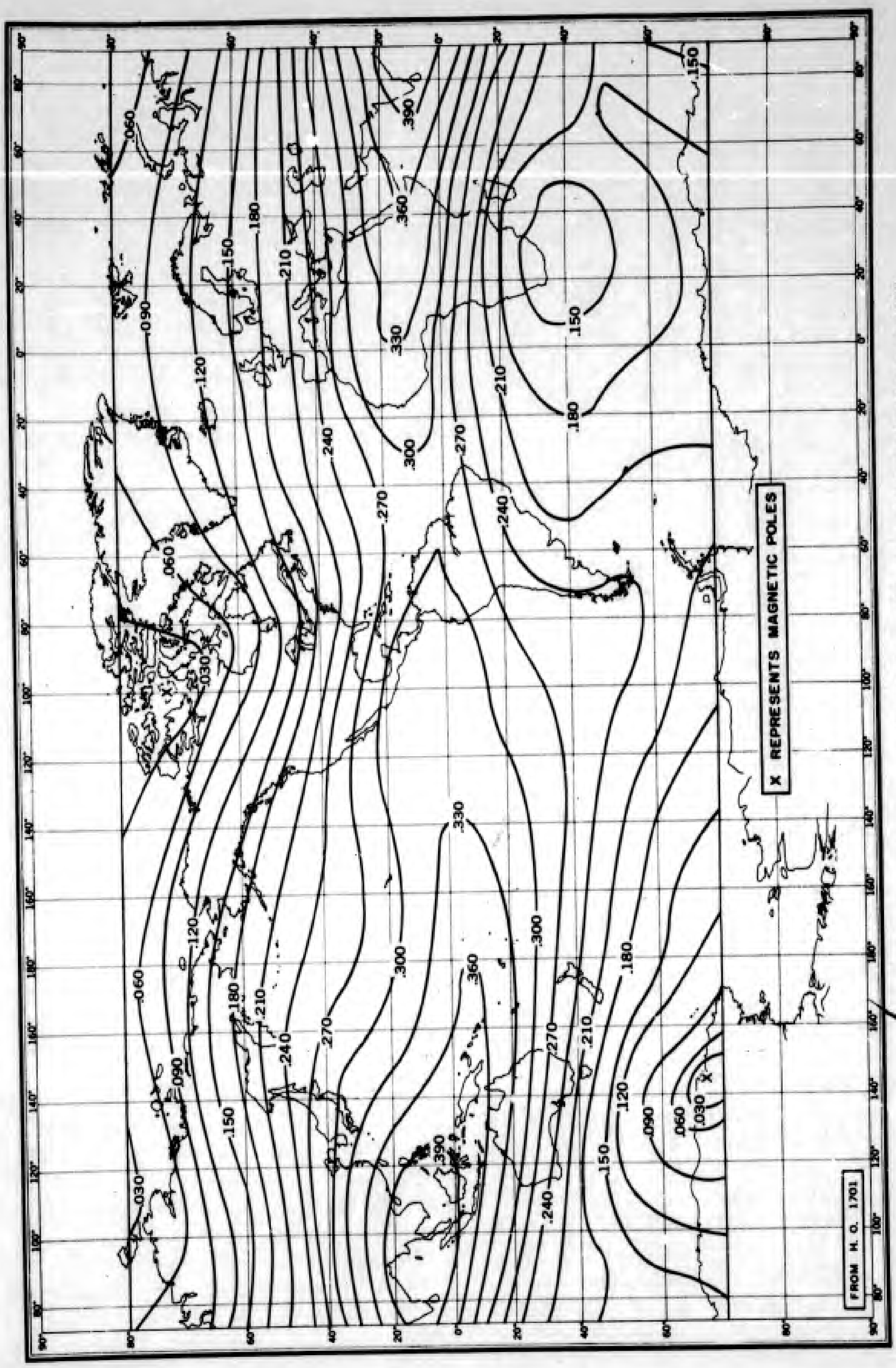

FIGURE 3.8.—The horizontal intensity of the earth's magnetic force for the year 1955.

which an electric current is flowing. A magnetized ship could well serve as the magnet which distorts the earth's field around it. A magnetic minesweeping loop would likewise cause similar distortions.

A second method of distorting a magnetic field is by the presence of magnetic material such as iron or steel in the field. Since the magnetic material offers less resistance (reluctance) to the magnetic flux than does the atmosphere or the ocean, the field is distorted as schematically shown in Figure 3.9.

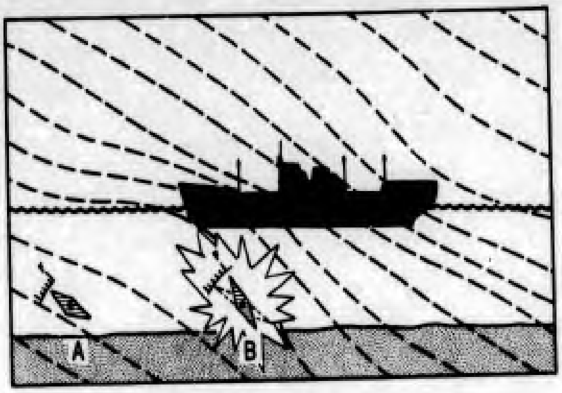

FIGURE 3.9.—Schematic drawing showing distortion of the earth's magnetic field by the presence of the magnetic material in the field.

Magnetic Mines

Magnetic mines are influenced by changes, either natural or artificial, in the earth's magnetic field. Two types of mines, dip needle and induction, have been devised and are in operational use today.

Dip-needle mines require a change in the direction of the vertical component of the ambient magnetic field which would cause the dip needle to change its angle, thus closing the electric circuit actuating the mine mechanism. Figure 3.9 shows that a dip needle at point A would change its dip angle (point B) as a ship approached. A mine with a similar type of dip needle might be adjusted to fire on such a distortion of the earth's field.

The *induction mine* consists of a *search coil* within which an electric current is generated when the earth's magnetic field is distorted by the proximity of a ship. This current detonates the mine or advances the ship counter. Changes in the ambient magnetic intensity may result in spurious firing; however, induction mines require field changes within a short period of time and are therefore sensitive only to short-period fluctuations.

Short-period geomagnetic fluctuations affect the life of a mine in that their frequency of occurrence may cause the mine mechanism to cycle and thereby deplete the battery even though a ship count or a detonation does not occur. Spurious firing of these mines may be reduced by providing sensitivity settings in accordance with the magnitude and frequency of local magnetic variations.

Effect of Geomagnetic Fluctuations

Magnetic storms are recorded generally over extensive areas of the world. However, the characteristics of a certain storm may vary from one locality to another. A characteristic of many magnetic storms is their sudden commencement. The initial activity is often a change in horizontal intensity which ranges from a few gammas to several hundred gammas (100 gammas = 1 milligauss). This sudden change generally lasts from a few minutes up to a fraction of an hour; however, the storm activity may continue for a day or more. In general, all larger fluctuations (100 gammas or greater) are concentrated during a few days each year. Figure 3.10 is a magnetogram of a magnetic storm showing several short-period oscillations of several milligauss in magnitude. Certain magnetic mines would have received magnetic looks had they been planted at this locality at this time. Points A–A′, B–B′ and C–C′ satisfy the requirements of three separate mine types.

Forbush and Vestine (1952) have summarized the frequency per year of short-period magnetic fluctuations of various magnitudes and durations below 400 seconds for various geographic locations for years of sunspot minimum and maximum. The significance can best be described by considering an example such as the graph for Thule, element H, 1932–1933 (year of sunspot minimum). This graph indicates that in the time interval of 10 to 400 seconds that 500 fluctuations were 25 gammas and greater, 84 fluctuations were 50 gammas and greater, and 30 fluctuations were 100 gammas and greater. Numbers of fluctuations within the time intervals of 10 to 100, 10 to 200, 10 to 300 seconds are tabulated also.

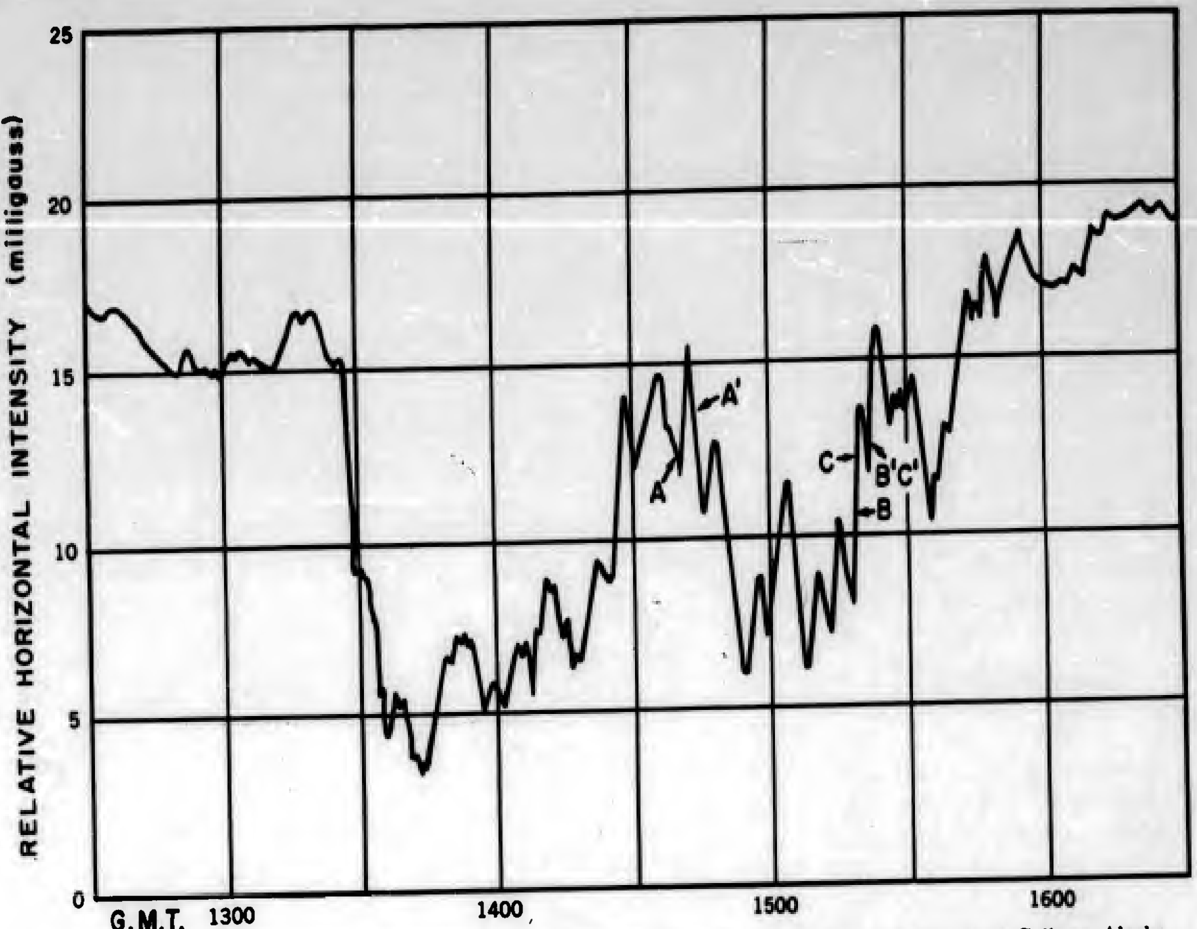

FIGURE 3.10.—Magnetogram showing naturally occurring fluctuations at geomagnetic latitude of College, Alaska on 17 January 1955. Points A–A′, B–B′, and C–C′ show fluctuations capable of actuating certain magnetic mines.

Limited data indicate that the maximum intensity of fluctuations attained per year increase by factors of 3 to 10 from sunspot minimum to maximum.

Bottom Resistivity and Q-Factor

The strength of the magnetic field produced by open-loop magnetic minesweeping gear varies markedly with location. Reconnaissance techniques developed recently have made possible areal surveys with simple gear, recording certain values of resistivity which will provide estimates of magnetic field strength of open-circuit magnetic minesweeping gear. Several factors contribute to magnetic field strengths in various ocean environments. They are primarily electrical conductivity of the sea bottom, depth of water, and thickness and types of underlying sediments.

Computations of magnetic field strengths in various areas are based on theoretical relationships between electrical and magnetic fields and on assumptions of simplified geological structure. Resulting estimates are therefore only approximate but nonetheless valuable.

In order to reduce the problem to workable terms, the marine environment may be considered to consist of two layers which are homogeneous and isotropic with respect to resistivity qualities. The top layer begins with the sea surface and continues down to some depth either at or below the bottom. The thickness of this layer is called *electrical depth* (d). Below this layer lies another layer which extends to an infinite depth.

The resistivity of the upper layer (ρ_1) is taken to be equal to the integrated value of the resistivity of the sea water between the surface and the bottom, even though the layer may extend deeper than the bottom. This appears justified since the soft bottom sediments are generally saturated with sea water, thus having

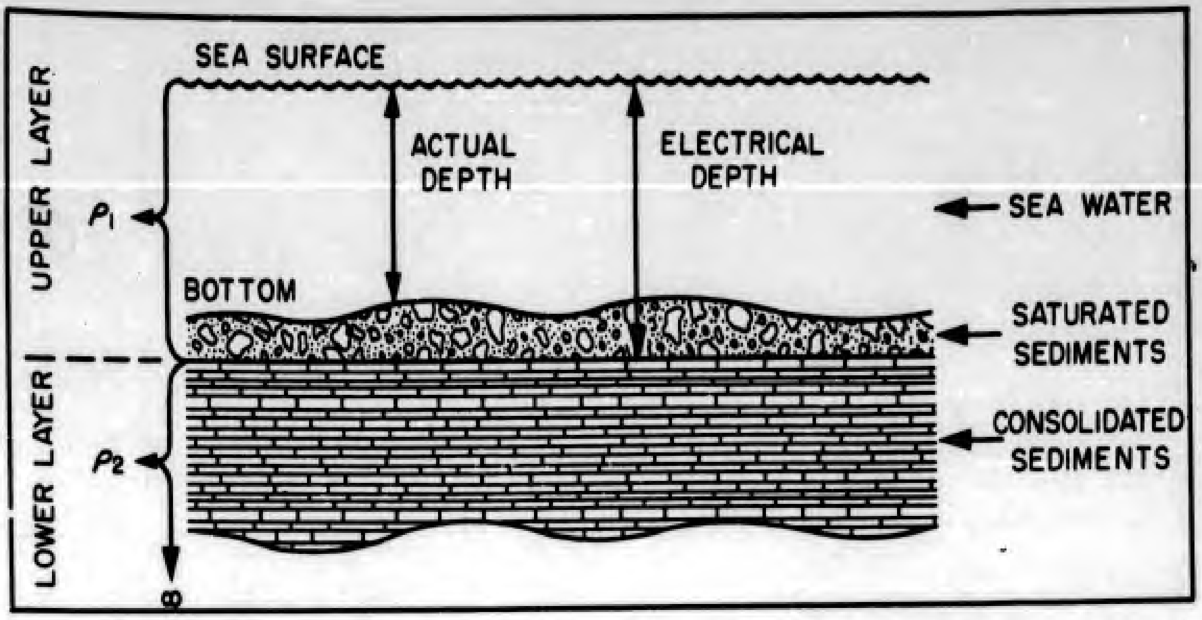

FIGURE 3.11.—Schematic cross section of ocean and bottom showing resistivity parameters.

a resistivity value very similar to the overlying sea water. Somewhere below these soft sediments are consolidated sediments which have most of the sea water squeezed out of them and consequently have a much higher resistivity, (ρ_2) than the upper layer. A model of the environment is shown in Figure 3.11.

Q is an expression for the degree of electromagnetic wave reflection that results from the interface of two layers of different resistivities, ρ_1 and ρ_2.

Q-factor is defined by the following expression:

$$Q=\frac{\rho_2-\rho_1}{\rho_2+\rho_1}$$

Although ρ_1 (the reciprocal of the sea water conductivity) may be measured directly, ρ_2 cannot be measured directly; therefore, the determination of Q is impractical from this equation.

An electrical field distribution is expressed in terms of Q and d. This distribution may be computed if Q and d are known, and conversely, if this distribution is measured, Q and d may be determined.

Q is a nondimensional term and generally ranges from about 0.5 to 1.0. Electrical depth may range from 1 to 3 times the water depth. When the Q-factor and electrical depth are known, the generated magnetic field strength may be obtained at the bottom for any distance from the sweep wire by the use of existing graphs for various current outputs and water depth. Figure 3.12 [1] shows typical curves for converting resistivity data into magnetic field intensity. These curves give the magnetic field strengths produced by the distributed electrical currents in the sea water and sea bottom. They are for single electrodes and assume the other electrode to be an infinite distance away. Furthermore, the cable field has not been taken into consideration. Therefore, these curves are not operational in this form.

Values of Q and d should be used cautiously as direct indicators of magnetic minesweeping effectiveness. Since the magnetic field strength is dependent upon the interrelationship of the three variables Q, d, and actual depth, high values of Q cannot be taken to represent superior magnetic sweeping conditions. Magnetic minesweeping effectiveness can be ascertained only after magnetic field strengths of sweep gear at various ranges have been determined by graphs similar to Figure 3.12, and operational variables such as ship speed and sweeper spacing have been considered.

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[1] "Magnetic Fields Produced by Distributed Electrical Currents", Bureau of Ships Technical Report No. 85, vol. I, 10 December 1945.

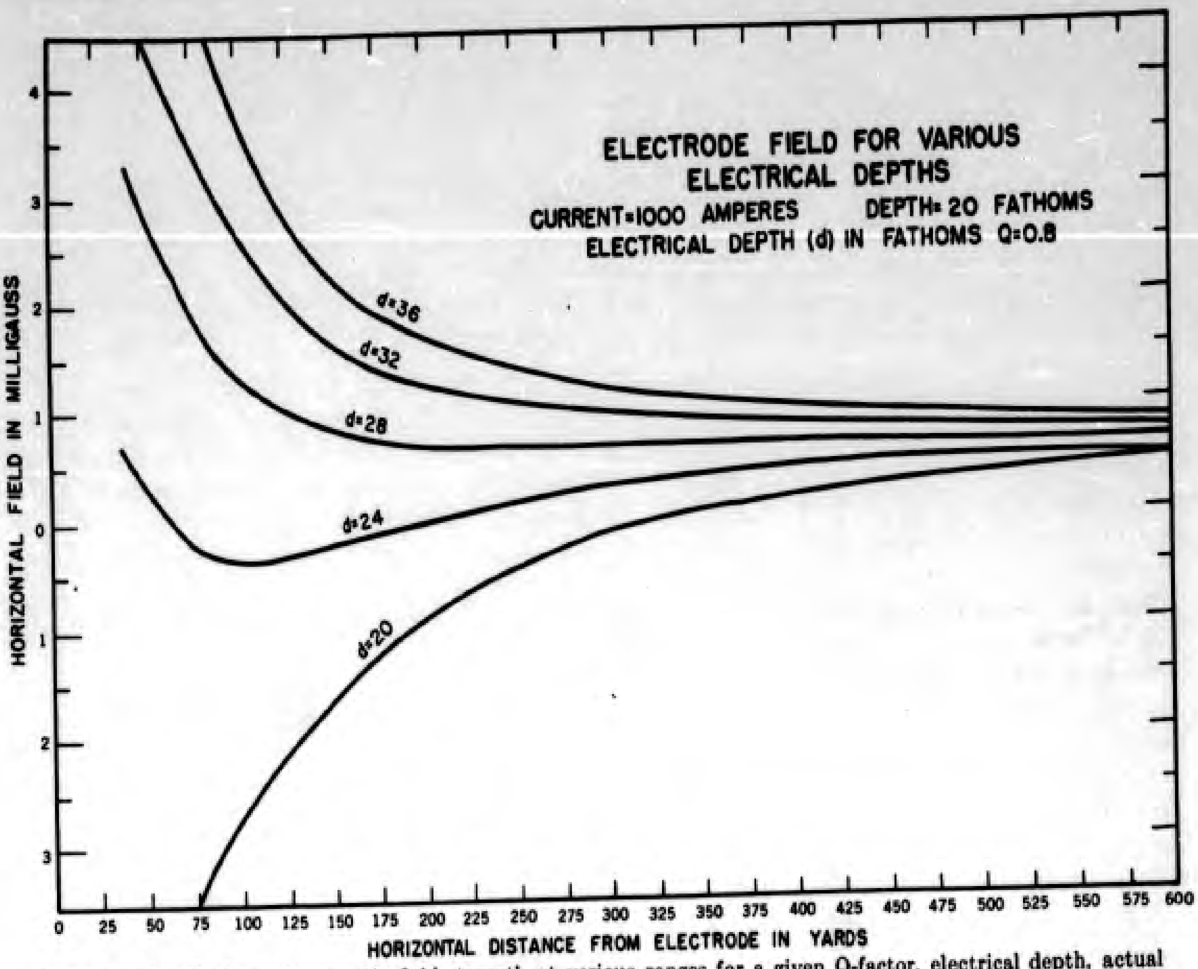

FIGURE 3.12.—Horizontal magnetic field strength at various ranges for a given Q-factor, electrical depth, actual depth, and current output

3.3 EFFECT OF ENVIRONMENT ON PRESSURE INFLUENCE MINES

In order to understand the effects of sea and swell on mines, it will be necessary to consider (1) surface waves and their effects on the change in water pressure at the bottom, (2) the change in pressure at the bottom resulting from the passing of a ship or displacement type sweep gear, and (3) operating principles of the pressure mine. Discussion here is limited to the simple type of pressure mechanism described below.

Waves

A wave may be defined by its height, period, and direction. Height is the vertical distance between crest and trough. Period is the time required for two successive waves to pass a fixed point. Direction is the point of the compass from which the wave comes. Wave length is the distance between two successive crests (Fig. 3.13). In deep water, that is, where the water depth is at least equal to ¼ the wave length, the theoretical wave length in feet (L) is approximately equal to 5 times the period (T) in seconds squared.

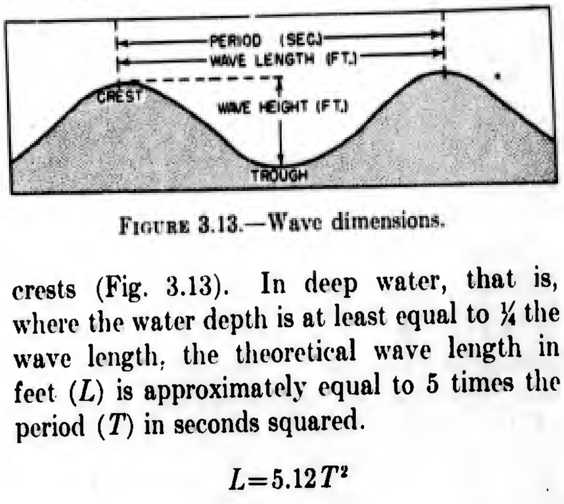

FIGURE 3.13.—Wave dimensions.

$$L=5.12T^2$$

Actual observations of wind waves show that the observed length is about one-third less than that given by this equation.

Many separate wave trains may normally occur at the same time, each having its own characteristic height, period, and direction. When all the wave trains are superimposed, the result is the complex configuration known as the sea surface.

In many places the sea surface will have two predominent trains present, one sea and one swell. *Sea*, or wind waves, is the result of local winds blowing over the sea surface. These waves are generally short in period and come from the same general direction as the wind. Waves that have moved out of the generating area are termed *swell*. Swell waves are comparatively long in period and generally low in height. Swell direction has no relation to the direction of the local wind and consequently may be 90° or even 180° from the sea direction.

In mineable waters, waves may extend their influence down to the bottom. The effective heights of waves at the bottom may be expressed in terms of pressure. Effective wave heights decrease with increase of water depth. In passing from surface to bottom, the rate of reduction is dependent upon the period of the wave as well as the depth of the water. This rate of reduction is expressed in Figure 3.14, where for a given water depth, wave period, and surface wave height, the pressure change at the bottom may be obtained.

EXAMPLE:

Find the bottom pressure amplitude change of a wave having a 12-second period and a deep water wave height of 9 feet. The water depth is 100 feet.

(1) Enter bottom left side of graph (Fig. 3.14) with water depth, $d=100$ feet.

(2) Follow 100-foot line up to 12-second period curve. Pressure response factor is 0.6.

(3) Follow 0.6 pressure response line horizontally to right where it intersects the 9-foot wave height line.

(4) Read this point of scale on lower right side of graph. Pressure amplitude change is 5.5 feet. To convert these values to pounds per square inch, use following formula:

$$X=0.44Y$$

where X = pressure in pounds/inches ^{2} and
Y = pressure in feet of water.

Shorter period waves (*sea*) are reduced in height much more than the longer period waves (*swell*). Since surface waves may be composed of a wide spectrum of periods, some waves will be reduced more than others; in fact, some may be completely damped out. As a result, the mean period at the bottom will be longer than the mean period at the surface. A comparison of surface waves and the bottom pressure fluctuations for various depths is shown in Figure 3.15.

Ship Signature

The ship signature is related to the changes in water velocity over the bottom due to the ship's motion. When a fluid flows through a tube with a constriction, the velocity increases in the constricted section. This increased velocity is accompanied by a decrease in pressure on the walls of the tube. This is the principle used in Venturi meters and atomizer devices (Fig. 3.16).

Δ_p represents the change in hydrostatic pressure associated with the increase in velocity in the tube in its constricted section.

As a ship passes through the water, a wave crest is piled up at the bow and at the same time water is pushed back from the stern, creating a wave trough. A hydrostatic head is thus created, with water moving at an increased velocity under the ship from bow to stern (Fig. 3.17).

Beneath the ship a pressure reduction will be associated with the increased water velocity. This is shown schematically in Figure 3.18. The magnitude of this pressure reduction depends upon the square of the ship speed, the cross-sectional area of the ship (the draft and beam) and on the depth of the water. The length of time the pressure reduction persists is dependent on the length of the hull and, again, the speed of the ship.

Pressure Mines

The pressure mechanism responds to a reduction in the pressure from the mean hydrostatic pressure. The minimum required reduction is termed *sensitivity*. If this reduction persists long enough, the pressure mechanism will take a look. The minimum length of time required is termed *time-out period*. These requirements are illustrated in Figure 3.19.

Any influence which will decrease the bottom pressure the required amount and will main-

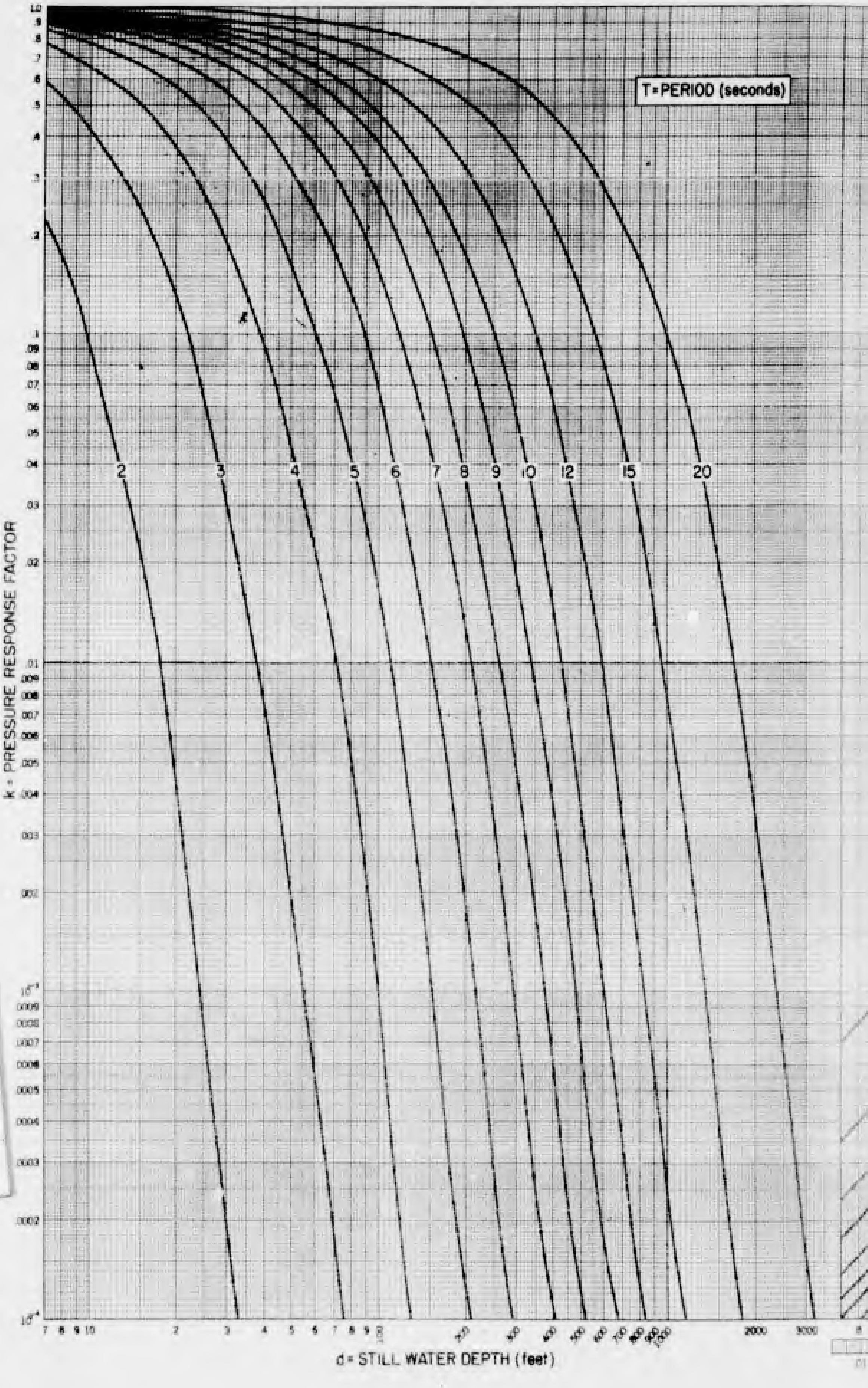
T=PERIOD (seconds)
k = PRESSURE RESPONSE FACTOR
d = STILL WATER DEPTH (feet)
2
3
4
5
6
7
8
9
10
12
15
20
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
.09
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Figure 3.

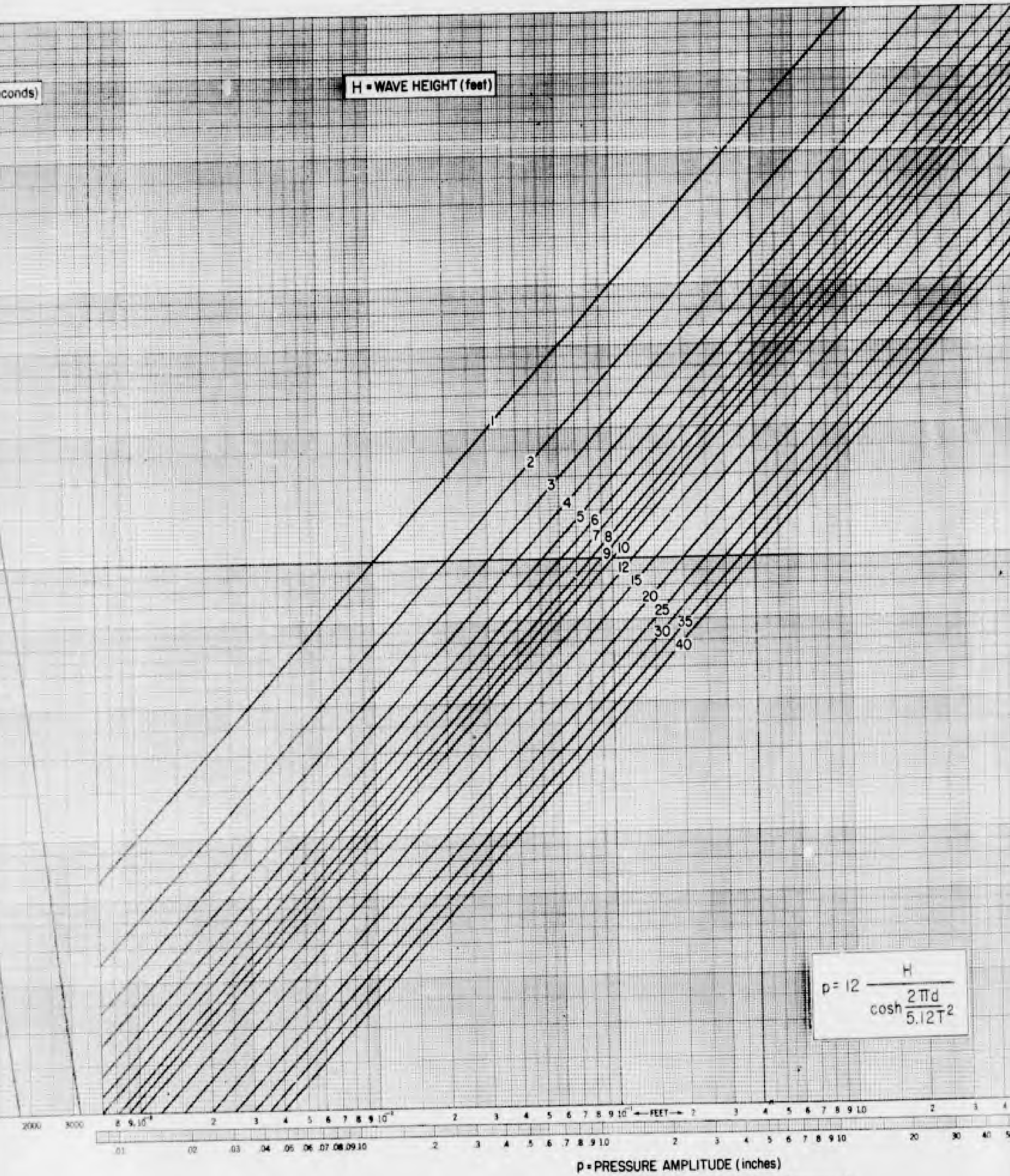
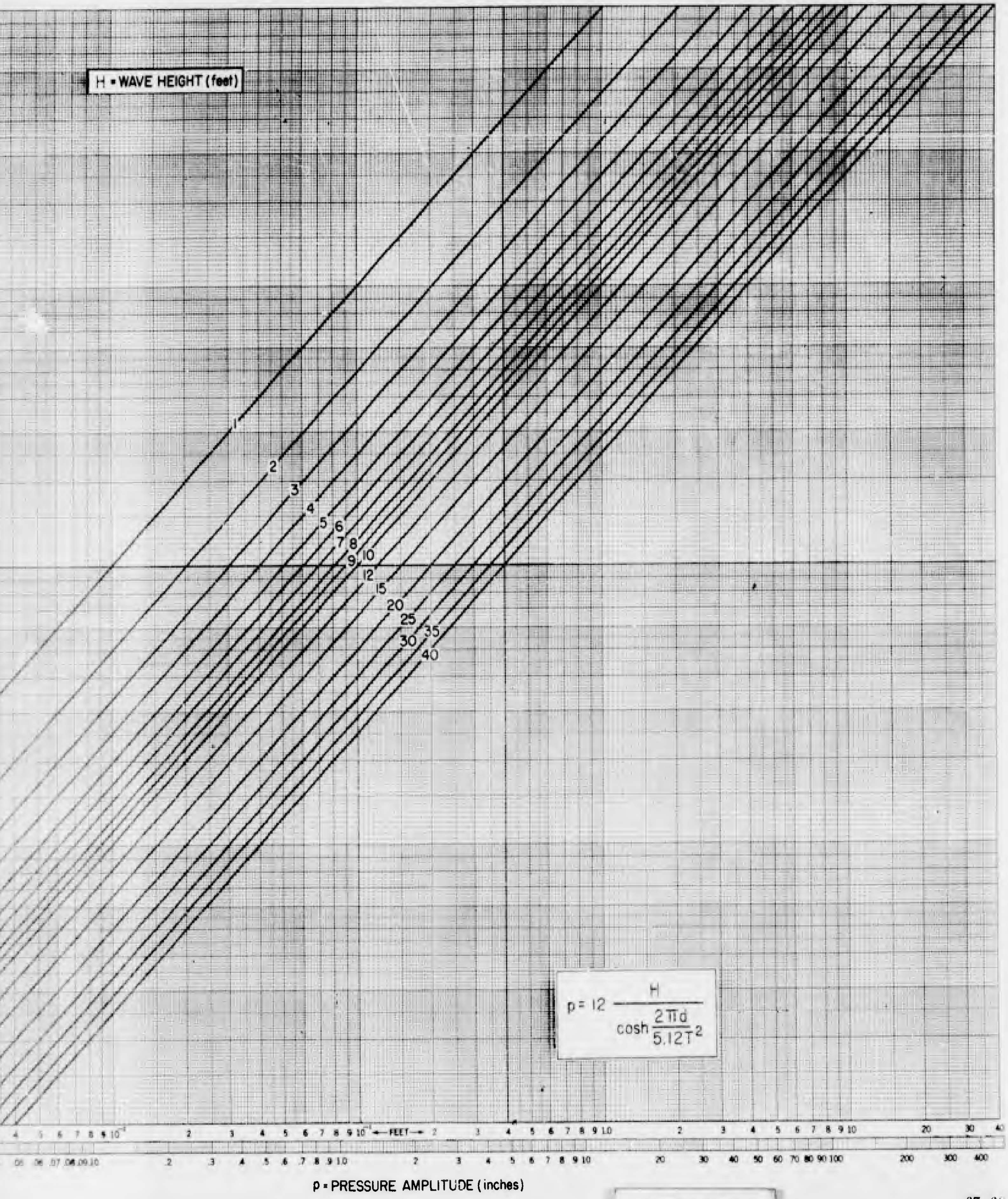


FIGURE 3.14.—Bottom pressure change as a function of wave height, period, and depth.



ange as a function of wave height, period, and depth.

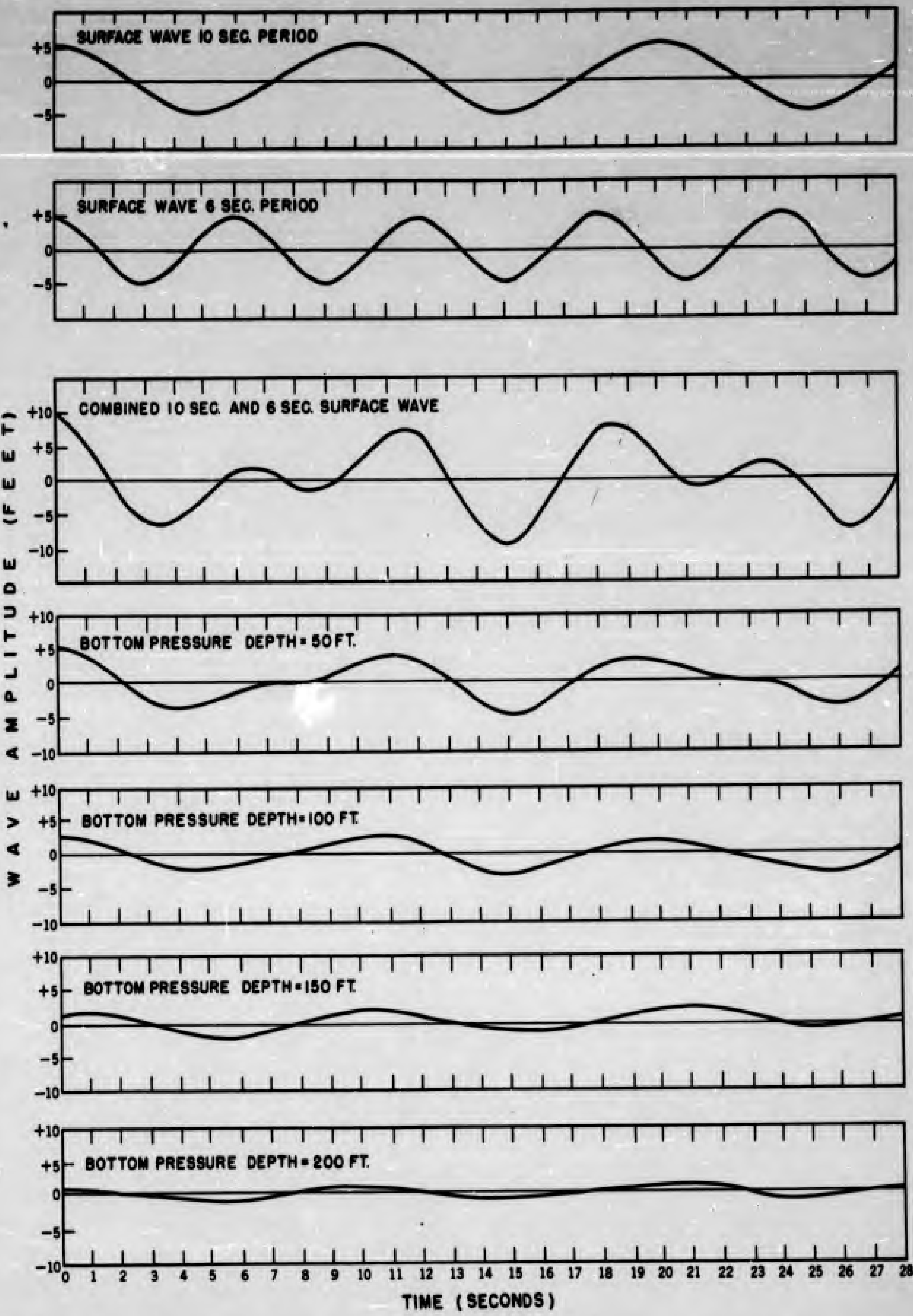


FIGURE 3.15.—Comparison of surface waves and bottom pressure fluctuations at various depths.

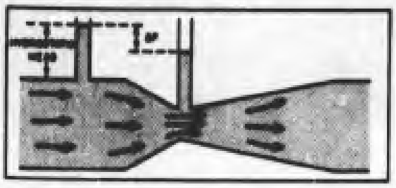


Figure 3.16.—Venturi meter in cross section.

Figure 3.17.—Changes in water velocity under a moving ship.

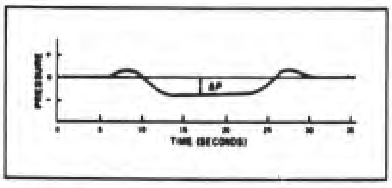


Figure 3.18.—Schematic drawing of ship's pressure signature.

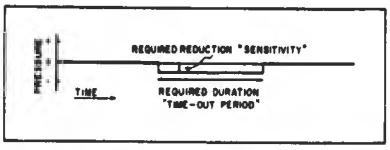


Figure 3.19.—Pressure mine actuation requirements.

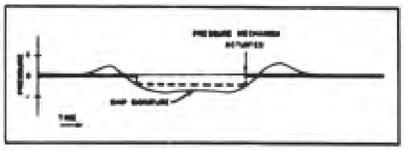


Figure 3.20.—Ship signature (solid line) superimposed on the pressure mechanism requirements (dashed line).

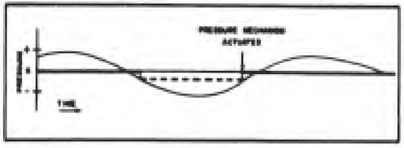


Figure 3.21.—Swell pressure imposed on mine requirements.

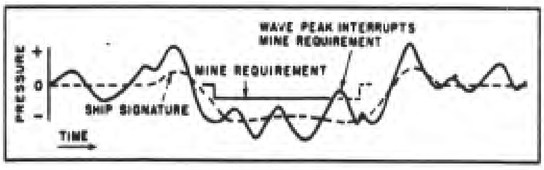


Figure 3.22.—The additive effect of waves and ship signature.

tain the decrease the required time will cause the mechanism to look. The magnitude of the required reduction may be only a fraction of an inch but the sustaining time is generally 8 seconds or more.

When the pressure signature of a ship is superimposed on the mine requirements, the mine requirements are satisfied and the pressure mechanism is actuated (Fig. 3.20).

Effects of Sea and Swell on the Mine Mechanism

Pressure changes at the bottom due to waves are termed pressure background and may satisfy the requirements of the pressure mechanism and cause it to look. This is especially true of long-period swell. For instance, an 18-second swell would exert negative bottom pressure amplitudes during about ½ of the wave period and if the water depth is right would result in spurious actuation of the pressure mechanism (Fig. 3.21). Actually, an 18-second swell is not necessary for such actuation since the additive effect of two or more wave trains of shorter periods may result in frequent combinations of waves producing the same effect.

In general, pressure mines require other influences, such as acoustic or magnetic, simultaneously in order for the mine to explode. Frequent cycling of the pressure mechanism, however, may greatly shorten the battery life of the mine.

During periods of heavy swell it may be only necessary to employ mine countermeasures of acoustic or magnetic mines to sweep pressure combination mines.

Another effect of wave pressure on mines is equally significant, that is, the ability of the background pressure peaks to nullify a ship signature by causing a momentary rise in the sustained negative pressure under the ship. This is illustrated in Figure 3.22. The sensitivity of the mine is effectively decreased by the presence of wave pressure fluctuations. Waves should be short in period as compared with the ship signature duration, but of sufficient height so that when projected to the bottom the pressure amplitudes are comparable to the magnitude of the ship signature.

The wave pressure and the ship signature are not necessarily algebraically additive in all cases. For instance, a ship traveling broadside to the waves will cause some reduction in surface wave heights in its lee. Consequently, a reduction in bottom wave pressure will result in the lee of the ship and possibly directly beneath the ship.

Wind waves can be forecast with reasonable accuracy. Prediction of swell, however, is subject to greater error since each area of swell origin must be treated separately. These techniques are given in Pierson, Neumann, and James (1955) and Hydrographic Office Publication No. 604 (1951). Bottom pressures resulting from discrete surface waves may be obtained from Figure 3.14. Bottom pressure spectra may be obtained by techniques discussed in Timme and Stinson (1955).

The use of bottom pressure recorders during mine-countermeasure operations would yield very useful information. An analysis of the resultant record would reveal the frequency of background fluctuations which will cause the mine pressure mechanism to actuate. Such information makes possible an evaluation of the effectiveness of acoustic and magnetic sweeps in clearing pressure combination mines.

In regard to minefield planning, a knowledge of sea and swell expected in an area is valuable in determining the feasibility of employing pressure mines. Frequent long-period swell in an area may preclude the use of pressure mines simply because continuous actuation of the pressure mechanism will rapidly deplete the mine batteries and render the mine useless. Geographical data on the distribution of wave heights and periods for many areas of the world may be found in various Hydrographic Office publications, such as Hydrographic-Oceanographic Data Sheets and Harbor Defense Atlases. An example of the presentations given in these publications is shown in Figure 3.23.

The pressure conditions shown in Figure 3.23 for the 50-foot depth for winter indicate that 15% of the waves are 16 seconds or more. These data show that a pressure mine with an 8-second time-out period would be very short lived and of limited usefulness in this area. Techniques for predicting life expectancy of pressure mines from data of the type shown in Figure 3.23 are given by Kleinerman (1955).

Effect of Currents on Ship Signatures

As previously stated, the change in bottom pressure resulting from a passing ship is proportional to the change in water velocity over the mine. In the presence of a current, even a ship at anchor will cause an increase in water velocity beneath the hull because of the constriction of flow. Conversely a ship drifting with the current will cause no increase in water velocity beneath the hull since no flow occurs relative to the constriction. The change in pressure at the bottom is a function of the ship velocity relative to the water velocity. The greater the water velocity past the hull, the greater will be the pressure drop.

While the magnitude of the pressure changes is determined by ship speed relative to water, the duration of the pressure drop is determined by the ground speed. For slow traveling vessels, the pressure drop will last for a long period of time, but may not be of sufficient magnitude to fire the mine. For fast traveling ships the pressure drop may be large but may not persist for the required length of time. Because of their length, however, large ships generally cannot avoid firing pressure mines by traveling at high speeds. Theoretically, small ships traveling at high speeds can pass over a pressure mine without firing it. Full advantage of the currents should be taken in this case to obtain maximum ground speed. The signatures of a very fast ship and a very slow ship are shown schematically in Figure 3.24.

The treatment given bottom pressure in this section has been greatly simplified in order to disclose the basic principles involved. Actually, the effect of background pressure on pressure mines and ship signatures is very complicated and not completely known.

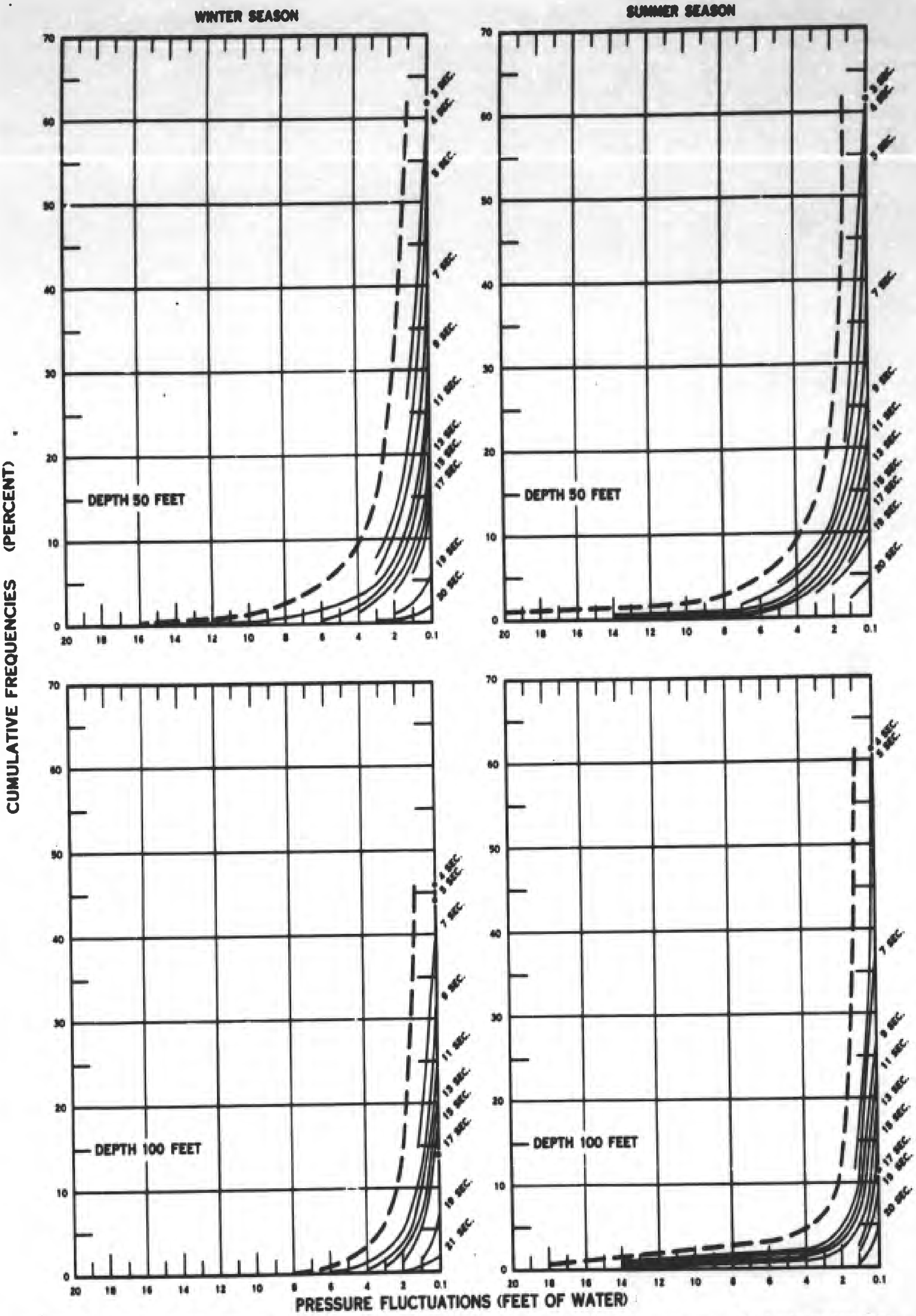


FIGURE 3.23.—Typical example of oceanographic intelligence information on bottom pressure fluctuations available for various areas.

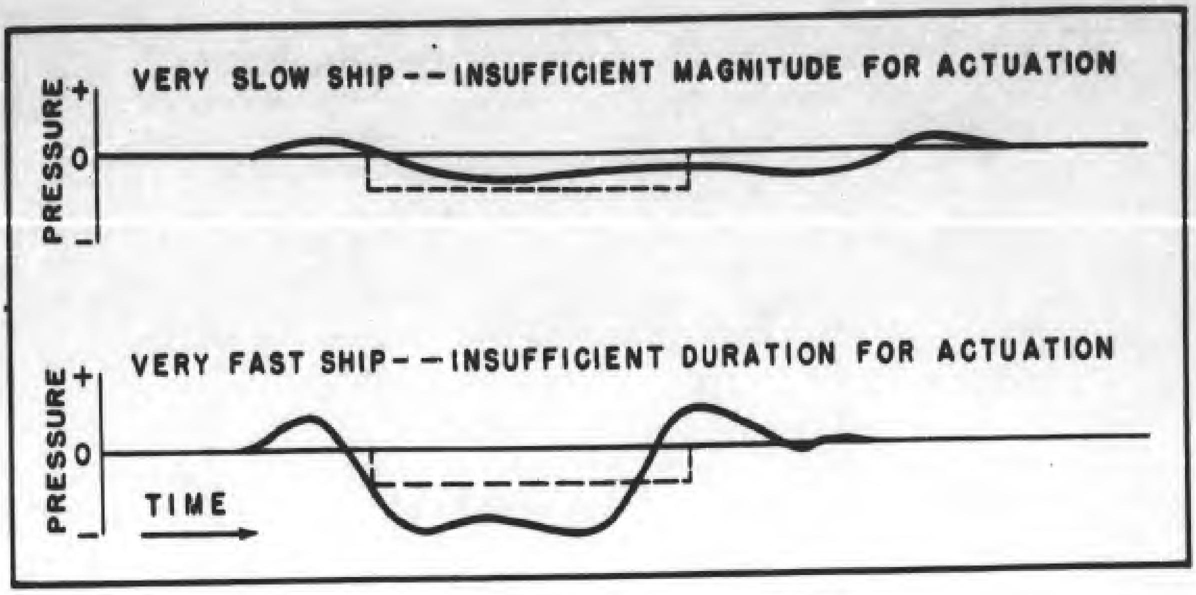


Figure 3.24.—Effect of ship speed on pressure signature.

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CHAPTER 4

EFFECT OF OCEAN ENVIRONMENT ON MINE HUNTING

Sea mines may be so complex in their various combinations of actuation mechanisms, ship counters, and delay arming devices that sweeping may become ineffective and other means of disposal are necessary. One of these other methods involves the location and neutralization of individual mines or *mine hunting*. Mine hunting methods include the use of acoustic, optical, electromagnetic, or mechanical devices each having limitations more or less dependent upon the oceanographic environment. The efficiency of acoustic mine hunting devices is dependent upon the local characteristics of the bottom, the water medium, and the sea surface. Optical mine hunting methods include divers and underwater television. Detection by optical means is seriously limited by underwater visibility, which varies tremendously in mineable nearshore waters. Electromagnetic mine hunting devices include magnetic and inductive ordnance locators. Detection is dependent upon contrast of the magnetic or electrical properties of mine cases against the natural background conditions. Some of these devices may be suspended from vehicles that are towed along the sea floor and are thereby vulnerable to bottom irregularities which prevent their mobility. Likewise, mechanical devices such as drags, nets, or galvanic locators are susceptible to fouling due to bottom irregularities. Table 4–I summarizes detection ranges and limiting oceanographic factors for various mine hunting devices.

4.1 ACOUSTIC MINE HUNTING

The detection of mines with high frequency transducers, such as UOL (underwater object locator) equipment, is essentially a problem of acoustically distinguishing mines from the background (Fig. 4.1). Moored mines are somewhat easier to detect than bottom mines inasmuch as the background provides more of an acoustic contrast. Recognition of the target echo further depends upon the minecase shape, flat angular surfaces producing stronger echoes than curved surfaces. Suspended sound

TABLE 4–I.—*Detection Range and Limiting Oceanographic Factors of Various Mine Locating Devices*

Device	Detection range	Limiting oceanographic factors
Acoustic	100–500 yards for search equipment. 75–200 yards for high resolution classification equipment.	1. Thermal and salinity gradients. 2. Sea state. 3. Bottom roughness and composition. 4. Suspended particles in the water. 5. Bottom debris. 6. Biological noise.
Optical (visual, television, and photographic).	0–60 feet	1. Transparency. 2. Sea state. 3. Water temperature.
Magnetic and electromagnetic (UEP, EDD, and inductive).	0–50 feet	1. Water and bottom sediment conductivity and magnetic properties of the bottom, including debris. 2. Bottom roughness and composition.
Mechanical and galvanic	Contact	1. Bottom topography and composition. 2. Bottom debris.

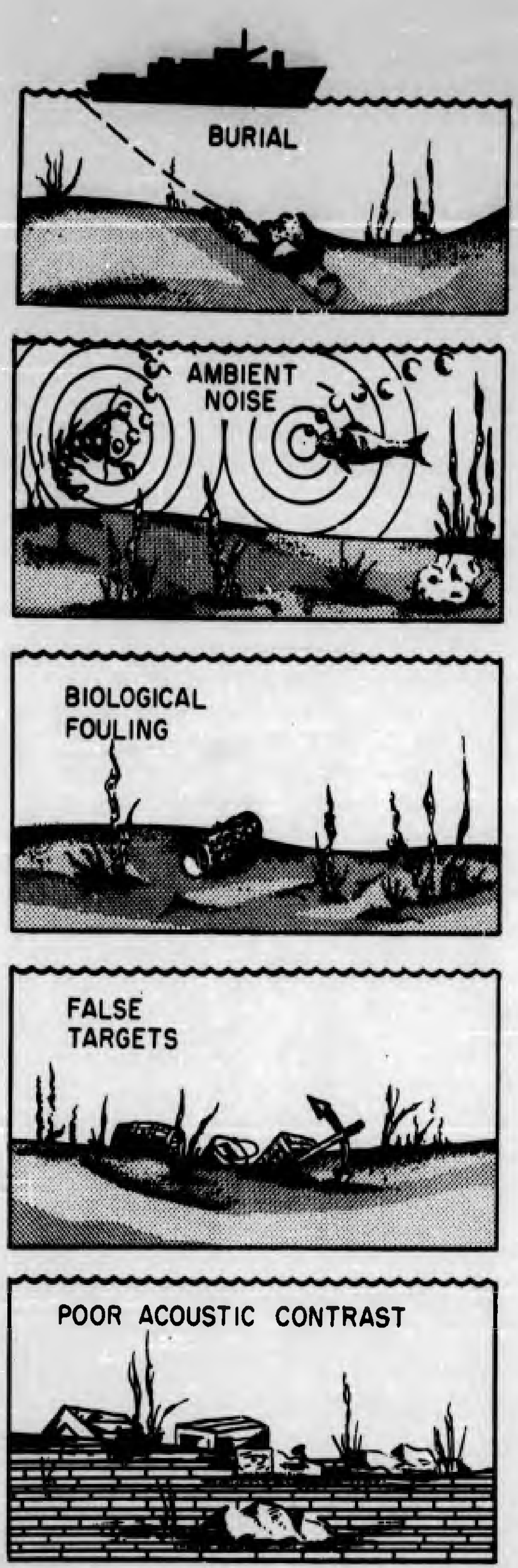

FIGURE 4.1.—Factors inhibiting mine detection by acoustic methods.

scatterers within the water volume will tend to mask the returning echo from the mine. In general, bottom scattering is more complex in nature than volume scattering.

Grain size, or texture, of the bottom sediment together with its water content and mineralogical composition will have a controlling effect upon the resultant scattering of sound energy. A bottom mine must have a sufficient acoustic contrast with the bottom background in order for a reasonable chance of detection to exist. Mud or sand bottoms provide a background of good contrast, whereas rock or stony bottoms provide numerous reflecting surfaces which may hinder mine detection in spite of the independent target echo-signal strength. The physical relation of the mine case relative to the surrounding bottom will affect the strength of the target echo. For example, a buried or partially buried mine may result in a weak echo signal, whereas undercutting of the area around a mine by the action of currents may render the mine more detectable. In the presence of a current, bottom mines are somewhat easier to detect from the up-current direction than from down-current, possibly owing to the masking effect of turbulent water in the lee of the mines. The physical behavior of bottom mines on various types of bottoms is discussed in Chapter II.

Mines covered with soft marine growths generally provide weaker echoes than nonfouled mines. Hard marine growths may cause the mine to be more easily detected. The progressive effect of marine fouling is shown in Figure 4.2. In general, submerged objects which have been coated with antifouling paint tend to retain their original acoustic qualities. Unprotected objects change their sound reflection characteristics.

Transducer tilt angle and refraction due to temperature and salinity structure will control the grazing angle at which the sound waves strike the bottom. Scattering of sound energy may also depend upon the relationship of the grazing angle with the bottom sediment type. At the steeper grazing angles, scattering appears less dependent upon bottom type.

Burial of bottom mines under relatively soft sediments may not prevent their detection by

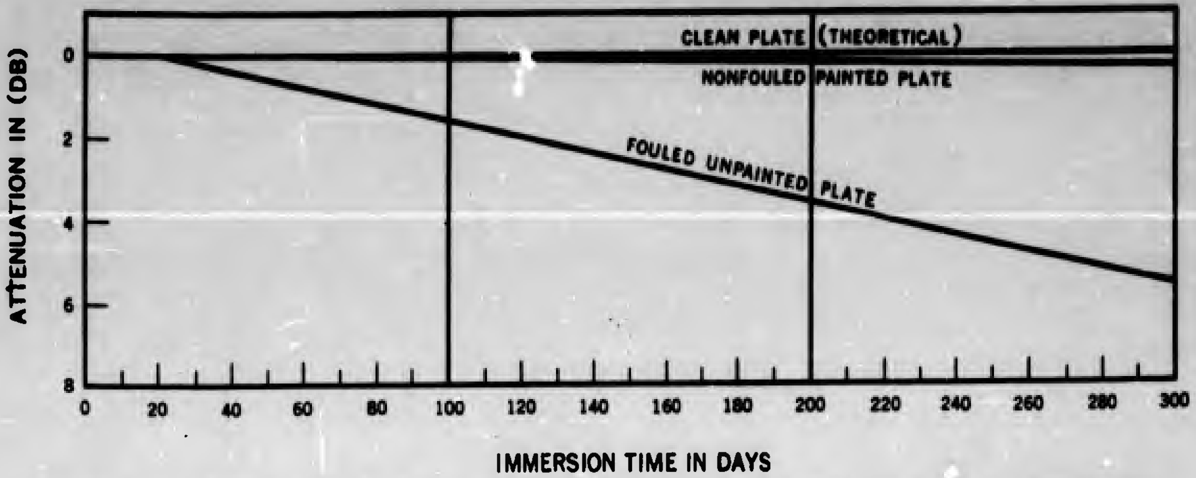

Figure 4.2.—Progressive effect of marine fouling in mine detection. (From Fitzgerald, Davis, and Hurdle, 1947).

echo ranging methods. Subsequent deposition of course sedients may effectively screen the mine from acoustic detection. Knowledge of bottom currents, either of a permanent nature or periodic tidal currents, provides means of estimating flow patterns of suspended material and the distribution of sediments.

The attenuation of sound energy penetrating the bottom will vary with the impedance, which is the product of the density and the sound velocity, of the sediment. The denser bottom deposits also have the higher sound velocities. Transmission of sound energy is slight across boundaries separating mediums of large impedance contrast. The lower frequencies are more capable of penetrating the bottom sediments although the inferior directional properties may detract from the advantages of effective bottom transmission. Submerged or buried features such as rock outcrops, coral heads, boulders, or debris may be confused with bottom mines unless high target resolution, high frequency echo ranging equipment is used. Precise knowledge of the bottom type will greatly facilitate the intelligent selection of proper transducer tilt angle, ping length, and sound frequency for the purpose of detecting and accurately locating bottom mines. At large transducer tilt angles bottom scattering will be less dependent on bottom type. Coarse or fine sediments will tend to have similar scattering effects. Small tilt angles will exhibit a strong sensitivity to bottom type, coarse sediments causing greater scattering. Reverberation due to scattering may be reduced to acceptable levels by reducing the ping length.

Mine detection involves a relationship between the target background and the target strength as determined by the geometry of the mine case and its aspect. Target strength depends, in part, upon the dimensions and the configuration of the mine case. Although spherical objects will have target strengths that do not depend upon their aspect, cylindrical objects, such as the MK-36 mines, tend to have strong aspect characteristics (Fig. 4.3). Beam and end-on target aspects of cylindrical mines produce strong directional characteristics when suspended above bottom, whereas quarter target aspects, owing to phase cancellation of sound energy, reduce the echo intensity. Target aspect tends to lose its significance in the detection of bottom mines although

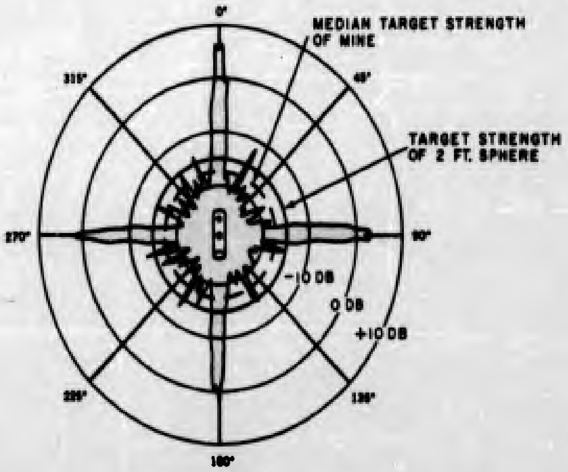

Figure 4.3.—Schematic drawing showing variation in free field target strength dependent upon mine aspect (Mk-36 ground mine). (From Batzler, Turner, and Ward, 1954).

it is of some concern in the detection of moored mines.

Nonmine Targets

Boulder-strewn bottoms, areas of scattered rock outcrops, and tropical coral reefs are typical areas for underwater contacts resembling mines. Debris discarded by vessels in transit will also constitute a source of nonmine contacts. Although nonmine objects on the bottom need not have minecase dimensions in order to possess minelike sound reflecting properties, very high frequency sonars have the capacity to determine target dimensions, thereby permitting target classification. Nonmine contacts will tend to occur in groups, although erratic, isolated occurrences are quite possible. If strong nonmine targets are removed or charted, future mine targets may be recognized more easily. Burial or subsequent exposure of natural reflecting surfaces of mineable areas will reveal changes in the environment with respect to existing false mine targets.

Ambient Noise Effects Upon Mine Hunting

The high frequency components of the ambient noise prevailing in an area tend to be of little consequence in mine hunting operations because of high receiver directivity. High sea states in addition to decreasing operation efficiency cause high noise levels, but at the lower frequencies. The spectral distribution of sea noise is shown on Figure 4.4. Variations of sonic fish, snapping shrimp, and sea mammal (porpoise and whale) noises have been recorded in the ultrasonic band of the sound frequency spectrum. Although noise is of lesser consequence with the use of high projector source levels and increased receiver directivity, biological noises have been recorded in all parts of the sound spectrum. In tropical areas over rock or coral bottoms, snapping shrimp noise becomes intensified (Fig. 4.4). Considerable diurnal variation may occur in the spectral characteristics of shrimp noise. This is indicated in Figure 4.5 by separate spectra for night and day.

Thermal noise caused by the increased molecular activity of the water with increasing temperatures is characteristically more intense at the higher frequencies. The spectrum of thermal noise is shown in Figure 4.6. Whatever its source, ambient ultrasonic frequency noise that is prevalent will tend to mask the echo signal and, as a result, reduce the maximum range at which mines may be detected or identified.

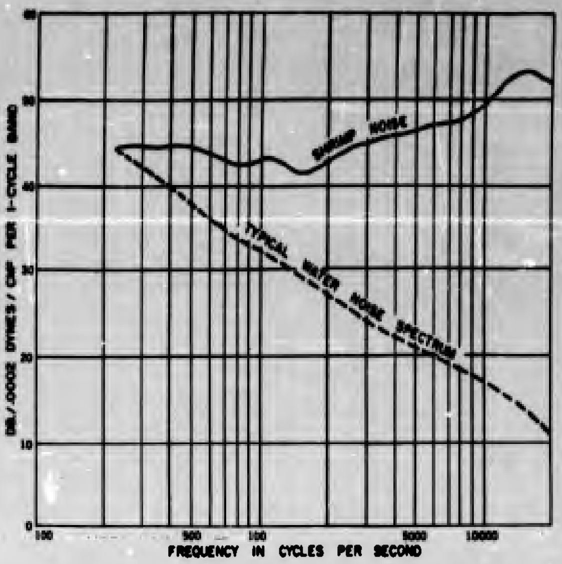

Figure 4.4.—Frequency characteristics of snapping shrimp noise compared with typical water noise in moderately quiet location.

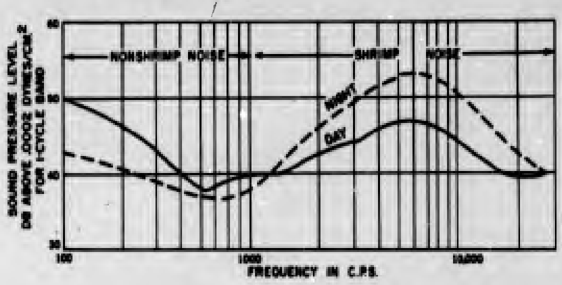

Figure 4.5.—Diurnal change in ambient noise spectrum.

When a mine hunting vessel backs down, drifts with the wind, or uses excessive engine or rudder changes, little energy may return to the transducer so that blanking may result. Maintaining constant headway has been considered as the best solution to avoiding blanking.

4.2 OPTICAL METHODS OF MINE HUNTING

Visibility of underwater objects depends upon three main variables: (1) the amount of illumination; (2) scattering of light rays entering the water; and (3) absorption of light rays by the water.

Divers have observed that underwater vision is usually best when the sun is 40° to 70° above the horizon. Normally, as divers descend the

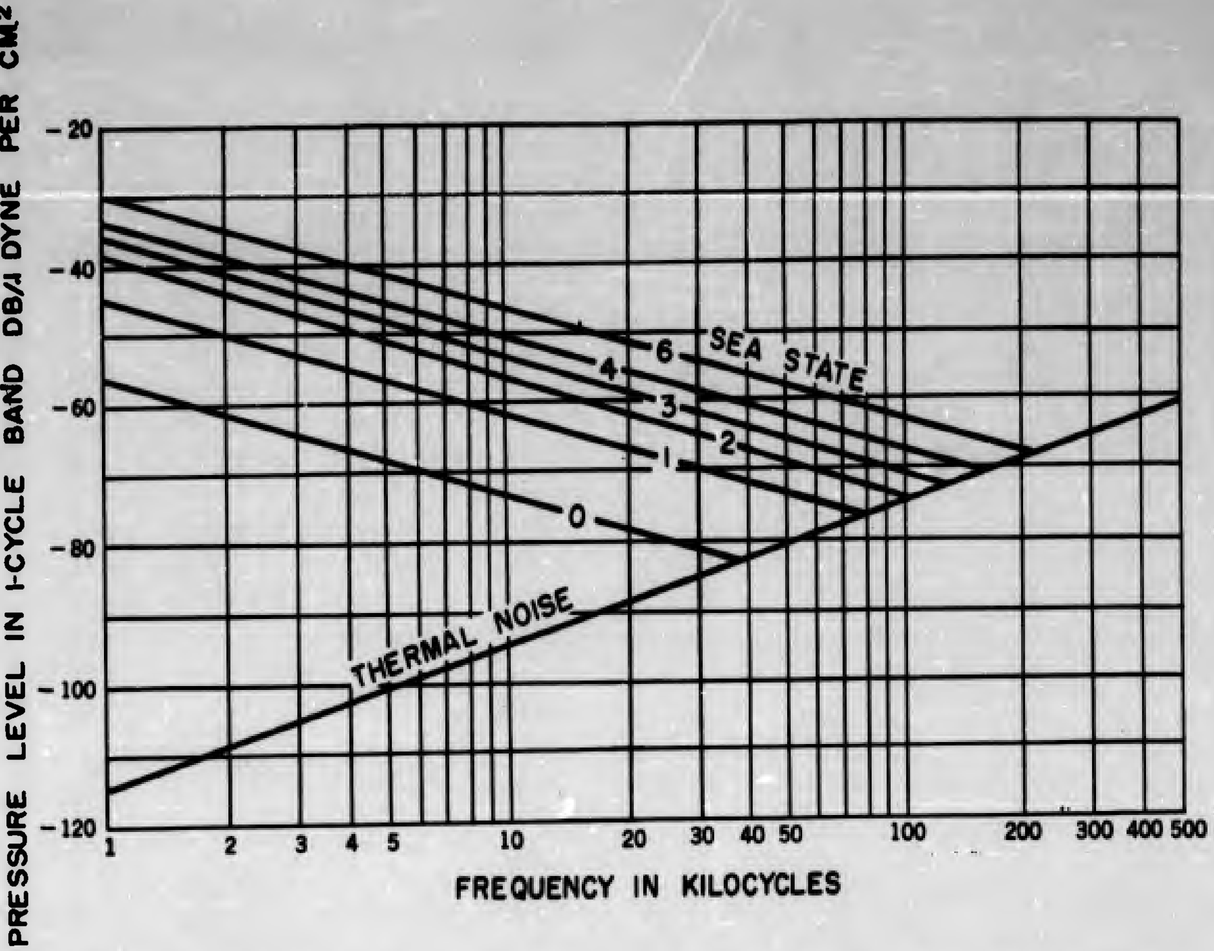

FIGURE 4.6.—Comparison of thermal noise spectrum and ambient noise spectrum caused by sea state. (From R. H. Mellen, 1952).

total light and hence visibility gradually decreases. However, turbid water may be found in layers, and occasionally a relatively clear layer permitting better visibility may be found under turbid water or at the bottom.

Absorption of light by the water is the process whereby light energy is converted into other forms of energy, thus decreasing its intensity. After white light has passed through a few meters of water it loses its red components. At somewhat greater depths, the yellow is filtered out and then all objects take on a green-blue color (Fig. 4.7).

Scattering is the result of the light rays' being deflected by water molecules and by suspended particles in the water. The fine particles, called debris, may consist of fragments of organic matter such as algae or of inorganic clay-size material, which frequently is the predominant bottom sediment. The physical property of sea water which depends upon the amount of suspended material in the sea is called turbidity. Pure water is relatively transparent, and objects in turbid water disappear at a distance as if in a fog.

Where the transparency is sufficient, the detection of mines by visual, photographic, or television search may be quite feasible. Generally speaking, two categories of search are possible: (1) by observers in hovering or slowly moving aerial vehicles (helicopters, blimps, planes); (2) by swimmers or underwater photographic or television cameras. These will be discussed separately.

Search by Aerial Observers

Moored mines and occasionally shallow bottom mines can be sighted visually by observers in low-flying helicopters. The essential conditions for success are clear water, a high sun in a clear sky, and a calm sea.

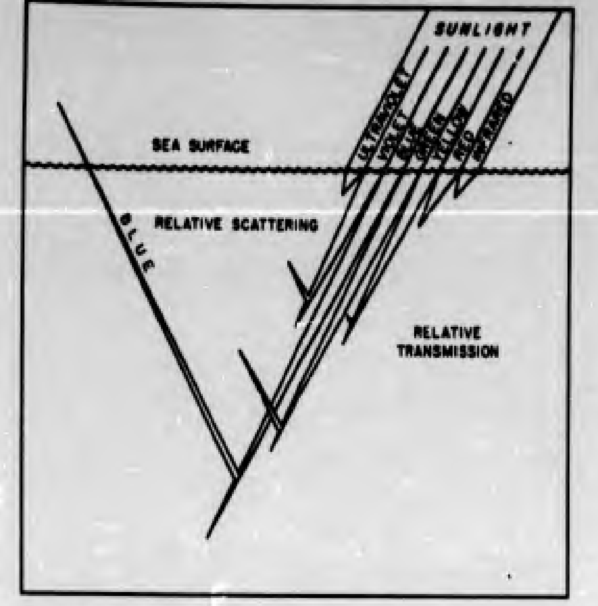

Figure 4.7.—Relative transmission and scattering of various colors by water.

The apparent color of sea water is often an index of its clarity. Ordinarily, a deep blue color characterizes water of the greatest transparency, while green, greenish-yellow, brownish or reddish, and white water are progressively less transparent. Although the clearest ocean (Sargasso Sea) approaches distilled water in transparency, the clarity of most sea water is reduced by suspended and dissolved foreign matter, including mud, silt, clay, plankton, detritus, and humic material. Measurements of water clarity applicable to search by aerial observers can be made by means of a *Secchi disc* (Secchi, 1866). This is a simple flat, white-painted circular disc about 30 centimeters in diameter, which is lowered into the sea until it disappears, then raised until it reappears. The depths of disappearance and reappearance are averaged, and the mean is called the *Secchi*

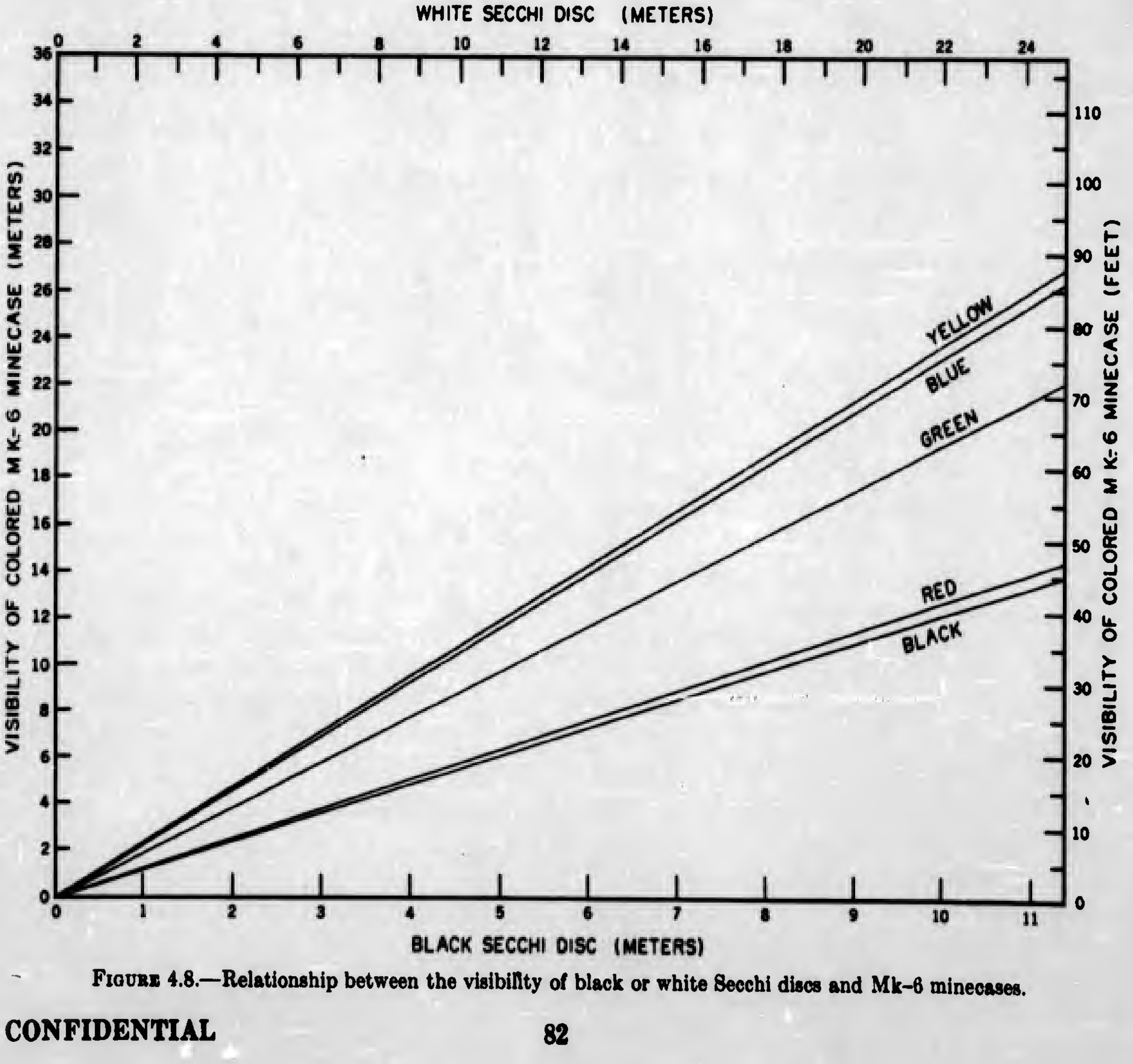

Figure 4.8.—Relationship between the visibility of black or white Secchi discs and Mk-6 minecases.

disc reading. A modification that has been found useful in mine work is to use a black-painted disc.

Secchi disc readings serve the practical purpose in mine hunting of furnishing data for estimating the maximum depth at which mines can be seen (Fig. 4.8). Obviously, standardization of reflectance, disc size, and observing technique is essential.

(*a*) *Reflectance.*—Discs should be freshly painted, with a flat paint, and glossy finishes should be avoided, particularly on black discs. Soiled or marred surfaces should never be used.

(*b*) *Disc Size.*—No real standard of disc size exists, but large discs (up to 2.5 meters in diameter) yield more reliable data than do small discs, particularly in very clear, blue water in which the discs can be seen at depths greater than 200 feet. Large discs are inconvenient, and are seldom used; the most common disc size is 30 centimeters in diameter (H. O. Publication No. 607, 1955); this size is adequate in turbid harbor waters in which the disc disappears a few feet beneath the surface.

(*c*) *Technique of Observation.*—Sky reflection, sun glitters, and the refractive effects of waves on the water surface greatly affect the Secchi disc readings. Ideally the observer should use a viewing glass hooded to exclude daylight. If this is not possible, observation should be made through a section of the water surface shadowed by the ship, and it should be remembered that ripple and wave patterns always reduce the depth at which the disc can be seen. The disc should be weighted to make it sink readily and keep the lowering line taut. Any relative motion between the vessel and the water will cause the lowering line to depart from the vertical; serious errors in the true depth of the disc can result. Wind drift can be minimized by anchoring, but this aggravates the effect of any current which may be present.

Interpretation of Secchi disc readings in terms of the maximum depth at which mines can be sighted is highly uncertain. One study of the relationship between the visibility of Mk–6 minecases painted various colors, white Secchi disc readings, and black Secchi disc readings is shown in Figure 4.8. The diameter of the Secchi disc used in this study was 30 centimeters. The Secchi disc technique should not be expected to produce highly precise or highly reliable results.

Some practical rules for aerial mine hunting, given by Capt. D. R. E. Brown of the U. S. Navy Electronics Laboratory, are as follows:

1. Search within 40° of the vertical.
2. Avoid looking directly into sun's azimuth.
3. Best solar altitude is probably 65°, at least between 40° and 70°.
    a. Below 40° not enough sunlight penetrates the water.
    b. Above 70°, usually not enough light appears on the sides of dark objects, besides the relatively greater glitter interference from surface reflection.

From the air, mines in blue water appear as light green objects. The shallower the mine the brighter its color. A group of mines is more readily detected than single units. Best results in searching for single units is 500–600 feet altitude. Mine patterns can more easily be spotted at altitudes of approximately 1,200 feet.

This apparent increase in visibility with altitude can be explained merely on the basis of reflection. As the altitude is increased the angle made by the edges of the target to the observer's eye decreases, and as this angle decreases the amount of surface reflection decreases. This can be illustrated by looking out across a body of water toward the sun. The farther away you look from straight down the greater is the apparent glare, that is, the angle is greater and reflection is greater.

Near shore, sharp changes of transparency over relatively short periods of time and distance may occur. Wave action, tidal currents, and river discharges account for the major portion of these fluctuations. An increase in the relative numbers of microscopic plants and animals (plankton) will also cause a decrease of transparency.

Mine Hunting From Ships

Visual detection and evasion of submerged moored mines from shipboard may not be feasible from deep-draft vessels. A ship probably could not be stopped in time if a submerged mine were sighted in its path by an observer on the bow no matter how slow the ship may be traveling.

Search by Swimmers and Underwater Cameras

Swimmers and underwater photographic and television cameras can be used both for mine hunting and for the classification of minelike objects.

Some practical rules for swimmers searching for moored mines have been given by Capt. Brown as follows:

1. When the sun is high, best direction to look is straight up at sun.
2. When water is clear, best method of search for dark objects is toward the sun's azimuth.
3. When searching for light objects, best direction is away from the sun's azimuth.
4. In turbid water, avoid looking directly toward the sun's azimuth.

The greatest distance at which a swimmer can see a moored mine depends upon the direction in which he looks. Generally speaking, visibility downward is the poorest and visibility upward is much the best, with horizontal sighting ranges intermediate but closer to downward values.

Water transparency measurements by means of Secchi discs give an indication of the clarity of upper strata, and they can be used to estimate the maximum depth at which a swimmer, just under the surface, can see a moored mine. They cannot, however, be used with certainty for predicting the horizontal or upward sighting ranges of swimmers. This is due, in part, to the stratification commonly encountered. Moreover, any discrete transparency measurement is subject to change with time. Specifically, for inshore waters where a rapid exchange of water occurs over a period of even an hour, any specific transparency measurement will not hold for an hour later. Coastal waters, which are subject to longshore currents or currents associated with wave motion, may have large changes in transparency within a few minutes. Divers have encountered situations where excellent visibility deteriorates in a few minutes as a large cloud of suspended material, similar to fog clouds, has rolled in along the bottom. Horizontal visibility in a turbid layer may be poor, but beneath it may be a clearer stratum within which horizontal visibility may be 15 feet or more.

The apparent color of submerged colored objects will change with distance in such a way that, just before they disappear, they assume the color of the background.

The color of water is often related to its clarity. The blue color of clear water is comparable to the blue color of the sky, in that blue light is scattered by the water molecules or by minute suspended particles. The change from blue to green and into yellows and red cannot be attributed solely to scattering. The inherent colors of suspended particles or dissolved matter contribute to the apparent color of the sea. This discoloration can partly be ascribed to planktonic matter (minute plant and animal life) which may impart a muddy, greenish, yellowish, brownish, or reddish color to the water. These planktonic masses appear most commonly in coastal waters where their food is plentiful. The green colors are frequent in waters near the coast or at sea in high latitudes, while the blue water is characteristic of the middle and lower latitudes. In blue water a target is visible at the greatest distances. These distances of visibility decrease generally as the apparent water color ranges from the blue to the green through yellow on into the reds.

Photography, Television

Since image-forming light is that light which travels directly from the target to the camera lens, scattering of light by suspended particles is the major inhibiting factor in the taking of photographs. The absorption of light, which results merely in a reduction of the amount of light, can be overcome by a more powerful light source. Although infrared light is not scattered in great amounts, its use is not a solution to the problem of taking good photographs since its rate of absorption is so high that sources powerful enough are unavailable. An adequate method of taking photographs in turbid water has not been developed. The same problems apply to television.

As a general rule, in water in which the Secchi disc reading is 40 feet or less, the maximum distance for satisfactory photography is one-half the Secchi disc reading, provided the light source is near the target.

4.3 MAGNETIC AND ELECTRICAL LOCATING METHODS

Detection of magnetic materials, such as ferrous mine cases, may be accomplished by various electromagnetic methods, namely by electromagnetic induction, by magnetic intensity measurement, and by magnetic gradiometry.

Magnetic detection and location of buried mines depends upon the magnetic qualities of the materials of which they are constructed. Mines made of nonferromagnetic materials are undetectable by these methods. The environment of the mines will affect their detectability as will the depth to which they are buried within the sediments of the sea bottom. The mineralogical composition of the bottom deposits may determine the magnetic characteristics against which the mine case is to be detected. Magnetization of most ferrous mineral deposits is very low and may be quite uniform. An abnormal concentration of metallic oxides, such as magnetite, or sulfides, such as pyrites, within the sediment will modify the normal magnetic qualities of the bottom. Sea currents traversing a nearshore area introduce new sediments having different mineralogical composition than that previously existing or may flush out the sedimentary complex thereby altering the magnetic qualities of the bottom. Hydraulic processes within the sea together with the availability of sources determine the concentration of magnetic materials. Volcanic regions and areas where basaltic (dark, fine-grained, igneous) rock occurs provide ready sources of magnetic materials for subsequent inclusion among nearshore deposits. Both sand or silt covered bottoms may contain appreciable quantities (up to 3% by weight) of magnetic materials. The magnetic susceptibility, that is, the measure of magnetization compared to the magnetizing force, of nearshore deposits is directly related to the concentration of the magnetic materials. Consequently little can be determined as to the susceptibility of the sediments from their general description. Differing susceptibilities of similar type sediments from various localities indicate the wide range of measurable conditions that may be encountered.

Imbedded masses within the bottom sediments may modify the magnetic field of the sediments alone. Scattered boulders having mineral compositions varying from that of the bottom will, to some extent, influence the magnetic signature obtained by the magnetic search coils, as will the presence of buried mines. Ferromagnetic materials jettisoned by passing vessels along ship navigation channels may resemble mine targets as a result of similarities in magnetic qualities to mine cases. Prior magnetic surveys of prospective navigation channels will reveal the location of minelike objects. Difficulties in accurate navigation and target positioning may complicate the task of determining the exact number, or identity, and future recognition of minelike objects. The depth of burial of mines or minelike masses within the bottom sediments will affect their detectability. The range of detection is related to the mine case permeability, and to the depth to which burial has occurred. With currently available equipment, detection ranges greater than 20 to 30 feet from the detector elements generally are not achieved.

By utilization of various electrical prospecting methods, foreign metallic objects may be detected because of their contrasting nature with the sediment background. Electromagnetic discontinuity discrimination methods are capable of detecting all foreign bodies within the bottom-sediment mass. A very low frequency alternating current field is generated so that foreign materials may be discriminated from the surrounding environment by the receiver owing to the contrasting nature of the mine case. The phase comparison of the received return signal with that transmitted is indicative of the conductive or nonconductive nature of the detected buried object.

All radiating or active electromagnetic methods of investigating the bottom sediments for mines involve measurement of the conductivity or resistivity contrast of the mine case with that of the surrounding water or sediment. Sea water laden sediments possess electrical conductivities that tend to approach that of the overlying water volume. Gases may be generated within the bottom sediments as a result of organic activity and may, therefore, cause an increase in the electrical resistivity of the sediment. The presence of rock, owing to its lower electrical conductivity, will cause a similar increase in the bottom resistivity. The conductive characteristics of the bottom sediments result from the individual conductivity of the minerals present.

Table 4–II gives ranges of resistivity of bottom materials:

Table 4–II.—*Typical Resistivities of Various Materials*

Substance	Resistivity (ohm-cm)
Steel	.00002–.00006
Sea Water:	
@Salinity 40°/₀₀ Temp. 86° F.	15
@Salinity 5°/₀₀ Temp. 32° F.	220
Clay, *dense alluvia*	100–3,000
Sedimentary rock:	
Geologically "new"	1,000–30,000
Geologically "old"	15,000– 200,000
Igneous rock	50,000– 500,000
Coarse gravel, Sand	75,000–5,000,000

Note.—Bottom sediment resistivities may be much less than indicated because of interstitial sea water content.

Electrostatic mine hunting methods involve the introduction of an artificially produced electric current into the bottom. Inhomogeneities that may be present within the sediment will decrease the areal resistivity so that higher voltages will be recorded, indicating the possible presence of mines or similar masses. Highly conductive, water-laden sediments may reduce the contrast so that lower detection ranges may result.

Passive underwater electric potential methods utilize the principle of an existing electrical current flow between two dissimilar metals that are in contact or have low resistances intervening provided a conductive return path exists through the surrounding medium, such as sea water. The electric potential fields established in the sea by metallic objects are detected by means of electrodes which need not be in contact with the mine. Ship-streamed chain or cable galvanic drags may be used for mine location which, upon contact with metallic objects, will initiate electrical currents whose magnitude may be appropriately presented upon various display devices. In this case direct contact between the streamed conductor cable and the mine case is required for a detection indication or strike, and therefore well buried mines cannot be located by the latter methods.

Knowledge of the presence and location of natural erratic materials within a sediment mass may enable differentiation between genuine mine strikes (contacts) or false mine targets. Owing to the limited range of electrical prospecting methods in detecting mines, surveys of navigation channels prior to mine hunting operations offer the best solution for the identification of nonmine targets. The closer spacing of electrodes positioned on the bottom will achieve a finer evaluation of the sedimentary inclusions. Variations in the water content due to the sediment grain size will affect the conductivity of the bottom deposits, the higher conductivity generally being related to the greater water content which is characteristic of the finer grained silt and clay deposits. Buried metallic mine cases, which have a lower resistance than the overlying sediment, will cause a stronger current to flow across the measuring electrodes thereby indicating their presence and approximate vertical location.

Induced polarization methods depend upon the momentary establishment of secondary cells as a result of an introduced electric current flow about metallic bodies on the sea floor. They are limited in range in a manner somewhat similar to other electrical prospecting methods.

All electrical mine-hunting methods may be subject to errors produced by cable insulation break-down losses and by signal alteration caused by electrochemical activity due to marine fouling of electrode elements. Proper condition of all equipment components is essential if maximum operating characteristics are to be attained.

Water depth variations must be known accurately in order to permit proper interpretation of variations in the received signal that are not due to foreign masses within the sediments. Electromagnetic discontinuity discrimination methods are particularly susceptible to misinterpretation. Charted depths or bottom types in nearshore waters are subject to change owing to the presence of strong currents which redistribute the bottom deposits. Frequent check surveys prior to mine-hunting operations will provide information that will lead to a more accurate evaluation of signal variabilities.

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CHAPTER 5

EFFECT OF OCEAN ENVIRONMENT ON DIVING OPERATIONS

Mine threats may arise in areas such as docks and crowded anchorages where minesweeping would not be acceptable owing to resulting explosion damage. Also effective sweeping methods for pressure and other types of influence mines are difficult and costly. Therefore, other methods of mine countermeasure, such as mine hunting and mine disposal, must be utilized.

One concept of mine countermeasures involves the establishment and maintenance of cleared channels. The channel's bottom must be cleared of all objects which may be mistaken for mines by any of the various types of detection equipment. The task of clearing and maintaining the channels is difficult and costly. Each object must be located and removed individually by a diver or must be raked from the ocean floor with dragging devices.

A knowledge of oceanography will be of great aid to the diver, especially in harbor areas where many oceanographic factors, such as currents, visibility, and bottom sediments, may adversely influence diving operations.

5.1 INTRODUCTION

The history of diving is probably as old as the history of man's efforts to swim. Early diving was performed without any equipment.

Historic references indicate that several centuries before Christ, the employment of divers was a recognized feature of naval warfare. Not until the Middle Ages did inventors attempt to supply air to a diver underwater, and then with only limited success. The history of modern diving is little more than a century old, beginning with the appearance in 1837 of the closed diving dress and helmet invented by Augustus Siebe (Fig. 5.1). Today, virtually the same closed diving dress and helmet is in worldwide use.

In 1825, before the invention of the closed diving dress, James invented a useable self-contained diving dress (Fig. 5.2). The first practical self-contained breathing apparatus was designed in 1878 by Fleuss (Fig. 5.3). Not until 1943, when the Aqua-Lung was invented by Gagnan and Cousteau, was a satisfactory self-contained diving unit using compressed air available (Fig. 5.4).

With the invention of the Aqua-Lung, new horizons were opened to the diver. Now divers are being used widely in the fields of

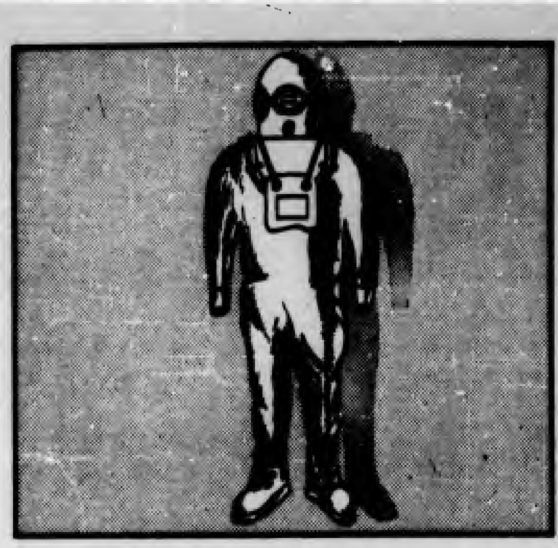


FIGURE 5.1.—Siebe's first closed diving dress and helmet (1837).

FIGURE 5.2.—The original self-contained diving dress of James (1825).

FIGURE 5.3.—First practical air-regenerating self-contained breathing apparatus designed by Fleuss in 1878.

marine biology, marine geology, mine location and demolition, as well as for all the older more established uses.

All types of SCUBA (self-contained breathing apparatuses) are for use by underwater swimmers and need no connections with the surface, such as lifelines, airhoses, or other features common to the deepsea diver's dress.

The SCUBA are of three general types:

(1) The most common type is the open-circuit equipment such as the Scott-Hydro-Pak (Fig. 5.5) or the Aqua-Lung, which employs compressed air and discharges used air into the water.

(2) Closed-circuit equipment employs compressed oxygen. The diver exhales into a breathing bag and rebreathes the same gas after it has passed through a canister containing a carbon dioxide absorbent such as soda lime or Baralyme.

(3) Semiclosed-circuit equipment employs a nitrogen-oxygen mixture. Part of the used air is recirculated through a carbon dioxide absorbent and part discharged into the water. This has the advantage of a long gas supply with reduced risk of oxygen poisoning.

A complete diving manual (U. S. Bureau of Ships, 1952) has been published by the Bureau of Ships. Topics include the basic principles of diving, diving equipment, procedures, medical aspect of diving, and diving with helium-oxygen mixtures.

In view of the numerous possible dangers of water pressure and other oceanographic variables such as tides, currents, and dangerous marine life, man cannot safely enter this foreign underwater environment to which he is not naturally adapted. However, when properly trained and equipped, man can operate efficiently and safely underwater, but in order to do so he must know the underwater rules imposed on him by the water and by his own physiological and psychological limitations.

5.2 OCEANOGRAPHIC FACTORS AFFECTING DIVERS WEARING SCUBA

Bottom Sediments

Generally, a SCUBA diver can work and move about without touching the bottom; thus, he will not be affected by the type of bottom sediment.

Visibility

Underwater visibility varies with locality. In tropical waters, visibility is usually considered to be good; in some places, it is frequently more than 100 feet at 30 fathoms. Channel and harbor areas are usually somewhat turbid, owing to the sediment-laden rivers emptying into these areas. Also ships and strong currents passing through a channel can stir up the bottom sediments. Thus, visibility will range usually from 0 to 20 feet. Visibility decreases somewhat during the rainy season of the year and during plankton bloom in spring and autumn. Visibility is discussed in Section 4.2.

Water Temperature

All divers are extremely sensitive to water temperature changes because water is a much better heat conductor than air. At present no equipment is available to protect a man against moderately warm water. Heat prostration may occur during exercise in water above 86° F. and at rest in water above 96° F.

Tolerance of low water temperatures varies with the individual SCUBA diver. Most men can tolerate water at 68° F. fairly well without wearing a protective suit, but they will require protection if immersed in water colder than 68° to 70° F. for more than an hour. When a

FIGURE 5.4.—Diver wearing the Aqua-Lung. (Photo by U. S. Navy Electronics Laboratory, H2065).

diver becomes extremely cold, his power of concentration and efficiency drops off rapidly.

Many types of suits have been designed for protection against cold water. Figure 5.6 shows various types of diving suits worn by SCUBA divers. Although the best designed diving suits will protect a self-contained diver for half an hour in near freezing water, the diver will become cold and his ability to do work will decrease with increase in time spent underwater. Also, when the diver is cold his ability to do work decreases rapidly with depth. Figure 5.7 is a summary of temperature effect on a diver.

Generalized worldwide seasonal temperature distribution and variation with depth can be found in the National Intelligence Surveys and Hydrographic-Oceanographic Data Sheets.

Biological Factors

Tides, currents, cold water, and surface weather conditions all may be hazards to the

FIGURE 5.5.—Diver wearing the Scott Hydro-Pak. (Photo by U. S. Navy Electronics Laboratory, H474)

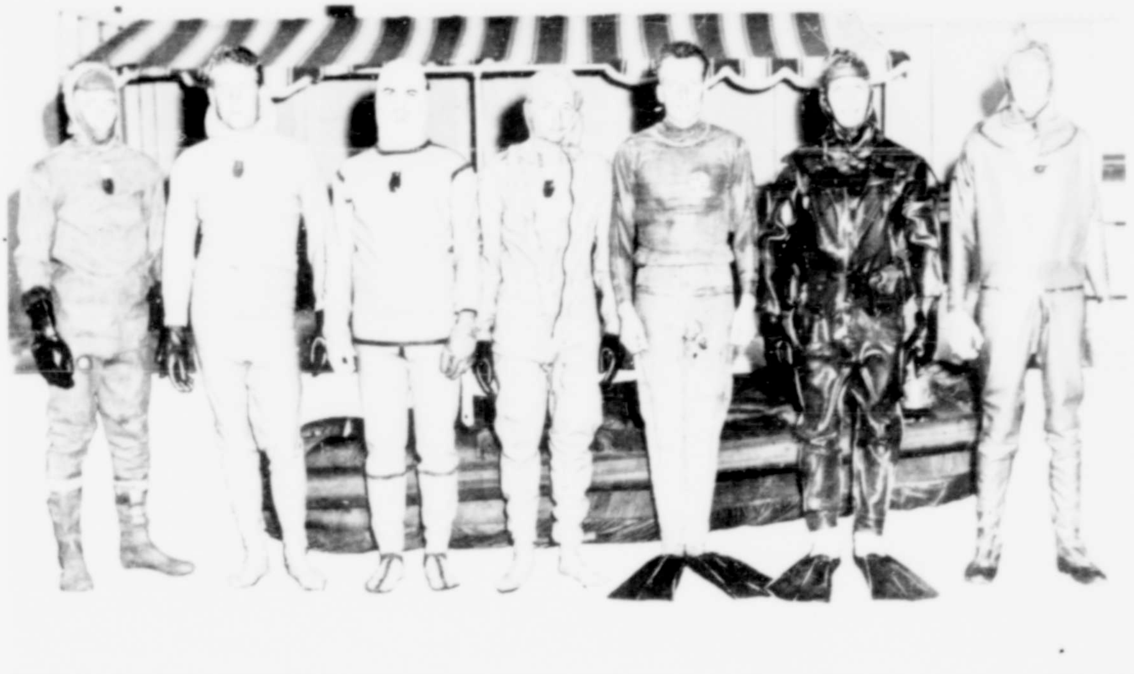


FIGURE 5.6.—Gear worn by Underwater Demolition Team during National Research Council Symposium, UDT Suits. L–R: Clamp, Two piece, Two-zipper, front view Home-made, Perilli, Kearny, and U. S. Divers. (Official U. S. Navy Photo).

diver, but probably the most publicized and generally overrated are the biological dangers. Actually, professional divers pay little attention to any form of marine life since they are rarely bothered. Some of the more dangerous biological forms are shown in Figure 5.8.

Biological factors to be considered by the SCUBA diver are not limited to animal life. Common causes of diver disability in tropical waters are slow healing superficial abrasions, many of which are caused by coral growths. Bottom seaweed and kelp growths are only a minor problem to a SCUBA diver, being a swimmer he can avoid entaglement. Figure 5.9 shows a SCUBA diver moving through a kelp bed.

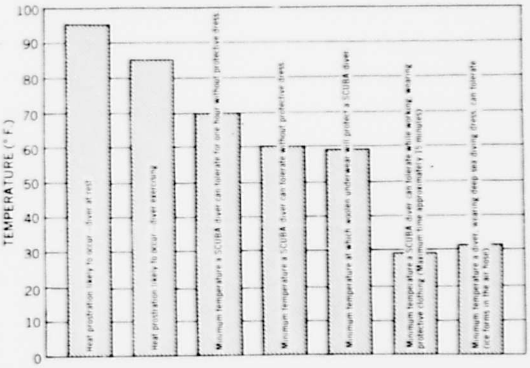
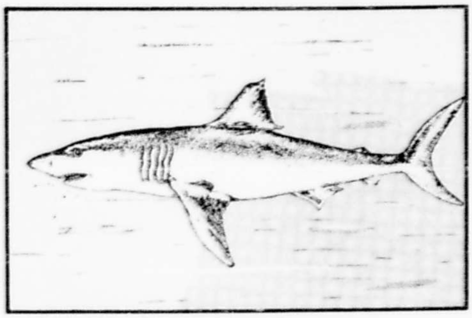


FIGURE 5.7.—Effect of temperature on a diver.

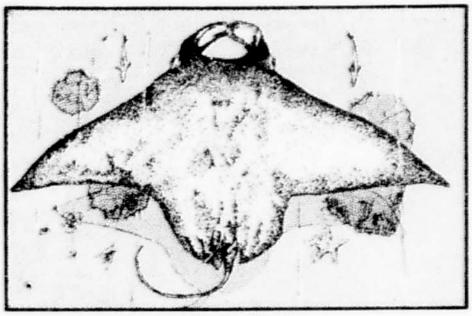
Sea, Swell, and Weather

Little information is available as to the effect of sea and swell upon a diver working on the bottom. However, wave motion at the bottom and at the surface, if sufficiently strong, will hinder the diver. The depth to which this motion extends depends upon the wave length. Wave motion is felt at the bottom when the water depth is about one-half the wave length. For example, if the waves have a length of 100 feet, a diver will just be able to perceive the wave motion at a 50-foot depth; in deeper water the wave motion will be imperceptible at the bottom. In shallow water, the motion becomes

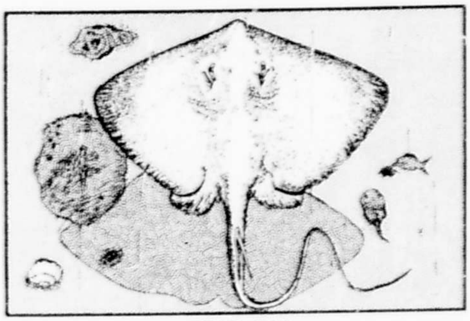
BARRACUDA



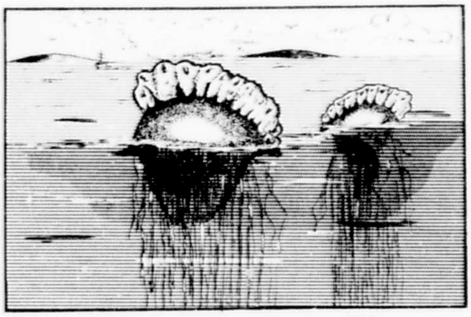
WHITE SHARK



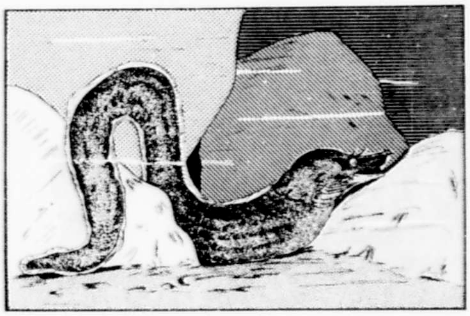
MANTA RAY



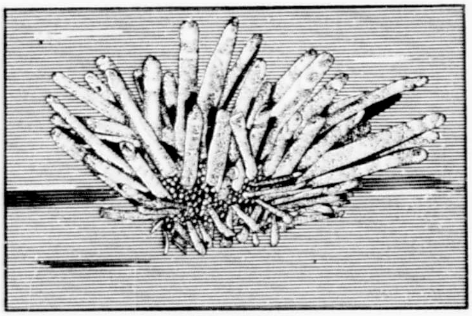
STING RAY



PORTUGUESE MAN-OF-WAR



MORAY EEL



SEA URCHIN

KILLER WHALE

FIGURE 5.8.—Sea animals to be avoided by divers.

FIGURE 5.9.—Scuba diver in a kelp bed. (Photo by U. S. Navy Electronics Laboratory, J911).

more noticeable as the wave height increases or the depth of water decreases, until the motion becomes so strong ~~that~~ the diver will find it impossible to work.

Near the surface the wave motion is circular, but as depth increases the motion becomes elliptical, and at the bottom only a horizontal oscillating motion exists. (Fig. 5.10). If the depth is not great compared to the wave length, the motion will remain nearly horizontal at all depths. In shallow water, if the sea or swell is running sufficiently high, surface wave motion extends to the bottom. Because of surface difficulties, 12-foot waves are the maximum in which diving operations can be carried out.

Experiments were made on the use of SCUBA divers for search of harbors and channels for underwater ordnance (U. S. Naval Powder Factory, 1955). The experiments found that jackstays could be laid from barges with difficulty in a state 4 sea condition (Beaufort scale) but not effectively when a state 5 sea condition existed. The sea did not appreciably affect the swimmers, but it did cause shifting of the barges and fouling of the lines. The glossary

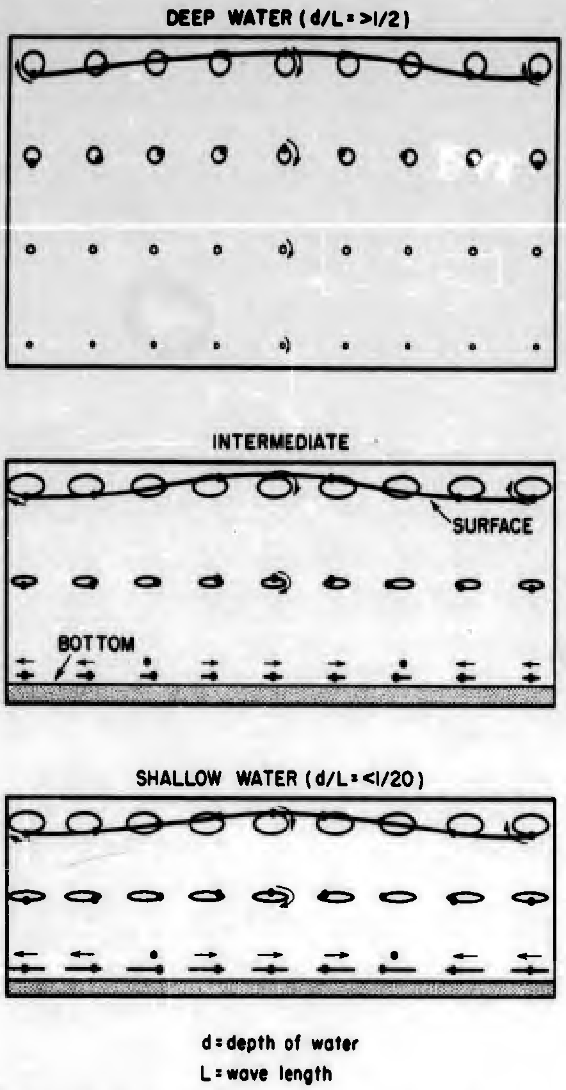


FIGURE 5.10.—Trajectories of progressive waves.

contains complete information on the wind, sea, and swell codes.

Currents

Knowledge of where and when to expect currents and how to use them will prove of great advantage to the diver. Currents will have a decided influence upon all divers regardless of the diving equipment worn.

Rip currents are associated with large waves breaking on an exposed coast, and flow seaward through the breakers along the coast (Fig. 5.11). Since rip currents of 2 knots are not uncommon, a SCUBA diver may not be able to swim against them. The rips extend about ¼ to ½ mile from shore. Thus, diving along a strange coast can be dangerous, especially if the onshore wind is strong and the waves are high.

Aside from local inshore currents, divers also will encounter widespread currents owing to tides and other factors. Frequently these currents near the surface will prove a hindrance to a diver, but sometimes currents can be used to the diver's advantage. For example, knowledge of the local tide and current conditions can be very useful to UDU (Underwater Demolition Units). The swimmers can enter a harbor on the flood tide, timing their work so that it can be done at slack water, and then they can swim out of the tideway on the ebb tide. For natural countermeasures against UDU, operational sites should be located where the water is turbid or where strong currents exist.

A SCUBA diver may be handicapped by even a slight current, or he may be able to use a faster current to his advantage. He can swim for an extended period against a current only if it is less than 1 knot. Currents below 0.3 knot will not affect appreciably the direction in which the swimmer may wish to proceed. Experienced divers can swim in the direction of currents of as much as 3 knots with no great difficulty. Thus, insofar as possible, visual mine hunting and other diving operations should be planned to take advantage of currents.

As the SCUBA diver usually wears only a small weight he has a near-neutral buoyancy. Thus, he cannot work on the bottom if the current is strong. However, he can wear additional weights and a lifeline can be tended like a surface-supplied diver. Under these conditions the SCUBA diver must employ quick-release fastenings for all weights and must avoid weighted shoes.

In certain areas at times of high or low tide the visibility may change within a few minutes; the water which had been rather clear may become turbid. This may be due to bottom currents, the effect of which is to stir up the bottom sediments.

Tide and current tables are available for many areas of the world. However, the tidal current may not extend to the bottom, and the current direction and speed is predicted only for the surface water. Current direction may change with depth, and near the bottom it

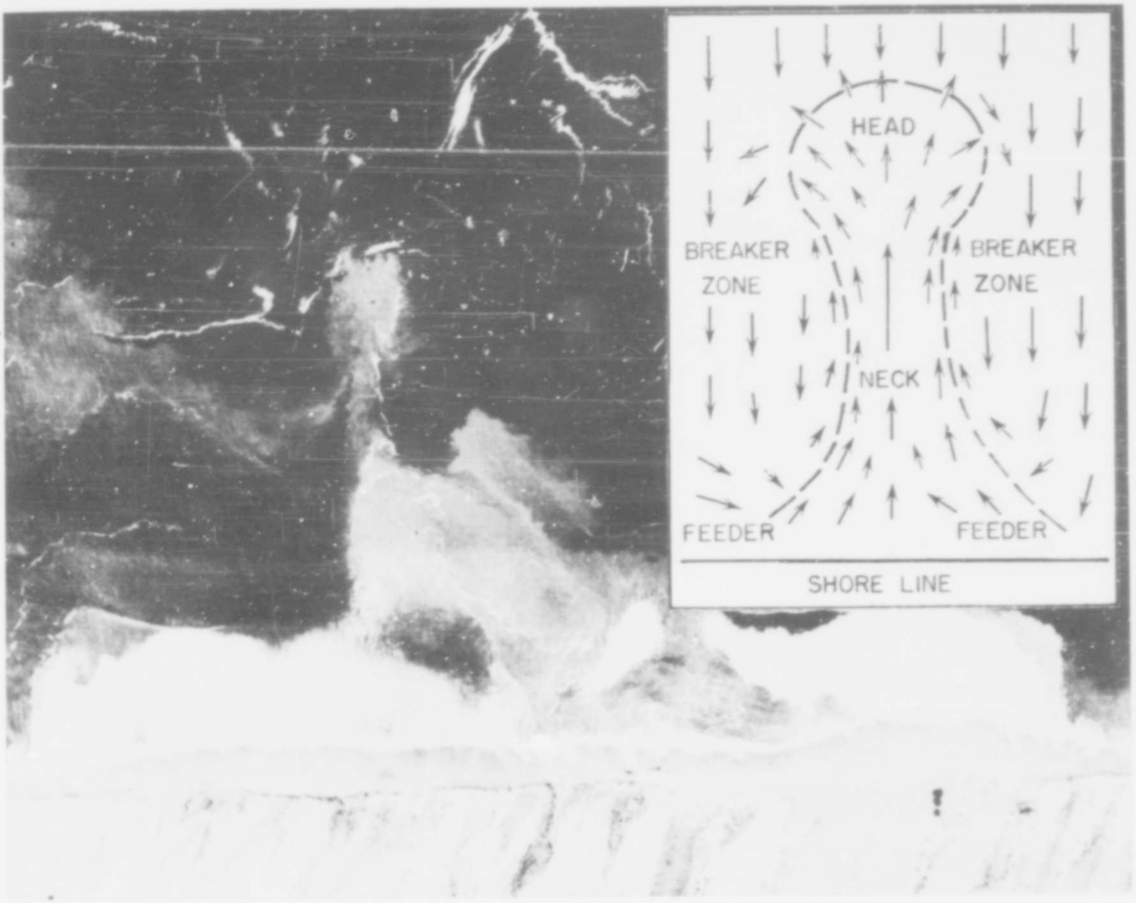


FIGURE 5.11.—Photograph of a rip current with a generalized sketch.

could be opposite from that at the surface. Current speed also changes with depth, usually it decreases as depth increases.

5.3 OCEANOGRAPHIC FACTORS AFFECTING DIVERS WEARING CONVENTIONAL DIVING DRESS

Bottom Sediments

Bottom sediments affect the deep sea diver in two ways; his ability to move about and his ability to see.

Deep sea divers have no difficulty walking upon a rock, gravel, shell, sand, and occasionally even a sand-silt-clay bottom. However, on most silt-clay bottoms (commonly referred to as mud) a diver wearing conventional equipment will sink into the bottom. The depth of penetration will depend upon several variables of the bottom sediments, such as the content of clay, water, sand, and organic remains. As the content of sand increases, the resistance to penetration also will increase, regardless of the other variables.

Movement should be restricted to a minimum on a muddy bottom, inasmuch as it will stir up the sediments and decrease visibility. Therefore, the diver should orient himself so that the current, if any, will carry the silt away from his work. The hazard involved in diving in muddy water is the inability to see such objects as pilings, debris, or other sharp objects that could cause the diver physical harm if he were to collide with them.

Visibility

See Sections 4.2 and 5.2.

Water Temperature

Since the deep sea dress is warm and waterproof and heavy woolen underwear and gloves are usually worn, the deep sea diver is not hindered by cold water. However, if the air temperature is cold enough (below freezing) the moisture in the compressed air, being pumped to the diver, may condense and freeze in the diver's airhose, thus blocking the diver's airhose. U. S. Bureau of Ships Diving Manual (1952) contains complete information on this subject.

Biological Factors

In general, the biological factors that effect SCUBA divers also must be taken into consideration by divers wearing conventional diving dress. The conventionally dressed diver, as well as the SCUBA diver when wearing some kind of diving suit, will have protection against abrasions caused by coral growths, jellyfish, and sea urchins.

Kelp is a large sea weed which grows extensively on a rock or cobble bottom in relatively cold waters. Near the bottom it grows in thick rubberlike stalks (stipes). At the water surface the fronds spread out covering large areas. The SCUBA diver, having no surface connection, can easily avoid the kelp. But the conventional diver, having an airhose and lifeline, would find movement very difficult in kelp beds. Also the attending vessel could not operate over dense kelp beds.

Sea, Swell, and Weather

In general, sea and swell will have much the same effect on a diver, no matter how equipped. Therefore, Section 5.2 is also applicable for the conventional diver; however, unlike the skin diver the conventional diver is attached to a surface vessel by lifeline and airhose. By this connection to the surface he is more under the influence of the sea state than is the SCUBA diver.

Frequently the bottom wave motion will not be as dangerous to the diver as the surface wave motion. The ship tending the diver, when in an exposed position, must be relatively large and seaworthy so that it can be substantially anchored, preferably heading into the sea, and not allowed to swing with the tide and wind. Otherwise, when relatively high sea or swell is running, the diver's lifeline and airhose are in constant motion.

In general, short choppy waves will influence the diver-tending ship, but will not bother the diver at any great depth; the long-period swell will not bother the tending vessel much, but the motion will be bothersome to the diver unless he is at a depth more than one-half the swell wavelength (Fig. 5.10).

When a storm is approaching, the diver should be brought up from the bottom in sufficient time to allow for decompression before the waves become large.

Currents

The deep sea diver, wearing a lifeline and heavy weights (with certain exceptions), will be less affected by currents than the SCUBA diver and will be able to work in stronger currents.

If deep sea diving must be performed in a tideway where the tidal current is very rapid, diving time may be limited to periods of slack water. The time of these periods can be found by consulting the tide and current tables for the area. The strength of the tidal current in which a diver can work varies according to his physical capabilities. The behavior of a descending line gives a good guide as to when a diver may do useful work on the bottom. When a 55-pound lead weight will not rest on the bottom, but is swept off by the tidal current, the diver generally cannot do useful work (Davis, 1935).

When a diver is working in a tideway such that he has to spend considerable time decompressing, he must be called off the bottom in sufficient time to prevent his being exposed to too strong a tidal current while on the descending line or diving stage. Otherwise, he may be dragged off and float up to the surface. To prevent this, the diver can put his back to the tide so that he will be forced against the stage or descending line and not away from it (U. S. Bureau of Ships, 1952).

Generally, the strongest current speeds in which a diver can do useful work range from 2.0 to 2.5 knots (Davis, 1935). When it exceeds this range the strain on the airhose and lifeline is liable to pull him away from his work, unless he is lashed to it. In all places where the current speed is more than 1.5 knots, the diver may have to wear additional weights.

U. S. Hydrographic Office Publication No. 607 (1955) includes operating instructions for various current meters. These meters can be lowered overboard in a matter of minutes to determine the current speed and direction at any depth.

When a diver works in strong tidal currents, more nitrogen than normal is absorbed by the diver, and the decompression time required for return to the surface should be increased to the next increment of depth, time, or both.

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GLOSSARY OF TERMS USED IN OCEANOGRAPHIC PUBLICATIONS

The terms listed below are defined primarily to clarify the application of U. S. Hydrographic-Oceanographic Data Sheets (HODS) and may be useful for other Hydrographic Office oceanographic publications.

ABSORPTION: When a sound wave travels outward from a source into the sea, some of the sound energy is converted into heat by friction due to the viscosity of the water. This process is called absorption.

ACID: *Geology*—When applied to igneous rocks, indicates presence of high percentage of silica.

AIR EMBOLISM: Is due to an excessive air pressure within the lungs. It is caused by holding the breath while ascending, the excess overexpands the lungs, ruptures their air sacs and blood vessels, and forces air bubbles into the small blood vessels of the lungs. These bubbles are carried into the left side of the heart and into the arteries, where they produce various symptoms of circulatory blockage in the heart, brain, spinal cord, or other vital organs.

ALGAE: Marine, brackish, and fresh-water plants (including marine seaweeds), ranging in size from microscopic unicellular plants to the giant kelps. Marine algae often have leaflike and stemlike parts similar to those of terrestrial plants, but differ from them in cellular structure.

ALLUVIUM: Silt, sand, gravel, or other rock fragments deposited by running water.

AMBIENT NOISE: Noise produced in the sea by marine animals, ship and industrial activity, terrestrial movements, precipitation, and other underwater or surface activity.

AMPLITUDE: One-half the wave height or half the vertical distance between wave trough and wave crest.

ANTICLINE: An upward fold in a rock layer or layers.

ARGILLACEOUS: Containing clay particles 0.01 millimeter or less in diameter.

ASPHYXIA (carbon dioxide poisoning): Or suffocation of a diver is caused by too much CO$_2$ or CO in the lungs. Symptoms are fogging of faceplate, shortness of breath, sweating, headache, fatigue, and a general feeling of discomfort.

ATTENUATION: A general term which, applied to sound, includes both absorption and scattering.

AURORA AUSTRALIS: A phenomenon in the Southern Hemisphere corresponding to the aurora borealis in the Northern Hemisphere.

AURORA BOREALIS: A luminous phenomenon in the Northern Hemisphere, usually in the form of streamers of light from clouds of ionized gases in the upper atmosphere; the *northern lights*.

AURORAL ZONES: Areas in higher latitudes where *polar lights* (aurora australis and aurora borealis) occur. These displays usually are associated with sunspot activity and magnetic storms, and are visible only at night.

AVERAGE DEPTHS (Low Water): The average water depths based on soundings reduced to low water datum.

AVERAGE LIMIT OF ICE: Average seaward extent of ice during a normal winter.

AXIAL PLANE OF FOLDING: A plane which intersects a fold in such a manner that the sides of the fold are more or less symmetrical.

BACKRUSH: The flow of water down the foreshore following the uprush.

BACKWASH: *See* BACKRUSH.

BAR: An elongate shallow-water feature composed of sand, gravel, or other unconsolidated sediments, bounded by water on at least both elongated sides, and either submerged or exposed.

BARNACLES: Marine crustaceans, most of which attach and grow on hard objects at or below the surface and have a calcareous shell. Some are called *sea acorns*.

BASEMENT COMPLEX: Crystalline rocks which appear to underly all other rocks.

BATHOLITH: A large igneous intrusive mass having an exposed area greater than 40 square miles and no visible or clearly inferable floor.

BATHYMETRIC CHART: Chart showing depths of water by means of contour lines or by color shading.

BATHYMETRY: Measurement of depth in water.

BATHYTHERMOGRAPH: A rugged instrument which may be used by a vessel at anchor or underway. It automatically draws a graph showing the temperature as a function of depth.

BEAUFORT WIND SCALE: (*See* table.)

BENCH MARK: A permanently fixed point of known elevation used as a reference for elevations. A *primary bench mark* is one close to a tide station to which the tide staff and tidal datum originally are referred.

BENDS: *See* COMPRESSED AIR ILLNESS.

BERM: The nearly horizontal portion of a beach or backshore, having an abrupt fall and formed by deposition of material by wave action.

BIOLOGY (Marine): The study of the life history and ecology of marine and brackish water plants and animals.

BEAUFORT WIND SCALE

Beaufort No.	Seaman's description of wind	Sea signs	Knots	Terms used in U. S. Weather Bureau forecasts
0	CALM	Sea like a mirror	[1]	Light.
1	LIGHT AIR	Ripples—no foam crests	1–3	
2	LIGHT BREEZE	Small wavelets, crests have a glassy appearance and do not break.	4–6	
3	GENTLE BREEZE	Large wavelets, crests begin to break; scattered whitecaps.	7–10	Gentle.
4	MODERATE BREEZE	Small waves becoming longer; frequent whitecaps	11–16	Moderate.
5	FRESH BREEZE	Moderate waves, taking a more pronounced long form; many whitecaps, some spray.	17–21	Fresh.
6	STRONG BREEZE	Large waves begin to form; extensive whitecaps everywhere, some spray.	22–27	Strong.
7	MODERATE GALE	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.	28–33	
8	FRESH GALE	Moderately high waves of greater length; edges of crests break into spindrift; foam is blown in well-marked streaks along the direction of the wind.	34–40	Gale.
9	STRONG GALE	High waves; dense streaks of foam along the direction of the wind; spray may affect visibility; sea begins to roll.	41–47	
10	WHOLE GALE	Very high waves; the surface of the sea takes on a white appearance; rolling of the sea becomes heavy and shocklike; visibility is affected.	48–55	Whole gale.
11	STORM	Exceptionally high waves; small and medium sized ships are lost to view for long periods.	56–63	
12	HURRICANE	The air is filled with foam and spray; sea completely white with driving spray; visibility very seriously affected.	64–71	Hurricane.
13			72–80	
14			81–89	
15			90–99	
16			100–109	
17			110–118	

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[1] Less than 1.

Bioluminescence: The emission of light by living organisms.

Bore: Propagation of rising tide upstream as an abrupt front of churning water or as a visible wave or series of waves.

Bottom Sediments: Marine sediments found on the sea bottom. Sediments include eroded rock material, plant residue, and undisolved animal remains.

Brackish Water: Water in which salinity values range from approximately 0.50 to 17.00 parts per thousand (°/oo).

Brash Ice: Small fragments of sea or river ice less than 6 feet in diameter.

Breakup, Earliest: Earliest reported date that landfast and pack ice begin to disintegrate prior to final clearance.

Breakup, Latest: Latest reported date that landfast and pack ice begin to disintegrate prior to final clearance.

Bryozoans: Minute animals, usually forming plantlike colonies, which attach from the tidal zone to great depths.

Calcareous: Containing calcium carbonate.

Calcareous Algae: Marine plants which form a hard external covering of calcium compounds. Calcareous algae are found in all oceans and frequently form reefs.

Chart Datum: The plane to which soundings on a chart are referred, usually low water.

Clastic Rock: Rock, such as sandstone and conglomerate, which is composed of fragments of other rocks.

Coastal Currents: *See* NEARSHORE CURRENTS.

Coelenterates: A group of marine animals which includes jellyfishes, corals, and hydroids.

Comb Jellies: Common name for members of the phylum Ctenophora; small jellyfishlike animals which live in the surface layers of the ocean, usually spheroidal and with comb plates. They are common marine animals, often occurring in enormous concentrations; many species are strongly bioluminescent.

Complete Freezing, Earliest: The earliest reported date when ten-tenths ice coverage was observed at a specific location.

Complete Freezing, Latest: The latest reported date when ten-tenths ice coverage was observed at a specific location.

Compressed Air Illness: Commonly called the *bends*, *decompression sickness*, or *caisson disease*, a condition resulting from inadequate decompression following exposure to pressure. Bubbles of nitrogen are formed in the tissues and blood vessels. Their obstruction causes pain, paralysis, asphyxia, and possible death.

Concentration, Ice: The percentage of ice cover in a given area of water, usually expressed in tenths.

Conglomerate: Consolidated gravel.

Consolidated Pack Ice: Any large area of drift ice driven so closely together as to produce ten-tenths ice coverage.

Consolidated Sediments: Sediments that have been converted into rocks by compaction, by deposition of cement in pore spaces, and/or by physical and chemical changes in the constituents.

Continental Deposits: Deposits laid down on land by rivers, winds, glaciers, etc., in contrast to deposits laid down in the ocean.

Continental Shelves: The zone surrounding continental blocks extending from the low water line to the depth at which a marked increase of slope to greater depth occurs.

Continental Slopes: The declivity from the outer edge of the continental shelf or continental borderland into great depths.

Copepods: Small crustaceans, usually less than ¼ inch in length, somewhat resembling tiny shrimp. Many species are bioluminescent, producing a brilliant sparkling light. Greatest concentrations occur in the surface layers of temperate and subarctic waters.

Coral: *Biology*—Marine coelenterates, solitary or colonial, which form a hard external covering of calcium compounds, or other materials. The corals which form large reefs are limited to warm, shallow waters, while those forming solitary, minute growths may be found in colder waters to great depths. *Geology*—The concretion of coral polyps, composed almost wholly of calcium carbonate, forming reefs, and treelike and globular masses. May also include calcareous algae and other organisms producing calcareous secretions, such as bryozoans and hydrozoans.

Coral Head: A massive mushroom or pillar-shaped coral growth.

Coral Reef: A calcareous structure built by large colonies of coral or shell-forming organisms.

Core: A vertical, cylindrical specimen of the bottom sediments from which the nature and stratification of the bottom may be ascertained.

Correction for Datum: A conversion factor used in tidal prediction to resolve the difference between chart datums of the reference and secondary station.

Cotidal Lines: Lines on a map or chart passing through all points at which high waters occur at the same time. The lines show the lapse of time, usually in lunar-hour intervals, between the moon's transit of the Greenwich meridian and the occurrence of high water for any point lying along the line.

Countercurrent: A secondary current adjacent to and setting in a direction opposite to the main current.

Crack: An unnavigable, narrow break in sea ice that may reveal the water surface. Cracks are usually caused by tides, temperature change, current, or wind.

Crest of Berm: The seaward margin of the berm. *See* BERM.

Critical Velocity: The speed at which a current can scour the bottom enough to maintain the required depth in a channel.

Crystalline: Composed of crystals. Can refer to structure of either igneous or metamorphic rocks.

Cumulative Frequencies: Percent of surface waves or pressure fluctuations exceeding any specified height and period combination.

Current: A movement of water. *See* TIDAL CURRENTS, NONTIDAL CURRENTS.

Current Direction: *See* SET.

Current Pattern, Secondary: Water movement which differs from the prevailing current pattern.

Current Rose: A graphical representation of currents, usually by 1° quadrangles, using arrows for the cardinal and intercardinal compass points to show resultant drift and frequency of set for a given period of time.

Datum: *See* CHART DATUM.

Datum Plane: *See* CHART DATUM.

Decay Distance: The distance between the waves' generating area to any point in the path of the wave.

Declination: *Terrestrial Magnetism*—The angle which the vertical plane fixed by the direction of the magnetic lines of force at that point makes with the plane of the true meridian. Declination is expressed in degrees and minutes and may be referred to as *variation* or *deviation*. *Tides*—The angle that the sun or moon makes with the plane of the equator.

Decompression: The degree of body saturation by various dissolved gases resulting from pressure depends upon length of time of exposure, depth of dive, and circulatory efficiency. For the diver to arrive safely at the surface, sufficient time must be allowed for this gas to escape without bubble formation in the body tissue. The escape of this gas is called decompression.

Delta: An area of alluvial deposit, usually triangular in outline, near the mouth of a river.

Deltaic Deposits: Sedimentary deposits laid down in a river delta.

Density: Mass per unit volume; usually expressed in grams per cubic centimeter.

Deposition of Sediments: A process whereby rock debris, which has been suspended in water, drops to the bottom out of suspension. This occurs when the transportation velocity of the medium drops below a minimum.

Descending Line: A line from the diving platform to the sea bottom, used to guide the diver to the bottom and for lowering tools and equipment.

Detritus: Particles worn from rocks by mechanical means; also broken organic material.

Dike: A barrier to prevent encroachment of sea water on land; usually constructed of earth, stone, rubble, or concrete. *Geology*—An igneous intrusion that cuts across the bedding or other layered structure of the surrounding rock.

Dinoflagellates: *See* PROTOZOANS.

Dip: *Geology*—The angle at which the rock structure is inclined with a horizontal plane. *Terrestrial Magnetism*—The angle formed by the lines of total magnetic force with the horizontal plane at the earth's surface; reckoned positive if downward. *Inclination*. *Mines*—The increase in depth of a moored mine case, due to current force against the case and cable.

Directivity: The property of sound energy which is confined to a beam.

Directivity Index: A measure of sound pressure level in one direction compared to that in all other directions.

Diurnal: *Tides*—Having a period or cycle of approximately one lunar day (24.84 solar hours): The tides and tidal currents are said to be diurnal when a single flood and single ebb occur each lunar day.

Diurnal Fluctuations: Variations occurring within a 24-hour period and related to the rotation of the earth.

Diurnal Inequality: The difference in height and/or time of the two high waters or of the two low waters of each day; also, the difference in velocity of either the two flood currents or the two ebb currents of each day.

Diurnal Range: Contracted form of *Great diurnal range*. *See* GREAT DIURNAL RANGE.

Diver's Decompression Stages: Platforms on which a diver stands to be moved over the side into the water and for bringing divers to the surface from the sea bottom, according to the decompression tables.

Drift: Speed of current flow downwind.

Drift Ice: Any ice that has drifted from its place of origin.

Drumlin: An elongate or oval hill of glacial drift normally compact and unstratified, usually with its longer axis parallel to the direction of the movement of the transporting ice.

Dunes: Hills or ridges of wind-blown sand.

Duration: *Terrestrial Magnetism*—Time required for the completion of a magnetic storm, short-period magnetic fluctuation, or quiet period; usually expressed in normal time intervals, for example, 5 days, 2 hours, or 150 seconds. *Tides*—The time elapsed from the beginning of flood, ebb, or slack to their culmination.

Earth's Magnetic Poles: Areas in the higher latitudes where lines of magnetic force converge.

Ebb Currents: Currents associated with a decrease in the height of a tide. They generally set in a direction opposite to tidal progression and perpendicular to the cotidal lines. Ebb currents generally set seaward.

Ecology: Study of the relationship between organisms and their environments.

Eddy: A circular movement of water. Eddies may be formed where currents pass obstructions or between two adjacent currents flowing counter to each other.

Eelgrass: A submergent marine plant with very long narrow leaves.

Effusive and Extrusive Rock: Molten rock which has escaped from an opening, such as a fissure or vent, and has cooled and solidified on the earth's surface. Common types are lava flows and tuffs.

Electrical Conductivity: The numerical equal of the reciprocal of resistivity. The unit of conductivity is mho/centimeter.

Emergents: Algae and sea grasses which are at least partially exposed at lowest low water.

Encrusting Forms: Marine life which forms a hard surface on submerged objects by attachment fouling.

Epicenter: In seismology, the point on the earth's surface directly over the focus or theoretical point of origin of an earthquake.

Epoch: *Terrestrial Magnetism*—A period of time over which magnetic elements are considered; usually 10 years.

Equatorial Tides: Tides that occur approximately every two weeks when the moon is over the equator. At these times, the moon produces minimum diurnal inequality in the tide.

Erosion: The general wearing away of the land by the destructive processes of wind, running water, and other physical agencies.

Erosion, Base Level of: The lowest level to which a river can erode its bed is called the base level. The sedimentary transporting power is minimal or has reached equilibrium at this level.

Estuary: A semi-enclosed coastal body of water having a free connection with the open sea and containing a measurable quantity of sea salt.

Extrusion: The process by which molten material flows out of, or is ejected from an opening in the earth's crust.

Extrusive Rock: *See* EFFUSIVE ROCK.

Fairway: The navigated areas of rivers, channels, bays, and harbors.

Fast Ice: *See* LANDFAST ICE.

Fault: A break or shear in the earth's crust, with an observable displacement between the two sides of the break, and parallel to the plane of the break.

Fetch: The distance of sea surface over which the wind blows unhindered by a land mass to generate waves.

Filtering Effect: The differential damping of pressures or of vertical oscillation of water particles with increasing depth, depending upon the wave period. Longer waves are damped less than shorter waves at a given depth.

Final Ice Clearance, Earliest: Earliest reported date after breakup that open water (less than 1/10 coverage) was first observed over a specific area.

Final Ice Clearance, Latest: Latest reported date after breakup that open water (less than 1/10 coverage) was first observed over a specific area.

First Appearance of Ice, Earliest: The earliest reported date on which sea ice in any form was observed at a specific location.

Flocculent Deposit: An aggregrate or precipitate of small lumps formed by precipitation.

Floe: Fragments of ice other than icebergs with no specific size intended.

Flood Currents: Currents associated with an increase in the height of a tide. They generally set in the same direction as the tidal progression and perpendicular to the cotidal lines.

Fluorescence: The rapid reproduction of plankton. *See* PLANKTON BLOOM.

Fluctuate: In tidal information, this generally refers to variations of the water level from mean sea level that are not due to tide-producing forces and are not included in the prediction heights of the tide.

Fold: A bend in a layer or layers of rock strata.

Forel Scale: The basic scale for measuring water color. *See* FOREL SCALE, MODIFIED.

Forel Scale, Modified: A variation of the Forel scale used to express water color of the sea.

Water color	*Modified scale number*
Deep blue	00
Blue	10
Greenish blue	20
Bluish green	30
Green	40
Light green	50
Yellowish green	60
Yellow green	70
Green yellow	80
Greenish yellow	90
Yellow	99

Foreshore: Portion of the shore or beach lying between the low-water mark and the upper limit of normal wave action.

Formation: A stratum or a set of strata possessing a common suite of lithological and/or faunal characteristics. A unit which can be mapped.

Fouling: The assemblage of marine organisms that attach to and grow upon underwater objects.

Fouling, Moderate: A relative term, indicating sufficient fouling accumulation to interfere with the mechanical operations of submerged gear.

Fouling, Severe: A relative term, indicating fouling accumulation to such a degree and nature as to interfere *seriously* with the mechanical operation of submerged gear.

Fouling, Slight: A relative term, indicating fouling accumulation to such a degree and nature as to interfere only *slightly* with the mechanical operation of submerged gear.

Frequency: *Terrestrial Magnetism*—The number of magnetic storms, short-period magnetic fluctuations, or quiet periods that occur within a designated time interval.

Freshet: The sudden increase, usually of limited duration, in river or stream discharge rate generally caused by heavy rainfall or spring thaws.

Frond (Blade): *See* KELP.

Gabbro: *See* IGNEOUS ROCK.

Gamma: A unit of magnetic force equal to 10^{-5} C. G. S. units.

Gauss: *See* OERSTED.

Geology: The science that treats of the origin, history, and structure of the earth as recorded in the rocks, together with the forces and processes now operating to modify rocks.

Glacial Drift or Glacial Alluvium: Rock debris which has been transported by glaciers and deposited either in place as the ice melts, or carried some distance by accompanying melt water before deposition.

Glacial Till: *See* SEDIMENTARY ROCK.

Glacier: A field or stream of ice, formed by the accumulation of snow, moving down a slope and spreading by its own weight.

Glaçon: A fragment of sea ice ranging in size from brash to a medium floe.

Glauconitic Sandstone: *See* SEDIMENTARY ROCK.

Gneiss: *See* IGNEOUS ROCK, METAMORPHIC ROCK.

Gradient: Rate of change of one quantity with respect to another, for example, the change of temperature per unit depth.

Granite: *See* IGNEOUS ROCK.

Granodiorite: *See* IGNEOUS ROCK.

Gravel: An unconsolidated mixture of clastics, ranging in grain size from sand to cobbles. *See* STONE.

Graywacke: *See* SEDIMENTARY ROCK.

Great Diurnal Range: The difference in height between mean higher high water and mean low low water over a 19-year period. Contracted form is *diurnal range.*

Great Tropic Range: The difference in height between tropic higher high water and tropic lower low water. Contracted form is *tropic range.*

Gypsum: (Geology)—Hydrous calcium sulphate.

Half Tide Level: A plane midway between mean high water and mean low water.

Harbor: An area of water affording natural or artificial protection for ships.

Harbor Area: The area of the water surface in a harbor or port, measured at a given datum.

Harbor Defense Atlas: A series of publications containing environmental data designed for mine countermeasures for specific harbors. This series is published by the Hydrographic Office.

Harbor Volume: The volumetric water content of a harbor or port measured at a given datum.

Headland: A portion of land jutting into a body of water.

Height-Period Combination: Waves with specified height and period.

Height: *Tides*—The vertical distance, either positive or negative, of any tide stage in reference to the datum of soundings of the largest scale charts of the locality; usually in feet above chart datum. *See* WAVE HEIGHT.

High Water: The maximum height reached by a tide. The height may be due solely to the periodic tidal force or it may have superimposed upon it the effects of meteorological conditions.

High Water Line: The intersection of the plane of mean high water with the shore.

Higher High Water (HHW): The higher of the two high waters of any tidal day or the single high water when a semi-diurnal tide becomes diurnal.

Higher Low Water (HLW): The higher of the two low waters of any tidal day.

Horizontal Intensity: The intensity of the horizontal component of the magnetic field in the plane of the magnetic meridian.

Hummocked Ice: Ice piled in the forms of mounds or hillocks.

Hydrographic-Oceanographic Data Sheets (HODS): Part of Air Target Materials Program (ATMP) published by the Hydrographic Office. Includes marine environmental intelligence for specific mining targets designed for use in aerial mining planning.

Hydroids: Slender-stalked marine coelentrates which attach to submerged surfaces and generally resemble plants. They range from tropic to northern waters.

Hydrostatic Pressure: The pressure due to water depth commonly measured in pounds per square inch.

Ice-Free Port: A port in which ice formations sufficient to interfere with navigation in the harbor or at the terminals has not been recorded.

Ice Period (Season): The time between first appearance and final clearance of ice during any year.

Igneous Rock: Rock formed by the solidification from a molten state.

Inclination: *See* DIP (*Terrestrial Magnetism*).

Indurated: Hardened; rocks hardened by heat, pressure, or the addition of some ingredient not commonly contained in the rock referred to, for example, sand indurated by limonite.

Initial Penetration (mine): The depth to which a mine sinks into the bottom upon impact.

Inshore: The region shoreward of a certain depth of water, usually either the 3- or 5-fathom isobath.

Inshore Currents: The movement of water inside the surf zone, including *longshore* and *rip* currents.

Inshore Water: Water contiguous to land in which the physical properties are considerably influenced by continental conditions.

Insolation: The absorption of solar energy by the ocean.

Intensity: The magnetic force, measured in oersteds or gammas, exerted upon a unit magnetic pole located at a given point.

Intensity, Acoustic: Intensity, I, in root mean square pressure, P, of a plane wave. $I = P^2/\rho c$ where ρ is the density and c the sound velocity. Units are measured in energy per square centimeter per second.

International Low Water (ILW): A plane of reference below mean sea level (MSL) by the following amount: half the range between mean lower low water (MLLW) and mean higher high water (MHHW) multiplied by 1.5.

Intertidal Zone: Generally considered to be the zone between mean high water and mean low water levels.

Intrusive Rock (Intrusives): Molten magma which has solidified beneath the earth's surface.

Isobaths: Lines connecting points of equal depth.

Isohaline: Having no change in salt content within a water mass or along a reference plane.

Isothermal: Having no change in temperatures within a water mass or along reference plane.

Jellyfish: Common name for medusoid coelenterates; they are semitransparent, pelagic, tentacled invertebrates. Some species have venom cells in their tentacles; some are capable of producing a glowing-ball type of bioluminescence.

Jetty: A pier or breakwater which extends out into the water and diverts or controls currents in order to protect channels.

Karst Topography: Topography in areas of limestone marked by sink holes, interspersed with abrupt ridges and irregular protuberant rocks, and by caverns and underground streams.

Kelp: Brown algae of the order Laminariales, including the largest known algae. Kelp typically grow on rock or stone bottom. They attain their greatest size in cold waters, with lengths as great as 100 feet and blades 4 or more feet in width.

Landfast Ice: All types of ice, either broken or unbroken, attached to the shore, beached, or stranded in shallow water; also called *fast ice*.

Lead: A long, narrow, but navigable water passage in pack ice. A lead may be covered by thin ice.

Limestone: A sedimentary rock consisting essentially of the mineral calcite (calcium carbonate).

Lithology: (a) Study of the characteristics of rocks, or (b) the composition of rocks.

Littoral Currents: *See* LONGSHORE CURRENTS.

Littoral (Zone): The marine environment influenced by a land mass. The coastal region.

Loess: A buff-colored, unstratified deposit ranging in grain size from clay to fine-grain sand and distributed and deposited by wind action.

Longitudinal Waves: Waves in which the vibrations of the particles are parallel to the direction of propagation.

Longshore Currents: Currents moving within the surf zone parallel to the shoreline. Generated by waves breaking at an angle to the shoreline.

Low Water (LW): The minimum height reached by a tide. The height may be due solely to the periodic tidal forces, or it may have superimposed upon it the effects of meteorological conditions.

Low Water Datum: An approximation of mean low water that has been adopted as a standard datum for a limited area, although it may differ slightly from a later determination.

Low Water Equinoctial Springs: Low water springs near the times of the equinoxes.

Lower High Water (LHW): The lower of the two high waters of any tidal day.

Lower Low Water (LLW): The lower of the two low waters of any tidal day or the single low water when a semidiurnal tide becomes diurnal.

Lower Low Water Datum: An approximation of mean lower low water that has been adopted as a standard datum for a limited area, although it may differ slightly from a later determination.

Lowest Low Water: A plane of reference whose depression below mean sea level corresponds with the level of the lowest low water of any normal tide.

Lowest Low Water Springs: A plane of reference approximating the level of the lowest low water during syzygy.

Lowest Normal Tides: A plane of reference lower than MSL by half the maximum range. (This does not take into account wind or barometric pressure fluctuations.)

Luminescence: *See* BIOLUMINESCENCE.

Lunar Day (Tidal Day): The time of the rotation of the earth with respect to the moon, or the interval between two successive upper transits of the moon over a local meridian. The mean lunar day is approximately 24.84 solar hours or 1.035 times as great as the mean solar day.

Magma: A naturally occurring liquid molten mass, the molten material from which igneous rocks are formed by solidification.

Magnetic Anomaly: Variation of the measured magnetic pattern from a theoretical or empirically smoothed magnetic field on the earth's surface.

Magnetic Elements: Consist of the declination (D), inclination or dip (I), vertical intensity (Z), horizontal intensity (H), and the total magnetic field (T).

Magnetic Equator: An imaginary line passing through the points on the earth's surface where values of the horizontal magnetic intensity are maximum and values of the inclination and vertical magnetic intensity are minimum.

Magnetic Storm: Marked and irregular variations in the values of magnetic intensity in the earth's magnetic field.

Magnitude: *Terrestrial Magnetism*—The intensity of a short-period magnetic fluctuation, usually expressed in milligausses or gammas.

Marble: A metamorphosed limestone. *See* METAMORPHIC ROCK.

Marl: Earthy mixture of clay and calcium carbonate in varying proportions.

Maximum Year: *Terrestrial Magnetism*—The year of greatest magnetic storm activity.

Mean Higher High Water (MHHW): The average height of the higher high waters over a 19-year period. Can be calculated for shorter periods by applying corrections for a 19-year period.

Mean High Water (MHW): The average height of the high waters over a 19-year period.

Mean High Water Neaps (MHWN): The average height of high water during quadrature over a 19-year period.

Mean High Springs: The average height of high water during syzygy over a 19-year period.

Mean Lower Low Water (MLLW): The average height of the lower low waters over a 19-year period. Can be calculated for shorter periods by applying corrections for a 19-year period.

Mean Lower Low Water Springs: The average height of lower low water during syzygy over a 19-year period.

Mean Low Water (MLW): The average height of the low waters over a 19-year period.

Mean Low Water Neaps (MLWN): The average height of low water during quadrature over a 19-year period.

Mean Low Water Springs (MLWS): The average height of low waters occurring at the time of syzygy over a 19-year period. It is usually derived by taking a plane depressed below the half-tide level by an amount equal to half the spring range of tide, necessary corrections being applied to reduce the result to a mean value.

Mean Range: The difference in height between mean high water and mean low water over a 19-year period.

Mean River Level: The average height of the surface of a river at any point for all stages of the tide over a 19-year period, usually determined from hourly height readings. Unusual variations of river level may be excluded in computation.

Mean Sea Level (MSL): The mean surface level determined by averaging all stages of the tide over a 19-year period, usually determined from hourly height readings and referenced to a fixed tide level.

Mean Tide Level (Half-tide level): The average of the high waters and the low waters over a 19-year period.

Mean Water Level (MWL): The mean surface level as determined by averaging the height of the water at equal intervals of time, usually hourly, over a considerable period of time.

Medusae: *See* JELLYFISH.

Metamorphic Rock: Rock formed by the alteration of preexisting rocks which have developed new physical and chemical characteristics as the result of pressure, heat, or other geologic agents within the earth's crust.

MHO/CM.: *See* ELECTRICAL CONDUCTIVITY.

Milligauss: Unit of magnetic force equal to 100 gammas or 0.001 gauss (oersted).

Minimum Year: *Terrestrial Magnetism*—The year of minimum magnetic storm activity.

Mixed Tide: Type of tide in which the presence of a diurnal wave produces a large inequality in either the high or low water heights, with two high waters and two low waters usually occurring each tidal day. This term is usually applied to the tides intermediate to those predominantly semidiurnal and those predominantly diurnal.

Mole: A massive, solid-fill nearshore structure of earth, masonry, or large stone which may serve as either a breakwater or a pier.

Molluscs (Mollusks): Marine animals (usually with shells) significant as fouling forms, including mussels, jingle shells, oysters, and boring forms, such as shipworms and boring clams.

Mud: A fine-grained moist sediment, the particles of which are finer than sand.

Mussels: Marine, brackish, or fresh-water molluscs; sometimes called *clams*.

Natural Frequency: The characteristic frequency, that is, number of vibrations or oscillations per unit time of a body controlled by its physical characteristics (dimensions, density, etc.). In a harbor, the natural frequency gives rise to waves, called *seiches*, which have periods and amplitudes dependent on the physical characteristics of the harbor.

National Intelligence Survey (NIS): A series of publications by the Central Intelligence Agency which include environmental data on a regional scale.

Neap Range: The average semidiurnal range occurring at the time of quadrature.

Neap Tides: Tides of decreased range occurring at the time of quadrature.

Nearshore Currents: Currents adjacent to and in conjunction with coastal areas.

Nearshore Water: *See* INSHORE WATER.

Noise Level: The comparison of sound intensity, usually measured in decibels, to a reference level. Underwater sound pressures are commonly expressed in decibels or dynes/cm.^{2}

Noise Spectrum: The relative amplitude of the several frequencies present in a complex tone (sound).

Nonemergents: Algae and sea grasses which are not exposed at lowest low water or chart datum.

Nontidal Currents: Includes the permanent currents in the general circulatory systems of the sea as well as temporary currents arising from winds.

Normal Ice Limit: *See* AVERAGE LIMIT OF ICE.

Normal Winter: Refers to normal ice season, that is, the average ice conditions based on a number of recorded winters in a given area.

Ocean Water: Water having the physical-chemical characteristics of the open sea and where continental influences are at a minimum.

Oersted: The magnetic force in dynes acting on a unit C. G. S. magnetic pole.

Offshore: Converse of INSHORE.

Offshore Currents: Nontidal currents outside the surf zone, which are not affected by shoaling and river discharge.

Offshore Water: Water adjacent to land in which the physical properties are slightly influenced by continental conditions.

Offshore Winds: Land breeze. Winds blowing seaward from the coast.

OHM–CM: *See* RESISTIVITY.

Onshore Winds: Sea breeze. Winds blowing shoreward from the sea.

Ooze: An unconsolidated deposit composed almost entirely of the shells and undissolved remains of foraminifers, diatoms, and other marine life, for example, diatom ooze, and foraminiferal ooze.

Open Port: A port which is not icebound during winter.

Open Water: Water with less than one-tenth ice coverage.

Ordinary Tides: The word *ordinary* may be used in tides as the equivalent of the word *mean*.

Outcrop: That part of a rock stratum which is exposed at the surface of the earth or on the sea floor.

Overfalls: Turbulent water surface produced either by strong currents flowing over shoal bottom or by conflicting currents. *See* RIP.

Oxygen Poisoning: Poisoning by high oxygen concentrations within the body causing strychnine-like effects upon the nervous and muscular systems and possibly irritating the delicate lung membranes.

Pancake Ice: Pieces of newly formed ice normally between one and six feet in diameter.

Pack Ice: Any large area of floating ice which has been driven closely together.

Peat: A dark brown or black residue produced by the partial decomposition and disintegration of vegetable matter (mosses, sedges, trees) that grows in marshes and similar wet places.

Pebble: A small rounded rock from 6 to 50 millimeters in diameter. Pebbles are not differentiated from gravel in HODS. *See* GRAVEL.

Pelagic Organisms: Pertaining to all organisms inhabiting the open sea, except bottom dwellers.

Period: *Terrestrial Magentism*—The time interval of a short-period magnetic fluctuation (in seconds) or a quiet period (in weeks). *See* WAVE PERIOD.

Permeable Rock: Rock having a texture that permits water to move through it under pressure.

Phosphorescence: Property of emitting light without sensible heat, luminescence. *Bioluminescence* is the preferred term.

Physical Properties: The physical characteristics of sea water—temperature, salinity, density, sound velocity, electrical conductivity, and transparency.

Phytoplankton: The plant life of plankton as for example, diatoms and algae. Unattached plants which are at the mercy of the currents.

Piling: Wood, concrete, or metal poles driven into the sea bottom for support or protection.

Plankton: All the drifting and floating life of the sea. It is made up of microscopic or relatively small plants and animals, which are at the mercy of water movements. Many of the organisms can swim, but their locomotion is relatively weak and ineffective.

Plankton Bloom: The rapid growth and multiplication of plankton (usually plant forms) producing an obvious change in the physical appearance of the sea surface, such as coloration or *slicks;* also called *sea bloom.*

Plastic Flow: A phenomenon whereby the bottom sediments under pressure of the mine's weight flow out from under the mine allowing partial or complete burial.

Plutonic Rock: Igneous rocks which have cooled some distance below the surface and usually possess phaneritic (fine-grained) structure.

Porosity: The percentage of pore space in the total volume of the dry bottom sediment sample. This percentage expresses the volume that can be occupied by water.

Precipitation: All forms of falling moisture, including rain, snow, hail, etc.

Pressure Fluctuations: Oscillation about static water pressure caused by wave action.

Prevailing Currents: The predominant or usual movement of water.

Protozoans: Minute one-celled animals, most of which are invisible to the naked eye and occur universally in the surface layers of the sea. Several genera are capable of producing bioluminescence, usually of the sheet type.

Quadrature: The two opposite points in the orbit of the moon at which its longitude differs by 90° from that of the sun, relative to the earth; points of first and last quarters.

Quiet Periods: Periods during which short-period magnetic fluctuations do not exceed specified magnitudes.

Range: The differences in height between consecutive high and low waters.

Ratio of Ranges (height ratio): The ratio of the height of the tide at the secondary station to the height of the tide at the reference station.

Reef: A chain or range of rocks or coral at or near the surface of the water in depths less than 6 fathoms.

Reference Station: A tide or current station for which tidal or tidal-current constants have previously been determined and which is iused as a standard for the comparison of simultaneous observations at a secondary station; also a station for which independent daily predictions are given in the tide or current tables from which corresponding predictions are obtained for other stations by means of differences or factors.

Refraction: In a homogeneous medium, sound will travel in a straight line. But sound rays are bent if the velocity of propagation is not the same at all points. When a sound wave passes obliquely from a medium of one velocity to a medium of another velocity, the sound wave will be bent toward the medium of lower velocity. This phenomenon is called refraction.

Relative Density: The number of one type of organism per unit area of a submerged surface or occurring in a period time compared with the number of other types of attaching organisms in the same fouling complex.

Resistivity: The resistance between opposite faces of a one-centimeter cube of a given substance. The unit of resistivity is ohm-centimeter.

Reverberation: The resultant of a large number of very weak echoes arising from small bodies (such as air bubbles or suspended solid matter) in the sound-wave path. These tiny particles scatter part of the sound energy as it passes. Some of the scattered sound energy will return back to the listening device where it is heard as reverberation.

Ridged Ice: Pressure ice having readily observed surface roughness in the form of a ridge or many ridges.

Rip: Turbulent water produced by conflicting tides or currents; generally, a vertical oscillation. *See* OVERFALLS.

Rip Currents: Narrow seaward-moving water currents which return to deep water the water carried landward by waves. Rip currents are believed to be almost universally associated with larger breakers on an exposed coast.

Rip Tide: *See* RIP CURRENT.

Roadstead: A tract of water near shore with good holding ground for anchors and some protection from heavy seas.

Rock: The naturally occurring material that forms the firm, hard, and solid masses of the earth's crust or ocean floor.

Rockweed: An algae.

Rotary Current: A tidal current that flows continually, with the direction of flow changing through all points of the compass during a tidal cycle. The tendency to rotate has its origin in the deflecting force of the earth's rotation, and, unless modified by local conditions, is clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. The speed of the current usually varies throughout the tidal cycle, with two maxima in opposite directions, and two minima with directions at approximately right angles from the directions of the maxima.

Salient Point: A point of land projecting sharply from the shore.

Salinity: The total amount of solid material in grams contained in one kilogram of sea water when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine, and all organic matter completely oxidized.

Sand: Grains of minerals or rock fragments the diameters of which vary from 0.015 to 2.0 millimeters in diameter; characterized by easily distinguishable grains.

Sandstone: Consolidated sand.

Sargassum: A marine algae which grows attached to the bottom in tropical and subtropical waters and becomes detached to form extensive drifts, sometimes called *gulfweed.*

Scarp: A sharp, steep slope along the margin of a plateau, terrace, etc.

Scattering: When a sound wave travels outward from a source into the sea, the energy produces a primary directional wave and also secondary wavelets which travel in other directions. This phenomenon is called scattering.

SCUBA: Abbreviation for self-contained underwater breathing apparatus.

Scour (Erosion) of Bottom Sediments: A process whereby the sediments are picked up from their resting place and are carried some distance. Energy, needed to carry out this process, is supplied by water currents and wave oscillations.

Sea (Wind Waves): Waves generated by local winds. These waves are relatively short in period and generally advance in the same direction as the wind.

Sea Bloom: *See* PLANKTON BLOOM.

Sea Code: (*See* table.)

Sea Grass: Seed-bearing marine plants, more highly organized than algae, found in shallow waters both brackish and marine, attaining lengths up to 8 feet.

Sea Level Datum: A determination of mean sea level that has been adopted as a standard datum for heights although it may differ from a later determination over a longer period of time.

Sea Slick: An area of sea surface, variable in size and markedly different in appearance (color and oiliness); usually caused by plankton blooms.

Sea State: Description of sea conditions such as calm, moderate, rough, etc. *See* SEA.

Seaweed Bed: An area of attachment and growth of many algae or eelgrass.

Secchi Disc: A white or varicolored disc, usually abour 30 cm. in diameter, used to measure transparency. The disc is lowered slowly in the water, and the depth in meters at which the disc disappears from sight is averaged with the depth at which it reappears upon raising; this average figure represents the transparency.

Secondary Station: A tide station operated only over a short period of time or one at which limited data are collected. *See* SUBORDINATE STATION.

Secular Change: Increase or decrease of intensity and/or change of direction of the total magnetic field over a period of several years; usually given as average gammas per year for intensity values and minutes per year for directional values.

Sedimentary Rock: Rock that is deposited in a more less finely divided state, such as sediment through the agency of water, wind, glacier, or precipitation from solution, and later compacted or cemented into a rock. Sandstone, limestone, shale conglomerate.

Seiche: A stationary wave oscillation with a period varying from a few minutes to an hour or more (somewhat less than tidal periods), being dependent upon the dimensions of the basin in which it occurs. Seiches usually are attributed to strong winds, atmospheric pressure changes, or seismic disturbances and are found in enclosed bodies of water or superimposed upon the tidal waves of the open ocean.

Seismic Activity: *See* SEISMICITY.

Seismicity: The phenomena of earth movements.

Semidiurnal: Having a period or cycle of approximately half a lunar day (12.42 solar hours). The tides and tidal currents are said to be semidiurnal when 2 flood and 2 ebb periods occur each lunar day.

Sessile: Fouling organisms which are firmly attached to a substratum.

Set: The direction in which a current is flowing; for example, when a current *sets* southward, the movement of water is toward the south.

Set, Frequency of: The number of times that a particular set occurs expressed as a percentage of the total number of observations in a specific area. *See* SET.

Shale: *See* SEDIMENTARY ROCK.

Shell Forms: Attachment fouling organisms which possess a hard external covering.

Ship Observations: *Sea and Swell*—Wind observations for a specific location tabulated by direction (compass) and Beaufort force (speed) and observed from a ship underway or at anchor.

Shoaling Effect: Alteration of a wave proceeding from deep water into shallow water.

Shoreline: The juncture of land and sea during low tide unless otherwise specified.

SEA CONDITIONS, U. S. HYDROGRAPHIC OFFICE SCALE

Code Fig.	*Approx. Height of Sea*	*Seaman's Description*
0	0	CALM—Sea like mirror.
1	Less than 1 foot.	SMOOTH—Small wavelets or ripples with the appearance of scales but without crests.
2	1–3 feet	SLIGHT—The waves or small rollers are short and more pronounced, when capping the foam is not white but more of a glassy appearance.
3	3–5 feet	MODERATE—The waves or large rollers become longer and begin to show whitecaps occasionally. The sea produces short rustling sounds.
4	5–8 feet	ROUGH—Medium waves that take a more pronounced long form with extensive whitecapping and white foam crests. The noise of the sea is like a dull murmur.
5	8–12 feet	VERY ROUGH—The medium waves become larger and begin to heap up, the whitecapping is continuous, and the seas break occasionally; the foam from the capping and breaking waves begins to be blown along in the direction of the wind. The breaking and capping seas produce a perpetual murmur.
6	12–20 feet	HIGH—Heavy, whitecapped waves that show a visible increase in height and are breaking extensively. The foam is blown in dense streaks along in the direction of the wind. The sea begins to roll and the noise of the breaking seas is like a dull roar, audible at greater distance.
7	20–40 feet	VERY HIGH—High, heavy waves developed with long overhanging crests that are breaking continuously, with a perpetual roaring noise. The whole surface of the sea takes on a white appearance from the great amount of foam being blown along with the wind. The rolling of the sea becomes heavy and shocklike.
8	40 feet and over.	MOUNTAINOUS—The heavy waves become so high that ships within close distances drop so low in the wave troughs that for a time they are lost from view. The rolling of the sea becomes tumultuous. The wind beats the breaking edge of the seas into a froth, and the whole sea is covered with dense streaks of foam being carried along with the wind. Owing to the violence of the wind the air is so filled with foam and spray that relatively close objects are no longer visible.
9		NOTE—Qualifying condition applicable to the previous conditions, for example, (5–9). A very rough, confused sea.

SINK HOLE: A topographic depression which results from the collapse of the roof of a naturally occurring subsurface limestone cavern.

SLACK WATER (Slack tide): The state of a tidal current when its velocity is near zero, especially the moment when a current reverses direction. Sometimes considered the intermediate period between ebb and flood currents during which the velocity of the currents is less than 0.1 knot.

SNAPPING SHRIMP: Species of shrimp which produce sharp cracking sounds through the rapid closure of the large pincer claw. Greatest populations of snapping shrimp are found in shallow temperate and tropic waters on shell, rock, coral, and sponge bottoms. The noise produced ranges in frequency from 1.5 to 45 kilocycles, and interferes with sound ranging.

SOFT FORMS: Fouling organisms which do not possess a hard exterior. Examples of soft forms include tunicates, algae (other than calcareous algae), and hydroids.

SONIC FISHES: Species of marine fishes which produce sounds that may interfere with sound ranging or may affect acoustic mines.

Fish	*Estimated sonic importance*	*Approximate frequency range (kilocycles)*
Cod	Slight	0.08–0.8
Croaker	Considerable	0.4–0.8
Demoiselle	Moderate	0.07–0.1
Drum	Considerable	0.4–0.8
Filefish	Slight	0.05–0.8
Grunt	Considerable	0.2–0.4
Gurnard	Considerable	0.04–1.4
Herring	Slight	0.05–1.2

Fish	*Estimated sonic importance*	*Approximate frequency range (kilocycles)*
Jackfish	Slight	0.05–1.2
Jewfish	Unknown	0.05–1.2
Mackeral	Unknown	Undetermined
Ocean Sunfish	Moderate	0.05–1.2
Pompano	Slight	0.05–1.2
Rosefish	Moderate	Undetermined
Scorpion Fish	Moderate	Undetermined
Sculpin	Slight	0.02–0.7
Sea Catfish	Moderate	0.3–0.6
Sea Robin	Considerable	0.04–1.4
Toadfish	Considerable	0.08–0.8
Triggerfish	Slight	0.05–4.8
Tuna	Unknown	Undetermined

Sonic Marine Animals: Species of fishes, marine mammals, and crustaceans which may produce noise of sufficient intensity and frequency to interfere with sound ranging operations and acoustic mines.

Sonic Marine Mammals: Sound-producing marine mammals, such as seals, porpoises, and whales, which often congregate in schools or pods and produce enough noise to interfere seriously with sound ranging or acoustic mines. Noise produced ranges from subsonic to supersonic.

Sound Pressure Level: The root mean square deviation in decibels from the average hydrostatic pressure in a sound-transmitting fluid produced by sound waves.

Sound Velocity: *Sea Water*—The rate of propagation of sound energy in sea water as a function of temperature, salinity, and pressure.

Specific Resistance: *See* RESISTIVITY.

Spit: A small point of land or a long narrow shoal (usually sand) extending from shore into a body of water.

Spreading: The diminution of sound pressure level with distance according to various laws of behavior, such as spherical spreading, cylindrical spreading, or dipolar spreading.

Sponges: Sessile invertebrates which inhabit fresh, brackish, or salt water and occur from tropic to polar areas. They attach to submerged objects and, in warm waters, afford shelter for great concentrations of snapping shrimp. Sponges vary in size from very minute to several feet in diameter.

Spring Range: The *average* semidiurnal range of tide at time of syzygy.

Spring Rise: The mean height of high water above chart datum during syzygy.

Springs: Contraction of *spring tides* or *spring tidal currents.* Tides of increased range or tidal currents of increased velocity produced during syzygy.

Spring Tidal Currents: Contracted form, *springs. See* SPRINGS.

Spring Tides: Contracted form, *springs. See* SPRINGS.

Squeeze: The human body can withstand water pressure in excess of 16 atmospheres without any apparent change provided the air pressure within the body is equal to the externally applied water pressure. If the internal air pressure is less than the external water pressure by as little as one pound per square inch, the pressure difference will alter the normal tissue shape causing swelling within and bleeding from the tissue. These changes in turn cause symptoms of pain, shock, and cell destruction commonly called squeeze.

Stamukha (pl. Stamukhas)**:** A fragment of ice stranded on a shoal.

Stone: A bottom sediment notation sometimes appearing on navigation charts. Stone is not differentiated from gravel in HODS. *See* GRAVEL.

Stratified: A term applied to rocks consisting of originally horizontal beds or strata.

Stratum: A layer of rock more or less similar throughout; a lithologic unit.

Strike: The line of intersection of the plane of a structural element in rock and a horizontal plane.

Submerged Objects: Any objects which are more or less constantly beneath the surface of the water, having such a position as to be rarely exposed to the atmosphere, and never to be exposed long enough to become dry.

Subordinate Station: A tide or current station at which a short series of observations is obtained, which is to be reduced by comparison with simultaneous observations at another station having well-determined tidal or current constants; also a station listed in *Tide Tables or Current Tables* for which predictions are to be obtained by means of differences or factors applied to the full predictions at a reference station. *See* SECONDARY STATION.

Subsequent Penetration (mine)**:** The depth to which a mine sinks into the bottom after the initial impact.

Subsurface Currents: Currents flowing below the surface current. These currents normally flow a a different speed than the surface currents and may have a different set.

Summer Season: *Sea and Swell*—Consists of the months of July, August, and September; however, where observational data are sparse, April, May, and June may be included.

Swell: Ocean waves which have advanced beyond the area of their generation.

Swell Code: (*See* table.)

Syzygy: The two opposite points in the orbit of the moon at which it is in conjunction or opposition to the sun; points of new and full moon.

Tectonic: An adjective pertaining to or designating structures resulting from deformation of the earth's crust.

SWELL CONDITIONS

Code figure	Approximate height in feet	Description		Approximate length in feet
0	0	No swell		0
1	1–6	Low swell	Short or average	0–600
2			Long	Above 600
3	6–12	Moderate	Short	0–300
4			Average	300–600
5			Long	Above 600
6	Greater than 12	High	Short	0–300
7			Average	300–600
8			Long	Above 600
9		Confused.		

Terminal Velocity: The velocity that a falling mine will reach when the force of gravity is balanced by the frictional force due to resistance of the medium, that is, the vector sum of all forces acting upon the mine is zero.

Terrace: A plain, natural or artificial, from which the surface descends on one side and ascends on the other. Terraces are usually long and narrow, and border streams, seas, lakes, and interior valleys

Terrestrial Magnetism: The study of the natural magnetic field within and surrounding the earth and the factors affecting it.

Thermal Structure: Refers to the temperature variation with depth of sea water.

Tidal Current Cycle: The complete oscillation of the flood and ebb as it passes through all phases of the tide from high water to the next succeeding high water. The deviation of a semidiurnal tide approximates 12.42 hours, while that of a diurnal tide approximates 24.84 hours.

Tidal Currents: Currents caused by the horizontal movement of tides.

Tidal Cycle: *See* TIDAL CURRENT CYCLE.

Tidal Day: *See* LUNAR DAY.

Tidal Difference: Difference in time or height of a high or low water between a subordinate station and a reference station. The difference is applied to the prediction at the reference station to give the corresponding time or height for a subordinate station.

Tidal Flat: A flat, soggy area which is characterized by the simultaneous deposition of clay and sand in tidal waters that partly emerge during low tide.

Tidal Prediction: The prediction of times and heights of high and low waters for various reference stations throughout the world. Tidal predictions generally are published by the hydrographic departments of various countries, but in the United States are published by the U. S. Department of Commerce, Coast and Geodetic Survey.

Tidal Prism: The volume of water required on the flooding tide to produce the rise of water level in a bay, estuary, fiord, etc.

Tide: The periodic rising and falling of the water level that results from the gravitational attraction of the moon and sun acting upon the rotating earth.

Tide Curve: A graphic representation of the rise and fall of tide in which time is represented by the abscissas and the heights by the ordinates. For a normal tide, the trace approximates a sine or cosine curve.

Tide Race: A very rapid tidal current in a narrow channel or passage.

Tide Rips: A turbulent water body produced by opposition to tidal currents.

Time: Time is measured by the speed of rotation of the earth with respect to some point in the celestial sphere and may be designated as *sidereal*, *solar*, or *lunar* according to whether the measurement is taken in reference to the vernal equinox, the sun, or the moon.

Time Meridian: Any standard meridian to which time is referred. (Greenwich, standard, or local).

Topography: The general configuration of the land surface; the sum total of the results of erosion and deposition on the physiographic features of a region.

Total Ice Season, Maximum: The longest ice season recorded over a period of years in an area. *See* ICE PERIOD.

Total Ice Season, Minimum: The shortest ice season recorded over a period of years in an area. *See* ICE PERIOD.

Total Intensity: The vector resultant of the intensity of the horizontal and vertical components of the earth's magnetic field at a point.

Transition Zone: The water area between two opposing currents manifested by eddies, upwelling, rips, and similar turbulent conditions occurring either vertically or horizontally; or a zone between two water masses of differing physical character, as of temperature and/or salinity.

Transmission Loss: As sound waves pass from one point to another some energy is lost, weakening the signal. This weakening is called transmission loss.

Transparency: The ability of water to transmit light of different wave lengths, usually measured in percent of radiation which penetrates a distance of 1 meter. As used in HODS, transparency is the average of the depths at which a Secchi disc (about 30 centimeters in diameter) disappears and reappears when lowered in the water.

Tropic Range: Contracted form of *Great tropic range.* *See* GREAT TROPIC RANGE.

Tropic Tides: Tides occurring approximately every 2 weeks when the effect of the moon's maximum declination north or south of the Equator is greatest.

Tubeworms: Segmented marine worms some of which secrete calcareous tubes.

Tuff: Cemented consolidated volcanic ash.

Tunicates: A subphylum of marine invertebrate animals which includes ascidians or sea squirts, and salps. Ascidians are either compound or simple, and many species attach to submerged objects. Several species of salps are bioluminescent.

Unconsolidated Sediments: Deposits consisting of uncemented clastic or organic material.

Uprush: The rush of the water onto the foreshore following the plunge.

Upwelling: An upward movement of water from a subsurface current or water mass generally caused by winds moving coastal surface water offshore or diverging surface currents.

Variation: *See* DECLINATION.

Vertical Intensity: The magnetic intensity of the vertical component of the magnetic field reckoned positive if downward, negative if upward.

Volcanic Ash: Finely divided, fragmental rock material blown from volcanoes during explosive eruptions.

Water Color: The apparent color of the surface layers of the sea caused by the reflection of certain components of the visible light spectrum coupled with the effects of dissolved material, concentration of plankton, detritus, or other matter. Color of oceanic water varies from deep blue to yellow and is expressed by number values which are a variation of the *Forel Scale.* Plankton concentrations may cause a temporary appearance of red, green, white, or other colors. *See* FOREL SCALE.

Water Content: Of a bottom sediment is a ratio 100×weight of water in a bottom sediment sample÷weight of the dried sample. Expressed as a percentage.

Water Exchange: The volume and rate of water replacement in a specific location. Some of the controlling factors being tides, winds, river discharge, and currents.

Wave Height: The vertical distance between wave trough and wave crest, usually expressed in feet.

Wave Level: Position of the sea surface above or below a reference plane at any specific time in the tidal cycle.

Wave Period: The time interval between the appearance of two consecutive wave crests at a given point, usually expressed in seconds.

Wentworth Scale: Classifies bottom sediments according to the diameter of the particle.

WENTWORTH GRAIN SIZE CLASSIFICATION

Sediment type	*Millimeter (fraction)*	*Millimeter (decimal)*
Mud:		
Clay	Less than 1/256	Less than 0.0039
Silt	1/256–1/16	0.0039–0.0625
Sands:		
Very fine	1/16–1/8	0.0625–0.125
Fine	1/8–1/4	0.125–0.25
Medium	1/4–1/2	0.25–0.50
Coarse		0.50–1.0
Very coarse		1.0–2.0
Gravel:		
Granule		2.0–4.0
Pebble		4.0–64.0
Cobble		64.0–256.0
Boulder		More than 256.0

Wet Density: Of a bottom sediment sample is the ratio of the weight of the sample to its volume.

Wind: *See* BEAUFORT WIND SCALE.

Winter Season: *Sea and Swell*—Consists of the months of January, February, and March; however, where observational data are sparse, October and November and December may be included.

Worms: *See* TUBEWORMS.

Zooplankton: The portion of plankton composed of animals. Unattached animals which are at the mercy of the currents.

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U. S. GOVERNMENT PRINTING OFFICE: 1957 O—431298

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