DATA LIBRARY
WOODS HOLE OCEANOGRAPHIC INSTITUTION

SCIENCE AND THE SEA

1967

U. S. NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON, D. C.

GC
1
.S33
1967

MBL/WHOI
0 0301 0035673 9

DATA LIBRARY
WOODS HOLE OCEANOGRAPHIC INSTITUTION

FOREWORD

Oceanography, the application of the sciences to the study of the oceans, has been the subject of considerable worldwide attention during the past few years. The reason behind its popularity is, of course, the almost universal acceptance of the sea's role in the future of mankind. In an address presented on July 13, 1966, President Lyndon B. Johnson took note of the importance of this role. He portrayed our newly awakened scientific interest in the sea as "a new age of exploration" and described the high adventure that still awaits those pioneers who enter upon "our last frontier on earth". Addressing himself in particular to a group of youthful guests consisting of outstanding high school students, the President stated, "I hope that there are among you some of the great oceanographers of tomorrow. You could not choose, in my judgment, a more important or a more challenging career".

Science and the Sea, a compilation of ten articles describing some of the practical aspects of the marine sciences, is presented to acquaint both teacher and student with a few of the realistic problems that face the modern oceanographer. The articles were selected on the basis of applicability from a series of original papers specially prepared for presentation on the reverse sides of the *Pilot Chart of the North Atlantic Ocean* and the *Pilot Chart of the North Pacific Ocean*. These charts are published monthly by the U. S. Naval Oceanographic Office to provide mariners with a graphic synopsis of meteorological and oceanographic conditions prevailing in the waters specified.

For sale by U.S. Oceanographic Office and Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 – Price 75 cents

CONTENTS

OCEANOGRAPHY AND THE MARINER

A. J. Barther
Marine Sciences Department
U. S. Naval Oceanographic Office

Oceanography can be properly defined as a combination of sciences which deals with physical, chemical, biological, and dynamic properties, as well as other phenomena found in, on, and around the earth's hydrosphere exclusive of strictly freshwater bodies.

HISTORY

Study of oceanography in the U. S. Naval Oceanographic Office had its inception about the year 1842, at which time Lieutenant Matthew Fontaine Maury was appointed Officer-In-Charge of the U. S. Naval Depot of Charts and Instruments. It was the foresight and persistent efforts of Maury during early attempts to collect worldwide data pertaining to the oceans which led to such developments as the Wind and Current Charts of the North Atlantic of 1847, originally presented as a series of six charts. Also collected were data pertaining to best sailing routes, fog limits, ice fields and icebergs, rain areas, feeding grounds of whales, and other information which he deemed of interest and value to mariners.

In 1854, the Depot was redesignated the "U. S. Naval Observatory and Hydrographical Office". Congress separated the two in 1866 to increase the responsibilities and scope of the latter by authorizing The Hydrographic Office to carry out surveys, collect information, and print every kind of nautical chart and publication for the benefit and use of navigators generally.

Purchase of the copyright to *The New American Practical Navigator* was one of the first acts of the new Office. Several volumes of Sailing Directions had already been published. The *Notice to Mariners* appeared in 1869. The first Pilot Chart was issued in December 1883. Radio Navigational warnings were broadcast in 1907, and the International Ice Patrol was established in 1912, following the TITANIC disaster.

Maury's tenure with the Hydrographic Office terminated in 1861, but his work in oceanography was furthered by his successor, Captain Robert H. Wyman, Hydrographer, who reorganized the Office in 1871 and created a department of meteorology. Though seriously understaffed, the Division of Marine Meteorology managed to produce Pilot Charts which were in high demand. In 1904, the Hydrographic Office was relieved of all responsibility for collecting ocean weather data by executive order of President Roosevelt. The majority of meteorological data used in the construction of Pilot Charts since that time has been furnished by the U. S. Weather Bureau. Development of a new depth finder and use of aerial photographs in 1922, led to improved charts and soundings.

In 1924, a conference of various Government agencies was organized for the purpose of investigating the possibility and feasibility of conducting a research expedition in oceanography with Navy vessels. Though many representatives from branches of the State, Treasury, War, and Navy Departments attended this conference, nothing seems to have developed at this first attempt to support an oceanographic program in the U. S. Navy. Investigations begun in 1927 by the Committee on Oceanography of the National Academy of Sciences—National Research Council resulted in the recommendation that oceanographic research be undertaken by a Navy vessel specially fitted for the work. These investigations enabled the Hydrographic Office to acquire its first supply of oceanographic equipment which was used only incidentally in the survey work of the hydrographic ship, U S S HANNIBAL, in 1931. Cooperating observers on merchant and naval vessels also submitted numerous oceanographic observations.

Late in 1945, with termination of the war, a conference was convened for the purpose of determining views with regard to formation of a Division of Oceanography in the Hydrographic Office. The Division became a reality on 1 February 1946 but got off to a slow start due to demobilization and deployment of practically all oceanographers to Bikini Atoll. The purpose of the Division was to collect, codify, coordinate, and implement basic oceanographic research for various government activities. It was also charged with the responsibility of preparing charts, manuals, and other publications of an oceanographic nature for the Navy, Merchant Marine, fishery industries, and airlines.

Many of Maury's theories in oceanography have been long since disproven. However, his methods of scientific approach to the problems of navigation cannot be denied as having been the foundation of oceanographic studies in the U. S. Navy.

GENERAL

Today the U. S. Naval Oceanographic Office makes hydrographic, topographic, and geomagnetic surveys in international waters and along foreign coasts. In addition, it occupies an important position in oceanographic work. Because of its responsibilities for the safety of ships and aircraft, the Oceanographic Office has a worldwide interest in the oceans. Data are systematically collected from public and private institutions and persons in all parts of the world. Another responsibility of the Oceanographic Office is to foster international cooperation in the study of the oceans and to promote free exchange with other hydrographic offices. The Oceanographic Office Oceanographic Analysis Division prepares classified and unclassified oceanographic charts, manuals, and special reports with the aid of available data. The Oceanographic Prediction Division provides ice, wave, and sea water temperature forecasts in addition to supplying experimental ship routing services. The Marine Survey Division performs oceanographic surveys in domestic as well as in international waters.

Recent establishment of the National Oceanographic Data Center administered by the Oceanographic Office, where all data are processed and distributed to interested parties, will contribute greatly toward achievement of the objectives of the science of oceanography.

TIDES AND CURRENTS

Increased interest in synoptic oceanographic conditions and development of forecasting techniques has resulted in increased basic and applied research in many fields of oceanography. Prediction of tides and currents has been presented for many years by means of tide tables and current charts.

Methods of air-sea rescue were studied thoroughly during World War II for the purpose of locating life rafts and survivors of downed aircraft. The principle consisted mainly of the application of available data on surface currents and wind drift to determine the probable direction and rate of drift of any object on the sea surface.

The chart on the reverse side of this article represents one of the most comprehensive current prediction studies to date.

Current charts have been prepared to show general surface and subsurface circulation of all oceans. However, more important large scale harbor and coastal current charts have been prepared to aid the mariner and engineer in circumventing navigational and constructional hazards incurred by treacherous effects of tidal, rip, overfall, and runoff currents produced by headlands, shoals, breakwaters, and the like.

Current measurements are determined by numerous methods including calculations from ship navigation, subsurface tracking, and by electronic or mechanical means, dyes, etc. Free-floating bottles and cards are used to give general direction of currents when drift rates are not a required measurement.

Tidal range can be predicted only by use of past conditions or through complicated calculations which take into consideration all major tide-producing forces. The latter system has been made relatively easy by development of the tide predicting machine, which to the present time has proven to be more practical than electronic computers. It is hoped, however, at some time in the future to convert the system to analog computer adaptation for more rapid and reliable predictions.

Storm surges, often found piled on the normal tides, are more difficult to predict in view of their relatively sudden occurrence. Importance of the tides can be seen in the braking effect which they have on the spinning of the earth. Across eons they have increased the rotation period from four hours to twenty-four hours. Though the change is not of sufficient magnitude or rate to be of concern to man, it nevertheless takes place and will eventually result in a greatly altered day consisting of longer periods of total light or darkness.

Tides are measured visually and mechanically with staffs and gages at numerous coastal stations throughout the world. In certain areas, they have been measured in open waters, e.g., stable platforms located on shoals in the Atlantic Ocean and the Gulf of Mexico. Measurements of sea level changes with precise surveying instruments have revealed tidal components with periods greater than those normally perceptible by human, mechanical, or electronic means. A tautly anchored spar buoy has been used as an experimental visual staff in the Gulf of Mexico. However, inherent problems due to wind and current drag preclude the use of this method in place of more precise measuring equipment. A variety of glass capillary tubes has been used to measure tides in private research projects.

The importance of tides and currents to the mariner cannot be overemphasized. In areas where these factors exert their greatest influences, ship's officers should familiarize themselves with outstanding oceanographic factors. Many ships have suffered damage ranging from slight to heavy or have become total losses owing to a lack of tidal knowledge. Good seamanship demands use of up-to-date nautical charts and publications together with full comprehension of their meaning.

One might think of the great ocean currents as being nothing more than great rivers of the sea since their lateral limits are relatively well defined. However, general ocean currents have neither beginning nor end and thus result in the formation of clockwise patterns in Northern Hemisphere oceans and counterclockwise patterns in Southern Hemisphere oceans. General ocean currents are the most important controllers of climatic conditions over land areas, and have become important factors in meteorological studies. Thermal and chemical concentrate changes in seawater are brought about by freezing, evaporation, heating, and precipitation; the first two factors increase the density of sea water, while the last two decrease its density.

Theoretically then, one would expect the more dense polar waters to sink and replace the less dense equatorial waters which would flow poleward on the ocean surface. This condition would produce simplified ocean current patterns which could readily be understood and predicted. However, the actual current pattern is made complicated by the effects of wind and rotation of the earth (Coriolis force). Ocean currents are the dynamic result of unbalanced physical conditions tending to right themselves in the direction of equalization.

Navigational safety took a great turn after the sinking of the TITANIC in 1912. Formation of the International Ice Patrol led to collection of varied data such as temperature, current, ice drift, and bathymetry in the North Atlantic. Benefits derived from the many seasons that the Patrol has operated include the prediction of ice limits and conditions not only for the safety of ships transiting regular shipping lanes in higher latitudes but also the ice-transits of supply and research ships in extreme latitudes. Since the greater part of an iceberg or floe is submerged, the ocean currents are a greater determinant of direction and speed of drift than is the wind influence. Oceanographic ice forecasts have led to many successful convoy transits through icebound waters and have undoubtedly reduced ship damage and loss.

This aerial photograph shows the "calving" of icebergs from the Antarctic ice sheet

Project Polynya conducted at Thule Harbor in Greenland has been successful in producing artificial water currents at dockside. Compressed air is distributed through the water from perforated tubes lying on the harbor floor. Lengthening the shipping season by direct application of dynamic principles is of primary concern in this experiment.

Many harbors, being located near or in river mouths, are subject to heavy silting due to currents. Silting rates for dredging purposes have been determined by oceanographic research projects in many areas. Knowledge of silting, erosion, and current rates is indispensable for the planning of breakwaters, piers, lighthouses, and also various types of oceanic construction.

Currents are an important factor in the distribution of biological organisms, determining the quantity and area of shell and egg deposition. Transportation of nutrients and plankton vital to the majority of life in the sea is provided by currents, thus determining which areas of the oceans will become commercially important. Marine fouling growth rates also are regulated by the distribution of these nutrients as well as by physical properties of sea water.

General surface current charts and some detailed information concerning local currents are provided in the Sailing Directions published by the Oceanographic Office. These publications also provide corange and cotidal line charts, i.e., charts which show lines connecting points having equal heights and times, respectively, of tides in any given area. All recent editions of Sailing Directions include a rather comprehensive section on the subject of general oceanography for the particular area covered by the publication.

SEA AND SWELL

Of all oceanographic parameters, probably the most familiar to sailors are sea and swell. According to definition, "sea" is composed of waves generated by local winds. These waves are relatively short in period and generally advance in the same direction as the wind. "Swell" consists of ocean waves which have advanced beyond the area of their generation.

Neither of these parameters serves the mariner beneficially, rather they are adverse under most conditions. Sea and swell coupled with intense cyclonic winds are definitely a great cause of severe damage to shipping and loss of life. Fire and explosion damage, sometimes attributed to direct effects of rough seas, also have been correlated with atmospheric thermal conditions. Other forms of meteorological disturbances such as hurricanes and waterspouts are responsible for more damage incurred by ships at sea.

Waterspout damage is caused by a combination of tornadic winds, suddenly reduced atmospheric pressure, and the deluge of water sometimes released. Although the funnel of a normal waterspout is composed of small water droplets formed by condensation from cooling due to atmospheric pressure reduction, it is believed that the more severe storm spouts carry considerable quantities of sea water up to fair heights.

Lack of knowledge concerning the structure and properties of waves and swell has been an obstacle to theoretical and practical applications of oceanography in the reduction of ship motions, a desirable goal for all oceangoing vessels. Benefits to be derived from such studies include improvement of speed, cargo safety, passenger comfort, and reduction of ship damage.

Each vessel will respond more violently to waves of certain periods, since this is a function of ship dimensions and center of gravity. When a ship encounters such wave conditions there is little that can be done to alleviate the magnitude of the stress and strain forces, outside of attempting to ease the ship's headway by speed reduction, by change of course, or by altering trim. Structural failures are apt to occur and, theoretically, ships have disappeared without a trace under such circumstances, especially when carrying extremely light or heavy cargoes while subject to pounding.

The first organized attempts at overcoming hazardous ocean conditions were made by Maury in 1847 by gathering ship logs and collecting oceanographic data. With assemblage of these data in the forms of wind and current charts, the mariner was provided with the means to avoid hazardous areas and to follow best tracks.

By 1961, at least several commercial companies and two government units predicted best routes for the mariner. Experimental routing has been conducted by the Oceanographic Office since 1956. Depending on the individual ship requirements, the predictors aim is to forecast either a least-time track, a maximum passenger comfort track, a maximum cargo safety track, or any combination of these conditions. Care is taken to avoid crossing of or sailing opposite standard tracks. Shipmasters and commands have written many comments regarding the ship routing programs. Besides the advantages of more economical operations and time savings, routing programs reduce worry on the part of the shipmaster by alerting him to forthcoming weather conditions. These programs also enable greater utilization of new crews.

Natural conditions and artificial methods exist for abating or somewhat calming the high seas. The most important natural abater is ice, which occurs only in higher latitudes. Hail, snow, and seaweed also exert calming effects, though they are considerably less than the effect of ice. Artificial methods of reducing wave height include breakwaters and the distribution of storm oil.

By measurement and analysis, oceanographers have shown the sea surface to be a complex composed of many different wave trains occurring simultaneously. Each of these trains has its own period, height, length, and direction of travel. Waves are measured from stationary platforms and along shores by means of electronic wavestaffs, pressure diaphragms, radar, and with instruments similar to tide gages. They can be measured from moving craft with sonic surface scanners, inverted echo sounders, and with accelerometer devices. Floating electronic wavestaffs and expendable accelerometer devices have been used successfully in open-ocean measurement of waves.

PHYSICAL PROPERTIES

Until about a decade ago, physical oceanography was probably one of the least understood science subjects. In general, its results found most practical application in the solution of marine fisheries problems. Therefore it was considered more of an adjunct to the field of marine biology, and, for this reason, most of the earliest advanced studies of physical oceanography stemmed from complex investigations made by investigators more interested in the general approach (classic oceanography). Specialized investigators were interested in the geographic approach. More recently, physical oceanography has evolved an aggregation of highly trained researchers, each a specialist in his own right. Because of the existence of several similarities between oceanic and atmospheric problems, many meteorologists have been inducted into and successfully adapted to the field.

Some of the more common physical properties of sea water are temperature, salinity, density, pressure, ice, water color, transparency, and sound velocity. Less commonly known or determined ones are specific heat, osmotic pressure, eddy viscosity, electrical conductivity, etc. Development of instrumentation for use in securing measurements of the most common of these parameters has been fairly rapid in recent years. The least common parameters are usually determined by complex mathematical calculation and formulation from one of a combination of the common parameters.

Much greater improvement in future instrumentation will be necessary before the study of physical oceanography can parallel the pace of present-day meteorology. Original instrumentation, instrumentation in numbers, and the feasible means of utilizing this instrumentation are needed before we will be capable of attaining our desired degree of worldwide synoptic observations.

Surface *temperatures* are obtained by the simple means of a scientific *mercury thermometer*, the bulb of which is immersed in a small attached container filled with sea water by submersion. Some *injection* temperature values are reported as surface values. However, since they are taken at various depths at engineroom intakes on ships, submarines, and offshore structures, they are unreliable for precise oceanographic work. Continuous recording of temperature for industrial research purposes is made with a *thermograph*.

The present common method of obtaining deep sea temperature data involves the use of paired specially constructed reversing *thermometers*, one protected by enclosing it in a glass sheath and the other unprotected. Through comparison of the two temperature readings obtained after reversing the thermometers and application of correction factors, one can readily determine the water temperature and correct depth at which the thermometers were actuated. A bathythermogram is a record made with an instrument known as a *bathythermograph* and consists of a continuous trace of temperature plotted against depth at a given location. BT's are collected by naval and merchant vessels the world over and forwarded to the Oceanographic Office for processing, use, and distribution. Hundreds of thousands have been collected and processed to date. However, processing this type of data is very time-consuming. Serial vertical temperature distribution values are also obtained by electronic methods incorporating parallel-connected electrical resistors, the values of which are directly dependent on water temperatures, e.g., the thermistor chain and the thermocline recorder. The latter is an improvement of the former in that the quantity of measurable resistance change is greater. Resistance thermometers operate on this same principle, however, they are not as sensitive as the thermistor chain or thermocline recorder.

Water temperatures have been obtained in the past with *insulated water bottles* to depths of several hundred yards. Owing to the large margin of error in this method, the reversing thermometer or thermistor methods are preferred when measuring deep water temperatures.

On the basis of considerable temperature data, charts have been constructed to indicate survival rates for immersed bodies.

Cargo temperature is dependent on temperature of the air and sea water, particularly in instances of bulk liquids or highly porous materials; passenger comfort is also to a degree dependent on air temperature and thus indirectly on sea water temperature. Cargoes with temperature values less than the dewpoint of the outside air will suffer condensation damage if ventilated when such conditions exist. In some cases, sea water temperature can either reduce endothermic cargo reactions or, conversely, it can cause buildup of cargo temperature. Cold spray or wash from stormy seas can reduce weather deck temperatures sufficiently to produce condensation within warm holds, thus abetting deterioration and waste of cargo.

Salinity of sea water is based on the quantity of dissolved salts contained in a given amount of sea water after certain chemical changes have taken place. Direct determination of these values by recommended procedure is rarely carried out at the present time, because the method is too difficult and slow. Sea water composition adheres to the Law of Constant Proportions, i.e., the total amount of the major constituents in any two samples is always present in the same relative proportions. Since chloride ions constitute more than half of the total amount of chemicals in sea water, salinity values can be empirically related to chlorinity once the latter has been established by chemical means. A relationship also exists between salinity and electrical conductivity values of sea water. Based on this knowledge, an extremely complicated electronic instrument has been developed and proven suitable for rapid processing of salinity samples. However, the technical nature and prohibitive cost of these machines have limited their distribution. A smaller portable underwater version of this apparatus, the *conductivity cell*, has been successfully used in many regional surveys. By correlating water temperature and electrical conductivity values, this instrument automatically furnishes the observer with immediate values of salinity.

Temperature values go hand-in-hand with salinity values to determine the extent and growth rate of marine fouling in all areas by controlling the environment in which the organisms must live. Certain combinations of temperature and salinity values can be highly conducive to corrosion of any type of structure. In particular, equipment constantly bathed in sea water is susceptible to adverse corrosive, contractive, or expansive damage. Condenser failure is usually due to corrosion of tubes and ferrules.

Temperature and salinity also combine with pressure effects to form the *density* values of sea water—values so important in calculating loadlines for freshwater to salt water transits and vice versa.

Many cases of improper stowage have resulted in loss at sea or serious listing after freshwater to salt water transits. Improper distribution of bulk cargo coupled with low-temperature conditions have proven disastrous for ships in rough waters. Extra buoyancy provided by empty fore and aft tanks and brittleness of metal produced by low temperatures have promoted cracking or complete severance of tankers.

Density of sea water is an important factor of economy in evaporator operation; the lower the density, the less the amount of fuel that is required. Density of surface water can be measured directly with a *hydrometer*. However, since it increases with rise in pressure and salinity and decreases with rise of temperature, it can also be determined directly for water beneath the surface from these latter values by use of oceanographic tables.

Pressure can be used to measure sea and swell heights and periods.

Currently, importance of the least investigated physical properties of sea water to the mariner is little understood. At best, the benefit to be derived from these is of indirect consequence in view of the fact that the properties themselves are not too well understood. Furthermore, as stated above, they are usually determined by complex mathematical calculations or by tedious laboratory experiments which always contain an inherent degree of error. If any of these least commonly known properties can be considered to have the slightest value to the mariner, it would definitely be indirect as seen in application of the values of specific heat or heat fusion in basic experimentation for ice-forecasting purposes. Another indirect application is the use of thermal expansion in determination of general ocean circulation.

Freezing of sea water takes place at lower temperatures than does freezing of freshwater, owing to the presence of dissolved salts which tend to depress the freezing point.

An ice-forecasting program has been pursued at the Oceanographic Office since 1952. Depending on requirements, either short- or long-range forecasts can be prepared, ranging in period from 5 to 30 days. The bases for these forecasts are extensive air reconnaissance missions and comprehensive reports of shore observers. Numerous favorable post-operative comments have been received from shipmasters directly concerned.

Water color may be caused by a variety of factors: sky cover, water depth, and particle content of water to cite a few. Particle content may consist of sediments, nutrients, or plant and animal matter whether dead or alive. As observed from shore or on board a vessel, water color may range from deep blue to intense green. In some special cases, water color may appear brown or red, especially in coastal waters. Open ocean water with a high degree of transparency usually assumes a deep blue color owing to scattering of light on water molecules or fine suspended particles. Greens occur in a variety of hues ranging from yellow-green to blue-green, the degree of tinting or shading being dependent upon the amount of suspended material such as algae or sediment particles. Extraordinary populations of minute plants and animals near the surface can be responsible for red or brown water. Color variations occur more frequently in coastal waters owing to addition of sediments and nutrients by river effluent or by disturbance of bottom sediments by wave action in shallow waters.

Transparency of sea water is closely linked with the distribution of suspended particles and concentration of dissolved colored substances. High values of transparency have afforded many mariners with a large margin of safety while navigating shallow hazardous waters. Rate of progress during salvage work is highly dependent on the amount of light penetrating the water. Little information is available with regard to depths at which animal life in the oceans can see, nevertheless, the distribution and color of various organisms, including fishes, are apparently also related to the amount of light at depths. The depths to which electromagnetic waves of various lengths, especially heat and light rays, will penetrate are directly dependent on this suspended or dissolved matter. Most of the radiant energy received at the sea surface is absorbed or reflected in the form of heat, thus becoming the basis for the study of the heat budget of the sea. The temperature and vapor pressure at the interface created by the sea surface and atmosphere play an important role in determining the rate of heat exchange between the two. Extent of cloud cover controls the amount of radiation gained or lost by the sea. The rate at which the downward traveling radiation decreases in water is determined by the "extinction coefficient". This coefficient is of concern to the oceanographer in that it can be used to calculate depths to which visible waves will penetrate. Measurements of extinction coefficients are rare.

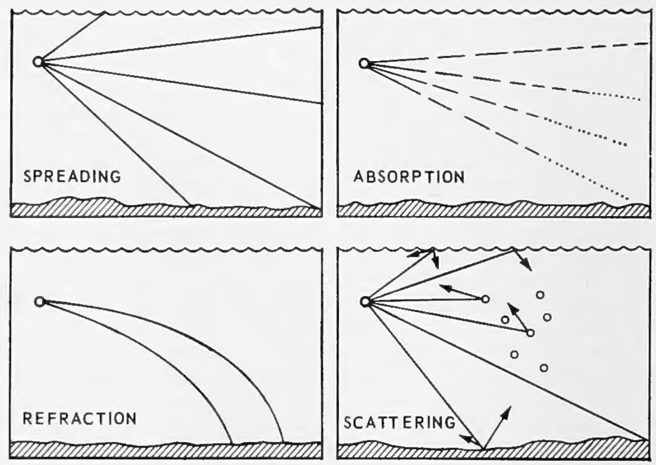
SOUND

Oceanographic research has considerably increased man's understanding of sound in the sea, although many aspects of underwater sound transmission remain to be investigated before full appreciation of its use can be made.

It has been shown that *sound velocity* is dependent on values of density and elasticity. Density, as stated above, can be measured directly or determined by use of tables when values of temperature, salinity and pressure are known. Elasticity is determined mainly by pressure. *Sound intensity*, or the sound pressure level at any point, is dependent on the sound generating source and properties of the medium.

Sound waves propagated in a homogeneous medium radiate outward from the source in all directions. This spreading of the energy is known as divergence and will result in reduction of the sound intensity at any distant point as compared with the initial intensity at the source, whether the distance travelled is from source to target (ping) or from target to source (echo). Thus the greater the range, the smaller the amount of energy imparted to a target surface or returned as an echo.

Other factors contributing to range limitations are reflection loss, reverberation, refraction, and absorption. *Reflection* occurs whenever sound waves are obstructed by solid objects or sharp discontinuities, such as the hulls of ships, the ocean floor, and the sea surface. If these surfaces are rough, sound energy will be scattered in all directions. That part which is returned to the location of the original sound source, thereby interfering with echo recognition, is known as *reverberation*. The bottom effects are generally important enough to be regarded as the controlling factor in echo ranging whenever the depth of water is less than about 100 fathoms. At short ranges (less than 1,000 yards), reverberation from the surface forms the principal background in echo ranging and is usually the controlling factor in the detection of small objects whenever the sea is not calm. Suspended particles and bubbles also cause reverberation by scattering the sound energy as secondary wavelets and



Factors affecting sound paths in water

reflecting part of it back to the sound source. *Refraction* is the bending of sound rays owing to changes of velocity caused by variations of density in the transmission media. These variations occur between water masses having different physical or chemical properties and between dissimilar mediums. Bending of a sound beam always takes place in the direction where velocity is lower. *Absorption* further reduces ping and echo intensities when part of the sound energy is converted to heat energy by friction caused by water viscosity or by vibration of suspended particles such as bubbles.

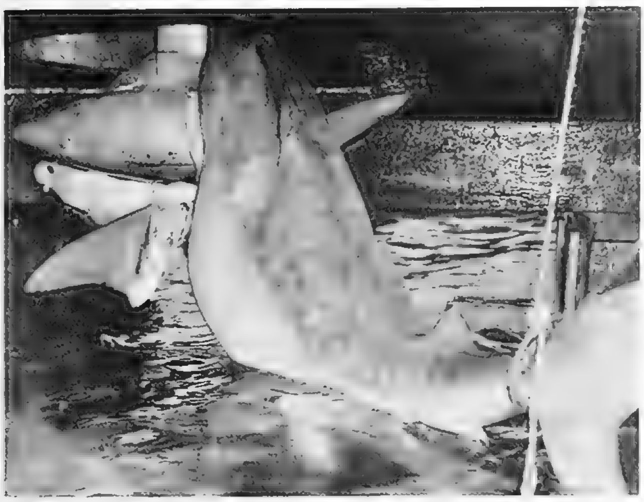
Echo intensity can also be attenuated by soft forms of biological growth on a target. Echo interpretation is further complicated by surrounding sources of extraneous noises. These noises are known as *ambient* noises and are classed in four categories according to their source, viz., thermal, biologic, water, and artificial or man made. *Thermal* noise is created by increased molecular activity of water with increasing temperature and is characteristically more intense at higher frequencies. *Biologic* noise emanates from numerous organisms, primarily fish and shrimp. *Water* noise is, of course, produced by wave and current action. *Artificial* noise originates from several sources such as ship machinery, bow waves, wake, or perhaps shore-based noise.

Whatever its source, ambient noise will tend to mask the echo signal and, as a result, reduce the maximum range at which an object may be detected or identified. In addition, when a vessel backs down, drifts with the wind, or uses excessive engine or rudder changes, little energy may return to the transducer because of bubble formation around the transducer and may result in *quenching*. Maintaining constant headway has been considered the best solution for avoiding the problem of quenching.

Keeping in mind the factors which promote or deteriorate sound propagation, we should now find it easier to comprehend the principles involved in the formation of *sound channels* which exist throughout the oceans. These channels are formed by a layer of water having a negative (decreasing with depth) sound velocity gradient overlying an adjacent layer having a positive sound velocity gradient. In these particular circumstances, sound waves are confined within these channels by refraction.

Discovery of the existence of such permanent sound channels in the ocean and their ability to permit transmission of sound for great distances led to the development of many methods of underwater communications and navigational aids. SOFAR (Sound Fixing And Ranging) was utilized during World War II for the purpose of locating survivors at sea. By means of triangulation, shore stations could determine the approximate position of survivors by detecting sounds of exploding preset depth bombs dropped into the vicinity of a sound channel by the survivors. A variation of SOFAR, RAFOS (SOFAR in reverse), later proved highly valuable for determining approximate positions of vessels by use of a hydrophone lowered to a sound channel to detect sound signals produced by known stations. More recently, underwater methods of navigational aid have given way to more accurate electromagnetic systems such as RAMARK (RAdar MARK), RACON (RAdar beaCON), SHORAN (SHOrt RAnge Navigation), HIRAN (HIgh precision shoRAN), electronic position indicator (EPI), DECA, and RAYDIST. Inertial navigation has been of considerable value in submarine navigation.

Oceanography is likely to play an increasingly important part in precise submarine navigation. The submarine navigator of the future will have much use for charts depicting expected sonar conditions based on thermal structure of the oceans, as well as charts showing such fixed features as bottom topography, major currents, and magnetic and gravity anomalies.



Shark impaled on SONAR dome

GEOLOGY

The greater percentage of geologic oceanography deals with the study and analysis of nearshore and open ocean depths (bathymetry) and sediment composition. Many other fields comprise the lot of the ocean geologist and geographer, e.g., magnetics, gravity, seismism, volcanism, and erosion. All involve long and costly investigation programs, requiring numerous manhours, complex instrumentation, ships, reinvestigation, and above all cooperation between the reporting mariners, investigators, and worldwide government and private hydrographic and oceanographic offices and observatories.

The study of bathymetry is properly the lot of the hydrographic surveyors, nevertheless, geologic oceanographers do construct numerous special bathymetric charts in conjunction with bottom sediment charts. All bathymetric charts are bound to contain a number of obsolete soundings; constant attempts are made to revise them and add to their worth by systematic hydrographic surveying.

Sudden shoaling also may be the result of volcanic action. In 1934, an area of discolored water with depth of 43 fathoms was reported in the North Pacific. A volcano in this same area attained a height of 150 feet above the sea within ten days in February 1946. Volcanic action usually occurs along the concave sides of the great ocean deeps, especially in the Pacific Ocean. Merchant and Naval vessels should report all depth aberrations immediately to proper port authorities for inclusion in the Notices to Mariners and Radio Navigational Warnings.

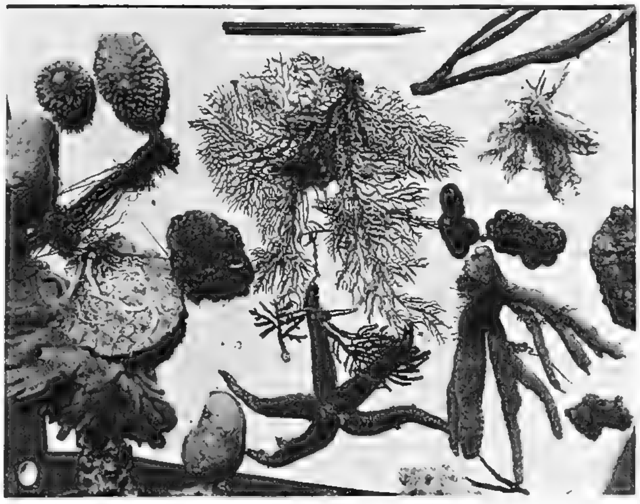
Bathymetric charts have been made for most ocean areas, however, information is very sparse in some of these. Usually only a fraction of the total number of soundings obtained in a thorough hydrographic survey are included in the final chart, though all are used in its preparation. Sparse or unevenly distributed soundings are indicative of an incomplete survey.

In deep oceanic areas, soundings taken about every half hour or five to eight miles are sufficient for hydrographic purposes except over the more outstanding features such as peaks and pinnacles. Any prominent bottom feature in the ocean which can be determined by fathometer readings can become a valuable aid to navigation if its location is accurately determined and plotted. Proposals have been made for the use of these prominent features as underwater beacons for surface ship and submarine navigation and as anchoring ground for deep water oceanographic telemetering instruments. Both of these proposals will possibly become realities.

Importance of the geologic oceanographers work in bottom sediment and seismic studies can be seen in the development of harbor and submarine natural resources. The construction engineer relies heavily on geologic and geophysical surveys for determination of bearing surfaces or bedrock depths for marine construction. The petroleum engineer relies on sediment analysis and seismic soundings to reveal the most probable oil-bearing strata and thus the area in which marine drilling is most likely to be successful. Detailed bathymetric and sediment charts can be used for selection of best holding grounds and anchorages of vessels.

Submarine earthquake activity affects the mariner in several ways: (1) interference with sonar operations, (2) disturbance of biological activity, and (3) formation of so called "tidal waves" (tsunamis). Other causes of extraneous underwater sound or motion of this nature are volcanic activity, heavy surf, strong winds, and landslides.

The study of magnetic anomalies, e.g., magnetic storms in relationship to radio communications and gravity surveys for the improvement of navigational charts, properly fall into the category of geophysics rather than geologic oceanography. However, these subjects often require sufficient understanding by the oceanographer for purposes of editing and incorporation in specially requested studies. Prediction of penetrating ability and travel path of electromagnetic (including sonic) waves has not been too successfully correlated with bottom sediment types. However, electrical conductivity or its reciprocal, resistivity, measurements can be made from the sea surface taking into account the varying conditions of the stratified nearshore water, of which each layer has differing temperature and salinity values, the saturated bottom sediments,



Part of the large variety of marine life taken off the bottom of the ocean by an underwater dredge the compacted and less porous buried deposits, and the bedrock. Much work is needed in this area for the improvement of degaussing techniques, sonar utilization, and minesweeping.

Marine geologists and geophysists conduct many other phases of oceanographic research, most of which do not directly concern the mariner. By studying the history of our planet as revealed by sedimentary deposits and bottom topography, man is enabled to further understand the history of the universe. Millions of years of erosive activity on land have deposited unknown and untapped amounts of mineral resources in the sea. These deposits become increasingly important as our present natural resources are slowly exhausted. Precise navigation, improved echo sounders, bottom photography, acoustical probes, and long coring tubes have all aided in locating and charting many areas having potential mineral reserves. Today, large quantities of oil and sulphur are obtained from beneath the sea floor. Magnesium, bromide, iodine, and a few other elements are extracted in smaller quantities from sea water.

BIOLOGY

It has been estimated that at least a million vessels of various sizes, and about four million men are engaged in some phase of the marine fisheries industry. Of importance to this industry is that phase of oceanography dealing with marine biology.

The endless search for old and new forms of life in the oceans has attracted freshwater biologists as well as marine biologists. These scientists probing in the many divisions of marine biology are constantly striving to discover and classify the numerous marine organisms and to clarify the ecological structure of the communities which they form. Working hand in hand, the taxonomists, ecologists, geneticists, biochemists, physiologists, evolutionists, and students of animal behavior are undertaking research problems which contribute to our overall knowledge of the life cycle of the sea.

These scientists are attracted to the study of marine life mainly by the unique research opportunities to be found in this field. Animals living in a liquid world, eating and breathing in a manner not too dissimilar to that of man but living under entirely different environmental conditions foreign to and impossible for man, are the basis for the never-ending research of marine biologists.

The possible variety of environmental conditions under which the sea creatures exist are countless and include extreme variations of temperature, pressure, salinity, light, nutrients, weather, and currents. Of these, the distribution of vital nutrients is probably the most important controlling factor in the ups and downs of the commercial fishing industry.

The study of the relationships of organisms to environment is known as *Ecology*. Much is known about these relationships, however, much more research regarding temporal and spatial distribution of nutrients and animals is necessary if we are to make more extensive, consistent, and complete charts of the ocean's communities. Formulation of such charts will require large-scale international cooperation. Simple observational methods of the past will not achieve our end; prior research must be performed, particularly in the solution of adequate technical sampling methods, both instrumental and statistical.

The sea is considered an inexhaustible source of animal protein. However, of the thousands upon thousands of species of animal life contained therein, only about 300 species of fish and shellfish are marketed by American fishermen. Sixty percent of the total annual catch is composed of only 9 species, indicating the specialization in a minority of what is actually available.

Much study has been conducted by biologists, physiologists, and students of animal behavior in determining the response of various marine organisms to applied artificial stimuli, especially electromagnetic waves of heat, sound, and light. The nervous system of a fish regulates its muscular response and can be controlled by application of variable-frequency electric stimuli. Pure AC electricity has been used successfully in whaling operations; undulating current has proven efficient for capturing small fish. Fish attracted by underwater light can be pumped aboard by suction hoses. What new methods are awaiting discovery through basic and applied research?

Worldwide surveys leading to complete oceanographic charts will pave the way to better fishing methods by enabling us to predict the times and places where fish will concentrate. They will also provide an understanding of the ecological relationships between the animals and the stimuli of their environment. Knowledge of prey, predators, competitors, and diseases will provide us with the key to increasing the number and possibly the size of fish in the sea. The prey, being the food source of the various animals, is the most important of the foregoing factors, but as yet little is known about it in spite of the amount of research already performed. Little is known regarding the distribution of plankton, i.e., organisms at the mercy of the currents. Why are the apparent numbers and eventual sizes of plankton in polar seas so much greater than those of plankton in warmer seas? What determines the discrete, regular distribution of plankton though they are at the mercy of the currents? What determines the balance between the size and numbers of zooplankton and phytoplankton? Open-sea waters are considered homogeneous when compared with waters of the intertidal zone, yet plankton seem to be more prolific in the latter environment. The phenomena of "red tide" in the Gulf of Mexico and "El Nino", a warm current counter to the Peru Coastal Current, are both only temporary occurrences, yet each exerts a disastrous effect on the biological communities in those areas. The "red tide" virtually suffocates fish by the millions, while useless organisms thrive. Beachside human communities suffer the aftereffects of these dead fish. Though much research has been performed on the "red tide", no cure has been found for the condition. "El Nino" has been studied less, but the effects are the same with the exception that a side-effect, known as "Callao painter", is the production of hydrogen sulfide in sufficient quantity to blacken the paint of entire ships. How many more similar undesirable conditions exist unknown in the oceans?

Lower half of photo shows preventive effect of antifouling paint applied to metal submersed for period of one year

Another important phase of marine biology which affects all ships sailing in both fresh and saline waters is the problem of fouling. Attachment, entanglement, and boring organisms and corrosion have long been the scourge of the mariner. Clogging of sea chests and intake lines can lead to serious damage to other major machinery and result in costly repairs. Fouling growth in lines can effectively reduce heat transfer in condenser operations. Accumulation of attachment fouling organisms on underwater portions of hulls can effectively reduce ships' speed.

Fouling also produces adverse conditions for the operation of underwater sound equipment. All forms of marine life, whether attached, free-swimming, or drifting reduce the efficiency of underwater sound transmission by interfering with the normal path of sound waves. Air bubbles entrapped by attachment fouling organisms on sound domes and transducer plates can reduce sound transmission by 30 percent, at the same time reducing echo intensity by a factor of one half. The importance of such effects can be seen in the application of sonar and fathometer equipment.

Few fouling organisms are found in fresh-water areas. For this reason, ships transiting such water are provided with some degree of temporary protection. Contrary to popular belief, marine fouling organisms do not detach themselves from the hull of a ship which enters freshwater; they are killed if they remain in it for a sufficient period of time. Studies have shown that the layer of dead organisms abets corrosion in some cases and delays it in others. In any event, the layer does provide an excellent substratum for the attachment of new organisms once the ship re-enters saline waters.

Growth and accumulation rates of fouling organisms are dependent on seasonal distribution of environmental factors such as temperature, salinity, sunlight, and nutrient material, all of which control breeding rates, and consequently, egg production and spat settlements. Through an understanding of the physiology of the various fouling organisms, the marine biologist and chemist are able to improve the effectiveness of fouling inhibitors.

Large ships enjoy considerable immunity from disablement by entanglement foulers by virtue of their sheer power and size. Smaller vessels, such as lighters and amphibians can become severely entangled in areas where extremely dense plant growth exists. Average size of the most troublesome entanglement foulers is only a few feet, however, the giant kelp of the Pacific sometimes attains lengths of several hundred feet. Growth of entanglement foulers is most luxuriant where the substratum provides a good anchoring ground for hold-fasts. Offshore rocky bottoms are typically good areas of growth, especially when the nutrient supply is ample and depths are sufficient to prevent or mitigate erosion due to excessive wave conditions. All shallow inshore areas, regardless of the nature of the substrata, are poor areas for growth if the bottom is subject to continual adverse effects of high waves or strong currents. Most of these entanglement foulers, so undesirable from the mariner's viewpoint, have been converted into edible forms, especially in countries such as Japan.

One remaining aspect of the ocean included in the field of marine biology is bioluminescence. Thousands of species of plant and animal life possess light-bearing or light-producing organs. The smallest of these forms of life, when disturbed within the water, can produce intense concentrations of light. Depending on the organism, involved, these light displays are classified as either glowing-ball, sheet, or spark-type.

Bioluminescence occurs most frequently in warmer surface water, but may be considerable under favorable conditions in cold northern waters. Several occurrences of bioluminescent displays in warm tropical waters have been attributed by shipmasters to high-frequency radiation from radar equipment. Lack of research along these lines prevents authentication of such reports. Of benefit to the mariner is the outlining of shoals and reefs by breaking waves containing these organisms. Much research on the physiology and chemistry of bioluminescence has been performed for the purpose of seeking-out uses for such manifestations. However, no valuable application has been found to date other than as a source of "cold light". Moistened powder produced from the bodies of luminescent marine animals served the Japanese as a wartime substitute for artificial light for reading messages at night. Fishermen of Portugal enhance the quality of bait by rubbing luminous exudate on it while fishermen of the Banda Islands use the luminous organ of a fish as an effective bait.

Color, transparency, and chemistry of sea water properly belong to the regime of the physical oceanographer. However, since these factors are of importance in understanding the relation between plants and animals and their marine habitat, they are also measured by the marine biologist during the course of his research.

THE FUTURE

Oceanography has had but a short life span in the United States. Foreign scholars, however, have been actively engaged in the fields of marine science for a considerable number of years. Through their studies, we have come to understand some of the vast ocean's mysteries. Their research has given sufficient impetus to the American school to enable it to grow from the handful of eight laboratories in 1920 to the present number of about seventy. It would be difficult, indeed, to predict the future course of marine sciences. At best, the prediction will be inaccurate owing to the very nature of research itself. Research and discovery in any field of scientific pursuit must necessarily be limited to the ability, ambition, and imagination of the individual scientist.

Due to the fact that oceanography is not a true science, but actually entails a combination of all earth sciences, the promotion of marine study has suffered greatly in the past if compared to other fields. One may ask, "Why do we want to know about the ocean?" Depending on one's views, this question may be answered in any number of ways. First of all, we want to study the ocean simply because it is there and unknown. Its challenge is equal in our eyes to the space problem; the adventuresome spirit of man does not rest until he has discovered and understood that which is strange and unfamiliar to him. Theoretically, all life including man arose from the sea, yet many of us look upon it with a feeling of awe. We also realize that the oceans hold the key to our past, present and future in that our unknown history is locked securely in its mysterious depths. By prying these secrets from the oceans, we can provide ourselves with a great deal of knowledge concerning the "whys" and "wherefores" of the oceans. Why do they exist? How long have they existed? What purpose do they serve? How can we further our utilization of them? On and on, many more similar questions evolve in our minds. Slowly but surely with both good and bad work, in difficult and trying situations, we will eventually force the oceans to reveal its mysteries. To be sure, we can learn much of the history of our planet by probing into space and going back in time, but the best way would be to delve into the oceans on our own earth. Through the ability to read the records which still lie in the sediments, rocks, and chemistry of sea water, we can learn much about the history of earth and of life itself.

Oceanography consists of much more than observing waves from the shore or collecting shells on the beach. For years, man has been limited to indirect methods of observing a small fraction of what lies beneath the opaque mantle of the sea surface. Development of skindiving equipment has enabled man to descend a short distance into his former element to observe first hand the environment which seems so remote to him now. Perhaps he is looking for the answer to what kind of life the fish lives, or could it in truth be an evolutionary inclination to return to the protective bosom of the sea? Man has surely exposed himself to numerous handicaps by emerging from the sea and lives without hope of ever completely conquering all the problems presented by his new environment. New avenues of ocean exploration have been afforded with development of underwater television and the bathyscaph. With the latter, man has almost penetrated the full seven miles to the known ultimate deeps. These research apparatuses have been in existence for only a few years. Who can say what as yet undiscovered apparatus lies in the future to serve man in his quest to better his knowledge of the ocean?

Our present knowledge and theories are amazing, but new-found answers in the future will be greater. We must explore and sample many new regions—the plains, ridges, fissures, trenches, and shelves which comprise the ocean floor. Revelation of ancient earth history will lead to better understanding of our environment and enable us to decipher the history of the planets. It is necessary and vital that we study the waters and animal life in the ocean in order to solve the origin and evolution of life on earth. We must find and study the undersea rivers which have flow rates a thousands times as great as the largest land rivers. We must find the way to determine the number of fish in the sea and how to control their quantity, if we are to increase their numbers. The welfare of many of the world's people is heavily dependent on the harvest from the sea. These and many other problems of the economic and defense requirements of society can be solved only by studying the oceans and the world above and beneath them.

A third of all sunlight striking earth is used for evaporation of sea water and a goodly portion of the remaining sunlight is absorbed as heat by the water or reflected into the atmosphere. If we can learn to control the distribution of this heat budget, understand the storage of gas in the sea, and complete our knowledge of the air-sea boundary and deep mixing processes, then we can possibly predict and regulate climatic conditions.

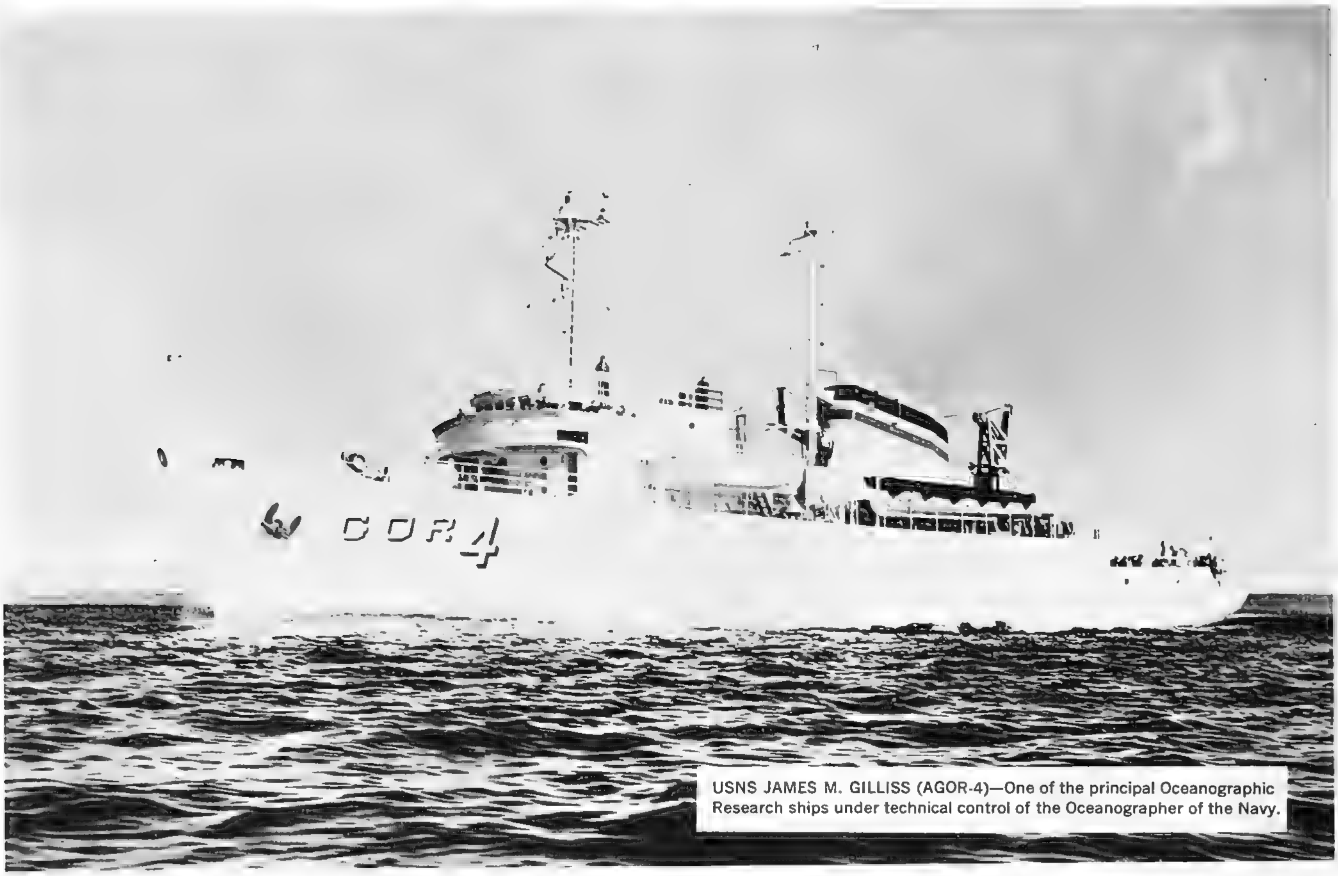
Electronically-equipped, nuclear and diesel propelled submarines have collected a considerable amount of oceanographic data which have intensified our knowledge of the behavior of the Arctic oceanic ice cover and have served as platforms for testing and developing oceanographic instruments for the future. More stable platforms such as the ARGUS ISLAND near Bermuda are excellent observation points for detailed information at given locations. A tube-shaped floating instrument platform (FLIP) is a novel vessel containing a free-floating manned laboratory for the measurement of parameters at various locations as it drifts with the currents. Like the rocket which is the basic vehicle for space study, research ships and platforms are the basic vehicles of the oceanographer. Combinations of ships, aircraft, and towers at predetermined locations and in sufficient numbers facilitate temporal as well as spatial observations of the ocean environs.

In the future, we must strive to maintain constant rates of data acquisition and instrument improvement. Complete gravity, magnetic, current, physical property, biologic, and geologic surveys will greatly enhance our knowledge and insure safety of surface and undersea precision navigation.

The importance of domestic and international cooperation cannot be overstressed. Though duplication of basic research is not particularly harmful, much of the unnecessary duplication in basic and applied research can be avoided by fostering good international relations. We must continue to collect and disseminate information gained in future oceanographic research through various agencies for application and use in underdeveloped areas of the world.

One of the ultimate goals of the Oceanographic Office is to provide worldwide oceanographic coverage comparable to that already provided by charts, Sailing Directions, and other navigation aids. To this end, it encourages and will assist other U.S. agencies in collecting additional data and in compiling all available information including that obtained through liaison and exchange with foreign sources.

It has long been hoped that the Oceanographic Office will eventually serve the same purpose for oceanography as it now does for hydrography, as the Weather Bureau does for meteorology, and as NASA does in the space program.



USNS JAMES M. GILLISS (AGOR-4)—One of the principal Oceanographic Research ships under technical control of the Oceanographer of the Navy.

TREASURE FROM THE SEA

J. W. Chanslor
Maritime Safety Division
U. S. Naval Oceanographic Office

The sea is "water" only in the sense that water is the dominant substance present. Actually, it is a solution of gases and salts in addition to vast numbers of living organisms, the majority of which are quite minute. Since the beginning, materials in solution and in suspension, carried by rivers, have been deposited in the oceans and seas of the world. It is to the wealth related directly and indirectly to these materials that this article is directed, rather than pirate treasure.

CUBIC MILE

Few consequential resources ashore are so little developed as those of the sea. Taken as a whole, the quantities of materials available from the sea are so gigantic that they can hardly be computed. Listed are a few of the more abundant compounds that are present in a single cubic mile of sea water. A cubic mile is a measure of enormous size and one rather difficult to visualize. It may be of some help, however, to point out that a body of water 26 miles long, 10 miles wide, and 3.3 fathoms deep would contain approximately one cubic mile.

Approximate amount of minerals in one cubic mile of sea water

Sodium Chloride (common salt)	128,000,000 tons
Magnesium Chloride	17,900,000 tons
Magnesium Sulphate	7,800,000 tons
Calcium Sulphate	5,900,000 tons
Potassium Sulphate	4,000,000 tons
Calcium Carbonate (lime)	578,832 tons
Magnesium Bromide	350,000 tons
Bromine	300,000 tons
Strontium	60,000 tons
Boron	21,000 tons
Fluorine	6,400 tons
Barium	900 tons
Iodine	100 to 1200 tons
Arsenic	50 to 350 tons
Rubidium	200 tons
Silver	up to 45 tons
Copper, Lead, Manganese, Zinc	10 to 30 tons
Gold	up to 25 tons
Uranium	7 tons

In the above table, the first five items show what great quantities of minerals can be extracted from sea water. With the exception of sodium chloride, however, these minerals still exist in dilute amounts compared with the medium in which they are suspended. Nevertheless, it has been possible to extract some of these products, such as sodium chloride, magnesium, and bromine from the sea. Other minerals, such as potassium and iodine, can be obtained with less expense from terrestrial salt deposits. These deposits of salt are, of course, the remains of ancient seas. Consequently, when their stocks are exhausted, we shall have to turn directly to the abundant seas.

MINING THE SEA

It should not seem strange to consider the sea as a vast mineral mine. For, our oceanic waters contain more minerals than have ever been mined by man.

On land, when minerals are taken from mines, they are not replaced. And, as this ore is used up, industry is forced to use lower and lower grades, making extraction more difficult and expensive.

Such, however, is not the case with our seas. For, as previously mentioned, the sea is a great reservoir constantly receiving the products of erosion, decay, and runoff. Although in great dilution, here is a source of almost limitless amounts of all the minerals and metals we use.

Mining the endless resources of the sea is not nebulous hope, but rather a growing actuality, with continued expansion—the frontier of chemists.

SALT.—The most common product from the sea is salt or sodium chloride. Every gallon of sea water contains just over a quarter of a pound of common salt. Or, stated differently, each cubic mile of sea water contains enough salt to supply the world's needs for nine years. Each year millions of tons are mined in places like San Francisco Bay, where sea water is trapped in shallow ponds and evaporated by solar heat. The world uses some 35,000,000 tons of salt each year, but only a comparatively small amount of this comes directly from the sea. Salt mined underground such as in Kansas, Michigan, Ohio, etc., is obtained from brine wells precipitated by ancient seas. Some of these deposits, 350,000,000 years old, are occasionally 1,000 feet thick and a mile or more below the present surface of the earth.

Salt is a prerequisite to good health, as well as a preservative and condiment. Some of the earliest trade routes of the world were established for the desire of this "luxury." When man's diet consisted of uncooked food, the fresh meat he consumed provided his required salt. But, when he began to boil his food, a considerable amount of the salt was lost. History does not clearly state when man first began to gather salt from the sea, but records do indicate that the Chinese obtained it prior to 1,000 B. C. by evaporation.

Upon the simple evaporation of sea water, the mixture of salts that remains is not at all like the table salt to which we are accustomed. Sodium chloride has a brackish but not bitter taste. On the other hand, calcium and magnesium salts are very bitter and hence the higher their content in common salt, the more bitter its taste. In addition to being quite bitter, calcium and magnesium salts are highly hygroscopic, and salt in which their contents are high is normally wet, refusing to "run." Several different grades of edible salt are manufactured, all predominately sodium chloride but none pure sodium chloride. Various procedures are undertaken during evaporation, giving different degrees of purification. Also, other chemicals are added for special purposes.

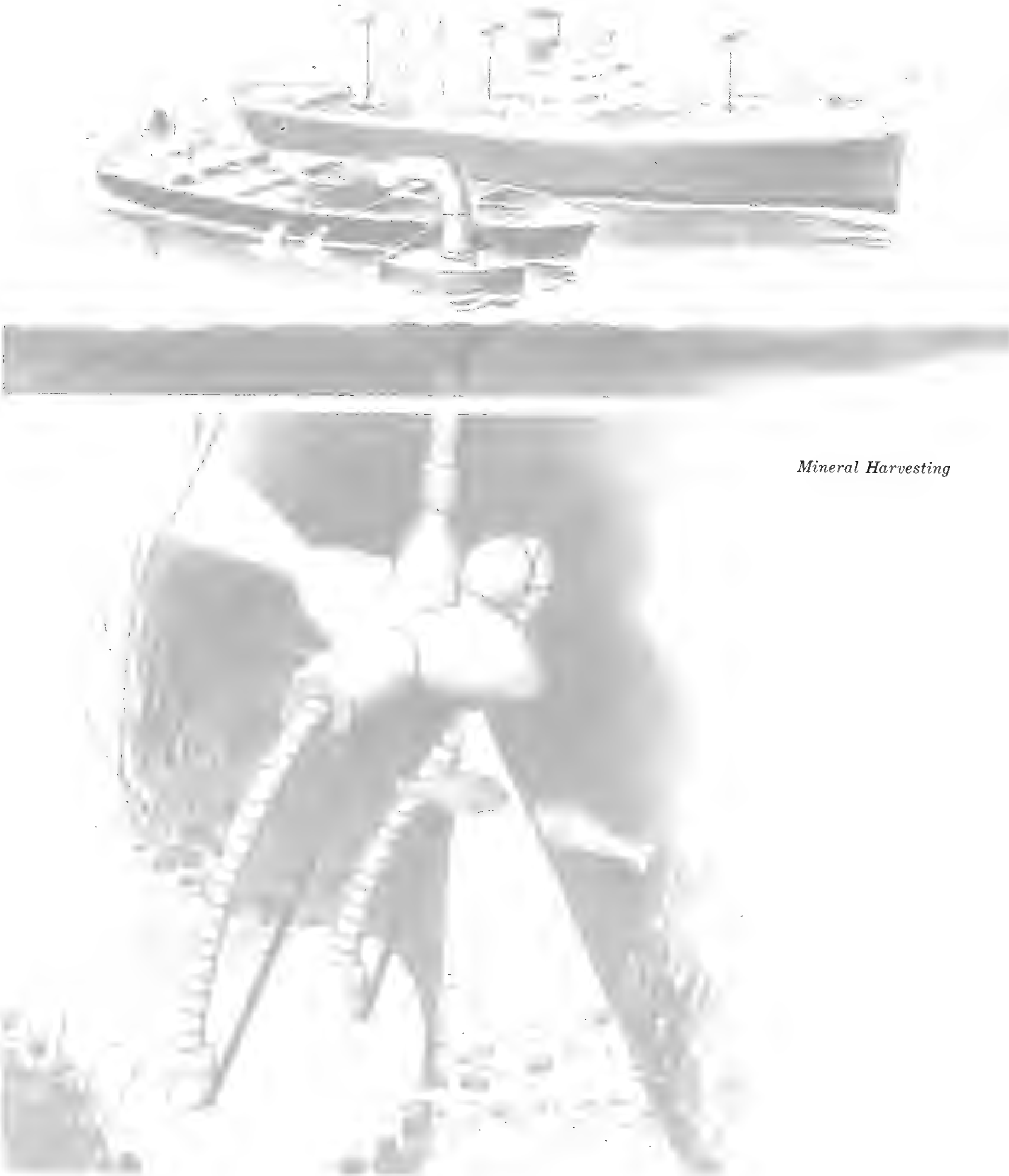
MAGNESIUM.—The most spectacular treasure from the sea is perhaps magnesium. The Dow Chemical Company began the manufacture of magnesium from sea water at Freeport, Texas in January 1941. This was the first time a metal had been produced in commercial quantities from sea water. There are currently four companies in the United States extracting magnesium hydroxide from the sea.

To make metallic magnesium from sea water, it is necessary to separate the magnesium from the sea water. This is accomplished by treating the sea water with lime, precipitating magnesium as "Milk of Magnesia." The milk of magnesia is treated with hydrochloric acid and evaporated to dryness as magnesium chloride. This salt is put through electrolytic cells where the electric current turns the compounds into metallic magnesium. In a million pounds of sea water there are approximately 1,000 pounds of magnesium.

Had it not been for World War II, the magnesium in the sea might well have remained there. But, with the war came great demands for metallic magnesium for use in incendiary bombs, flares, etc. This new and sudden demand ran into millions of pounds per year. A very significant contribution to winning the war can be attributed to sea water magnesium, and the ability of the United States to master conversion problems before its enemies did.

BROMINE.—Of the many elements present in sea water, the first to be recovered systematically was bromine. Unlike many products from the sea, there has long been a demand for bromine compounds due to their sedative properties. They are also used in photography and in the manufacture of certain dyes. Bromine was formerly extracted from the ash of burned seaweed. Later it was obtained from brine or salt deposits of ancient seas. The technical experience gained by the Dow Chemical Company in the extraction of bromine from brine wells, was of great value when the demand for this product exceeded the supply.

During the 1920's, the General Motors Corporation, while trying to improve gasoline for use in more powerful internal combustion engines, discovered that tetraethyl lead added to gasoline allowed much higher compression ratios to be obtained and prevented "knocking."



Mineral Harvesting

This metallic lead, however, tended to build up on valves and exhaust parts of the engine and a detergent was required to be mixed with the lead for removal purposes. The first solvent used was a compound of iodine, but it was soon apparent that iodine could not be produced in the required quantities. It was found, however, that bromine was equally effective in preventing lead build up. Anti-knock gasoline was of far reaching importance and even with brine well production of bromine, it became apparent that the demand would exceed maximum production. From the inexhaustible sea came the answer, for bromine exists in solution at the rate of 68 pounds per million pounds of sea water.

The procedure for extracting bromine from sea water is, theoretically, not difficult. Sea water is treated with sulphuric acid and then chlorine is passed into it. The bromine is then free in solution, and air is blown through the sea water carrying off the bromine as vapor. This vapor is then absorbed by an alkaline solution, and from this bromine can be recovered as required.

Approximately half of the bromine currently used in the United States comes from the sea. Twenty cubic feet of sea water is processed to obtain the bromine required for each gallon of leaded gasoline. To give some idea of the ability of the inexhaustible sea as a source for bromine—if all the bromine now used in the United States each year for gasoline came from the sea, one cubic mile of sea water would last two years.

SULPHUR.—Sulphur deposits are basically salt pillars that were thrust upwards from ancient sedimentary beds. As oxygen and other elements were expanded the sulphur content remained. In the more productive deposits, the domes are capped with limestone, tending to seal them off. These sulphur deposits, however, are rare, with less than ten percent of the 250 salt domes so far discovered in the United States, suitable for commercial recovery. Of the twenty successfully mined domes, eight are now exhausted. And, as virtually all known salt domes within the proximity of Texas and Louisiana have been examined for sulphur it is improbable that many, if any, new profitable sources ashore will be found. Consequently, our need to again turn to the sea for supply, becomes more apparent.

As a result of the constant search for new mineral reserves, in June 1960 the world's first offshore sulphur mine began operation. Known as the Grande Isle Project, it is located in approximately 43 feet of water and seven miles off the coast of Louisiana. The platform is the largest steel structure to ever be erected in the ocean. This sulphur deposit is the third largest known in the United States, varying from 220 to 425 feet in thickness and covering several hundred acres.

The operation of a sulphur well whether drilled at sea or ashore is basically the same. That is, hot water is pumped down to melt the sulphur, which is then aerated with compressed air and forced to the surface.

At the above offshore site, wells are drilled directionally i.e., laterally from the surface. Using this process, it is possible to drill and operate over 100 wells from the one platform.

Coupled with a mining venture of this type is the hazard of "subsidence". The removal of the sulphur weakens the rock structure sufficiently to cause collapse. As the upper sediments offer but little resistance, the ocean bottom subsides. Such will eventually be the case at the Grande Isle wells.

Sulphur was first commercially produced in Sicily during the fifteenth century. But, the world did not begin its quest for the product until 1735, when a process was developed to manufacture sulphuric acid. Four-fifths of all sulphur now mined is utilized for the manufacture of sulphuric acid. Today, this indispensable item is used in the production of such items as drugs, detergents, rubber, paper, petroleum and many others.

OIL.—The earliest use of oil is rather obscure, but it is known that King Nebuchadnezzar used asphalt to surface the streets and build the walls of ancient Babylon. The Assyrians and Persians also used asphalt as a building material and ancient Egyptians utilized pitch in the coating of mummies.

When the Jesuit missionaries came to North America they found Indians using oil, scooped up from surface pools, as a fuel and also as a medicine. The famed scout and frontiersman Kit Carson collected oil from seepage pools in Wyoming and sold it as axle grease, to pioneers.

Although oil was produced in Romania and Canada in 1857, it is usually agreed that the beginning of the industry on a large scale was in 1859 when Edwin L. Drake drilled his famous well near Titusville, Pennsylvania. Commercial production of oil then rapidly spread throughout the world.

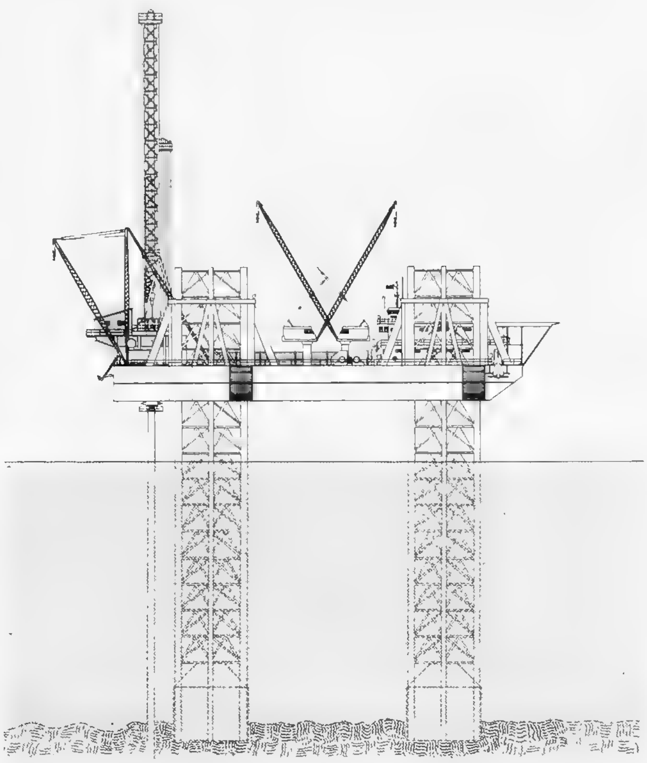
The modern quest for oil is reminiscent of the old gold rushes, with industry looking for "black gold" under the sea instead of "yellow gold" in the California hills.

With the increasing lack of new oil prospects ashore, industry began to look to the offshore tidelands as a source, and on 6 October 1937 the first offshore oil well in the Gulf of Mexico was "spudded in". This well is located approximately a mile off the coast of Cameron, Louisiana and gauged some 22½ barrels an hour, starting the ever growing "forest" of platforms and derricks now located in the Gulf of Mexico. After the completion of this first well, the platform was enlarged and ten more directional producers were drilled. These eleven wells are still producing today, having given a yield of over four million barrels of oil.

Increasingly within the reach of modern floating drilling equipment, great reserves of petroleum hydrocarbons exist in the submerged lands of the Gulf of Mexico and the Caribbean Sea. Along the islands stretching from Florida to Trinidad are subsea pinnacles and shelves that may very well hold immense prospects. Recently 21 salt domes were identified in the deepest part of the Gulf.

Within the Gulf of Mexico and the Caribbean Sea bounded by the 100-fathom curve, are approximately 300 million acres. Of this vast area, only about 35 million acres off the coast of Texas and Louisiana have been more than sparsely explored. Hence, one of the "world's largest deep hunting grounds."

As a result of offshore deposits, the largest oil boom ever is taking place off the coast of Louisiana, with approximately 90 drilling rigs in operation and at a daily drilling expenditure of over a million dollars.



Bottom supported drilling rig. Courtesy Union Oil Co. of California.

The Gulf of Mexico has been called the proving ground for offshore drilling rigs, and the year 1963 saw the development of a new trend in such rigs. This was the change from bottom supported units to floating drilling units. It will be years before floating units replace bottom supported units, but the trend has started and most all new construction is directed toward the "floaters."

Actually, the first offshore production came from wells slant-drilled from the beaches of California, out under the Pacific. As the ocean floor of the Pacific falls away quite steeply from the shoreline, this leaves only a narrow band offered for prospecting. It is primarily due to this type of submarine relief that deepwater drilling techniques have developed more rapidly on the west coast. In fact, it was here that the first floating drilling vessels were used, rather than in the Gulf of Mexico.

The oil industry decision to build floating drilling rigs rather than bottom supported units is based upon several factors, some of which are:

a. The ability to drill in deeper water.
b. Mobility for foreign as well as domestic operations.
c. Less expensive to operate than some bottom supported units.
d. Those with a hull similar to a ship can head into the sea during severe conditions, thus minimizing roll and pitch.

Cuss III — a floating drilling vessel. Courtesy Union Oil Co. of California.

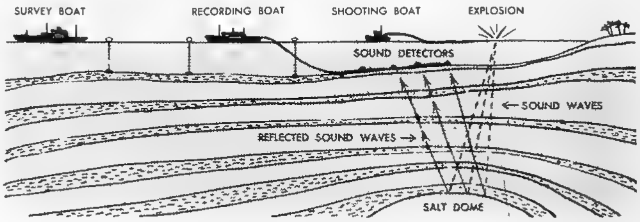
The oil boom is not confined to the Gulf of Mexico, but is in fact becoming world wide. To some extent, this has caused an exodus of marine drilling rigs from the Gulf, to such places as Lake Maracaibo (where there are approximately 4,000 offshore wells), Cook Inlet, Alaska, the Gulf of Suez, the Persian Gulf, the Gulf of Guinea, and many others.

Concerning foreign oil prospecting, the majority of interest is probably now directed to the North Sea, a sedimentary basin almost as big as Texas. A major discovery on the threshold of the world's thirstiest gas and oil market would be not only a bonanza, but could also have a direct bearing on the European Common Market, as the holder of such a find would have a key to much of Europe's energy.

In 1960 Slochteren, Netherlands became the third largest gas field in the world. And, these producing sands are the same ones that have been discovered on the northeast coast of England. The question as to whether these sands are also under the North Sea, is the reason for great acceleration of oil prospecting in that area.

The prospects are so great in the North Sea that it will take approximately three years of drilling to check the prime geologic structures already located. With the ratification by Great Britain, the 1958 Geneva Convention on the continental shelf became effective on 10 June 1964. This convention proclaims that the sea-bed and subsoil of the submarine areas adjacent to the coast belong to the coastal state as far out as the "depth of the superjacent waters admits of the exploitation of the natural resources of the said areas." It contains also provisions for drawing of boundaries where the claims of two or more countries overlap. Hence, the oil and gas rights of the North Sea will be divided up among Belgium, Denmark, England, France, Germany, the Netherlands, and Norway.

The greatest portion by far, of all geophysical prospecting has been in the search for oil and gas geologic structures, with but a small fraction of expended effort directed to solid minerals. In petroleum exploration, the seismic reflection method is the most widely used, with gravity, seismic refraction, and magnetic survey methods following in that order. With the data provided by this method it is possible to chart depths to subsurface interfaces with accuracy exceeded only by measurements in wells. Similar to the fathometer operation in many respects, the system depends on travel times of elastic waves reflected back to the surface from different earth formations.



Seismic reflection shooting offshore.

The advantage of the reflection method is that it permits charting of many horizons from each shot, with the precision approximately the same for the deeper horizons as for the shallow ones. In the other mentioned methods, reliability decreases with increasing depth.

With seismic reflection, depth determinations are not exact, as sound velocity within various layers is not precisely known. This inaccuracy, however, is not too important as it is the position of local humps or domes in the rock layers that is sought by the geophysicist.

DIATOMS.—As oil is referred to as "black gold", so has diatomite, the lightweight remains of diatoms, been called "white gold." Diatoms are members of the yellow-green group of algae and are the most numerous plants of the phytoplankton, sometimes amounting to ninety percent of the total. There are many different species of diatoms, all of which are unicellular and microscopic, with an above average one measuring perhaps 1/200th of an inch. Although they are a form of vegetation, diatoms possess no leaves, stalks or roots. Rather, their most characteristic feature is a transparent shell of silica, filled with the protoplasm of the cell.

Like plants ashore, diatoms are seasonal, with their numbers fluctuating accordingly. It is seldom that thay are completely absent from any portion of the surface waters. Ordinarily, they are more numerous near land as their required nutrients are normally more abundant in coastal waters. With the extended hours of sunlight in the spring, occasionally their numbers become so vast that they tend to change the very color of the sea. During these times the waters may become green, brownish-green or even red, and a single cup of sea water may well contain hundreds of thousands of diatoms.

These silicified diatom skeletons, sinking to the ocean floors in earlier eras, resulted in large deposits of packed diatomite. Today these deposits are mined in places such as California, Nevada, Oregon, Washington, Denmark, Finland, and France.

Due to its light weight in relation to bulk, industry has found many uses for diatomite. Albert Nobel created dynamite in 1870, by soaking nitroglycerine into diatomaceous earth. When made into strainers, it is porous enough to let liquid flow through it, while its lacy particles strain out bacteria. It is for this quality, that drug firms use the product. It has also been used as a cigarette filter, to strengthen concrete and to produce a flat or semigloss finish in paint.

GOLD.—Concerning recovery from the sea, the only "trace element" that has really attracted attention is gold. Just one of our 300 million cubic miles of sea may contain as much as 25 tons of this precious metal. But, it is in such minute particles that extraction is not currently financially feasible. There have been a few attempts, all of which met with failure. A minute amount was extracted experimentally as a by-product of bromine production. The final cost, however, amounted to approximately five times the value of the gold recovered. Also, there was the unsuccessful attempt in 1927 of the German *METEOR* expedition. This was the German attempt to obtain sufficient gold from the mid-Atlantic to pay off their war debt.

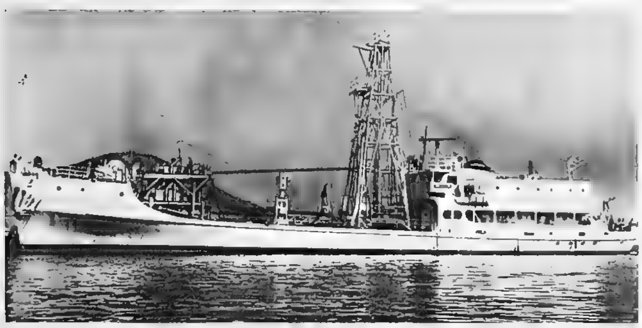
Research on gold extraction will no doubt continue, to some extent. If an economic method is not found, scientists will still gain other useful information from their efforts.

NODULES.—In 1870 the famed British oceanographic vessel *CHALLENGER* dredged from the ocean bottom, lumps of a mineral that to some extent resembled blackened potatoes. The assays later proved the nodules to be rich in manganese, copper, cobalt, nickel, and iron. Industry, however, failed to become interested.

More recently, during the International Geophysical Year, tremendous quantities of these metal bearing nodules were rediscovered on the ocean floor and interest concerning them has now been raised. These ore nodules grow in layers like onions, have taken millions of years to form and often have a small nucleus of clay, pumice or glass. The majority recovered have ranged in size from a few inches in diameter to two cubic feet. At least one, however, has been reported to weigh almost a ton. The rate of growth is approximately one millimeter in a thousand years. But, so many nodules are forming continuously that they could supply our major needs and the growth rate, though exceedingly slow, would exceed the rate of depletion.

Thus far, no one has mined nodules on a commercial basis, although there are some companies at least investigating the possibilities. Recovering these ore deposits promises to be an engineering feat of gigantic proportions and may not be accomplished until land deposits become exhausted, or nearly so. The engineering reward, however, will be vast as it has been estimated that by vacuum-cleaning a square mile of ocean bed surface, in a selected area, the ore recovered could amount to 6,000 tons of manganese, 4,000 tons of iron, and 125 tons each of cobalt, copper, and nickel. These are, of course estimates only. It has been further projected, however, that the value of mineral deposits within one square mile of ocean floor, might well amount to half a million dollars.

OTHER MINERALS.—Other similar treasure, in the form of rich tin ore, lies off the coasts of Thailand and Indonesia. Also, there is gold in the gravels and sands in the proximity of Nome, Alaska and a barge dredging approximately $200,000 worth of diamonds a month off the southwest coast of Africa.



M. V. Rockeater—first ship designed and built for mineral prospecting.

The first of its kind and owned by the Ocean Science and Engineering Inc. of Washington, D. C., the newly completed ship *ROCKEATER* has just recently joined in the search for minerals off the Diamond Coast of southwest Africa. It is employed by the De Beers group, and will determine the value and extent of under sea diamond deposits in that area. The ship is capable of prospecting either by drilling geological core samples of hard rock, or by dredging and processing large quantities of unconsolidated material. All dredging and drilling is accomplished through a 7 by 11 foot center well, located amidship at the point of minimum motion. This well is surmounted by a 52-foot derrick.

For primary propulsion, *ROCKEATER* is equipped with twin screws. In addition, it has a bow mounted propeller plus an additional outboard motor on the stern, for greater maneuverability. All four propellers are controlled from a central steering console, on which a "joy stick" directs ship movement in any direction. This equipment is an extension of the "dynamic positioning" system used in Phase I of the MOHOLE Project.

PEARLS

This "Gem of the Ocean" has been sought by man for thousands of years. In the past, many civilizations have attributed powers of romance and magic to the pearl, probably resulting in today's association of the pearl with love and marriage.

The origin of the pearl was for ages a mystery. The ancients believed that at certain times oysters came to the surface and opened their shells. Then the tear of an angel was deposited within the shell, where it became a pearl upon crystallization. The Greeks were of the belief that when lightning struck the sea, pearls were created. And, after seeing oysters attached to mangrove roots in the West Indies, Columbus suggested that dew drops falling into the open shells, from the trees above, resulted in the formation of pearls.

Pearls are found in many parts of the world and from a number of different mollusks. They are produced in fresh water as well as salt water. The majority of the more valuable pearls, however, come from the oyster *Margaritifera*, that flourishes in tropical waters. The pearl oyster is a distant relation to the edible oyster and is more closely related to the mussel. As the common edible bivalves do not produce nacreous pearls, one is not likely to find one in a platter of oysters or clams on the half shell.

Essentially, a pearl is of the same substance as the "mother of pearl" of shells. It is composed mostly of calcium carbonate and held together by a tenuous network of organic conchiolin. They are formed when a foreign substance is ingested accidentally into the pearl bearing oyster. It is the oysters attempt to reduce irritation and prevent itself from being harmed. If the shell of the oyster is penetrated by a parasite, the oyster seals off the entrance with a secretion that in time becomes a "blister pearl". Blister pearls are hence attached to the shell, but can be cut off. It is the symmetrical or round pearl though that is so highly prized. These are formed around a nucleus, which may be any small irritant—a grain of sand, marine larva, or other debris.

The most valuable pearls are found near Ceylon and in the Persian Gulf. The nucleus of these pearls is believed to be the egg of a tapeworm, found in a certain ray. If the floating tapeworm egg enters the oyster shell two possibilities exist. A ray may eat the oyster, thus giving the tapeworm a chance to develop and hence lay other eggs. Or, the oyster may deposit numerous layers of nacreous material around the egg, thus forming a valuable pearl.

The demand for pearls has always exceeded the supply, as the average find is only one pearl in a thousand pearl oysters. Actually, in many areas the mother-of-pearl brought up by divers is worth as much as, if not more than, the pearls.

A round pearl ⅛ inch in diameter will weigh approximately one grain, a ¼ inch pearl about 7 grains, and a ½ inch pearl about 55 grains. The largest known pearl is the 1,860 grain pearl, in the Hope collection. The general value of a pearl may be estimated by establishing a base one-grain value for a pearl of the same shape, color and luster, then multiplying this amount by the square of the number of grains that the pearl weighs. For example, if the base one-grain value is determined to be $1, then that would be the worth of a 1-grain pearl; but a 2 grain pearl would be worth four times as much, or $4, and a 10 grain pearl would be valued at $100.

The lack of pearls formed naturally in the sea, has led to the development of cultured pearls. And, although the development of cultured pearls has caused a drop in price of natural pearls, the value of unusually large specimens remains high as cultured pearls come from oysters that do not produce the larger gems.

Men have tried for centuries to discover ways to induce mollusks to produce pearls. The earliest known cultivated pearls were produced during the thirteenth century by the Chinese, by hand inserting irritants into fresh water mussels.

During the sixteenth century, the Chinese started inserting small lead Buddhas into the mussels which resulted in Buddha-shaped pearls. And, these pearl coated images are still, to some extent, produced in the Orient.

A Swedish naturalist, Linnaeus, perfected a method for producing pearls in 1761. His method was to drill a hole in the oyster shell and with the aid of wire, push a small piece of limestone through the opening.

Neither of the above two methods, however, produced round pearls. The majority produced were "blisters", or baroques (misshapen pearls). This was due to the foreign object being placed between the mantle and the shell. Symmetrical pearls are produced within the connective tissues of the oysters body, rather than next to the shell. Further, the pearl is produced within the connective tissue only when the nucleus or irritant, on its entry into the tissue, has been accompanied with epithelial cells. Epithelial cells must be in contact with the pearl nucleus and these nacre producing cells are found only on the outside of the oyster mantle, i.e. next to the shell. This is the theory on which the more than 100 pearl farms operate in Japan, the largest of which is the Mikimoto Company. Kokichi Mikimoto, founder of the Mikimoto Company, died a few years ago at the advanced age of ninety-five. He often attributed his health and longevity to the fact that he ate two crushed pearls for breakfast each day.

AMBERGRIS

The sole source of this treasure of the deep, is the sperm whale. The fact that it is produced in the intestine of the sperm whale is well known. The manner of formation, or how it is formed, however, is still a subject of debate and conjecture. Although ambergris has been found in numerous places, the majority has been recovered in the middle latitudes, as the sperm whale is basically a temperate water animal.

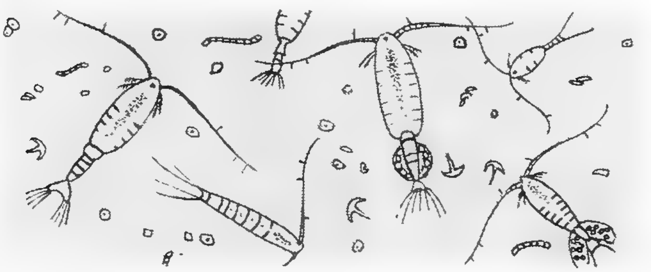
When ambergris is ejected by the whale, it resembles black stones. It is abominably malodorous, but as it spends more and more time floating on the sea its odor improves somewhat. It lightens in color also with age, fading to shades of brown and eventually becoming a chalky white.

The uses of ambergris have been many and various throughout the ages, with strange powers attributed to it. It has been used as an aphrodisiac, a condiment in food, drink, tobacco and medicines. Its current use, however, is devoted primarily in the manufacture of perfumes. It is used as a fixative in the manufacture of only the most expensive perfumes and it is for this reason that the scent of perfumes made with ambergris will last much longer.

Most of the ambergris now comes from the whaling industry, with ships and beachcombers reporting occasional finds. Sizes of ambergris found vary from less than an ounce to some 982 pounds. As the size of finds vary so does value, ranging from $2 to $9 per ounce, in accordance with the market and quality. A further example is a 151 pound 8 ounce chunk that sold in the United States for $20,000.00. Although not as valuable as it once was, due partially to synthetics, it does promise its finders a considerable reward.

AQUACULTURE

As the term implies, aquaculture is the cultivating and managing of the ocean's resources in much the same way foresters and farmers husband the land's resources. Aquaculture is a word not too well known today, but a subject that has enormous possibilities and is gaining world wide popularity. There is no doubt that further improvements to increase yield will be made in agriculture. The land area, however, is limited and hence must obviously limit the quantity of food it can produce. This limit has been reached and indeed has been exceeded in many locations of the world. Consequently, our need to turn again to the sea, as aquaculture is the means most conducive to conquering the world's undernourishment.



Zooplankton feeding on phytoplankton, the basis of the sea's food chain. Enlarged about 15 diameters.

Oceanographers have calculated that approximately nine times as much vegetation is available in our seas as is cultivated on land. The main bulk of this vegetable life consists of microscopic plankton, upon which zooplankton (small grazing sea animals) feed. And, zooplankton in turn is eaten by fishes—a cycle similar to the one on land in which grass is eaten by cattle and converted to beef. Actually, this chain of life in our seas has its beginning with sunshine and the dissolved chemicals in the water, for it is upon these that vegetable plankton prosper. The ocean currents and tides tend to stir the plankton's food supply of nutrients, with the smallest changes in quantity of nitrogen or phosphorus having a direct bearing on plankton population. Hence, this in turn, affects the entire chain of life in the sea, as animal life is basically dependent upon plant life.

The aquacultural concept has led scientists and oceanographers to speculate regarding methods to herd fish, increase and improve the stock and increase the richness of waters via forced upwelling. For, where the waters are rich in nutrients there is a bloom of plankton and hence a far heavier concentration of fish.

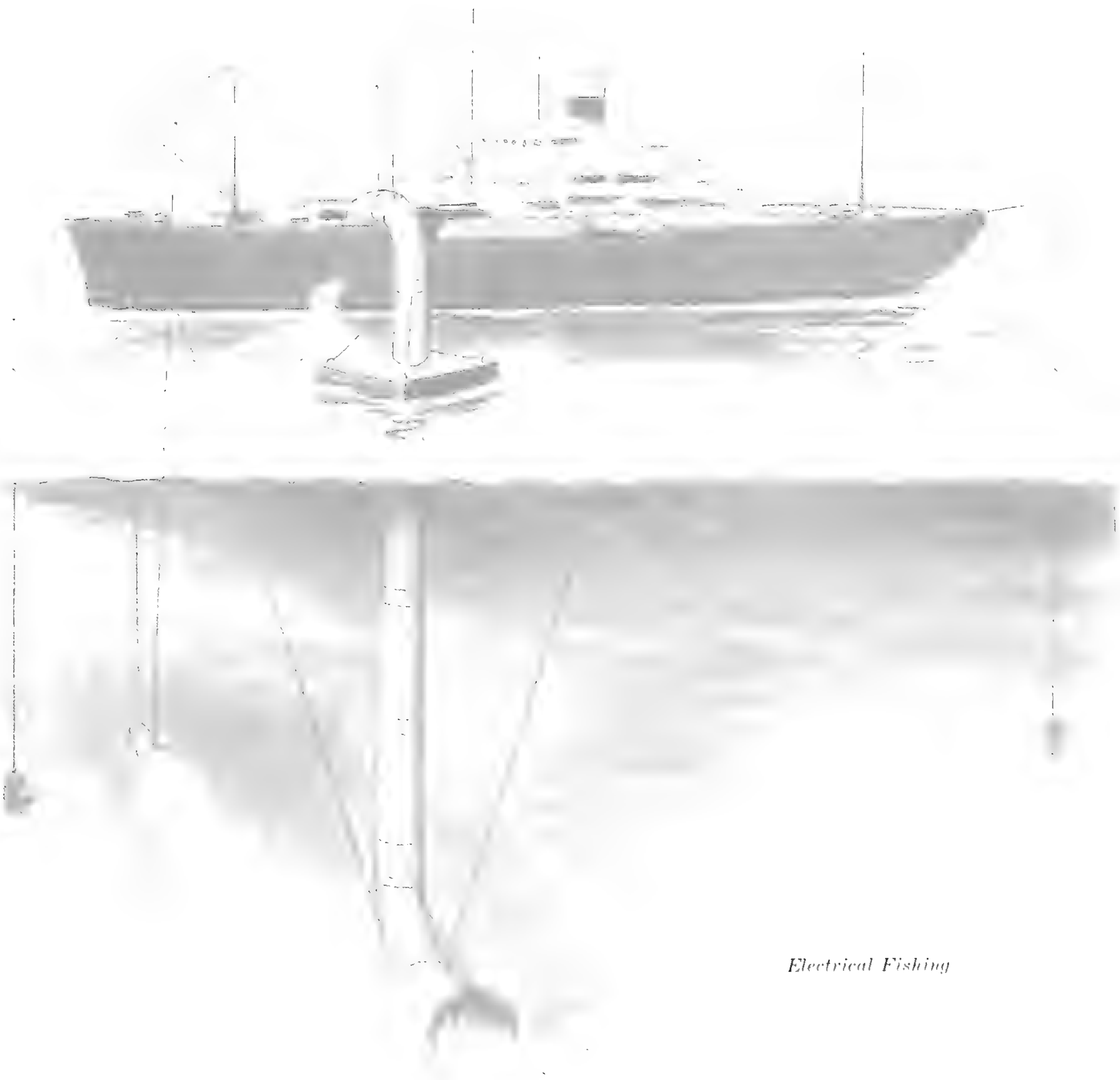
On land it takes considerable more acreage to raise a ton of beef than it does to grow a ton of wheat or corn. Similarly, the same situation holds in ocean pasturage. The advantages a farmer gains by growing vegetables in lieu of beef are quite small compared to those that could be gained were it feasible to harvest plankton directly, instead of having the fishes harvest it for us. This is due to the extended ladder of life in the sea, between plankton and man. If man could harvest plankton directly, he could increase the ocean's food yield by as much as a thousand times. At each link in the chain of sea life there is considerable waste, for whether it is zooplankton feeding on vegetable plankton or large fish devouring smaller ones, there is about 90 percent loss of energy or food. It therefore follows that it takes approximately 1,000 pounds of plant plankton to produce one pound of medium size fish with increasing amounts for the development of larger fish such as tuna.

If man could bypass the process and go directly to the bottom of the sea's ladder of life, there would be a tremendous saving of food materials. This currently is not economically feasible due to the high cost of pumping and sieving. In addition, the final product would be one barely palatable. So until a revolutionary technique is developed, man will have to depend on the fishes of the sea for conversion.

Even though we cannot yet economically harvest plankton, we can aid in the growth of plankton and thus advance the fish harvest. This can be accomplished by bringing to the surface the rich bottom nutrients on which plankton flourish, i.e. by forced upwelling. Where upwelling occurs naturally it causes plankton to bloom and fish to congregate, a good example of which is the Grand Banks of Newfoundland. Here the Gulf Stream meets the Labrador Current, causing a complex vertical circulation and produces an area of constantly renewed fertility. Another example of copious sea life, is off the coast of Peru. The prevailing winds along the west coast of South America are offshore. Water thus is blown offshore and is replaced by the nutrient rich deep waters of the north flowing Peru Current. Consequently, upon reaching the Peruvian portion of the Continental Shelf these waters produce sea life unsurpassed elsewhere in the world—phytoplankton, zooplankton, fish and even numerous sea birds are in abundance. Such are the possibilities of aquaculture.

The farming phase of aquaculture also offers many possibilities, for the most astonishing fact about sea life is the tremendous loss of young. A single female Cod, for example, will produce from one to five million eggs each season. For the species to continue in existence, only two of these eggs need survive to maturity. Here we have a tremendous egg potential offset by enormous mortality. As the eggs develop, they float to the sea surface and become a part of existing plankton, which is destined to be eaten by other fishes. After developing into small fry, the remainder tends to settle near the bottom where they attain their best growth in five or six years.

There is little that can be done to cause more of the cod eggs to grow into adult fishes, as they are affected by various factors. To raise young fish in huge numbers artificially for transplanting without providing additional food, would be similar to a farmer trying to double his land's yield by planting twice as many seeds. Life in the sea exists almost entirely by cannibalism and the rate of destruction would be high until the numbers of fish had been reduced to the natural food level. Actually, if the majority of fish eggs were not destroyed, the oceans would soon overflow with fish. This point may be further stressed by using the oyster as an example. For, if the progeny of a single pair of oysters survived 100 percent, in five oyster generations their combined bulk would be equal to approximately eight times the size of the earth!



Electrical Fishing

Pond culture has proven successful in several areas, with a yield higher than that of agriculture. For instance, in China production is said to be 5,000 to 7,000 pounds of fish per acre, compared to 800 pounds per acre for beef. Oyster cultivation, however, has been one of man's most successful attempts at aquaculture. The Romans were among the first to try their hand at aquaculture some two thousand years ago. Growing oysters were attached to ropes in protected areas, while they were fattening. Today, where conditions are favorable, oysters are cultivated in many areas of the world.

One oyster will produce several million young of which only a very few ever emerge as adults. Were this not the case, a few oysters could, within a short time, produce enough food to feed the entire world population. When the spat (young oysters) emerge from the plankton stage, they settle to the bottom. If at this critical period of their life they do not find sand, or a rock on which to attach themselves they soon expire from silt and pollution. It is at this most important phase of their life that man can best promote their growth, for the numbers are few that ever find the necessary type of bottom. For this reason, some states wisely require that a certain percentage of marketed oyster shells be returned to the growing areas.

FISHERIES

Fishing has been referred to as man's oldest industry. It has certainly provided him with a substantial portion of his diet since pre-historic times. Currently seafood probably makes up less of man's diet than it did in earlier times, as fishery products now constitute less than three percent of the world's food.

In the less fortunate areas of the world, millions of people suffer greatly from protein deficiency, due to their economic diet of rice and other starchy foods. Fish from the sea, however, offers a thrifty solution to this nutritional problem. For, fish is a concentrated protein diet, with the advantage of holding all of the essential amino acids.

In addition to the calorie producing foods, our body chemistry requires other sources of energy such as vitamins and minerals, which are all contained and well-balanced in seafood. Further, the fat in fish provides vitamins A, D, & B complex; and it is now believed that natural vitamins may contain beneficial qualities not found in the synthetic product. Concerning minerals, fish contains phosphorus, calcium, potassium, and magnesium along with adequate quantities of iodine, iron and copper. So, not only is fish a most palatable and economical food, it is also the most digestible form of protein and a well rounded source of energy and health.

The remedy for protein shortages is in the sea and waiting utilization. But, all too frequently the fish are scattered and so far removed from the hungry mouths it is beyond the means of economy to catch them. New devices and methods are sorely needed, as very little has been accomplished of a radical nature, concerning methods, in the past several hundred years.

A wide variety of new gear, with a completely new approach, is presently being studied by scientists. They have discovered some of the ways fish respond to what they feel, see, hear, and smell and are taking advantage of these facts. One of the items receiving interest is the tendency of fish to react to electric fields. A strange fact concerning electrical fishing, is that fish line up with the field, facing the positive pole. Upon becoming aligned with the electrical fields of force, the fish then begins an inexorable move towards the positive pole and so continues as long as the current persists. At or near the anode electrode the fish becomes stunned and may be scooped up. This process, although not yet too successful in salt water, has been going on for some time in fresh water.

The basic reason for the lack of success in salt water is the fact that salt water has less resistance than fresh water. Or, stated differently, the higher the salt content of water the greater the conductivity. This range of resistance is quite great, with a minimum of 9 to 20 ohms per cubic inch for sea water and going up to 1,000,000 ohms for pure rainwater.

As electricity takes the path of least resistance it can be seen that it would bypass a fish with a resistance of perhaps 250 ohms swimming in sea water of, say, 15 ohms. On the other hand, were the fish swimming in river water of 1,500 ohms resistance it would quickly be effected. Consequently, to produce the required effect in sea water, considerable more power is necessary.

The advantage of this process is that the size of fishes caught can be controlled, as the larger the fish the less current is required for response. Other items include dye curtains, a net of sonar transmitters that emit a repellent noise, gigantic nets that can be closed before the fish become frightened, underwater television cameras and many others.

Whatever improvements and advances are made in the near future, commercial fishing will still largely be a matter of hunting and finding the fish. It is therefore not only important that catching methods be improved, but also the means of locating the fish is of paramount importance.

To awaken the general public's interest in the protein rich food of the sea, marketing experts are continually at work. New methods of packaging along with new products such as breaded shrimp and fish sticks are now conveniently available at most grocers.

FRESH WATER

Of all the riches from the sea, the one that may well prove to be of highest value to man, is water itself. For, neither industry, agriculture nor man himself can long survive without this all important element. In parts of the United States, North Africa, Australia and Central Asia the need for fresh water is becoming desperate. During the draught years several United States cities place special restrictions on the use of water. An extreme example of the lack of water was in Dallas, Texas in February 1957 when 5 gallon jugs of drinking water sold in grocery stores for $1.25.

So, where shall we get additional water? More reservoirs would help, but a vast supply of water in a northern reservoir would be of no value to the draught-stricken south. Again we should look to the sea for help. Man has long been in quest for a means of irrigating deserts and arid lands. Several methods have been known for years, but the problem has been not only to obtain fresh water abundantly, but cheaply. The answer to this age-old problem will probably be nuclear power. For, as has been the case with so many subjects, "nuclear energy has been a solution in search of a problem."

The Department of Interior has been conducting research on obtaining fresh water from the sea, for more than a decade, and has a few pilot plants in operation. In any event, the day is probably not far off when deserts will bloom and arid countries will be able to produce the crops that their populations so desperately need.

CONCLUSION

The Malthusian theories hold that the population of the world tends to multiply faster than its means of subsistence can be made to do, and that, unless an increase of population be checked by prudential restraint, poverty is inevitable. The views of political economist Rev. T. R. Malthus (1766-1834) might well have been quite different if he could have forseen more of the capabilities of our inexhaustible sea.

The potentials of Neptune's treasure are vast. Minerals and chemicals exist beyond one's comprehension. Food is available in quantities more than sufficient to lift all of the world's wants. In addition, if the power of the ocean's currents, tides and waves could be converted for use, it would be considerably more than all the power currently produced.

Our conquest and understanding of inner space may well prove more important to our very existence than the greatest of achievements in outer space.

BIOLOGICAL OCEANOGRAPHY

F. W. Fricker
Maritime Safety Division
U. S. Naval Oceanographic Office

Oceanography, a relatively new word in our vocabulary, has been generally defined as the "application of the sciences to the phenomena of the oceans". Broadly speaking, oceanographic research can be said to embrace four major scientific disciplines: biology, chemistry, geology, and physics. Oceanography can, therefore, be further defined as the corporate study of the biological, chemical, geological, and physical components of the world's oceans and adjacent waters.

Biological oceanography specializes in the study of the living, or organic, content of the sea, its myriad plants and animals. It is, in its own right, a broad field of scientific effort embracing separate disciplines of which morphology concerns the form and structure of organisms, taxonomy their classification, physiology their functions, and ecology their environmental relationships. Of these, ecology is the dominant field in modern marine biology as biologists strive to understand the complex interrelationships that exist between marine organisms and their environment and between the organisms themselves. The importance of understanding these relationships is tied to a number of existing and anticipated problems.

From an economic and social standpoint, the sea contains vast quantities of foodstuff upon which much of the present world population looks for sustenance. As the burgeoning population of the future will place fantastic demands upon this source, scientists, industrialists, and statesmen the world over have begun to focus their attention upon the seas as a vast latent source of nutrients. To cultivate, foster, reap, and conserve this fabulous natural resource is an important part of biological research.

From the purely military aspect, the sea, as a three-dimensional medium for naval operations, has assumed new significance. Extensive efforts are being expended to find possible means of combating the limiting and damaging effects of marine organisms upon ships, installations, and equipment; to investigate the source of the scattering effect upon sonic impulses; to catalog the sounds created by marine animals; to determine the predictability of bioluminescence; and to explain numerous other phenomena which affect naval operations.

In brief, biological oceanography is cast in an important role in the conquest of earth's last remaining frontier, inner space. To highlight this role is the purpose of the following article. As a complete monograph of the science is quite beyond the scope of a single article, it has been limited to those facets of apparent interest to mariners.

BIOLOGICAL ASPECTS OF FISHING

It has been generally estimated that 10% of the world's present protein supply is comprised of aquatic organisms. Disregarding possible inaccuracies in this rate, sufficient evidence now exists to predict a much greater usage of seafood in the not-too-distant future. Theoretically, the presumption that the sea can provide increasing amounts of food is well founded. Scientists realize, however, that fulfillment of this promise can only be achieved through progressive advancements in fishery technology. Better conservation measures must be instituted, new fisheries discovered, capturing techniques improved, and the range of useful products widened to ensure that the world's fisheries keep pace with expected population demands. The issues involved are essentially biological in nature and, certainly, oceanographic in scope, for the development of rational theories concerning present and future exploitation of oceanic resources must be based on a more complete knowledge of the various organisms and their interrelationships with environment.

Fish are very similar to land animals in that each kind has its own preference of food and environment. Because of this, they tend to congregate in regions where their particular food is most plentiful and water temperature is agreeable. Most fish migrate during certain seasons of the year along comparatively well defined routes, stimulated by an unconscious urge to spawn, feed, or winter in a different location. Many species tend to feed and migrate as a group, or shoal. Obviously, a sound knowledge of the migratory cycles, routes, and shoaling behavior of desired fishes is necessary in forecasting the most favorable catch areas. Fishery charts, currently being developed on a worldwide scale, are largely based on this knowledge. As the many species have varying habits, the task of collecting, collating, and cataloging the required data is enormous. An example of the details investigated as a result of research in this field is the recently developed theory that salmon migrations are initiated by the organism's preference for water of varying salinity, due to a change in the rate of its thyroid activity.

Food is undoubtedly the most dominant influence in the lives of fishes; and consequently, their behavioral patterns, as well as their growth, are largely affected by the type, location, and abundance of their food supplies. The fact that the world's great fisheries coincide with the areas of bountiful plankton growth is no mere accident. The first link in the sea's food chain is its drifting algae, or phytoplankton. Feeding upon these vast quantities of microscopic plants are the myriad zooplankton, tiny shrimplike creatures barely visible to the naked eye. These creatures form the staple diet of most commercially important fishes at some stage of their development. The fishes, in turn, are preyed upon by larger predators, mammals, and birds, thus completing the chain. As productive imbalances at any level of this progression may adversely affect commercial production, intensive studies of feeding relationships is an important part of fishery research. The construction of rational methods of exploiting our fisheries would be impossible without an understanding of the manner in which a particular fish exploits its food resources and the nature of the relationships between the fish and others which consume the same food.

At the present time, the greatest danger resulting from a constant expansion of our marine fisheries is that of overfishing. Biologically, overfishing is that condition created by excessive catches in which the reproductive capacity of a remaining population of fish is unable to compensate for the losses sustained. Economically, the practice eventually results in a proportionate decline in catch per effort expended, making further production of a fishery unprofitable. While the latter condition probably prevents fishing of a species to the point of extinction, it is of little consolation to the fisherman and the conservationist. Although the imposition of conservation measures rests with legislative bodies, the problems involved are basically biological.

Ocean perch infested by parasitic copepods.

In addition to the adverse effects of overexploitation, there are many natural conditions which affect reproduction and maturation of marine organisms. Several bacterial and virus diseases attack fish, and some fungi can kill them. Parasites do enormous harm, and predators take a huge toll of commercial fishes. The amount of fish consumed by piscivorous birds is very large, so that in areas where they abound birds can cause serious losses to fisheries. Mussel poisoning on our west coast results from periodic blooms of the plant *Gonyaulax*, and a similar one-celled organism, *Gymnodynium brevis*, has been associated with the fish killing "Red Tide" along Florida's west coast. In the interest of enhancing our fisheries, biologists must develop methods of reducing or eliminating these harmful elements.

Researchers are also combating relatively new threats to fish survival. Pollution of the seas by oil and other substances has a serious adverse effect on fish by upsetting their metabolisms, contaminating their food supplies, and destroying the reproductive qualities of spawning areas. The blocking of spawning grounds by dams, log rafts, and debris has grave effects upon reproduction.

Although the sea harbors at least 40,000 species of fish and an even greater number of other aquatic organisms, only about 300 kinds of fish and shellfish are utilized for food in the United States. Furthermore, of the nation's total annual catch, 60% is composed of only 9 species. This overspecialization in only a few of the species available places a severe limitation on the expandability of the source. It appears evident that future demand will gradually necessitate a wider usage of the many edible species now classified as commercially unimportant. Oceanography will play an important role in determining the exploitability of new stocks.

Biological research has provided several methods of augmenting existing stocks of commercial fishes. By artificially rearing fish in controlled hatcheries and on fish farms, eggs and larvae can be protected from a number of adverse conditions, thus assuring a higher rate of maturation. The productivity of a water-mass can also be enhanced by artificially raising its food content, either by fertilization to encourage the growth of organisms upon which the larvae feed, or by introducing cultured fishfood into the area. Transplantation of desirable species from one environment to another has, in many cases, been successful.

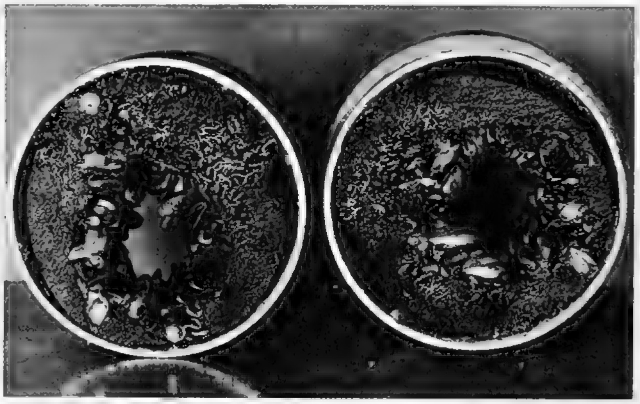
To realize the full potential of harvest from our oceans, however, effective methods of utilizing the many species inhabiting the extensive geographic regions of our open oceans must be devised. Many of these resources, like those of the tuna family, may form natural aggregations only periodically, may make themselves available only seasonally to existing fishing systems, or may be widely dispersed thoughout the sea. Exploratory expeditions conducted by various nations have resulted in the discovery of several new offshore fisheries of commercially valuable fish. It seems reasonable to assume that many more await discovery in the vast reaches of our oceans. However, economical exploitation of any new oceanic species must be preceded by a careful appraisal of the creature's shoaling, feeding, spawning, and migratory habits so as to forecast and chart the areas of highest concentration.

Equal in importance to the discovery and forecasting of their aggregative traits, increased harvests of offshore species will require vast improvements in capturing gear and techniques. Most methods in use today evolve from systems designed to capture fish within close proximity to land, relying on environmental features and biological characteristics of fish to form required concentrations. The perfection and effective application of fishing gear is impossible without a sound knowledge of the reactive processes of fishes, particularly their shoaling behavior and the characteristics of their sense organs by which they orient themselves to fishing gear. The form, size, color, and other properties of capturing gear, and the region in which it is applied, have a definite bearing upon its effectiveness.

Refinements in fishing techniques may require the use of more sophisticated capturing methods, to facilitate economical harvesting. The attractive influence of strong artificial light upon fish is well known, and fishermen the world over have exploited its use. Recent experiments have further revealed that fish behavior is affected to some extent by the color, as well as intensity, of artificial light. Biologists have recently confirmed the fact that fish respond to an electromagnetic field, first, by orienting themselves to the lines of flux, then by swimming toward the anode. By placing an electrode in front of a trawl, shoal fish can be attracted and guided into the catching area. Furthermore, experiments show that by the use of direct, alternating, or pulsating current, electrical fishing gear can be made to frighten, block, or "fence" fish, or to narcotize or kill them. Guiding herring into nets or traps by use of a wall or stream of air bubbles has been experimented with and employed with some success. Perfection of such techniques, however, will require a better understanding of the behavioral reactions of fishes to artificial stimuli.

FOULING AND DETERIORATION

Among the many important problems associated with marine biology, none has greater economic significance than the control of marine fouling and deterioration. Anyone familiar with the sea and ships is well acquainted with the costly effects of marine growth on ships' hulls and salt water intakes. Equally important is the damage of shore installations resulting from the penetration of wood, plastics, concrete, and other structurally important materials by several marine organisms. It has been conservatively estimated that the annual cost to the Navy alone for the protection and maintenance of ships, waterfront structures, and offshore equipment against biological deterioration and fouling is approximately $100,000,000. Far more importantly, however, uncontrolled fouling and deterioration by marine organisms can effectively reduce the combat readiness of naval ships and shore facilities.



Sections of 6-inch pipe taken from over boiler on Navy ship. The pipe is almost closed by marine-fouling growth.

The fouling of ship's hulls is, of course, an age-old problem. Man's historic efforts to discourage marine growth has resulted in the development of chemical agents which today, can protect hull surfaces for as long as 24 months. The problem is far from solved, however, for the development and use of submerged equipments vital to naval operations and technological progress constantly introduce new requirements for enduring antifouling agents.

The biological fouling of a sonar transducer can seriously impair its effectiveness by attenuating sound transmission. In certain areas of the world, critical fouling of unprotected surfaces can occur within a few months, rendering sonars unfit for ASW operations. Some success in developing reliable protective coatings for sonar domes has been realized, but the problem is complicated by the requirement that the agent used must not alter the equipment's acoustic properties.

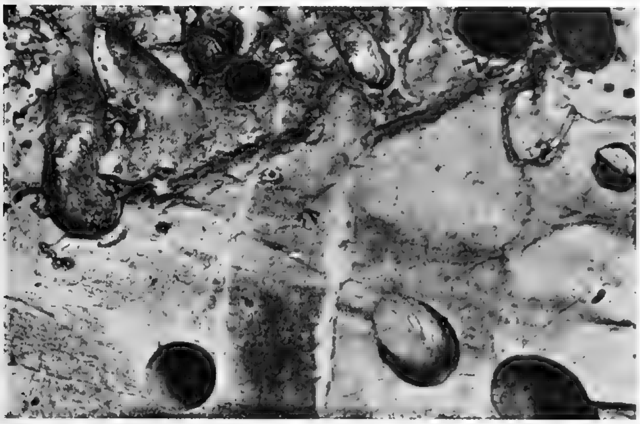
The growing use of underwater optical instruments presents further complications. Complete fouling of an underwater television lens can be accomplished in an incredibly short period of time. Obviously, the lens cannot be painted with antifouling paint as in the case of a ship's hull. The development of durable but transparent protective coatings is a necessary preliminary to the planned installation of submerged optical equipment such as television monitoring stations.

Moreover, the proposed construction of large, stationary structures in relatively deep ocean waters for various military and commercial projects creates additional fouling problems. Already, the underwater structures used in the recovery of offshore petroleum are approaching deeper waters. Because of the size and permanency of proposed structures frequent maintenance will be impractical, if not impossible. Therefore, anti-fouling agents of enduring effectiveness must be developed. But little field data is available at the present time to warrant the assumption that deep-ocean fouling will not differ from that occurring in shallow coastal waters. For this reason, far more data must be obtained about the ecology of fouling organisms in the deep sea before reliable fouling deterrents can be developed.

Wood gribbles bore into a piling.

Deterioration of submerged installations by marine organisms is another serious threat to present and proposed marine operations. Extensive destruction is caused by species of *Limnoria*, or gribbles. These animals are related to the shrimp and lobster and are worldwide in distribution. They are normally found attacking the surface of submerged piling and other wooden structures in shallow water, but materials other than wood, such as the gutta-percha insulation of submarine cables in depths up to 360 feet, have been penetrated by gribbles. Other crustaceans burrow into, and consequently weaken, stone seawalls.

Certain mollusks, such as the well known teredo, or "shipworm", relatives of the clam and oyster, attack submerged wooden structures in harbors, or burrow into rocks and coral. Mollusks are also responsible for destructive attacks on gutta-percha insulation of cables at depths ranging from a few feet to 7,200 feet, causing physical damage and short circuits. Others have been found to penetrate solid lead sheathing of submarine power cables. Even concrete is not immune to destructive attacks by these creatures.



Rock-boring bivalves, worms and sponges attack hard limestone.

Marine bacteria play a surprisingly important role in the deterioration and fouling of materials and equipment in sea water and marine sediments. These micro-organisms accomplish their destruction in a number of ways. By forming over antifouling agents, to which they are apparently immune, they provide a foothold for barnacles and other fouling animals. Cellulose-decomposing bacteria cause millions of dollars worth of damage to net cordage, seines, and lines used by commercial fishermen. Also present in the sea are cellulose-consuming fungi which infest natural fibers and woods. Rubber products such as hoses or gaskets, generally regarded as being impregnable, have been found to be decomposed by the action of marine bacteria. Sulfate reducing bacteria have been associated with the accelerated corrosion of submerged metals. Here again, the problem of protecting deeply submerged materials from the ravages of these organisms is complicated by the fact that some bacteria actually thrive in deeper water, reproducing only when subject to great pressures.

Even the color of materials used in underwater installations has an influence on the attacks by marine fish. Attracted by its white color, the polyethylene insulation of marine cables has been extensively damaged by the nibbling of certain fishes. Biologists have suggested a less attractive insulation color to reduce such attacks.

Vulcanized insulation of submarine cable slashed by shark who left some imbedded teeth as evidence.

The fouling and destructive potential of a segment of the sea's population is, thus, clearly illustrated and defines present and future requirements for more effective control. To meet the requirements our understanding of the vital processes which govern the life cycles and behavior of the offending organisms must be broadened. Adequate knowledge of such processes should lead to the discovery of an inherent weakness in each organism which is susceptible to external control.

BIOLUMINESCENCE

A biological phenomenon well known to mariners is the relatively common yet curious sight of luminescence in the sea. At first believed to be caused by the presence of the element phosphorus within the water, it has been known for almost two centuries that the phenomenon is biologically induced. In its most familiar form, luminescence is observed as a bluish-green fluorescent glow in waters disturbed by bow waves and wakes, and by cresting waves. Luminescent displays occasionally attain more spectacular proportions, however, forming parallel bars, or "wheel spokes", of pulsating light extending from horizon to horizon. Sometimes the wheel spokes appear to rotate like a giant pinwheel.

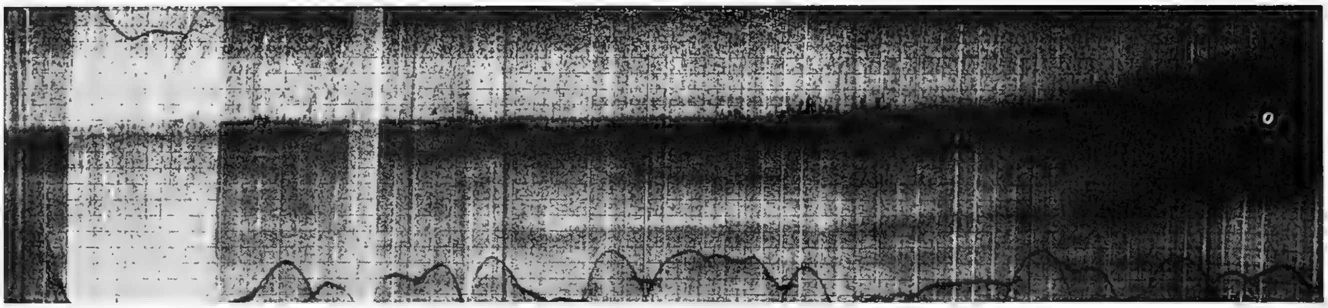
A simplified version of the occurrence is that tiny plants and animals, some even microscopic, exist in the near-surface regions of the sea in countless numbers and react to various stimuli by emitting light. The light emitting properties of many of these organisms permit them to alternate, or flash, their light in a manner similar to the common firefly. The rhythm of flashing depends in most cases upon the kind of stimulation introduced. Some of the lowly dinoflagellata, a group of single-celled organisms strangely cast on the borderline between plants and animals, are known to possess this characteristic. Since they abound in the upper portions of the oceans, dinoflagellata are among the better known organisms responsible for the luminescence observed by seafarers.

Because they often exist in huge concentrations, luminescent organisms are capable of producing an amazing amount of light. In certain geographic regions, agitation of the sea by the passage of a vessel at night produces enough illumination on deck to enable one to read. When the stimulation is passed through them in waves, their rhythmic reaction may give the impression of a symmetrical swirling movement of light, thus creating the pinwheel illusion. The parallel bar effect occasionally observed is accounted for by the movement of the sea, which even under calm conditions, circulates vertically in such a way as to concentrate the organisms in horizontal streaks.

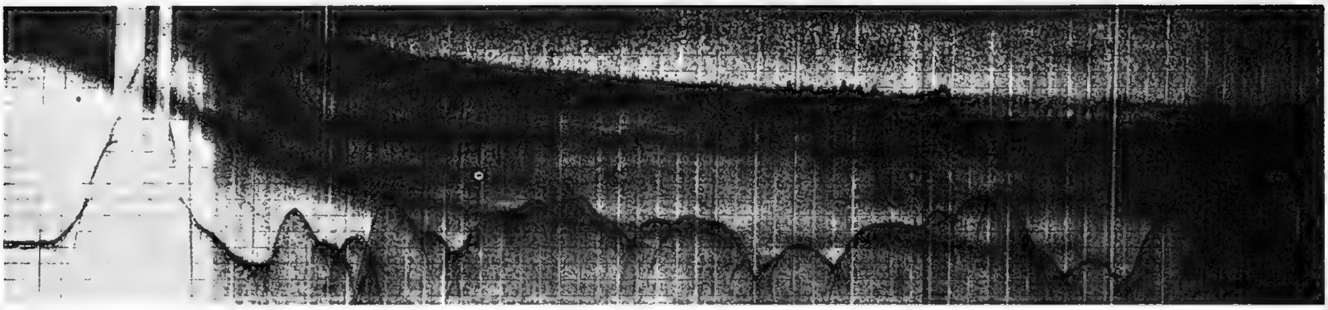
While surface displays are the most frequently observed, bioluminescence is not confined to the upper regions of the sea. Light producing organisms have been found to exist at every depth. In the blackness of the abyssal depths, where sunlight never penetrates, the light produced by certain animals provides almost constant illumination, to the mutual benefit of themselves and others not so equipped. The fact that the latter creatures have well-developed eyes, and are obviously dependent upon alien sources of light, is evident of the close interrelation of these deep dwelling species. To fully understand the significance of luminescence in the ecology of marine life is a constantly expanding project for oceanographers.

A 6" stomiatoid fish taken in net tow at 2,000 feet (approx.)

To the casual observer, luminosity of sea water is but a harmless manifestation of natural wonder. In the conduct of naval operations, however, the phenomenon is viewed with a jaundiced eye. Observed from the air, or from the bridge of a large vessel, the luminous wake of a ship travelling at even moderate speeds can be detected for some distance, clearly revealing its position and, roughly, its direction and speed. During World War II amphibious landings and other naval movements were, on several occasions, compromised by the presence of bioluminescence. Consequently, another goal of the oceanographer is to eventually establish a pattern of reoccurrence so as to forecast the periods of luminescence in areas of projected naval operations.



At first light scattering layers begin descending to various depths at which they remain throughout the day.



At night layers ascend and merge near the surface.

THE DEEP SCATTERING LAYERS

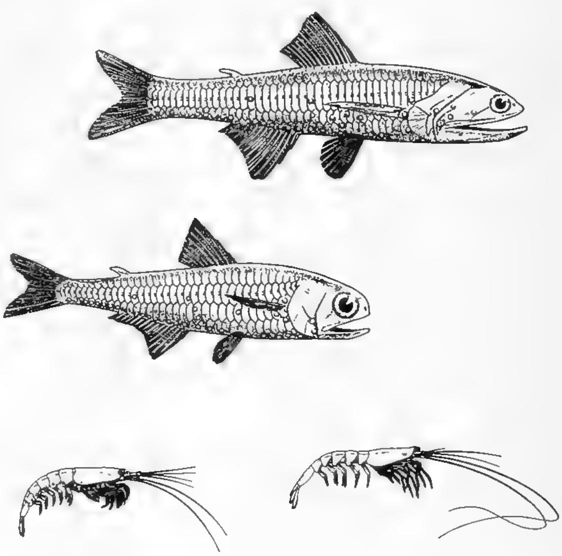
Another biological phenomenon which has gained increasing importance to both mariner and oceanographer during the last two decades is the sea's "deep scattering layers (D.S.L.s)". Briefly, these are the horizontal sound reflecting bands that exist at various depths over broad reaches of the world's oceans. Mariners today are probably quite familiar with the physical aspects of the D.S.L.s as they often produce "false bottoms" on the recording traces of echo-sounding devices. Indeed, it has been widely conjectured that misinterpreted "echograms" may have led to the charting of non-existent shoals. Today, determination of the exact composition, behavior, and distribution of the layers is a continuing oceanographic project, for much more information is needed regarding their possible influence on sonar systems.

Discovered by accident during World War II, the "layers" have a relatively brief but interesting history. A group of physicists experimenting with sonic submarine detection gear consistently, and annoyingly, recorded echoes from a uniform layer some distance above the sea's floor. During daylight hours an exceptionally well-defined layer was frequently observed at 150 to 175 fathoms. At night it disappeared. The feature could only be attributed to a suspended stratum of some sound reflecting, or scattering, agent, and thus derived the name "deep scattering layer". The name was pluralized after subsequent experiments revealed the existence of multiple layers.

Soon after initial discovery, a causative solution was sought in some physical property of the sea capable of producing the sonic reflection. To this end, attempts were made to correlate the phenomenon with density discontinuities, or abrupt temperature differences, in the sea. However, workers were unable to suggest any physical effect that would account for the layers' characteristic of ascending to the surface at sunset and descending to depth at sunrise.

Observing the close parallel between this characteristic and the diurnal vertical migrations of certain marine animals, biologists postulated that the scattering layers were of biological origin. This theory has endured the test of time and is universally accepted today.

On the basis of this correlation and later field experiments it was concluded that huge aggregations of tiny planktonic animals were reflecting some of the sonic impulses, or "pings", from sound apparatus. The animals, it was suggested, rose to the surface at nightfall to feed upon the abundant phytoplankton. At daybreak they would again seek the darkness of depth, either through the fear of predatation or their natural sensitivity to light. Further investigations have shown that during the day the layers remain at depths roughly between 700 and 2,400 feet. At night they rise almost to the surface and diffuse, or they may merge into a broad band as much as 500 feet thick. Most places in the deep ocean usually have three layers, the deepest at an average of 1,900 feet. Sometimes, sounding traces show very diffuse layers that stay at the same depth day and night.



Tiny fish and crustaceans found in scattering layer. Shown at approximately actual size are two forms of lantern fish, a euphausiid, and a sergestid.

From physical evidence as a result of sampling and bathyscaph observations, many researchers are of the opinion that shrimp-like crustaceans called *euphausiids* and *sergestids* are the reflecting agents in the layers. Others, however, argue that crustaceans rarely occur in sufficient densities to produce reflection layers. In rebuttal, the the latter workers suggest that fish and similar animals with swim bladders, or gas filled bubbles, are the causative agents. Quantities of *myctophid* or lantern fish, 2- to 3-inch predators which feed upon crustaceans, have been collected in net tows to reinforce this contention. At least one observer has concluded that concentrations of tiny jelly fish equipped with gas-filled floats are the source of the scattering layer.

The complexity of the problem is indicated by the apparent likelihood that several agents are involved, for a single layer often "splinters" during vertical migration into as many as four separate elements. These elements never cross one another, each seeking a precise depth as though adjusted to a particular level of twilight. Because of this stratification, exact identification of each element is dependent upon the selectivity of sampling devices which, at present, leaves much to be desired.

The inevitable development of improved sampling techniques and echo sounding apparatus will, undoubtedly, resolve the problems of the deep scattering layers. But apart from the acoustical problems they present, biologists view the phenomenon as a valuable ecological tool for understanding the mass distribution of life within the sea.

NATURAL SEA NOISES

Marine animals contribute another source of acoustic interference. Contrary to the belief that the sea was a silent environment, many aquatic animals are now known to produce noises of widely varying nature. At times, concentrations of animal sound-emitters can set up a veritable clangor beneath the sea, and because of the diverse properties of air and water, little of it ever reaches the casual listener above the surface. Over hydrophones, however, these "fishy" noises can be plainly heard and recorded. While the sea's inhabitants are apparently well adjusted to the condition (having no other choice) such noises can have serious effects on naval operations.

The military implications of natural sea noises were not fully realized until World War II, when their intensity and worldwide distribution were recognized as limiting factors in anti-submarine operations. Early researchers found that hydrophone reception was decidedly hampered by the ambient noise level produced by animal sound-emitters. Some of the sounds detected and identified as biological were remarkably similar to sounds characteristic of surface and underwater craft. At least one organism, or group, produces a sound like an unrythmic hammering on steel to the understandable dismay of a hydrophone operator.

Mindful of the obvious operational and psychological stress the noises placed on ship's crews, the Navy initiated a program to record and identify them. The object of the program was to train operators of acoustic gear to discriminate between biological sounds and mechanical sounds and to possibly redesign equipment to filter out undesirable sounds.

The problem of identification is complicated by the fact that, over hydrophones, the sounds made by an individual animal may differ from the effect produced by a group. Thus, the croaker often makes a drumming sound, but the noise produced by a dense shoal of croakers has been described as resembling that of a pneumatic drill tearing up a pavement. In some instances their chorus becomes so voluminous that it drowns out completely any ship or propeller noise. The snapping shrimp, an inedible variety smaller than a man's little finger, produces a sharp "snap" with its lobster-like claw, but the over-all noise created by a large number of such animals is a continuous crackling noise similar to radio static.

In the effort to catalog marine animal noises, workers found it necessary to correlate the sounds recorded with more familiar terrestrial ones. Today, it is known that porpoises and whales whistle, click, bark, and moan; barnacles slurp; black mussels crackle; toadfish croak, growl, and whistle; weakfish, silver perch, and spot perch produce a rapid, raspy croak; the Atlantic croaker, true to its name, makes a similar, almost drumming sound at a slower rate; the northern puffer or swellfish squeaks and coughs among other noises; the striped barnfish coughs; and the striped sea robin makes a sound like fingernails being scraped over a drum. On the other hand, many fish have been found to be practically mute, such as the flounder and mullet.

The manner in which the organisms produce their sounds is fairly well known. Crustacea sounds are normally of the percussion variety, such as the claw-snapping of shrimp. The noises made by free-swimming fish are usually the product of their swim-bladder. This organ varies in form with the species of fish, and the type of sound emitted is a particular function of its size, shape, and the manner in which it is vibrated. Fish also produce rasping, scraping, grinding, or whining noises by either grinding their teeth or by rubbing their fins together.

The exact function of marine animal noises is still uncertain. They appear in some instances to be associated with breeding and spawning, in others to be defensive and protective. It seems likely that sounds produced by at least some fish are used by them for spatial orientation in a manner similar to sonar. It has also been determined that some of the sounds made serve no useful purpose at all, and in some cases even reveal the originator's presence to a lurking predator.

Marine biologists are particularly interested in determining the exact biological significance of sounds and look upon the non-military use of hydrophones as a valuable oceanographic instrument. It is evident that if certain sounds are peculiar to certain animal groups, underwater listening could be used to plot the distribution of such animals. Moreover, by classifying the creature's various sounds, such as those made while spawning and feeding, and those believed to be "emotional", biologists hope to broaden their understanding of the behavioral traits of marine animals.

CORAL REEF BUILDERS

Probably no branch of oceanography involves as many of the earth's sciences as the study of the origin and development of coral reefs. Primarily an active biological process, the building of a reef embraces geological, chemical, and physical processes, the extent of which varies with the location and type of formation under construction. While considerable work has been done in this field over the years, there remain wide gaps in knowledge which impede progress, particularly in the physiology and ecology of reef organisms.

A bed of both calcareous and stony coral

Common sea coral

Stinging coral

Elkhorn coral

Following World War II, a war fought in coral seas of which little was known, a marked intensification of coral reef investigation took place which has resulted in the acquisition of valuable biological data. The importance of continued research lies not only in the fact that the constantly growing reefs pose a serious threat to present and future marine operations, but improved harbor maintenance and the stabilization of many important islands may depend upon a better knowledge of coral formation. The studies are also important in expanding our knowledge of the general ecology of the sea, for as a reef develops, other organisms become adapted to the environment, thriving and contributing to a relatively "closed system" of existence.

The most important builder on a coral reef is a creature very low on the scale of evolution known as a polyp. These animals cement themselves to an underwater platform and proceed to secrete an external layer, or skeleton, of calcium carbonate which, due to the shape of the young polyp, produces a stony limestone cup. As each polyp matures it grows in size and complexity of structure, branching and multiplying to eventually form large masses of dense rock. At certain times of the year, the polyps reproduce their kind by releasing larva which are carried by the currents to other sites, where, if suitable conditions of temperature and depth exist, a new reef is formed. It has been estimated that billions of tons of rock are thus created each year.

Corals are specialized carnivores, subsisting on tiny planktonic animals which they capture with their paralyzing tentacles. Typical reef building corals characteristically contain within their tissues numerous algae cells which they are incapable of expelling. This symbiotic relationship between animal and plants contributes mutually to each other's well being, the exact significance of which is the subject of considerable controversy among marine biologists. It appears evident that the relationship is beneficial, at least to the host polyp, for the most vigorous coral growth occurs within the lighted depths, from 20 to 30 fathoms, apparently due to the fact that the contained algae, like all plants, require light for survival.

Coral growth is also dependent on other factors which include favorable temperature, salinity, and nutrient value of the surrounding water mass.

A secondary but integral part of reef construction are the various calcareous algae which grow upon the reef. In the course of time, these stony plants have a mortise-like effect upon the environment that binds the reef mass together, contributing to its over-all strength.

Coral reefs are constantly subject to various forces that can damage or weaken them. Erosion from the constant battering of the sea can eventually cause massive breakage, and the deposition of sediments on living coral beds results in eventual death of the beds. A number of snails, worms, and barnacles bore deeply into the very foundation of coral colonies. Naturally, a greater knowledge of the effects of these forces is essential to present and future coral reef studies.

THE HARMFUL AND USEFUL ASPECT OF MARINE LIFE

Probably the most important problem that man associates with survival at sea is the danger of attacks by obnoxious animals. Whether this or other factors are the primary detriment to survival is debatable. The fact remains that sea life poses a serious threat to naval operations involving swimmers and divers. Furthermore, as the rapid advances in underwater equipment and techniques extend the depth and range of such operations, there is a greater need for effective deterrents against the threat.

The number of species of marine animals capable of harming man has been estimated at more than 3,000, and these are separable into three categories—poisonous, venomous, and carnivorous. The last category is undoubtedly the most familiar for it includes the biters such as the fearsome shark. For a man-in-the-water the fear of sharks is well founded, for out of approximately 250 species that inhabit the seas, more than 50 are known to be dangerous. Furthermore, sharks are to be found in all oceans from 45° north to 45° south latitude.

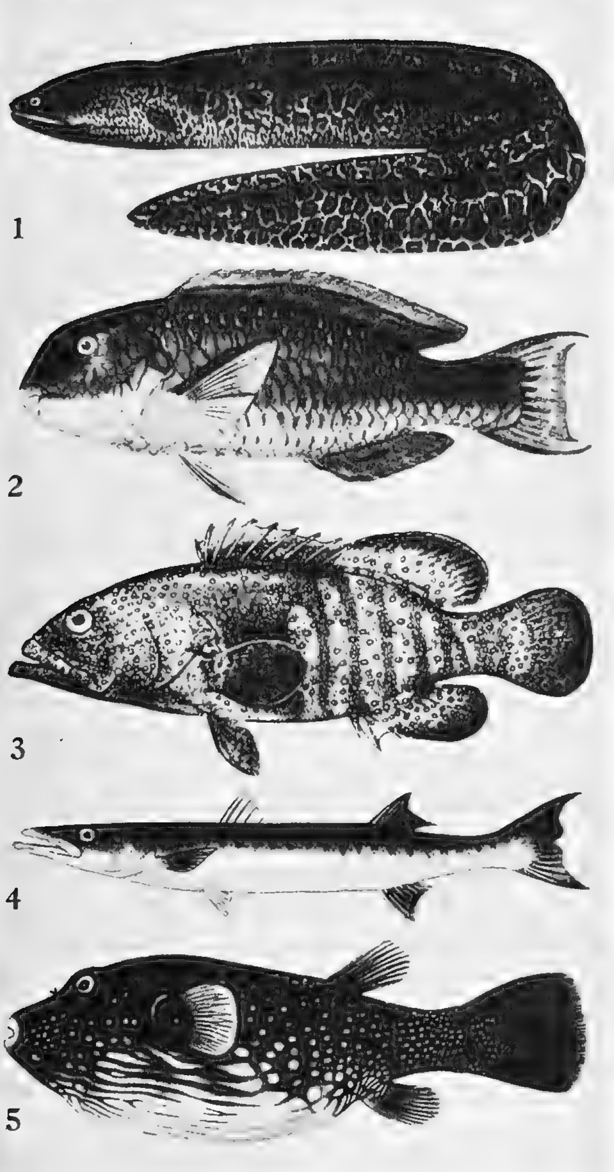
Because of the many attacks attributed to them, no other marine animal has been more extensively observed than the shark. Over the years, chemical repellent agents have been developed and used in survival circumstances. Their effectiveness has been less than complete, for incidents have been recorded in which sharks have demonstrated unpredictably savage conduct in apparent disregard of the repellents released.

Attacks by other marine carnivores such as the barracuda and the moray eel present a physical, as well as psychological hazard to many types of underwater operations. Venomous animals, such as the stone fishes, sea snakes, and numerous invertebrates, and a variety of stinging organisms represent a constant menace to the survivor at sea or the unwary swimmer or scuba diver. The development of truly effective defenses against all of these forms will require far more ecological and behavioral information than is now available.

On the brighter side, however, there are good indications that marine life itself can provide the answers to these and many other problems. It has been observed that certain marine animals and plants produce substances which either kill, repel, or confuse other forms. By isolating and examining these substances, biologists hope to discover more effective repellents or deterrents for use against obnoxious animals.

Studies of the pharmacological properties of marine plants and animals may open the door on a new family of drugs. The defensive poisons exuded by many sea organisms are believed to be the source of potent new drugs for possible use in the war against cancer as well as other human diseases. Anti-cancer drugs are also being sought in the tissues of shark brains.

Studies of the amazing swimming characteristics of certain marine animals, such as the dolphin and seal, may provide information useful in the design and construction of new hulls for surface ships and submarines. Research on the swimming techniques of marine animals indicates that many possess highly efficient propulsion mechanisms, completely silent and accomplished without detectable



Some obnoxious fishes: 1. Moray eel. 2. Parrot fish. 3. Sea bass, or grouper. 4. Barracuda. 5. Puffer.

turbulence. This phenomenon is of considerable interest to the Navy in the development of future submersibles.

Biologists have determined that many kinds of marine animals have the ability to detect and identify targets at great distances and then swim toward them with unerring accuracy. Closely related to this phenomenon is the ability of shoals of fish to perceive and respond quickly to some sort of self induced signal. These signals suggest a highly effective system of underwater communications. Research in this field is expected to evolve new concepts of target detection and identification, long range submerged navigation, and underwater communications.

Many other unique capabilities of marine organisms are being studied in an effort to create new, and improve existing, man-made devices. Biologists are investigating how marine animals such as whales, porpoises, seals, and numerous fishes can sound rapidly to great depths without developing the bends and other diseases contracted by humans under similar conditions. The remarkable process by which some marine animals can replace lost or damaged parts of their bodies may hold secrets of cell formation useful to medical sciences. The anti-bacterial activity of marine algae may aid in the development of new antibiotics. The possibility of emulating natural processes of air purification by constructing analogues based on the photosynthesis of algae is being investigated as a means of improving submarine habitability. These are but a few of the potentially great discoveries at hand, and, in every instance, success will depend upon the systematic acquisition of fundamental biological data.

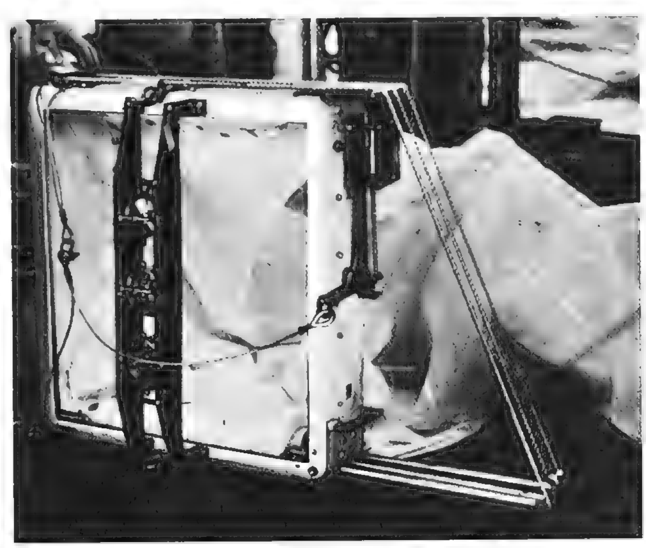
FIELD METHODS

A fundamental step in biological research is the collecting of sample organisms for laboratory examination. In marine biology, this step is complicated by the fact that the specimens must normally be removed from a murky, three-dimensional medium, the sea. As the objects of the search are, therefore, usually hidden from direct view, they must be groped for in a manner vaguely comparable to hunting for a button at the bottom of a well-stowed sea bag. The search is, for the most part, dependent upon gear which can be lowered to a desired depth from the deck of a ship.

The size, mobility, and natural habitat of a sought-for organism determines the type of sampling gear to be used. Traditionally, the basic gear is the net, with a number of variations. The free swimming animals are sampled with gear similar to the trawls used by commercial fishermen. Bottom dwelling organisms are collected by dredges and grabs. A dredge is simply a bag-like net attached to a heavy framework which is dragged along the sea's floor. A grab consists of a pair of heavy metal jaws, not unlike the construction workers' "clam shell" shovel. Coring devices are used for collecting undisturbed samples of bottom sediments. Because the microscopic nannoplankton, such as the smaller diatoms, dinoflagellates, protozoans, and bacteria pass through the finest nets, they must be collected in water samples and then separated, usually by centrifuge, in a laboratory.

In sampling the zooplankton, as required in studies of the deep scattering layers, specially designed nets are towed through the water at a predetermined depth. The depth is maintained constant by a paravane-like device attached to either the tow wire or the net. Accurate quantitative samples require that the amount of water filtered be known, and this is dependent on mesh size, area of filtering surface, shape of net, area of opening, and the speed of the towing vessel. A more modern innovation of this technique employs a meter at the net opening which registers the amount of water that enters the net during a tow. Of course, some means must be provided to open and close the sampling device at any desired time and depth.

Because of their superior swimming ability, many of the larger planktonic animals elude towed nets. Such losses can be reduced by increasing the speed of the tow, but speed is limited by the strength of available nets. To obviate many of the difficulties associated with net tows samples have been collected by pumping them up, with measurable quantities of water, through a hose from the required depth and caught in filters aboard ship. A more recent variation of this technique eliminates the hose and employs a submersible pump, electrically controlled from deck, which is attached to a net and lowered to a precise depth. A meter on the pump measures and records the amount of water screened.



A multiple plankton sampler.

A mechanical device known as a *continuous plankton recorder* is used to supplement the data acquired by nets. The device is essentially a torpedo-shaped tube about 3 feet long, and it is designed to be towed behind a ship at full speed. The planktonic organisms enter the machine through a front opening and come to rest on filtering material which is slowly wound across the tube. The material, with the plankton it has accumulated, is continuously rolled onto a storage spool. Since the winding mechanism is actuated by an external propeller, the speed at which the filtering material passes across the opening is proportional to the speed of the towing vessel and, consequently, the number of organisms collected can be related to the distance traveled.

A specially equipped research vessel is required for most types of plankton investigations. Unfortunately, these specialized ships are too few in number to provide the numerous observations necessary to chart the changing patterns of plankton distribution throughout the world. To implement such a program the use of merchant ships and warships is being contemplated for the systematic collection of data along their normal routes. Automated instrument packages operated from these "ships of opportunity" could yield valuable biological data without affecting their routine or schedule.

Marine scientists are aware, however, that the classical methods of data collection are not wholly sufficient for the needs of modern oceanography. For one thing, the depth at which existing sampling gear can be effectively used is limited. For another, the remote operation of such equipment, however precise, precludes any real study of the overall environment, so important in ecological work. To fully understand the nature of the deep, biologists must use all of their senses, particularly that of sight.

Diver using underwater camera.

In intertidal waters and on coral reefs, the work of both scuba and "hard hat" divers are augmenting the data collected by instruments. The use of remotely controlled, underwater cameras has permitted biologists to observe bottom-dwelling organisms under natural conditions. An even superior technique lies in the use of underwater television cameras. In the abyssal depths of the sea, observations from manned deep-diving vehicles such as bathyspheres and bathyscaphs have contributed materially to our knowledge of that region. But, because man is essentially a frail instrument, the use of highly sophisticated robot vehicles will doubtlessly play an important role in the future of deep-sea research.

EPILOGUE

The foregoing is a brief attempt to present some of the more challenging projects in biological oceanography. If after reaching this point the reader has concluded that the unsolved problems are numerous, the objectives of the article will have been well served. The very fact, however, that few of us entertain serious doubt that these problems can be solved is a tribute to the present level of our technology. But this is not to predict any forseeable end to such problems, for historically, each success becomes a stepping stone to greater achievement. The results of applied research today will be merely the basic knowledge of tomorrow, as whole new concepts and goals will undoubtedly come into focus. This, however, is a healthy progression and one which will provide the necessary motivation for continued effort.

The modern challenge to marine biologists is to understand, explain, and predict the intricate interrelationships of life in the sea. It is, of course, impossible to foretell the extent that this knowledge will affect the future of mankind. That it will be profound appears evident in the many imaginative programs being undertaken. The ultimate goals are far reaching and constantly being extended as the sciences adjust, almost daily, to an increasing awareness of the oceans' great potential. Today, it seems reasonable to envision spectacular achievements in inner space that will parallel those of outer space.

The present and future plans of the National Oceanographic Program include the concerted efforts of many institutions, governmental and private, toward common goals. The U. S. Naval Oceanographic Office is an active participant in this great enterprise and will play an important role in unlocking the door to that strange world beneath the seas on which we sail.

DANGEROUS SEA LIFE

J. W. Lermond
Maritime Safety Division
U. S. Naval Oceanographic Office

Since the beginning of time the sea has stimulated the imagination of man. A most interesting part of this speculation has always centered around dangerous marine animals. Ancient writings abound with tales concerning legendary creatures of the deep. Early mariners feared destruction of their vessels in a sea of imaginary monsters. Picture and legend illustrate some of these ancient beliefs. Superstitions connected with the sea, outlining its mysteries and vastness continue to influence our thoughts to the present time.

Legend and superstition concerning the sea were a part of the religious life of each member of an ancient coastal tribe. The awe inspiring power of the sea in its many moods held the ignorant in reverent terror. Tribal taboos restrained the conduct of the individual, thus protecting him from the more poisonous marine species in the area. Veneration was but little short of worship and these imagined beneficial elements later took the form of deities. Half-human, half-fish gods and goddesses are depicted on many ancient temples and were also used as figureheads on ships. Some were beautiful, some were horrible, while a few, such as the Greek sea god Poseidon, assumed human form. All seafarers came under the mythical protection of Poseidon who ruled the waters in conflict with the land deities. Poseidon's uncontrolled stormy temper tantrums, symbolic of great strength, could reportedly produce earthquakes or control the shape of continents. Poseidon, of course, held full sway over all marine animals, and the dolphin was symbolic of his protection.

Many persons and some nations depend upon the sea for food and other necessities of life. Others must ply the sea lanes in pursuit of a commercial existence. An increasing number fly above the oceans to satisfy a variety of travel needs. Recent observation has thus revealed a great many details concerning the sea and marine animals. Concentrated efforts of many scientific investigations have been devoted to study, to describe, and to tabulate present day knowledge concerning the ocean and its inhabitants. The sea has, notwithstanding all this effort, kept many secrets locked in the gloomy depths beneath the surface. Present efforts in the field of oceanography endeavor to reveal facts which have long been the subject of theory or mere speculation.

Losses of surface vessels and aircraft during the last war, with accompanying casualties due to nature's perils, brought about a greater interest in survival techniques. The reports of survivors, rescuers, action reports, and original papers on survival were studied in an effort to improve the situation of a downed aviator or shipwrecked mariner. After the war, the combined experiences and researches on the subject were critically examined to improve the various survival manuals. This work continues in an effort to perfect all details.

Survivors in life rafts narrated in detail every sight of a shark, yet few stories were found of survivors being attacked or killed by sharks. Off the coast of New Guinea, one flier was attacked by a shark when swimming outside the coral reef and lost a leg; however, he lived through the ordeal. Another story concerned a Navy plane which had ditched. The pilot and gunner were kicking hard to keep clear of the wreckage; perhaps the splashing attracted the sharks. The gunner had removed his trousers and shoes and still wore white shorts. Sharks nosed him several times and finally one bit his right thigh. The bite was not clean; the man was pulled under but broke free and bobbed to the surface, shouting for help and continuing to splash in the water. The sharks continued to attack, biting and pulling the gunner under the water until he was drowned. The pilot, who survived to report this shark attack, said that the sharks kept pulling at the bobbing body until it finally disappeared. The sharks then followed the pilot, who splashed at them and finally hit one shark on the snout. The shark turned quickly and struck the pilot in the face with his tail. This broke the man's jaw and caused abrasions on his face. The sharks then left and were not seen again.

Survivors in life rafts reported seeing many sharks, few sharks, or a single shark; yet a flier spent twelve days without seeing one. Life raft survivors tied extra clothing on a line and used it as a sea anchor; this sea anchor was attacked by sharks several times.

Other life raft accounts mentioned seeing large fish. One pilot saw a 40-foot whale surface near him and spout into the air; the same pilot glimpsed an 8-foot marlin which swam around his raft several times. A sea turtle nosed the raft of another pilot for 15 to 20 minutes; the pilot did not hit the animal for fear his sudden movement or that of the turtle would upset his craft.

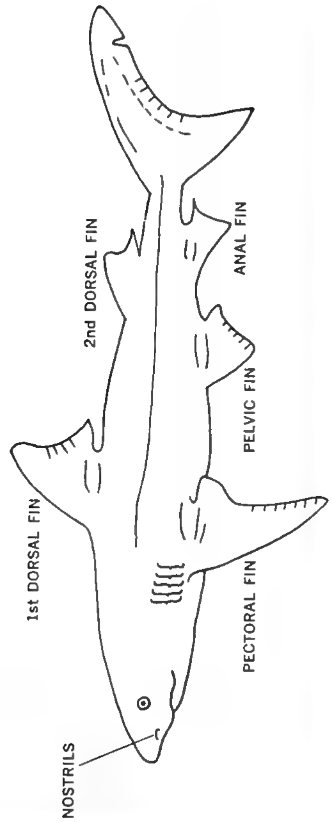
Other survivors reported injuries from coral reefs in the form of cuts and lacerations from walking or falling on the sharp edges. Coral cuts are painful, difficult to treat, and usually slow to heal. One survivor noted a method used by the natives in the treatment of wounds sustained by coral. The acid juice of limes or other fruit was used to apparently help dissolve the calcium carbonate of the coral fragments left in the wound. While the lime juice itself was painful, such treatment seemed to promote healing. A flier reported that sea spines could be removed much more easily after such treatment.

A review of the facts concerning wartime survival experiences has shown many interesting details concerning dangerous sea life. The objectives of this article are to present brief essential details concerning habits and characteristics together with distribution and environment data for the more dangerous species of sea life. In order to be of practical value to those concerned, much technical detail had been eliminated, but may be found in the many good books on the subject. A simple division of material, suggested by the type of injury inflicted on humans, has been followed. Marine animals that bite and a few that sting are described and illustrated.

DESTRUCTIVE BITERS

SHARKS

Among the more dangerous marine animals, the shark, being most numerous and voracious, has established a fearful reputation. Through the years, however, much sensational journalism has been lavished on sharks. Although found to be peaceful and retiring in nature, investigation of the records and scientific evidence indicate that only a score or less of the shark species, out of several hundred known to exist, are likely to attack man. A knowledge of sharks and their habits, if judiciously applied, may avoid an attack. Certain rules of conduct should be carried out to avoid attracting or exciting sharks.



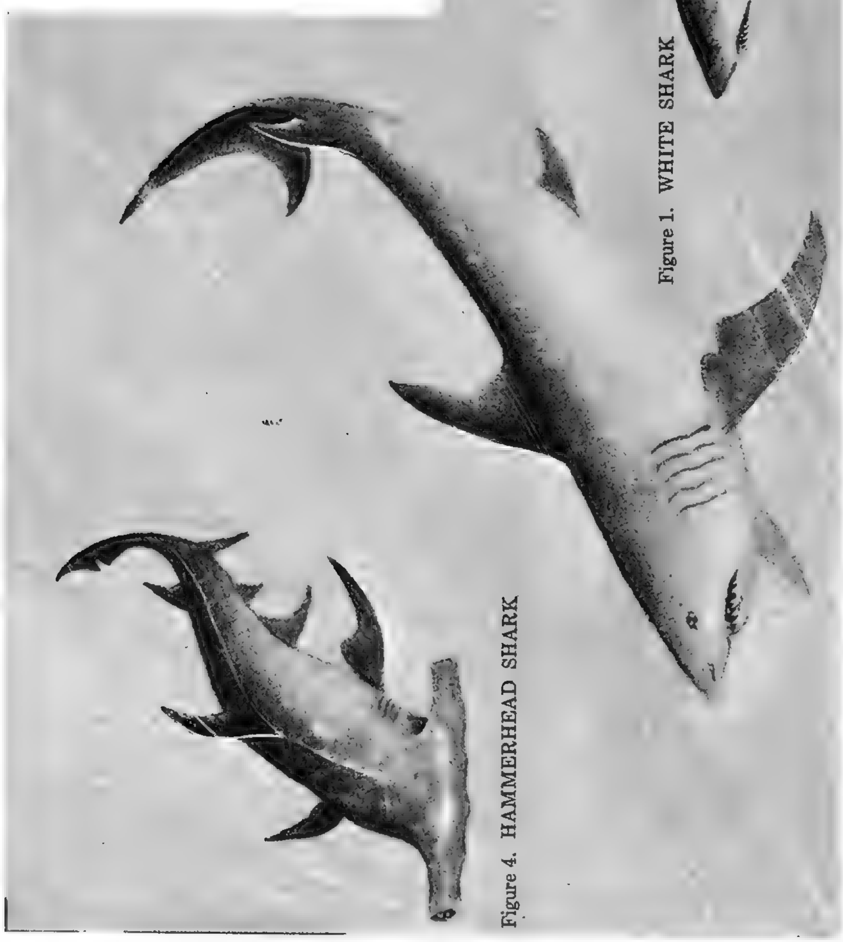
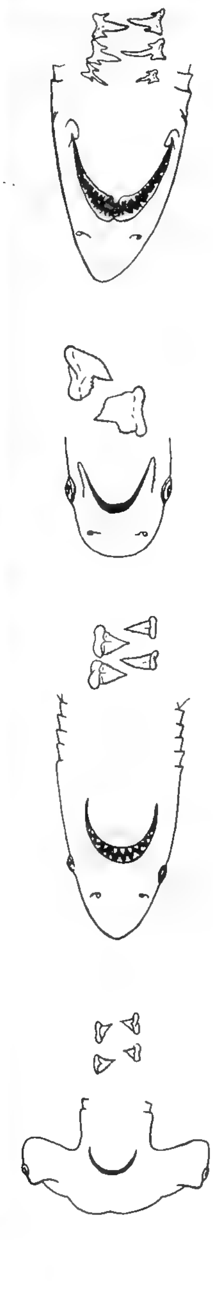


Figure 1. WHITE SHARK

Figure 2. TIGER SHARK

Figure 3. SAND SHARK

Figure 4. HAMMERHEAD SHARK



Adult sharks range in size from 18 inches to more than 50 feet in length. The giant whale shark and many other species feed exclusively on small marine organisms and do not ordinarily pose a great threat to a man in the water. A great many sharks eat large and small fish, including other sharks, seals, and a variety of organisms or material, depending upon feeding circumstances. Many sharks are too small or are equipped with inadequate teeth to be of any real danger to a man in the water. Considering the feeding habits of all sharks more than 4 feet in length and adequately equipped with teeth, the situation may be considered dangerous for swimmers or divers if blood or other attraction may be present.

Detection by sharks of blood, food, or injured animals in the water has always posed a subject of considerable interest. Although possessed of poor visual acuity and a low order of intelligence, a shark's ability to detect food is phenomenal. Detection is probably accomplished by a highly developed sense of smell and an extremely sensitive system for reception and detection of low frequency vibrations in the water. Their ability to detect a disabled or wounded animal at long range has been considered most uncanny.

In addition to these abilities and habits concerned with casual eating, either alone or in small numbers, sharks have also demonstrated unpredictably wild conduct, under circumstances involving many sharks or much food. This may occur subsequent to an explosion in the water, the sinking of a vessel, or crash of a plane. When resorting to these mob tactics, sharks may be observed in a frenzy, attacking vertically from the depths, dramatically breaking the water, and snapping savagely at everything in sight. During this most dangerous situation, nearly all repellant devices are ignored. Sharks may be seen ripping and devouring each other, with one unfortunate fish the target of attack by several larger ones. It is under circumstances like these that sharks may attack one swimmer out of many in the water and concentrate on this one to the total exclusion of those attempting a rescue. This, however, cannot be depended upon, and experienced divers explain that shark conduct even under mob frenzy conditions is unpredictable.

The danger of attack by sharks is greatest in tropical and subtropical areas between Latitudes 30°N., and 30°S. Temperate waters are generally considered to be free of shark attacks. However, this is not always true, as the records prove. Certain shark species migrate periodically into cooler waters in search of food. Areas which have been found particularly dangerous are Australia, South Africa, and the Pacific coast of Panama. Most recorded attacks have taken place in water temperatures greater than 70°F., but fatalities have taken place in temperatures of 60°F. or less. The season with the greatest number of recorded attacks is during the summer, especially from 3:00 p.m. to 4:00 p.m. daily. This is also the time when most recreational bathers are attracted to the beach. Sharks are round-the-clock eaters, however, and frequently feed during the hours of darkness when the risk of attack may be even greater.

In considering those sharks most dangerous to man, members of 4 families are believed to be of greatest concern to divers or swimmers:

(a) The Mackerel or Man-eater Shark family (*ISURIDAE*)
(b) The Requiem Shark family (*CARCHARHINIDAE*)
(c) The Sand Shark family (*CARCHARIIDAE*)
(d) The Hammerhead Shark family (*SPHYRNIDAE*)

Four species are described and illustrated as being representative of these families, but are not to be considered the only dangerous members:

(1) White Shark, *Carcharodon carcharias* (Figure 1), is one of the most dangerous of its kind. It is savage, aggressive, fast-swimming; it has been known to attack boats. Numerous human attacks are accorded to this species. Distinctive characteristics are the lunate or moon-shaped tail fin and coarse serrate teeth. Color is slate-brown, slate-blue, gray, or almost black above, shading to dirty white below. The tips of the pectoral fin are also black, usually with some adjacent spots black. They may attain a length of 30 feet or more. Distribution is oceanic —widespread in tropical, subtropical, and warm temperate belts of all oceans.

(2) Tiger Shark, *Galeocerdo cuvier* (Figure 2), is sluggish in character except in pursuit of food. The tiger shark when stimulated becomes a vigorous and powerful swimmer. Attacks on humans are credited to this shark, although it tends normally to being a scavenger. Distinctive features are the very short snout and sharply-pointed tail. It is colored gray or grayish brown, and darker above than on the sides or belly. The oblique transverse bars usually appear only in the smaller specimens. It attains a length of 30 feet, but the largest recorded specimens measured 18 feet. The tiger shark is widespread in the tropical and subtropical belts of all oceans, both inshore and offshore and is reported to be the commonest large shark of the tropics.

(3) Sand Shark, *Carcharias taurus* (Figure 3), is a shore species which lives on or close to the bottom and is comparatively sluggish but has a voracious appetite. This shark, in East Indian waters, enjoys a bad reputation, however, this is not true of the North American species. Gill openings in front of the pectoral fin, a second dorsal fin about as large as the first, with the first dorsal entirely in front of the pelvic are distinctive features. It is colored a bright gray-brown above, darkest along the back with the snout and upper sides of the pectorals shading to gray white on the belly. The body rearward from the pectorals is marked with round to oval yellow brown spots. The sand shark may reach a length of 10 feet. It inhabits the western Atlantic from the Gulf of Maine to Florida and southern Brazil, as well as the Mediterranean Sea, tropical West Africa, Canaries, and Cape Verde Islands in the Eastern Atlantic. In Argentine waters and the Indo-Pacific it is represented by similar species.

(4) Hammerhead Shark, *Sphyrna diplana* (Figure 4). This powerful swimmer may frequently be seen at the surface, inshore, or far at sea and is definitely known to attack humans. It is colored ashen-gray above, fading to white below. The hammerhead is readily distinguished by the widely expanded head with eyes at the outer edge. It may attain 15 feet in length or more, and closely related species are distributed throughout tropical warm temperate zones of all oceans, including the Mediterranean Sea.

The bites of sharks are almost always severe, and death is usually due to loss of blood and to shock. Fifty to eighty percent of those bitten may die. Severe skin abrasions are suffered by brushing against the very rough, sharp skin of sharks. First aid requires prompt and vigorous action to control the bleeding and shock. The patient must be kept warm. Use of large gauze pressure bandages held with elastic bandages may be best to control the bleeding. Tourniquets have been described as dangerous and impractical for use by the inexperienced person. Hospital or surgical treatment is required. Intravenous fluids should be administered as soon as possible, while whole blood may be required later.

The prevention of shark bite depends mostly upon avoidance of the contact. When sharks are present, persons should not dangle arms or legs in the water. Injured swimmers should be removed from the water quickly. If obliged to be in the water, the use of dark clothing and equipment is preferred. All movements should be slow and purposeful to avoid attracting sharks. Should sharks appear and individuals unavoidably remain in the water, they should remain perfectly still. In a number of instances, curious sharks have left the scene under these circumstances. In other cases, they have been successfully thrust away by use of a large stick. In close contact, some sharks have departed when struck on the snout, eyes or gills. However, attempts to wound the shark may be useless and may only aggravate the situation.

BARRACUDA

Barracudas are an extremely pugnacious and dangerous fish which may attain a length of 6 to 8 feet. They have a large mouth equipped with knife-like canine teeth, and, being swift swimmers, strike rapidly and ferociously. They are feared more than sharks in some areas of the West Indies.

Great Barracuda, *Sphyraena barracuda* (Figure 5), which is found off Brazil, in the West Indies, and northward up to Florida, appears to be the most feared fish. It is also known in the Indo-Pacific area from the Red Sea to the Hawaiian Islands. Other species are widely distributed throughout the tropical and subtropical waters of the world. Among these species are some which differ greatly in nature and size and are never known to attack man, however, none of them seems to exhibit any undue fear of man.

Barracudas are attracted by almost any bright or colored object in the water and may attack indiscriminately. This is especially true in murky water where it appears they are handicapped by poor vision, but because of their predatory nature they attack anyway.

Wounds inflicted by a barracuda differ from those of a shark by the shape of the wound. The former leave straight row toothmarks, while the latter take a U-shaped curve like that of the particular shark jaw involved. Bites and wounds inflicted by the barracuda should be treated with the same general care as shark bites previously described. Hospital or surgical care will be required.

Prevention of attack appears to be one of respect and caution when in waters known to be inhabited by this dangerous species. Any shiny or bright object in the water will attract their interest and attack may swiftly follow.

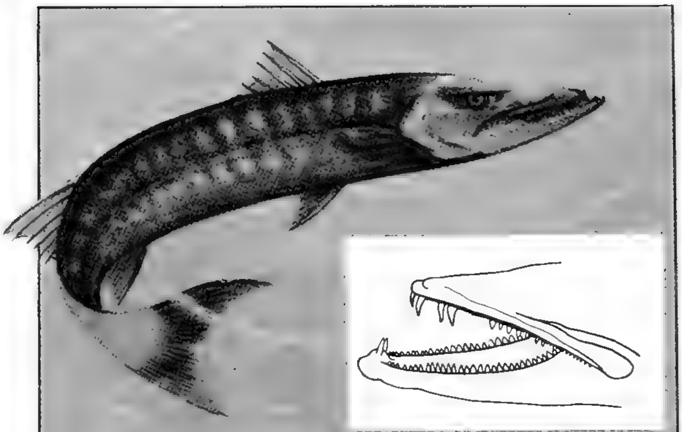


Figure 5. GREAT BARRACUDA

KILLER WHALE OR GRAMPUS

Killer whales usually hunt in packs of 3 to 30. The grampus is a toothed whale, voracious enemy of all sea creatures, including its own kind. Although measuring only 15 to 30 feet in length, they may attack much larger whales, using wolf-pack tactics. Killer whales are characterized by a bluntly rounded snout, high black dorsal fin, white patch just behind the eye, and with a striking jet-black color above, contrasting with snow-white underparts. These whales have large conical teeth which interlock when the jaw is closed. They are swift swimmers, the implacable enemy of seals, walruses, and even penguins. Scientists regard this whale's intelligence as being about on the level with that of a domestic dog. Many remarkable experiences have been described to illustrate the superior mentality of these whales. They have been reported to collaborate with whalers in obtaining their prey and to utilize wolf-pack tactics to harry larger whales into shoal water where they may be easily killed.

The Killer Whale or *Grampus ocra* (Figure 6) is found in all oceans and seas from the Barents Sea or Bering Strait to beyond the Antarctic Circle. The only defense against this ruthless and ferocious killer is a hasty retreat. Divers should get out of the water if killer whales are observed.

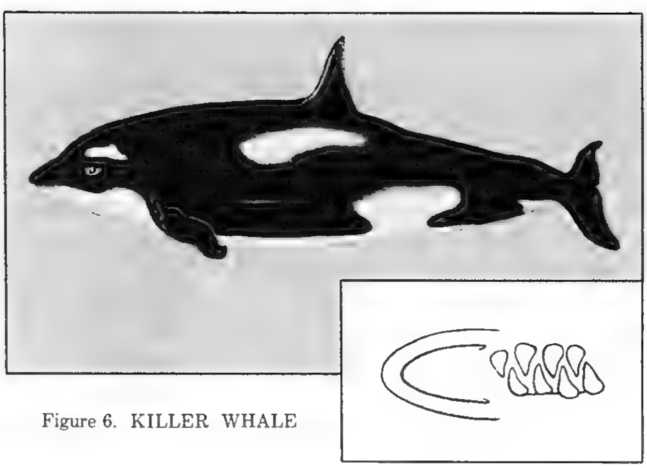


Figure 6. KILLER WHALE

TRIDACNA CLAMS

These giant clams abound in the reefs of Pacific tropical waters. Specimens measure up to 4 feet in length and several hundred pounds in weight.

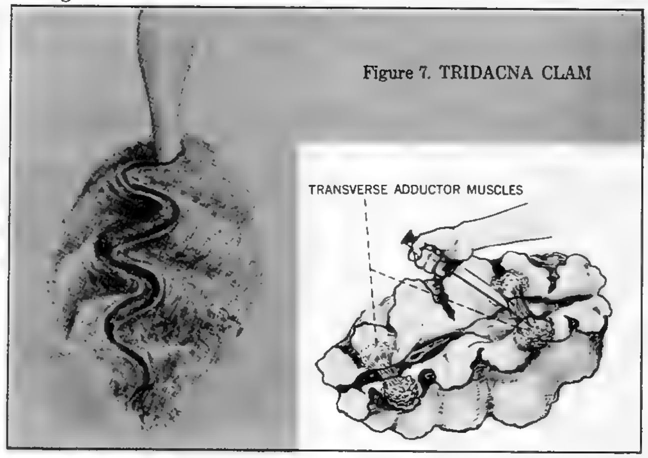


Figure 7. TRIDACNA CLAM

This mullosk, named *Tridacna gigas* (Figure 7), if prodded while open, will close with a tight vise-like grip. Divers and others have been reported trapped by the giant clam. Release can be gained by inserting a knife between the valves and severing the 2 large transverse adductor muscles which hold the 2 halves together.

MORAY EELS

Moray eels are possessed of powerful muscular bodies and may attain a length of 10 feet. Their narrow jaws are armed with knife-like canine teeth, well able to inflict severe lacerations or to hold a bulldog-like grip until death. Morays are incredibly slippery and difficult to handle. They dwell mostly on the bottom in crevices and holes under rock or in coral.

Moray eels, of the family *Muraenidae* (Figure 8), of about 20 species, are largely confined to tropical and subtropical seas. Several temperate zone species are known to exist in California and in European waters.

Because injury resulting from a moray eel bite is of the tearing, jagged type, similar to that inflicted by the barracuda, the same principles of treatment should be followed.

Avoidance or prevention of wounds from moray eels may be accomplished by exercising due diligence and caution when exploring crevices and holes under rocks or coral where eels may be lurking. Hands and feet must be kept out of rock crevices. Although moray eels are vicious biters, they have seldom been known to attack except when provoked.

MISCELLANEOUS

There are many other aggressive and dangerous marine animals capable of causing serious wounds or abrasions. A downed aviator, beached mariner, or diver must guard against becoming the target for attack or inviting a rubbing acquaintance with the following types:

1. The Giant Devil Ray or Manta, *Manta birostris* may reach a spread of 20 feet and a weight of 3,500 pounds. The greatest danger is caused by the huge size of the manta and by the cephalic fins covered with a coarse skin. This sharp skin is capable of producing a severe abrasion on close contact. Active curiosity while investigating air bubbles may lead the manta into entanglement with air hose. Normally, the manta swims or basks near or on the surface and feeds on plankton, small fish, and crustaceans. Mantas may be observed in tropical seas as they leap out of the water, and may be heard to fall back with a resounding smack. Their color is reddish brown to black above and light below.

2. Sea Lions are not usually ferocious, but during the breeding season the larger bulls become irritable and may take exception to any intruder. They may take a nip at a diver or swimmer during this season, whereas ordinarily they are merely curious.

3. Seabass or Grouper, *Serranidae*, may reach a length of 8 to 10 feet and attain a weight of 800 pounds or more. Because they are unusually curious and bold, large groupers become a potential hazard to divers or swimmers. Although not aggressive, they are voracious feeders, possessed of a fearless attitude,

and cavernous jaws. They may usually be found lurking around rocks, caverns, or old wrecks.

MARINE ANIMALS THAT STING

The lethal abilities of stingrays were described in early Greek literature. Numerous other references to the harm inflicted by the stings of marine animals have been recorded in ancient literature and in news reports of later years. While the stings of fish were being analyzed as a recognized danger before the turn of the century, the causes of many disabling occupational illnesses experienced by marine workers remained obscure until fairly recent times. The sponge fishermen's disease, for example, has been found to be caused not by the sponge but by the stinging tentacles of very small sea anemones which adhere to the sponge.

A. *Invertebrates*

The poisonous invertebrate marine animals that inflict injury by stinging may be divided into 4 main groups:

(1) The coelenterates, including corals and sea anemones, jellyfishes, and hydroids.
(2) The molluscs, including univalve shellfish and octopuses.
(3) The annelid worms, including bloodworms and bristle-worms.
(4) The echinoderms or sea urchins.

COELENTERATES

Coral polyps and sea anemones of the coelenterate group are often mistaken for sponges. In reality they are a more advanced form of life. The coelenterates may be likened to an uncorked flexible bottle, with a circle of tentacles at the mouth designed for capturing food. The points of interest, however, are the remarkable stinging cells which are used for the capture of food or as a defense against enemies. This apparatus consists of a trigger hair which, when touched, actuates a spine followed by a hollow-thread through which a paralyzing drug is injected into the victim. The stinging cells or nematocysts are the source of many illnesses encountered by skin divers, sponge fishermen, and other marine workers.

Coelenterates are divided generally into 3 classes, examples of which are as follows:

1. The hydroids, which are commonly encountered tufted on pilings, seaweeds, or rocks. The more common types, all of which possess stinging cells, are:

(a) Fire Coral, *Millepora alcicornis*, a false coral, sometimes called stinging coral, is generally found among the true corals in warm waters of the tropical Pacific or Indian Oceans, as well as in the Red Sea and Caribbean.

(b) Portuguese Man of War, *Physalia physalis*, also called Blue Bottle, is often mistaken for a jellyfish. This hydroid floats on the surface of the water in all tropical oceans and the Mediterranean Sea. The stinging tentacles may trail several feet down into the water.

2. Jellyfishes; this includes the large bell-shaped medusae having 8 notches on the margin, and many other species which can be considered especially dangerous:

(a) Sea Wasp, *Carybdea alata* (Figure 9), inhabits the tropical areas of all oceans.

(b) Sea Wasp, *Chiropsalmus quadrigatus*, is an especially dangerous inhabitant of Australian and Philippine areas and the Indian Ocean. A less dangerous, but related form, is found in the Atlantic Ocean.

(c) Sea Nettle, *Dactylometra quinquecirrha*, is a widely distributed form which may be found as far north as New England coastal waters, as well as in all tropical sea areas.

(d) Sea Blubber, *Cyanea capillata*, inhabits the North Atlantic and Pacific to the Arctic Ocean. Other stinging species of this genus exist southward into tropical areas.

3. The sea anemones and corals include venomous members as follows:

(a) Elk Horn Coral, *Acropora palmata* (Figure 10), inhabits the Florida Keys, Bahamas, and West Indies.

(b) Sea Anemones, *Actinia equina*, inhabits the Atlantic from the Gulf of Guinea to the Arctic Ocean and the Mediterranean and Black Seas, including the Sea of Azov.

(c) Rosy Anemone, *Sagartia elegans*, inhabits eastern Atlantic Ocean waters from Iceland to the African coast and the Mediterranean Sea.

Coelenterate tentacles may be sticky for holding, or long for entangling, and may be equipped with stinging cells. The stinging cells, or nematocysts (Figure 11), are situated in the outer layers of tissue on the tentacles and may be likened to tiny, diabolical hypodermic syringes and needles arranged to inject a paralyzing drug into an unwary victim. They are elaborately armed weapons, cocked and ready to fire on contact. Swimmers who brush against a jellyfish may be stung by literally thousands of tiny poison weapons or minute sting organs.

Symptoms produced by coelenterate stings vary according to kind or locality. Some persons react in different ways than others. Wounds are primarily local skin irritations. A few are painful and ulceration may follow. The sea wasp or *Chiropsalmus* is a most venomous organism and can produce human death in 3 to 8 minutes.

Stinger symptoms vary and range from a mild prickly or stinging sensation to a throbbing pain which may render the victim unconscious. The pain may be localized or may radiate to the armpit, groin, or abdomen. Local redness may be followed by inflammatory swelling, blistering, or minute skin hemorrhage. There may be shock, muscular cramps, loss of sensation, nausea, vomiting, severe backache, frothing of the mouth, constriction of the throat, loss of speech, difficulty in breathing, paralysis, delirium, convulsions, and finally, death.

The usual treatment is directed toward relieving the pain, alleviating the effects of the poison, and controlling shock. Morphine may be used to relieve the pain. Histaminics by mouth, or creams applied locally, may prove valuable in treatment of the rash. Soothing lotions such as olive oil, ethyl alchohol, sodium bicarbonate, and dilute ammonium hydroxide have been used. Artificial respiration, stimulants, and other measures may be necessary. Specific antidotes are not known.

Avoidance of original contact with the tentacles is important. The tentacles may trail as long as 50 feet, so jellyfish must be given a wide berth. Rubber suits or tight fitting woolen underwear have proven to be useful protection. Dead jellyfish found on the beach are also hazardous, as the nematocyst remain potent. Waters which have been storm lashed may contain many shreds of tentacles which can each inflict a wound. Swimmers or others, after contact, should leave the water and seek treatment. Washing of the poisoned skin area with dilute ammonia or alcohol, as soon as possible, will be helpful. Mineral oil or baby oil may help to alleviate the stinging sensations.

CORAL CUTS

Wounds inflicted by the stony corals are an ever-present annoyance to marine workers in tropical areas. The calcareous, razor-sharp edges produce wounds which are notoriously slow to heal. Coral cuts, if left untreated, may, under adverse living conditions, become ulcerous. Stinging cells, similar to those of jellyfish, may complicate the conditions. Red welts and itching are often a primary reaction to ordinary coral cuts.

Treatment involves prompt cleansing of the wound and removal of particles. Application of antiseptic agents should follow. If the case is severe, bed rest or elevation of the limb may be required. Various poultices and applications have proven helpful in varying degrees. Antihistaminic drugs taken by mouth or applied locally may afford a measure of relief to the patient.

Activity carried out in the vicinity of coral requires the wearing of appropriate protective clothing. Heavy shoes, gloves, and outer garments will help to prevent contact.

MOLLUSCS

Typical members of this group that may produce a venomous sting or bite, fall into 2 categories: (1) those with a spirally twisted single shell, (Gastropods), and (2) those with no shell, such as the octopus or squid, (Cephalopods).

GASTROPODS

The Gastropods or univalve molluscs include land, freshwater, and marine snails and slugs. They are characterized by a single spirally coiled shell, or, as an exception, without a shell as is the case of the slugs. Typically, a distinct head, 1 or 2 pairs of tentacles, and a flattened fleshy foot exist. The shell or coned type are potentially dangerous and may be of concern to those who work or live near the beach. Cone shells of this type (Figure 12) have long been collected because of the attractive patterns displayed. Of more than

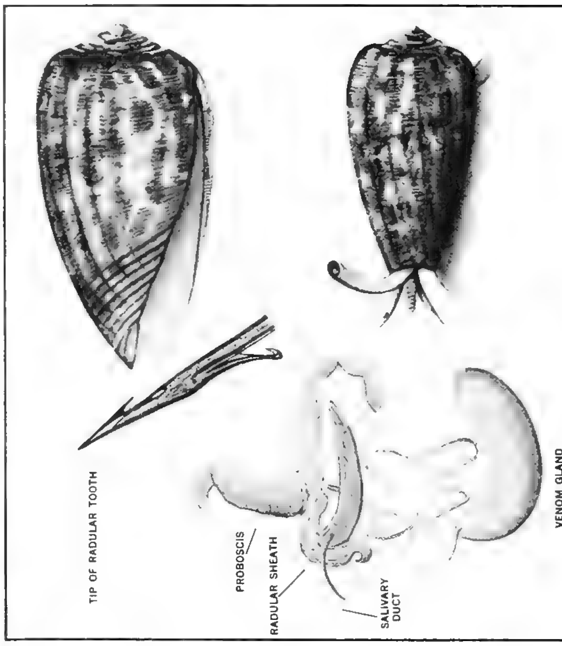


Figure 12. STRIATED CONE


Figure 10. ELK HORN CORAL


Figure 11. NEMATOCYST

400 species, however, most contain a fully-developed venom apparatus. Cone shells may be seen crawling along the sand or may be found under rocks or near coral. Some of the more dangerous tropical species are listed as follows:

(a) Court Cone, *Conus aulicus*, ranges from Polynesia to the Indian Ocean.

(b) Geographer Cone, *Conus geographus*, inhabits the Indian Ocean and the Pacific Ocean from Polynesia to east Africa.

(c) Marbled Cone, *Conus marmoreus*, ranges from Polynesia westward to the Indian Ocean.

(d) Striated Cone, *Conus striatus*, inhabits the area from Australia to east Africa.

(e) Textile Cone, *Conus textile*, ranges from Polynesia to the Red Sea.

(f) Tulip Cone, *Conus tulipa*, ranges from Polynesia to the Red Sea.

The venom apparatus of cone shells lies near the shell opening. The radular teeth are thrust into the victim, and the venom is believed to be forced under pressure into the wound opening.

The sting of a *Conus* usually produces a numbness or burning sensation. The numbness and tingling may spread rapidly and become particularly pronounced about the lips and mouth. Respiratory distress is usually absent. Paralysis and coma may follow. Death may be the result of heart failure.

Specific treatment for cone shell stings has not been discovered. Efforts should be devoted to alleviating the pain, combating the effects of the poison, and preventing secondary infection. The wound should be promptly irrigated and washed clean with sterile saline, if available. Suction may be applied to remove poison. A small incision may be required. A 30-minute soaking in hot water or hot compresses, according to location of the sting, has been recommended. Under conditions of unfavorable delay in treatment, the administration of antibiotics may be desirable. The patient should be kept warm and stimulants may be required. Early hospitalization and treatment, as in the case of venomous fish sting, is recommended. Cone shells, if still alive, should always be handled very cautiously to avoid stings.

CEPHALOPODS

Nautilus, squid (Figure 14), cuttlefish, and octopus (Figure 13) are included in this group. Members are characterized by 8 or 10 tentacles around a muscular central body mass. A powerful, parrot-like beak, concealed in the mouth, is used in conjunction with the tentacles for tearing captured food. A well developed venom apparatus exists. Fast movement through the water is accomplished by water jet propulsion.

Because the octopus has been subjected to much publicity for many years, it is now vastly over-rated as a hazard. Actually, the octopus is timid and will usually hide in holes. They are curious but very cautious. They are often found in the intertidal zone and most, if not all, species live in depths of less than 100 fathoms. The actual damage to be feared by humans is the danger from poisoned biting. A relatively small octopus can cause as much damage as a large one in this respect. Although some may attain an overall length of 25 feet, there is no reported increase in demonstrated aggressiveness. They are normally a fearful sight, whether seen out of the water or encountered while swimming.

Identification of the various species of Cephalopods is difficult. The bite is similar for all species and usually consists of 2 small puncture wounds, according to the size of the particular specimen. A burning sensation with localized discomfort may later spread from the bite. Bleeding is usually profuse and indicates that clotting has been retarded by the poison. Swelling and redness commonly develop in the immediate area. While recovery is fairly certain, a fatality has taken place from the bite of a small unknown variety.

Treatment of wounds from octopus bites should be carried out as for fish stings. Prevention of the bite relies on avoidance of the octopus and the wearing of an outer cloth garment. Gloves should be worn for handling the octopus, if handling is required. The best method for killing an octopus has been described as a forceful stab between the eyes.

ANNELID WORMS

Segmented seaworms possess tufted, silky, chitinous bristles in a row along each side. Upon contact or stimulation of any kind, the bristles rise on edge, the worm contracts and presents a defensive armor of tiny spears to the intruder. The fine bristles penetrate the skin in much the same way as prickly pear cactus spines. They are difficult to remove and produce a burning sensation. Later, the area becomes inflamed and may afterwards swell or become numb. Other worm species have strong jaws, which inflict a painful bite. These worms, up to 12 inches long, may be encountered under rocks or coral.

Representative species of both types are illustrated as follows:

(a) Bristleworm, *Eurythoe complanata* (Figure 15), is found in the Gulf of Mexico and throughout the tropical Pacific area.

(b) Bloodworm, *Glycera dibranchiata*, is found on the Carolina coast and northward into Canadian waters.

The bite of the bloodworm, round and with a red dot in the center, may or may not penetrate the skin. The bite is usually surrounded by a pale area, later becoming hot and swollen, and then turning numb or itchy. A bristleworm contact, on the other hand, produces inflammation, swelling, or numbness which may persist for several days.

Since it is not definitely known whether the bite is poisonous or not, all sea worm bites or stings should be treated in the same manner as fish stings. Bristles are best removed with forceps, since scraping may break the bristles off and complicate matters. An effective method of removal is by the application of adhesive tape over the bristles. After removal, the area may be treated with ammonia or alcohol to alleviate the discomfort. Certain of the sea worms inflict a painful bite and should not be handled, except while wearing protective gloves.

ECHINODERMS

Most members of this division of sea life are characterized by radial symmetry and may bear a rigid or semirigid skeleton of calcareous plates or spikes on a flexible body wall. Included are starfishes, sea cucumbers, and sea urchins.

Sea urchins occur in large numbers and variety in shallow coastal waters. All possess spines, some long and slender, many with a poison apparatus of some sort. Certain of the sea urchins are of prime danger to the diver or swimmer. These may produce deep wounds and may be difficult to identify until after a very painful encounter.

The spines of sea urchins vary greatly from species to species. Most spines are solid, with blunt or rounded tips, and are not venomous. Others, however, are long, slender, sharp, and hollow, permitting easy, deep entrance into flesh. Because of extreme brittleness, these spikes may be difficult or impossible to withdraw in one piece. Some of these may be a foot in length and may secrete a deadly venom.

Distributed among the spine tips are small, delicate, globe-shaped, seizing organs called pedicellariae. This globe-shaped head, in one type, serves as a venom organ and is armed with a set of pincer-like jaws for holding. A sense bristle, on contact, causes a small muscle to contract, releasing venom. A function of the pedicellariae is defense of the sea urchin. If an object contacts the extended organ, it is immediately seized and poisoned. If the object is large and strong, it will tear away from the urchin, but the pedicellariae remains fast on the object and continues to poison for several hours after being parted from the sea urchin.

Representative species, only a few, of the large numbers in existence are:

(a) Long-Spined or Black Sea Urchins, *Diadema setosum* (Figure 16), distributed throughout the Indian and West Pacific Ocean areas northward to Japan and eastward to Hawaii.

(b) Sea Urchin, *Toxopneustes pileolus*, inhabits the Indo-Pacific area from East Africa to Melanesia and Japan.

(c) Sea Urchin, *Toxopneustes elegans*, inhabits Japanese waters.

(d) *Asthenosoma ijimai* inhabits the Japanese area southward to the Molucca Sea.

Penetration of the skin by the spines usually produces an immediate and intense burning sensation. This is followed in a short time by redness, swelling, and a generalized aching sensation. Muscular paralysis has been reported and secondary infections may ensue.

The sting from sea urchin pedicellariae may produce immediate distress and in some severe cases, death. The sting produces intense radiating pain, faintness, muscular paralysis, loss of speech, and respiratory distress. However, it may be of short duration, diminishing in 15 minutes and disappearing altogether in an hour.

Sea urchin stings should be handled in the same way as other venomous stings. Prompt attention must be given to the removal of the pedicellariae, as it will continue to introduce venom if not removed. Although the ordinary spines of some species may be absorbed in the course of a day or two, most will require removal. A purple discoloration in the area of the wound, due to a secretion of the animal, is not a cause for concern.

Sea urchins with long needle-like spines should not be handled. Special protection must be arranged as ordinary leather or canvas gloves and shoes do not afford adequate protection. Marine workers and others must exercise critical care in working at night without adequate light. This is especially important in those areas where the lethal species may be encountered.

B. *Vertebrates*

The vertebrate marine animals that inflict injuries by means of venomous stings may be divided into 2 groups:

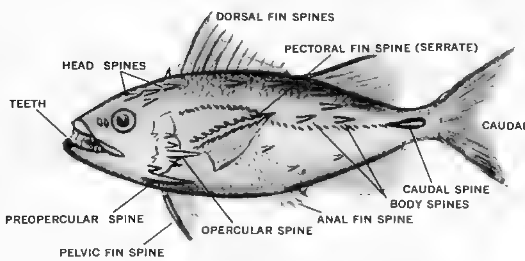
(1) Fishes, including a numerous and interesting variety.

(2) Reptiles, limited to a few sea snakes.

FISHES

Dogfish Sharks

The larger sharks, previously described, depend on speed or teeth for defensive or offensive operations. Some of the smaller, less powerful species are equipped with venomous spines for protection. Many variations in poison spine arrangement exist in these sharks. The common spiny dogfish, *Squalus acanthias*, is a small shark, up to 3½ feet in length, found along both coasts of the Atlantic and Pacific Oceans. Closely related spiny dogfish are found throughout the temperate and tropical seas of the world.



COMPOSITE DIAGRAM

(showing injury-producing structures on body of fish)

Dogfish sharks may be recognized, in comparison to the larger species, by the absence of the anal fin. Another feature peculiar to all dogfish is, of course, the presence of two short, stout spines, one situated immediately in front of each dorsal fin. Although dogfish are somewhat sluggish, this does not prevent them from thrashing around with much vigor when caught in commercial fishing nets. The teeth of a dogfish are not feared too much, but the spines are capable of causing painful wounds unless appropriate caution is taken. The venom is a glistening white substance in a shallow groove of each spine. The poison secretion enters the skin with the spine. These smaller sharks appear to be dangerous only if handled and will not attack.

The poison sting brings on an intense, stabbing pain, which starts immediately and may last for 6 hours. Much redness and severe swelling may follow and local tenderness may last for several days. Treatment is the same as for any other venomous fish sting. Some dogfish stings have been fatal.

Prevention of the sting depends, in most cases, upon adequate care in handling the spiny dogfish. Removal of the fish from a net, hook, or spear should be accomplished with caution. A sudden jerk or reflex of the fish may drive one of the stings deep into the flesh of the unwary.

Stingrays

Stingrays of many kinds are much feared inhabitants of coastal areas. They form a serious menace to waders, not only because of their abundance but also because of their habit of striking from a concealed position on the bottom in shoal water.

Most rays have a sharp spine near the base of a whiplike tail. The spines may be lost in an adversary but will be replaced. Deep, glandular grooves of the spines contain poisonous tissues. While some rays merely create a painful dirty wound, others may inflict a mortal stab.

Rays inhabit tropical, subtropical, and warm temperate seas of moderate to shallow depths. Their favorite areas are sheltered sandy bays, lagoons, and river mouths. They may be seen lying in shallow water, on top of the sand, or partly concealed in mud or sand with eyes, spiracles, and tail exposed. They can dig in with their pectoral fins for the purpose of concealment or in order to feed upon worms, molluscs, and crustaceans.

Some rays are free swimmers, relying more upon speed for an escape from an enemy than upon ability at concealment on the bottom. Because most rays are scavengers by habit, they will readily accept a baited hook and may frequently appear in the commercial fisherman's net, where they may cause as much trouble as the dogfish shark. Sharks that commonly feed upon rays may be branded with numerous "stings" imbedded in the skin area of the shark's head and jaws.

Stingrays ordinarily glide through the water by a rippling wing-like motion of both fins. When at rest on the bottom they may, quite suddenly, with a quick move of the wings, stir up enough sand and mud to cover themselves, leaving only the eyes, spiracle, and tail exposed. Under these conditions, water intake is by way of the exposed spiracles located behind each eye.

Because of their flat shape, the weight of a person stepping upon a ray serves both as a target and a dead weight necessary for leverage. Thus anchored, the ray whips the barbed tail with great force and precision. At times the spines are found to be driven clean through a foot or through the flesh and into the leg bone of the hapless victim.

Stingrays are a large group of venomous marine organisms to which may be attributed several thousands reported attacks each year. The rays may be divided into 7 families:

1. *Dasyatidae*—stingrays or whiprays
2. *Potamotrygonidae*—river rays
3. *Gymnuridae*—butterfly rays
4. *Myliobatidae*—eagle rays or bat rays
5. *Rhinopteridae*—cow-nosed rays
6. *Mobulidae*—devil rays or mantas
7. *Urolophidae*—round stingrays

Representative examples of some of these according to area are:

Diamond Stingray, *Dasyatis dipterurus* (Figure 17), British Columbia to Central America.

Bat Ray or Spotted Eagle Ray, *Aetobatus narinari* (Figure 17), tropical or warm-temperate belts of the Atlantic Ocean, Red Sea, Indian Ocean, and Pacific Ocean.

Round Stingray, *Urolophus halleri* (Figure 17), waters of the Pacific between California and Panama.

The stingray wound usually causes immediate and severe pain.

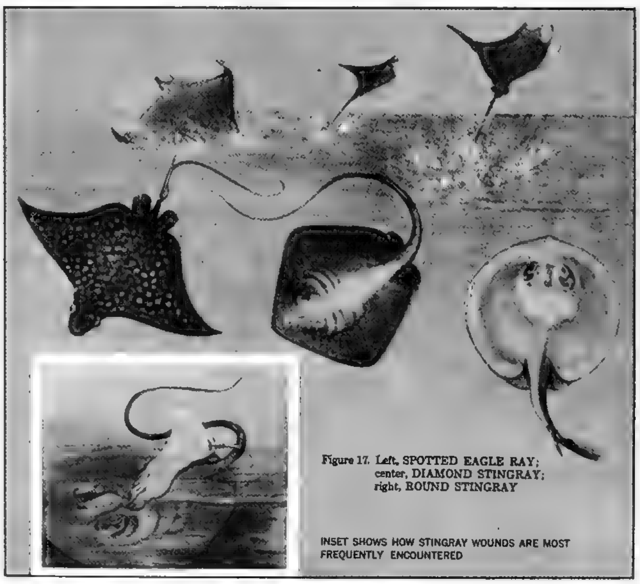


Figure 17. Left, SPOTTED EAGLE RAY; center, DIAMOND STINGRAY; right, ROUND STINGRAY

INSET SHOWS HOW STINGRAY WOUNDS ARE MOST FREQUENTLY ENCOUNTERED

This pain has been variously described to be sharp, shooting, spasmodic, or throbbing in nature. Swelling in the wound area is accompanied by an ashy appearance, which later turns red. Most wounds occur on the feet or ankles, but fatal wounds have been inflicted to chest and stomach areas.

Treatment, as described under venomous fish stings, should be undertaken. Even a freshwater stingray may cause an extremely painful wound with generalized symptoms as; fall in blood pressure, vomiting, diarrhea, sweating, rapid heart beat, and paralysis. Death may occur in severe cases.

Catfish

Catfishes of about 1,000 species may assume many different sizes and shapes. Body shape may be elongated, almost eel-like. Heads may be oversize in a variety of ways. The mouth is usually provided with long barbels or feelers. The skin is thick and slimy, without scales, although bony outer plates may exist in some species.

Venomous catfishes are provided with a stiff spine in the front part of the dorsal and pectoral fins. Venom glands are located in the outer skin or sheath of each. The venomous spine of the catfish is additionally treacherous to the unwary because of a locking device which maintains the spine erect when desired. Certain species have recurved teeth on each spine. This makes venom absorption by the victim more certain.

Although many freshwater catfishes are used for food, the saltwater species are not often eaten. A representative marine species of the catfish, *Galeichthys felis* (Figure 18), ranges from Cape Cod to the Gulf of Mexico. Another catfish, *Clarias batrachus*, inhabits the waters of India, the Netherlands Indies, and the Philippines. Catfishes are abundant in rivers, estuaries, and the open reef areas; they are also particularly numerous in certain large sandy bays.

The wound of a catfish spine is generally accompanied by an almost instant stinging, throbbing, or scalding sensation. The pain may radiate or may localize, numbing an arm or other parts. Certain tropical species, such as the oriental catfish, *Plotosus lineatus*, is capable of inflicting a violently painful wound which may endure for 48 hours. A paleness about the wound area is followed by redness and swelling. Gangrene may set in, or a secondary bacterial infection is possible. Death may result from a catfish sting.

There are no known antidotes for this and other fish stings. Care should be taken in handling marine catfish, especially those having sharp, rigid fin spines.

Weeverfish

Weeverfish, all of the family *Trachinidae*, are a very venomous fish of the temperate zone. They are small marine fishes, less than 18 inches in length, and inhabit mostly sandy or muddy bays. Because of an aggressive temperament, combined with a well-developed poison apparatus, the weever presents a continuing source of danger to divers or others. Weevers habitually bury themselves with only part of the head exposed. Upon little or no provocation they dart out with fins erect and gill covers expanded and strike with unerring accuracy at any offending target.

The Great Weever, *Trachinus draco* (Figure 18), may be found along western Africa, in the Mediterranean Sea, and in the vicinity of the British Isles and Norway. The Lesser Weever, *Trachinus vipera*, inhabits the North Sea, southward along the European Coast, and the Mediterranean Sea.

The aggressive armament of the weever consists of venomous dorsal and opercular spines. The dorsal spines, 5 to 7 in number, are needle sharp and are equipped with a venom groove and thin walled sheath. The blade-like opercular spine has an attached venom gland. The venom is similar to some snake venoms and acts both as a neurotoxin and a hemotoxin.

A weever wound normally produces instant pain of a burning or stabbing type which gradually spreads in the affected part. Within 30 minutes, pain becomes severe and the victim loses consiousness. Pain is usually severe to the extent that the victim may scream and thrash about wildly. Other symptoms as, headache, fever, chills, delirium, nausea, vomiting, sweating, loss of speech, palpitations, and convulsions follow. Morphine often fails to give any relief. Pain subsides in a few hours and redness and swelling then develop. Secondary infections are common in cases not properly treated. Recovery time extends to several months, depending upon the condition of the patient and the amount of venom received. There are no known antidotes for this and other fish stings. Immediate first aid and treatment by a physician may save the patients life.

Since weevers are ordinarily encountered while wading, care must be taken to avoid contact. Adequate footwear should be worn where weevers are known to exist. The fish should neither be antagonized into an attack nor handled in a careless manner, even after death.

Scorpionfish

The scorpionfish family contain some of the most virulent of all venomous fishes. The sting of any of these fish will produce serious results, and a few of the Stonefishes, *Synanceja* (Figure 18), may be ranked with the cobra in comparing the deadliness of the poison secreted. These fish are divided into 3 main groups:

(1) Zebrafish, *Pterois*
(2) Scorpionfish, *Scorpaena*

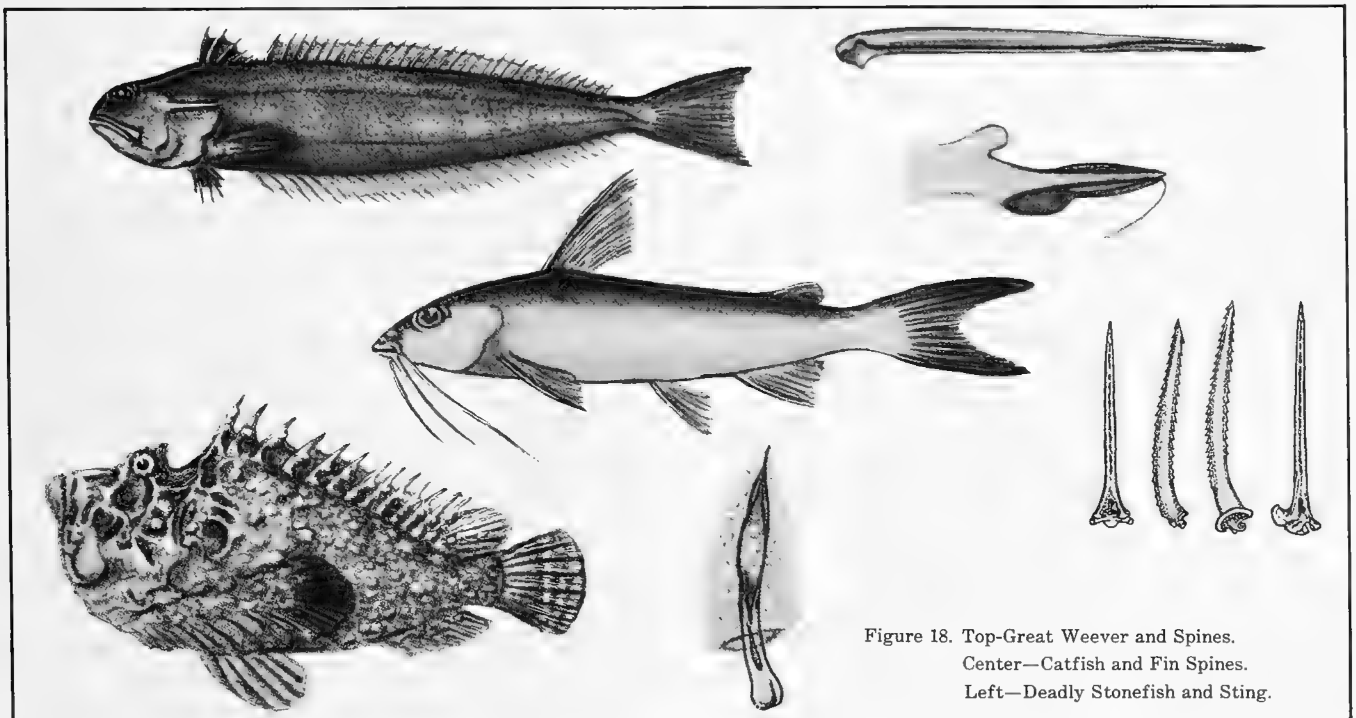


Figure 18. Top-Great Weever and Spines.
Center—Catfish and Fin Spines.
Left—Deadly Stonefish and Sting.

(3) Stonefish, *Synanceja*

Zebrafish are a beautiful and ornate shallow water fish of tropical and temperate seas. They parade about coral reefs, spreading their fan-like and lacy fins in much the same manner as peacocks. They are found in pairs and present an invitation to disaster if touched. Beneath the finery are hidden long, straight needle-sharp fin spines which are a spectacular menace to anyone exploring tropical coral areas. These fish are armed with as many as 18 potentially lethal spines, each equipped with venom.

The scorpionfish are inhabitants of shallow water bays and reefs. A habit of concealing themselves in crevices among debris, under rocks, or in seaweed along with a nearly perfect protective coloration makes this fish almost invisible. Upon discovery and removal from the water these fish erect spiny fins and spread out gill covers in an aggressive display.

Stonefish are encountered in tidepools and shoal areas. They lie motionless while concealed or even partly buried and are fearless or even disinterested in any careless intrusion. This presents a dangerous situation to anyone with bare feet. The fish is equipped with as many as 13 dorsal spines, 3 anal spines, and 2 pelvic spines; all are short and heavy with enlarged venom glands. In natural concealment, the fish looks like a piece of mud or debris.

Symptoms produced by all 3 types of scorpionfish vary in degree, but the pain is immediate, sharp, and radiates. Pain may cause a victim to thrash in a wild manner, scream, or lose consiousness. The immediate wound area may be pale, surrounded by a zone or redness, swelling, and heat. Paralysis of an entire arm or leg may result, and intense swelling of a member may impair movements. Many other symptoms may also be present. Death may be the result of an encounter, or the victim may recover after months of treatment but with general health impaired. Treatment, as for other venomous fish stings, must be administered promptly.

Prevention of the sting, based on previous experiences, depends upon the warning of individuals not to handle scorpionfish with unprotected hands. Attraction of the uninitiated to touch the lacy fins or the placing of hands or feet in crevices inhabited by the fish must be prevented to avoid the danger.

Recommended treatment of Venomous Fish Stings

Treatment of venomous fish stings should be directed to the achievement of 3 objectives:

1. Alleviate pain.
2. Combat the effects of the venom.
3. Prevent follow-up infections.

The pain is generally a direct result of the damage caused by the spine. Additional effects are produced by the venom and the introduction of slime and foreign material. Certain stings, as in the case of rays and catfish, may produce greater damage if spines are recurved or barbed edges are present. Such wounds should be carefully washed out or irrigated with cold salt water or with sterile saline, if available.

It is advisable in most cases to make a small incision across the sting wound. Immediate suction for removal of poison and irrigation should then be accomplished. Since fish do not inject venom in the manner of snakes, results from this suction are not entirely satisfactory.

Use of a ligature in the treatment of fish stings may help. The ligature, if used, should be placed immediately between the sting site and the body, as near the wound as possible. Adequate circulation should be allowed periodically every few minutes. Hot soaking of the wound site for 30 minutes to an hour should be maintained, with the water as hot as the patient can bear without injury. Hot, moist compresses may be used on areas not convenient for immersion. The addition of epsom salts to the water is believed beneficial. Following the soaking, a surgical removal of the lacerated or contaminated parts should precede closure of the wound by sutures. A small drain may be left for a day or two if the need is indicated by size or nature of the wound. The wound site should be covered with an antiseptic sterile dressing. Supportive measures, as described in "THE SHIP'S MEDICINE CHEST AND FIRST AID AT SEA" under shock, should be attended to immediately. The patient must be watched carefully for complications and prompt attention given as described. The assistance of a physician should be obtained or medical advice requested by radio.

Reptiles

Notwithstanding all that has been written concerning the subject of sea snakes, and the universal fear of most people concerning them, there has always been a great deal of misunderstanding concerning their actual existence. The sea snakes are closely allied to the cobras and form a specialized group, adapted by structure and habit to a marine existence. All are poisonous and many deadly, however, they will not generally attack without provocation and have often been described as docile in habit. Fishermen who unintentionally contact sea snakes in their work suffer most of the fatal bites. Fatalities are quite common in the Gulf of Siam and the Philippines area.

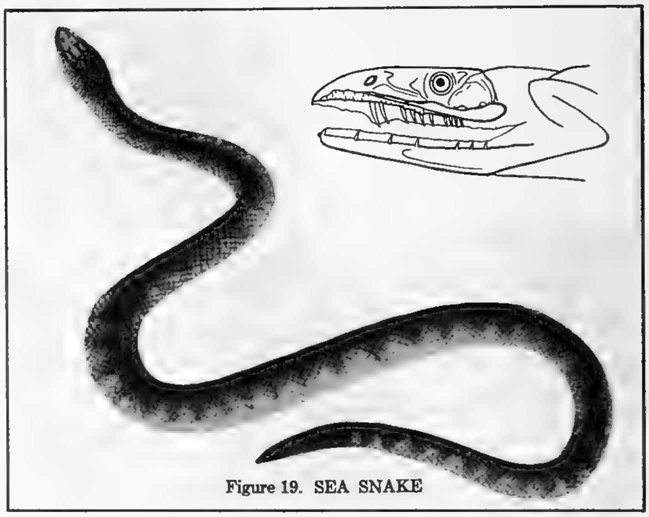


Figure 19. SEA SNAKE

Few sea snakes exceed 4 feet, but 10-foot specimens have been caught. Color is dark above and light below with cross-bands of black, purple, brown, gray, green, or yellow. All of the marine species may be distinguished from the land forms by a paddle-shaped tail. Any confusion with eels may be resolved by the fact that sea snakes are true snakes, and their bodies are covered by scales. Eyes are covered by transparent scales and have no lids. The tongue is slender and forked. Hollow venom fangs are present.

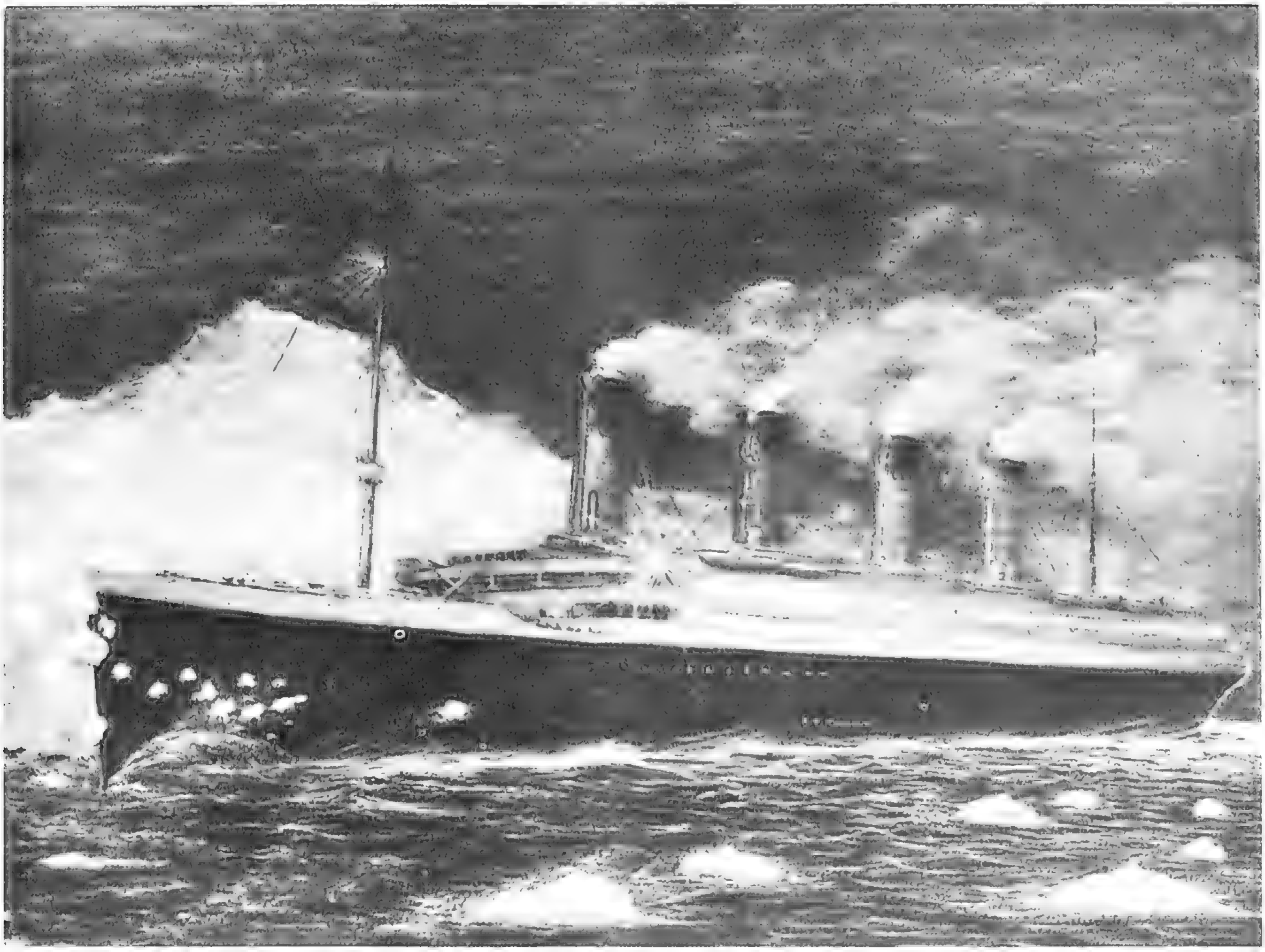
Marine snakes inhabit sheltered coastal waters, particularly the areas near river mouths. They penetrate upstream to the limits of brackish water, and a few species are found in fresh water. They tend to collect close along shore and among coral reefs in the breeding season, when they are more active and sometimes become aggressive. During this season, fishermen may net as many as a hundred at a time. This presents an especially hazardous condition, since some sea snakes have been reported to possess venom of a potency exceeding that of the king cobra.

Swimming is accomplished by a lateral undulation and use of the oar-like tail. A peculiar ability to move backwards as well as forward has been reported. Although sea snakes may float on the surface for extended periods of time, they are also able to remain submerged for hours. Most of their food is obtained underwater and consists nearly entirely of fish swallowed headfirst. Many of the items of food, such as eels and fish, are quickly killed by the deadly first bite of the snake. Like many other marine animals, sea snakes often feed at night and many are netted after dark when attracted by artificial lights exhibited by fishing boats. Individual snakes are frequently taken by line fishermen as they will readily accept the baited hook.

The yellow-bellied Sea Snake, *Pelamis platurus*, ventures beyond coastal waters and is the most widely distributed of all sea snakes. It exists in East Africa and Asian waters northward to Siberia, Japanese east coast, the Philippines, Oceania, and eastward to tropical America. The sea snake *Enhydrina schistosa* (Figure 19) is a more aggressive species which ranges from the Persian Gulf eastward to the north coast of Australia. Other species, nearly 50 in number, inhabit the tropical Pacific and Indian Oceans from the Persian Gulf to Samoa. They also follow the warm currents northward into the western Pacific to the Ryukyus and Japan. They are not known to inhabit the Atlantic.

THE TITANIC—50 YEARS LATER

O. L. Martin Jr.
Maritime Safety Division
U. S. Naval Oceanographic Office



THE TITANIC — 15 April 1912.

The great bow knifed serenely through the calm, sunlit sea as three mighty engines pushed the 46,000-ton titan through the water at a speed well in excess of 23 knots. Double bottoms ran throughout the full length of her 852-foot hull, which contained a massive collision bulkhead forward, followed by 16 watertight compartments containing 11 decks. The passenger accommodations included private promenades, exquisitely furnished suites, plush cabins, beautiful lounges, a heated swimming pool, a gymnasium, and a hospital. This was the ultimate in ship design: the safest, largest, swiftest, and most comfortable vessel afloat. As she steamed majestically westward across the North Atlantic on the evening of April 14, 1912, to keep her lonely appointment with fate, everyone making this memorable maiden voyage knew the TITANIC was unsinkable.

The CARONIA radioed that ice lay ahead; as the day wore on messages from the BALTIC, the MESABA, and the AMERIKA revealed the probability of an ice field, 12 miles wide and 70 miles long, lying across the course of the TITANIC. Day faded into night, and a bite was noted in the air as the ship neared the Grand Banks. The CALIFORNIA reported icebergs dead ahead. Yet the TITANIC steamed on with ever increasing speed as the First Officer slowly paced the bridge, 90 feet above water. Twice the lookout, in the crow's nest, reported ice in the distance, but with speed unabated the unsinkable ship steamed on. Meanwhile, the TITANIC's radio operator, when working Cape Race at 2300, heard the CALIFORNIA break in loud and clear and say, "We are stuck in the ice." He answered, "Keep out, you are jamming my signals." Tired after a long day and irritated at the TITANIC's rebuff, the radio operator aboard the CALIFORNIA secured his set and turned in.

The goliath of the sea steamed on, unwittingly drawing ever closer to her icy rendezvous with death. The lookout sighted another iceberg ahead and notified the bridge. Instantly, the First Officer reversed the port engine and put the rudder hard over in an attempt to make as tight a turn to port as possible. Seconds ticked by, the mighty bow swung safely past the ice but the advance of the vessel carried her bodily forward against a knife-like protrusion, slashing a 300-foot gash in the hull well below the waterline along the starboard side. However, the impact of the collision was so slight and the concussion so muffled that only several of the stokers and engineers realized the stark truth. She was doomed.

Upon reaching the bridge, the Captain received a full report of the known facts, and immediately dispatched an officer below to survey the damage. This officer upon finding ice on the foredeck inspected the forepeak but found it dry. Working his way aft along the starboard side he found the boiler room flooded and being abandoned, firemen scarcely having time to pull their fires. Water rushing into No. 3 hold was already 20 feet above the keel. Returning to the bridge, he informed the Captain that the ship would sink. Upon learning the facts, the Captain ordered the radio operator to request help from nearby ships. Fifty-eight miles away the CARPATHIA heard, turned, and proceeded at full speed through the ice strewn waters to the rescue. Soon the VIRGINIAN, the BALTIC, the OLYMPIC, and Cape Race heard—then the whole world knew that the TITANIC, with 2,224 persons aboard, was sinking. However, salvation of the doomed passengers was only a few miles away — aboard the CALIFORNIA, but her radio was silent and she did not hear of the disaster so near at hand.

In the meantime, the Captain ordered the senior officers to clear away the boats and prepare to abandon ship, while the junior officers fired distress rockets from the flying bridge and attempted to raise an unknown ship, possibly the CALIFORNIA, only a few miles away, by blinker light. The stewards awakened the sleeping passengers, assisted them into their lifejackets, and shepherded them to the waiting boats. Meanwhile, several decks below, the immigrants, closer to the rising water, fearfully realized the urgency of the situation. However, when the first lifeboat pulled away from the ship, one hour after the collision, it was only partially filled. The first class passengers on the boat deck, far above the water, were reluctant to leave the warmth and security of the great unsinkable bastion of strength for the flimsy protection of a small frail lifeboat tossing precariously on the icy seas far below.

Few realized there were only enough lifeboats to accommodate about one-half the people on board. All the distress rockets were gone and the attempt to contact the vessel so near, yet so far away, had failed. At 0205 the last boat was lowered and shortly afterwards a great wave swept over the boat deck. The tremendous screws were now entirely out of the water and rising higher as the vessel settled faster by the head. The forward funnel sheared off and tumbled into the sea—the stern rose even higher. A great thunderous rattling rent the air as the heavy engines, tearing away from their beds, lurched forward and crashed downward through bulkhead after bulkhead by the sheer force of their great weight. The seconds ticked into minutes, and the minutes into an eternity, as the after 150 feet of the stern hung vertically, then slipped beneath the cold desolate waters of the North Atlantic.

Nature in the guise of a small iceberg had met man's challenge to flout her in 41°46′ north latitude, 50°14′ west longitude and in only two and one-half hours defeated him at the cost of 1,517 lives with the sinking of the TITANIC at 0222 on 15 April 1912.

THE GENESIS OF THE TRACKS

Ironic as it may be, the White Star Line, owners of the TITANIC, was one of the first steamship companies to advocate lane traffic across the North Atlantic Ocean as a safety measure for their passenger vessels. Separate east- and westbound lanes were first proposed after the disastrous ARCTIC-VESTA collision, during thick fog off Cape Race in 1854. The following year, Matthew Fontaine Maury, known as the "Path Finder of Seas", then in charge of the U.S. Navy Hydrographic Office, devoted a section of the 1855 edition of his "Sailing Direction" to the proposal, specification, and justification of separate lanes for east- and westbound passenger traffic.

Yearly, during the latter half of the nineteenth century, the rising tide of immigrants created new demands on an already flourishing trade route. Simultaneously, the advent of steam permitted vessels to operate without benefit of the wind. Therefore, schedules could be maintained, but the inefficiency of the early boilers, consuming enormous quantities of coal, required vessels to follow the shortest distance between ports. Vessels sailed a great circle track from Europe to a position southward of Cape Race, then rhumb-lined to the various North American ports. This congested the bulk of the North Atlantic traffic in the foggy and often ice-laden waters of the Grand Banks.

At this time it was believed the paramount danger was from collisions between vessels, not icebergs. However, early safety advocates, in proposing a system of separate east-west lane routes clear of major fog areas, minimized the iceberg threat. Maury's westbound or northern, route was about 100 miles southward of Cape Race, cutting through the southern limits of the fog and ice area; although slightly longer it offered far less fog, thus passages should be quicker. The eastbound, or southern, route passed about 300 miles southward of Cape Race, well out of danger, but was considerably longer than great circle route. However, this route afforded the advantage of following the easterly drift of the Gulf Stream and the improved weather conditions usually prevalent in that area. A representative of the White Star Line stated in Liverpool on 1 January 1876, at the "North Atlantic Steam Traffic Conference," that ships of his company had been complying with Maury's trans-Atlantic lane recommendations since 1874. He also strongly urged other steamship companies to do the same as a measure of safety for the increasing number of passengers carried across the North Atlantic each year.

The U.S. Navy Hydrographic Office launched a new service for the mariner in December of 1883, with the inauguration of the Pilot Chart series. These charts depicted in a nautical manner, hydrographic, meteorological, and early oceanographic information pertaining to the North Atlantic Ocean. Commencing with the May 1884 issue, the approximate calculated limits of ice for the month and a safe track from New York to Northern Europe, skirting the ice menace, were charted. The ice sighted during the previous month was also shown. The Pilot Charts were the first to publicize the seriousness of the ice menace in attempting to locate, identify, and disseminate ice and weather information relative to shipping along the critical routes adjacent to the Grand Banks. At once shipmasters realized the value of this information. The increasing demand to provide mariners with more up-to-date navigational data created a new service from the fledgling Branch Hydrographic Offices in Boston and New York. These offices collected daily ice information from all possible sources and maintained a master ice plot available to mariners prior to their sailings. The information was also forwarded to interested steamship companies along the eastern seaboard.

Meanwhile, delegates from 26 maritime nations met in Washington for the "International Marine Conference" of 1889 and proposed that trans-Atlantic lanes be adopted on a voluntary basis by the steamship operators. Representatives of the five principal trans-Atlantic steamship companies met in 1891 and formally adopted seasonal tracks to be followed by their vessels. During the ice season these routes were considerably longer, but it was believed if a steamship obeyed the Rules of the Road through the ice and fog areas of the Grand Banks, the utilization of the proposed tracks would be safer and more economical.

STUDY OF THE ICE

In the interest of gaining more scientific knowledge of the ice menace of the North Atlantic, the Hydrographic Office dispatched a team to the Newfoundland area to study the origin and drift of icebergs. Lighthouse keepers, fishermen, and whalers were engaged as voluntary observers to report regularly ice conditions to the Hydrographic Office. The results of this study were published in 1890 as H.O. Pub. 93, "Ice and Ice Movements in the North Atlantic Ocean."

Today more thorough research has revealed that most of the icebergs menacing the trans-Atlantic shipping lanes are products of the Greenland Ice Cap. A stupendous mass of compacted ice and snow covers the interior of Greenland, varying in thickness from several hundred to several thousand feet. Although at an imperceptibly slow rate, ice under great pressure attempts to flow outward and downward to the sea level following paths of least resistance. Giant rivers of ice called glaciers extend from the ice cap through the coastal mountain passes and into the fjords. The flowing ice gradually pushes the toe of the glacier farther and farther into the waters of the fjord until the outer extremity of the ice becomes buoyant. The internal stresses created by wave and tidal action causes the buoyant portion to break off, or calf, and drift down the fjord into the sea as an iceberg. Newly-calfed bergs may vary in size from a few tons to hundreds of thousands of tons.

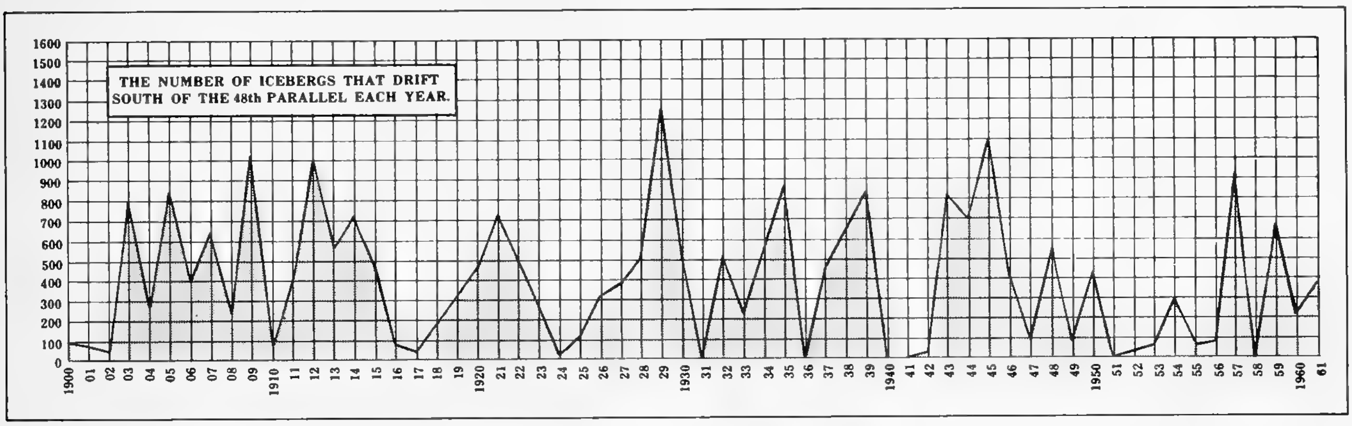
Each year a few bergs are spawned along the east coast of Greenland; they usually drift with the East Greenland Current toward Kap Farvel, and thence are carried by the West Greenland Current along the eastern portion of Davis Strait and into Baffin Bay. However, it is in this area along the west coast of Greenland above 68°30′ N. that the bulk of the icebergs sighted in the North Atlantic are produced. Here about 100 tidewater glaciers spawn approximately 15,000 bergs each year. Glaciers may calf at any time but most of the icebergs are produced in the warm summer months.

Once the icebergs are waterborne the long drift to the shipping lanes is underway. First the icebergs drift northward with the West Greenland Current into the Baffin Bay Basin, where they may spend their first winter frozen in the ice. Thence, drifting westward across Baffin Bay, they commence their southerly movement under the influence of the Labrador Current. Many bergs that survive the first winter ground and break up along the treacherous Labrador Coast. The surviving icebergs may spend their second winter frozen in the Davis Strait region and from there, as soon as the pack breaks up in the spring, the remaining bergs drift southward with the Labrador Current toward the Grand Banks.

In an average year, about 400 icebergs drift below the 48th parallel with about 35 continuing their southerly drift past the Tail of the Banks to menace the trans-Atlantic shipping lanes. Yearly variation is great. During the peak ice year of 1929 an estimated 1,352 icebergs drifted southward of the 48th parallel. Yet in 1958 only one iceberg was observed. However, the following year, 1959, there were 693 bergs in evidence. This variation has not been fully explained but is probably related to climatological conditions over the entire iceberg-producing area and the distribution of pack ice in the Davis Strait. Icebergs may be encountered any month of the year, but in the Grand Banks area over 90 percent of them are encountered from March thru July, which constitutes the usual ice season, with the heaviest concentration from mid-April to mid-May.

icebreaker techniques, convoying, and towing in ice. A comprehensive glossary of ice terms is also included in this reference.

Natural deterioration commences as soon as newly-calved icebergs are waterborne. Melting processes are always at work. Although nearly dormant during the winter months, they speed up as the temperatures rise in the spring and reach an accelerated pace when the bergs drift farther southward into the warmer waters off the Tail of the Banks. In areas where the air temperature is well above the water temperature bergs will melt faster above the water, retaining their stability, and, as the bulk decreases, gradually rise out of the water, leaving tell-tale encircling rings of former waterlines. If the water temperature is high enough to melt the underwater portion faster, bergs become unstable and frequently oscillate to new positions of equilibrium, thereby creating new strains on protruding portions that may cause them to calf off, thus inducing another shift in the equilibrium of the berg. Sea water is the principle factor in the natural disintegration of an iceberg. Therefore, the area of a berg near the waterline is subject to the greatest melting, or actual erosion, by the continuous wave action sloshing warmer surface waters against the waterline of the berg, eating into cracks and crevices, and undercutting the sides, thus creating new protrusions, new strains, and renewed calfing. Melting of the underwater portion also releases the innumerable tiny pockets of entrapped air which bubble to the surface in an audible effervescent effect. Throughout their



The density of icebergs may vary slightly as galciers are composed of compacted snow. In the upper layers of the Greenland Ice Cap the entrapped air content may be as great as 50 percent of the volume. But, by the time the ice has traveled along the glacier to the sea, the great pressure has reduced the air content by volume to somewhere between 7 and 15 percent and the density is about 0.899 as compared to a density of 0.917 for fresh water ice. The average iceberg floating in sea water with a density of 1.028 will have about 87.5 percent of its mass below the surface of the water; therefore, the portion above water represents approximately one-eighth of the bulk of an iceberg. Arctic icebergs may weigh as much as about 1,500,000 tons, but icebergs found off the Grand Banks are seldom larger than about 150,000 tons. Berg ice in solid condition, is very hard and melts slower than artificially made ice, despite the general appearance of softness. Icebergs are of a peculiar opaque flat white color resembling snow, often with soft iridescent hues of green and blue. The snowy appearance is caused by surface weathering and the affect of the sun's rays releasing innumerable air bubbles. Bergs may be striped with blue or green veins of hard transparent ice which stand out strikingly against the porous white background. Brown and yellow patches, probably due to some form of planktonic life, may appear on them. Rock and earth remnants of old glacial moraines dart through the bergs in ribbons of brown, gray, and black.

An excellent and convenient reference on the formation, growth, movement, and dissolution of ice in general can be found in Chapter 1 of H. O. Pub. No. 47, "Sailing Directions for the Northern USSR." This reference also discusses the hazards involved in handling, maneuvering, and navigating a vessel in ice, as well as

Removing Nansen Bottle.

U. S. NAVAL OCEANOGRAPHIC OFFICE

No. 8

April 20, 1965

WEEKLY ICE CHARTLET

NORTH ATLANTIC LANE ROUTES—UNITED STATES

In accordance with the North Atlantic Track Agreement, the Oceanographic Office advises that Track "B" is effective as follows:

TRACK "B" (SOUTHERN)

From April 11 to June 30, inclusive

EASTBOUND.—Cross long. 47°00′W., in lat. 40°30′N.
WESTBOUND.—Cross long. 47°00′W., in lat. 41°30′N.

The Weekly Ice Chartlets are issued each Wednesday during the annual ice season in the North Atlantic. They are based primarily upon the twice-daily ice information bulletins issued by the International Ice Observation and Ice Patrol Services. All ice information received during the week (up to 1230 G.M.T. on the date of publication) is included (for complete text, see reverse side hereof).

Copies of Weekly Ice Chartlets are available at the U.S. Naval Branch Oceanographic Office in Norfolk and the Offices of the Collector of Customs in Chicago, Portland, Boston, New York, Philadelphia, and Baltimore. Copies may also be obtained from Oceanographic Office Sales Agents in the above ports and from the Office Services Officer, Eisenhower Lock, Massena, New York.

Radio ice information bulletins are issued twice daily by the Oceanographic Office and are transmitted at 0430 and 1630 G.M.T. by NSS (Navy Radio Washington) on the regular "Hydro" broadcasts.

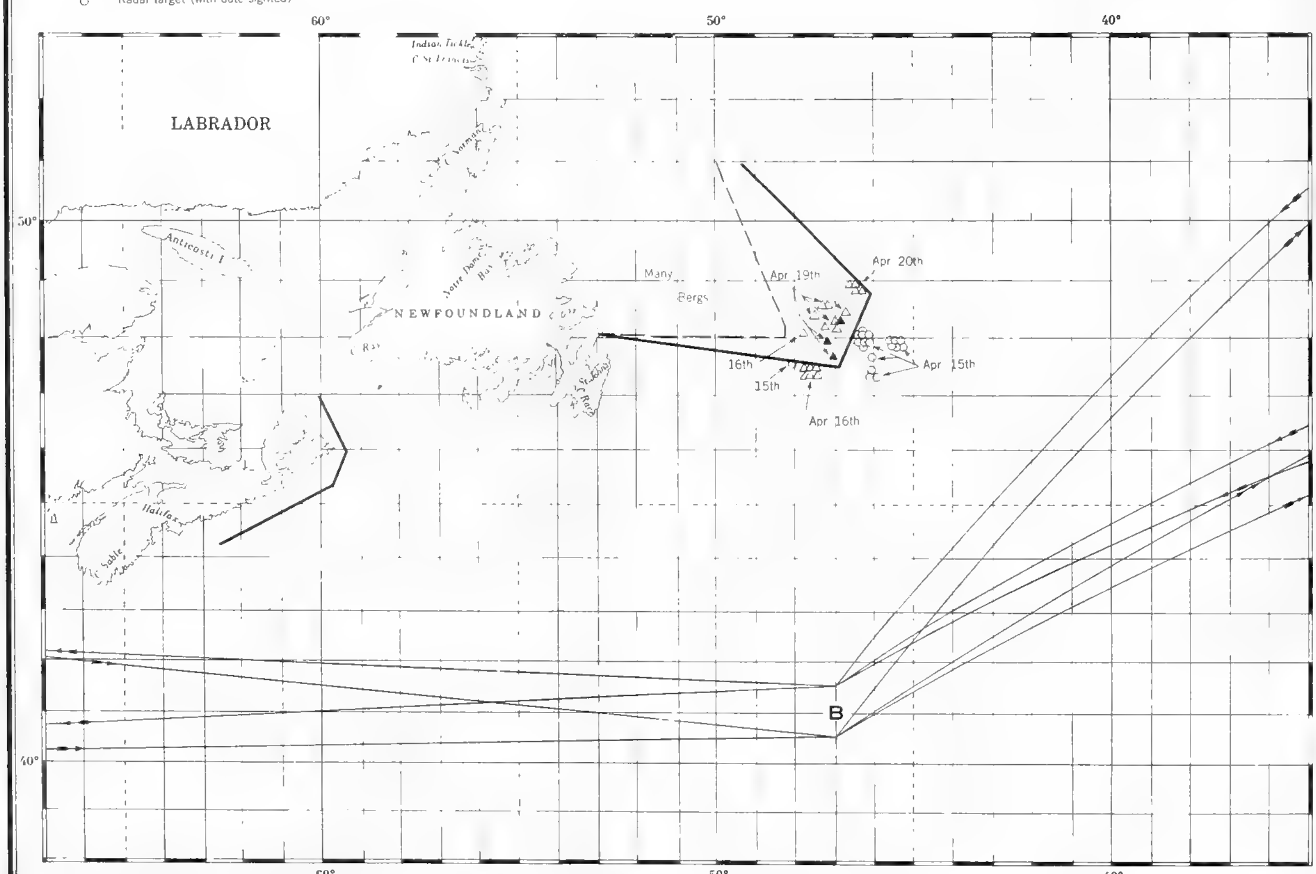
A daily ice chartlet, with detailed text, is included in the *Daily Memorandum,* (East Coast Edition).

KEY TO SYMBOLS

- ——— Estimated ice limits Apr. 20th
- — — Sea ice limits
- △ Berg (with date sighted)
- ▲ Growler (with date sighted)
- ○ Radar target (with date sighted)

NOTICE

Each issue of the Weekly Ice Chartlet supersedes all previous issues.

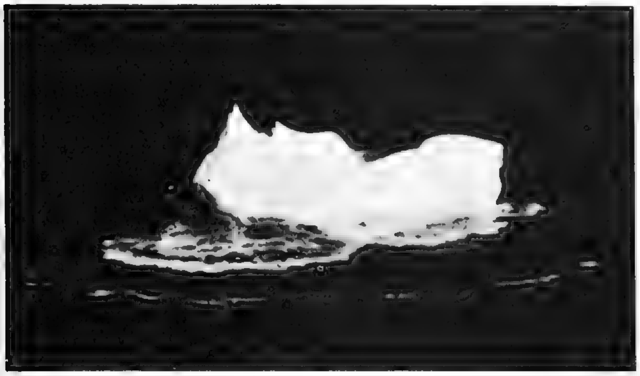


Published by the U. S. Naval Oceanographic Office, Washington, D. C., March 1965
under the authority of the SECRETARY OF THE NAVY

H. O. Misc. 11,845-B

life, icebergs continually emit weird sounds as if the ice is being alternately contracted then expanded.

A warm rain will have a marked affect on the surface of an iceberg. If the temperature becomes higher, melting water will cascade from a berg as a brook hurtling down a mountain side, cutting ever-deepening furrows into its surface. Possibly at night with a drop in temperature, water that seeped into cracks and crevices during the day may freeze. Sun's rays produce still another temperature gradient, causing a different amount of expansion to a piece of ice that may already have internal stress caused by slight variations in density and composition. These new forces, slight as they may be, might possibly be enough to cause calfing along internal natural cleavage planes. Although an iceberg in a solid state is almost indestructible, when it becomes rotten it may be completely broken up, under certain conditions, by relatively small external forces.



Drifting southward in the Labrador Current along the eastern slope of the Grand Banks an iceberg is usually in water temperatures lower than 35°F and disintegrates very slowly. In the mixed waters off the Tail of the Banks the dissolution is accelerated by water temperatures above 36°F. However, when the water temperatures reach 50°F the change can be observed from hour to hour. In the mixed waters southward of the Grand Banks the average medium-sized berg will survive as a menace to navigation for a period of 12 to 14 days during April, May, and June, but no longer than 10 to 12 days thereafter. Should the same berg drift even farther southward into the 65° to 70°F temperature of the Gulf Stream it would probably survive no longer than 7 days.

HISTORY OF THE ICE PATROL

The institution of an efficient patrol and warning system for the critical iceberg area was evolved with the perfection of the marine radio which enabled vessels to communicate freely with others within a reasonable distance. Immediately after the TITANIC disaster, upon the recommendation of the Hydrographic Office, the U.S. Navy, in the interest of safety of life at sea, dispatched a cruiser on 19 May 1912 for patrol duty near the ice regions of the North Atlantic. Primarily, the purpose of the patrol was to locate icebergs and field ice nearest the trans-Atlantic shipping lanes, patrol along the southern limits of the ice, and endeavor by radio communications to inform ships in the vicinity and the Hydrographic Office of these conditions. To cover effectively as large an area as possible, vessels were requested to report by radio observed ice conditions to the patrol ship. The Hydrographic Office and its Branch Offices in Boston and New York promptly disseminated the daily reports along the eastern seaboard. Circumstances did not permit the Navy to undertake a patrol of the ice regions the following season. Consequently, the 1913 patrol was carried out by revenue cutters of the United States Treasury Department and by the British steam trawler SCOTIA. The ice information received daily by the Hydrographic Office was published in the Daily Memorandum and the Weekly Hydrographic Bulletin and was also disseminated daily by the Branch Office in New York.

The subject of protecting trans-Atlantic shipping from the ice menace was thoroughly discussed by the first International Conference on "Safety of Life at Sea", convened in London on 12 November 1913 as a result of the TITANIC sinking. Representatives of the various interested maritime powers signed an agreement on 20 January, 1944 providing for the inauguration of an international derelict destruction, ice observation, and ice patrol service. This triple service, consisting of two vessels, was conceived to patrol the ice regions during the season of danger from icebergs and attempt to keep the trans-Atlantic lanes clear of derelicts during the remainder of the year. The United States was invited to undertake the service for which the expenses were to be defrayed in agreed fixed proportions by the nations signing the agreement. Thus, the patrol became international in character when the Revenue Cutter Service (now the United States Coast Guard) began the 1914 patrol.

Upon the subject of trans-Atlantic lanes, the Conference also adopted the following: "The selection of the routes across the North Atlantic in both directions is left to the responsibility of the steamship companies, nevertheless the High Contracting Parties undertake to impose on these companies the obligation to give public notice of the regular routes which they propose their vessels should follow, and of any changes which they make in them. The High Contracting Parties undertake, further, to use their influence to induce owners of all vessels crossing the Atlantic to follow as far as possible the routes adopted by the principal companies."

Each year as soon as reports from the northern waters indicated icebergs were beginning to drift southward, a cutter would be dispatched to the Tail of the Banks. Arriving on station the Coast Guard Cutter would notify the various radio stations and vessels in the vicinity of the official commencement of the International Ice Patrol. Thereafter, ice reports would be broadcast on several frequencies twice daily and forwarded to the U.S. Navy Hydrographic Office. Two cutters alternated in a continuous patrol, remaining on station about 2 weeks each. The patrol located and guarded the southern ice limits, giving particular attention to the critical ice area between the Tail of the Banks and the westbound B-track, constantly in use throughout the ice season. Serious ice conditions are likely to be encountered any time northward of the 48th parallel, but this is common knowledge to shipmasters sailing in higher latitudes; so, for practical purposes, the surface ice patrol was conducted in an area southward of the 48th parallel but northward of latitude 40°30′N. and between longitudes 43° and 54°W.

U. S. Coast Guard Cutter TAMPA

TECHNIQUES OF ICE DETECTION

Icebergs present no particular problem when they can be detected in time. However, throughout the ice season the Grand Banks area experiences some of the poorest visibility in the world. Detecting and forecasting the drift of icebergs during extended periods of fog has been a continuing problem for the Ice Patrol. Formerly, during periods of reduced visibility, patrol cutters would stop their engines and drift with the current in the vicinity of the icebergs they were guarding. Often the patrol would lie-to at night as it was impossible to search out bergs in the darkness.

Under excellent conditions a large berg may be sighted at a distance of about 18 miles, but with a hazy horizon this distance can be reduced to less than 10 miles, and in a light fog or drizzling rain the detection range may fall to 1 mile or less. In dense fog, an iceberg may not be seen until it is close aboard and then it will appear as a luminous, white mass if the sun is shining or as a dark, somber mass if the sun is not shining. On a clear dark night an iceberg will seldom be picked up at a distance greater than about ¼ mile, but if a sea is running, the wave action against the base might be sighted as far-away as 1 mile. A moon in the direction of an iceberg may hinder its detection, while the light from a moon on the opposite horizon may produce enough of a blink to allow the berg to be seen up to 3 miles. Often an icefield can be detected by a yellowish glare, or ice blink, in the sky above the field; should there be snow on the ice the glare will be whiter. If an iceberg is in the process of disintegration, its presence might be detected by the cracking, roaring sound as calfing takes place.

An early method of iceberg detection was the echo, and under proper conditions it is still useful. Sound is reflected off at the same angle it strikes a reflecting surface; thus, unless striking a steep-sided or cliff-like face, the sound may reflect aimlessly off in a useless direction. If the echo bounces back, the approximate distance and bearing of the iceberg can be obtained. Abrupt changes in air and sea temperature or the salinity of the sea water cannot be assumed as a reliable sign of the approach to ice. Temperature and salinity changes as great as those experienced in the Grand Banks area may be experienced in many areas of the ocean that are entirely ice free. However, it has been noted that icebergs tend to remain in the cooler, less saline waters of the Labrador Current.

Although the majority of the tremendous bulk of an iceberg is submerged, early attempts to locate ice with a sonic fathometer were unsuccessful. However, the fathometer was put to excellent use in producing data for very accurate bottom contour charts of the area. More recent Ice Patrol experiments proved that sonar can be useful in detecting icebergs at relatively short ranges. Under favorable conditions bergs may be detected at a range of about 3 miles and growlers at about ½ mile.

Before the advent of early radio aids to navigation, accurate positioning was frequently impossible as atmospheric conditions often prevented the patrol from obtaining celestial fixes despite many ingenious methods perfected in early patrols. Radio compass and radio direction finder equipment made this task easier. Improved methods and equipment, such as the electric salinity indicator, increased the scope of the oceanographic work that could be undertaken. After establishing the position of an iceberg the prediction of its drift remained a challenging problem. The patrol vessels maintained up-to-date isotherm charts by plotting the sea surface temperatures received regularly from vessels within the affected area. These isotherm charts show the surface distribution of the warm Gulf Stream and the cool Labrador Current and give an indication of the general drift of the surface waters. However, a prolonged wind or severe storm can mix the surface waters so that the underlying general drift of the water mass will be impossible to determine. Since the bulk of an iceberg is underwater it is the deeper general movement of the water mass that asserts the greatest effect on their drift.

Therefore, another method, involving the construction of a dynamic current map depicting the unstable pressure conditions for an entire water mass, offered a more reliable system of iceberg drift prediction. This method required the undivided attention of a patrol vessel for several days at a time, and was therefore impossible for the Ice Patrol as constituted. The "International Conference on Safety of Life at Sea," held in London during 1929, considerably broadened the responsibilities of the Ice Patrol, in requiring "a service for the study of ice and current conditions." Thus, from 1932 on, a third vessel was employed each year for this scientific pursuit.

The construction of a current chart depicting the dynamic topography of the sea surface adjacent to the Grand Banks is a scientific achievement of the oceanographer. To be useful, the area to be charted must be of sufficient size to portray a fair picture of the current circulation. Many oceanographic stations (50 to 100) are taken as quickly as possible, usually in rows radiating out perpendicular to the slope of the Grand Banks. The oceanographer is able to compute the relative dynamic or pressure height in decibars of a water column at each station from a deep isobathic plane to the sea surface. In oceanographic work, water pressure or dynamic potential is commonly expressed in decibar units. This unit is convenient because it is very close to the pressure exerted by 1 meter of water. Thus the pressure height in decibars of a water column is approximately the same as the depth of the column in meters.

Because sea water is not a homogenous substance, particularly in the critical iceberg area near the confluence of the warm, salty Gulf Stream and the cool, less saline Labrador Current, the computed relative pressure heights in decibars will vary from station to station. The oceanographer plots each station geographically with its corresponding pressure height, then by scribing a line through areas of equal pressure heights he obtains a chart depicting the dynamic topography of the sea surface. The resulting chart closely resembles an isobar weather map and actually portrays Highs and Lows in the pressure level of the sea surface. Thus, in the Northern Hemisphere, the unequal water mass from the Highs, attempting to equalize the depressions, flows counter-clockwise around the Lows similar to the flow of an air mass around a barometric low. However, if the complicated details of the water circulation are to be determined, oceanographic stations must be placed much closer together than weather observation posts, with the density of stations even greater along the slope of the Grand Banks than in the deeper water off the Grand Banks. Whereas, a weather map may be constructed in hours, and is useful only for hours, the construction of a current map takes days but it is useful far longer, as the rate of the everchanging water circulation is slower than that of an air mass.

EARLY EXPERIMENTS IN ICEBERG DESTRUCTION

The shapes, sizes, heights above water, and depths below water of icebergs differ tremendously, each variation contributing to the many variable factors determining their drift. Observations have shown that, with the best current charts available, drift predictions are not always accurate. Consequently, if the rather short life span of an iceberg in the critical area south of the Tail of the Banks could be shortened by only a few days it would greatly, percentage wise, reduce the time it is a menace to navigation. Experiments in artifically increasing the meltability or in the demolition of icebergs have been carried out intermittently by the Ice Patrol since its beginning. These experiments have included sound, gunfire, mines, demolition charges, depth charges, and even fire hoses. All attempts have had no real practical results. However, studies available revealed that with the strategic positioning of half a ton of conventional explosives about 2,000 tons of ice can be broken up, but this could require upwards of a hundred charges to destroy a berg and would be both physically and economically unsound. Melting by heat would be equally impracticable as it would require the heat energy contained in 2.4 million gallons of gasoline to melt a medium-sized berg of 100,000 tons.

Plane and iceberg target after bombing.

The Ice Patrol has long been aware of the experiments, results, and theories of the late Professor H. T. Barnes, of McGill University, using strategically placed thermite explosive charges on grounded icebergs off Newfoundland. Large bergs were literally shattered by a series of explosions and reactions. The thermite theory involves the high temperature of combustion when thermite, an intimate mixture of powdered aluminum and iron oxide, reacts to produce molten iron. The high temperature gradient, though from a relatively small heat source, may set up shock waves within the berg and fracture it along planes of internal stress. Boarding an iceberg in the open sea to plant the charges is not only very hazardous and foolhardy but frequently impossible.

INTRODUCTION OF ELECTRONIC AIDS

Throughout the war years of 1941 thru 1945 the Ice Patrol was suspended as it had been between 1916 and 1918. However, during the Second War many scientific advances were made, and their application greatly increased the efficiency of the post war International Ice Patrol. During the absence of a surface patrol, aerial observation flights of the ice area were successfully flown. After the resumption of the regular ice patrol in 1946, aircraft continued to play an ever increasing role. Equipped with radar for probing areas of reduced visibility and Loran for a system of precise positioning, aircraft were able to systematically search the ice areas quickly and fairly thoroughly. Patrol planes flying set patterns at an altitude of 500 to 1,000 feet, cross and recross the ice area on parallel courses about 25 miles apart, while obtaining Loran fixes at 3 to 5 minute intervals. These ice observation flights have been so effective that during light ice years continuous surface patrols are unnecessary. Normally preseason ice observation flights begin in January and continue until the commencement of a continuous surface patrol. Flights are resumed after the surface patrol is terminated.

Yearly the number of vessels equipped with radar increases. Consequently, since 1945, the Ice Patrol has conducted continuing research programs in iceberg detection by Radar. These experiments prove radar is useful in detecting ice, but the atmospheric conditions over the Grand Banks that create a need for radar often cause subnormal propagation of radar waves. The research indicates there is no preference to the frequency of the equipment as ice is not frequency sensitive and the response of ice to S- and X-bands is the same. The effect of fog on either band is negligible, but rain can

Aerial ice observer.

Boarding party preparing iceberg for thermite charge.

effectively hide dangerous growlers on the X-band. The reflective quality of an iceberg is very low, about 60 times less than that of a ship of equivalent physical cross sectional area. Due to the shape and irregularity of the reflecting surfaces of icebergs, their range of detection by radar varies greatly. An observant radar operator, experienced in ice detection, is a definite advantage. Often, even with the expert use of the FTC and STC anti-clutter devices, dangerous growlers can be lost in the sea return when a moderate sea is running. If ice is not picked up beyond the area of sea return it will not be spotted and the maximum range for the detection of a growler is only about 4 miles. Usually, better results can be obtained from a sector scan of a particular area, say 30° on each side of the bow, than a general scan, and nearby ice which may not appear on the minimum range setting often will appear on the intermediate or maximum range settings.

RADAR IS AN EXCELLENT AID FOR ICE DETECTION WORK BUT EVEN WITH DILIGENT USE IT WILL NOT ASSURE A SAFE PASSAGE THROUGH THE ICEBERG AREA OF THE NORTH ATLANTIC.

RECENT EXPERIMENTS IN ICEBERG DESTRUCTION

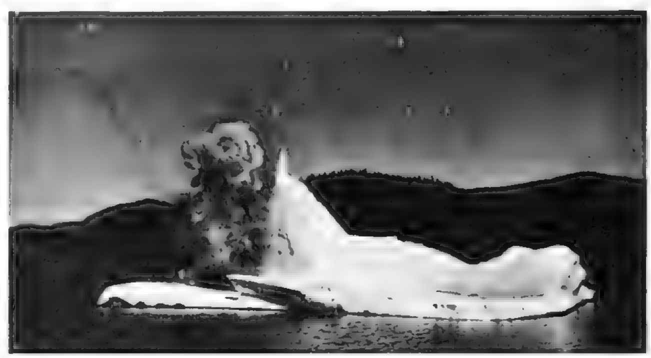
Although not primarily concerned with iceberg destruction, the Ice Patrol, despite the previous unsuccessful attempts, evaluates each new technique or theory that might hasten the disintegration or melting of an iceberg. The highly successful aircraft offered a practical approach to utilizing the thermite theory of ice destruction. Therefore, aerial bombing experiments were conducted on selected icebergs with thermite type bombs in June 1959. Each bomb consisted of clusters of incendiary bomblets and was designed to open about 100 feet above the target and spread the destructive power of the thermite bomblets over a wider area. Sixteen out of the twenty bombs dropped scored hits, but no icebergs were destroyed. The heat, spread over too wide an area, did not deliver the concentrated high temperature source necessary to the thermal stress theory of ice demolition. The following year, 1960, high explosives were substituted for the thermite and twenty 1000-pound bombs were dropped on a single iceberg for a total of 18 hits. The iceberg at the conclusion of the bombing was estimated to be one-fourth to one-third smaller. Although natural deterioration was in progress throughout the eight days of the experiments, the bombs were believed to be a factor in the reduction of the size of the iceberg.

The Ice Patrol felt that before further bombing experiments were conducted the thermite theory should be re-evaluated. Due to the great danger involved in boarding icebergs in the open sea this had not been done previously, but permission was obtained from the Canadian Authorities to conduct the experiments in the sheltered waters of Bonavista Bay. Forty 28-pound thermite charges and related ice equipment were obtained for this experiment. A small tabular berg was boarded and a 196-pound thermite charge planted. The resulting explosion, aside from calfing a few small bergs around the waterline, appeared to have little effect on the berg. Nearby, a large pinnacle berg was boarded and a second charge of 560 pounds of thermite was planted at the base of the pinnacle. There was a magnificient display of smoke and molten iron hurled hundreds of feet into the air, but the iceberg remained virtually unchanged. This experiment showed that this type of detonation will not necessarily cause the disintegration attributed to the thermite theory.

Spreading carbonblack on iceberg

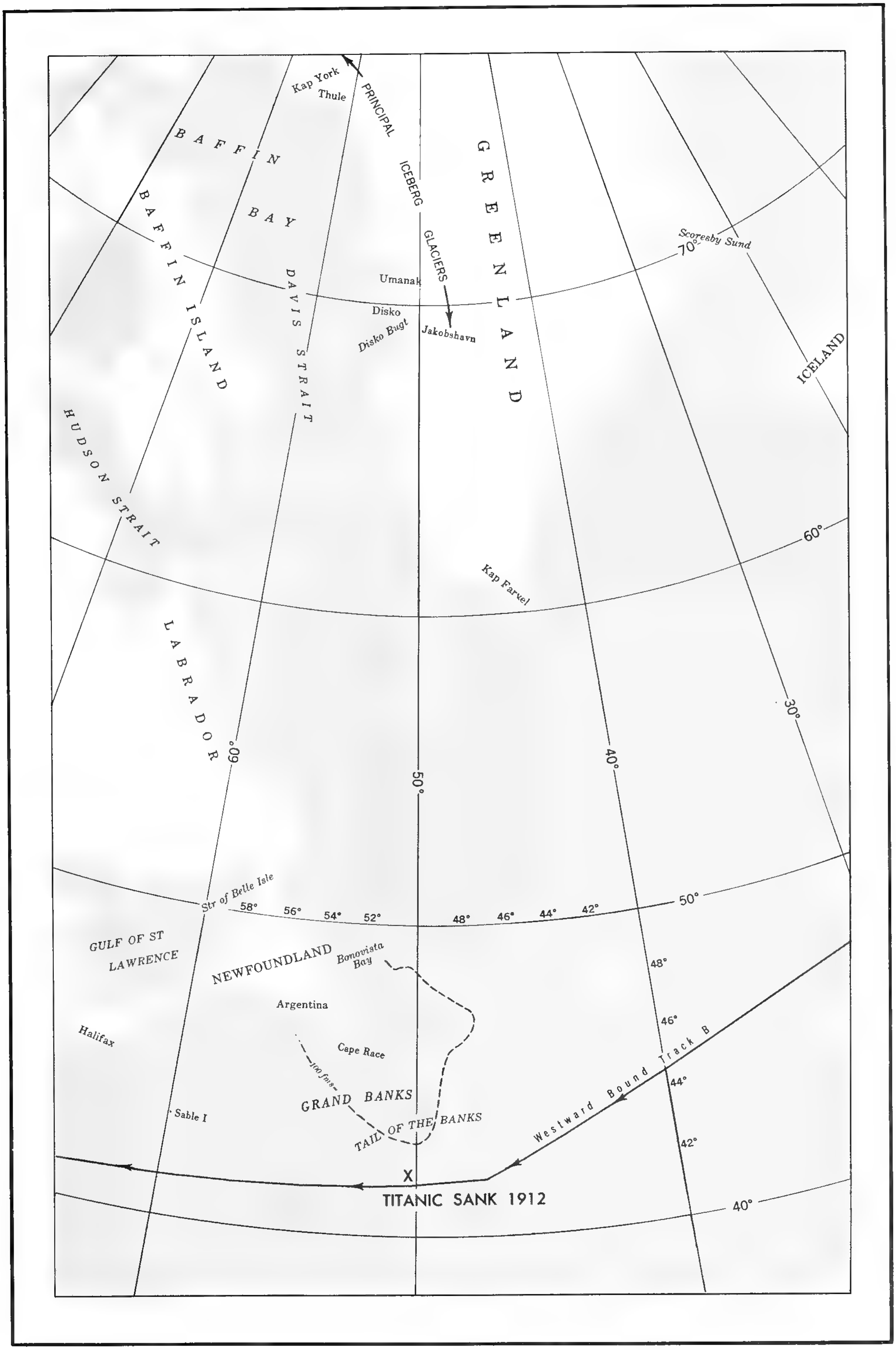
Iceberg 12 hrs after spreading carbonblack

Practice bombs filled with carbonblack, sand, ground clay, iron fillings, and oil were also dropped from a patrol aircraft, but the results were unsatisfactory. However, the small tabular berg used in the first thermite experiment was reboarded on 10 June, in the middle of the afternoon, and 25 pounds of carbonblack were spread manually with fiber brooms over half of the iceberg. Five hours later the berg underwent major calfing, and on close inspection the following morning, it was found to be less than 1/3 its previous size. The calfing of the iceberg after the carbonblack experiment could be coincidental; further experiment will determine the feasibility of this type of deterioration.



WIND EFFECT

For years the draft-height ratio for icebergs was believed to be about 5 or 6 to 1, but recent wire drags and submarine observations reveal a much smaller ratio. The approximate ratios for the various types of icebergs are 7 to 1 for flat tabular bergs, 3.5 to 1 for spherical shaped bergs, 2 or 3 to 1 for pinnacled bergs, and 2 to 1 for drydock type bergs with the average ratio for all bergs somewhere near 3.5 to 1. If the mean draft of icebergs is not as great as originally estimated then the effects of surface winds on their drift should be greater than previously believed. Therefore, in 1960, the Ice Patrol conducted experiments to establish the proper relationship between the wind and berg drift. Results obtained indicated that winds between 10 and 50 knots imparted a drift velocity in knots of 0.023 that of the wind speed and in a direction 50° to the right of the direction of the wind.


Kap York
Thule
PRINCIPAL ICEBERG GLACIERS
BAFFIN BAY
BAFFIN ISLAND
DAVIS STRAIT
GREENLAND
Scoresby Sund
70°
Umanak
Disko
Disko Bugt
Jakobshavn
ICELAND
HUDSON STRAIT
60°
Kap Farvel
LABRADOR
60°
50°
40°
30°
Str of Belle Isle
58° 56° 54° 52° 48° 46° 44° 42°
50°
GULF OF ST LAWRENCE
NEWFOUNDLAND
Bonovista Bay
Argentina
Halifax
Cape Race
100 fms
GRAND BANKS
Sable I
TAIL OF THE BANKS
48°
46°
44°
42°
Westward Bound Track B
X
TITANIC SANK 1912
40°

TODAY

The present seasonal trans-Atlantic lane routes were last revised by the "North Atlantic Track Agreement" of January 1950. The 1960 convention for the "Safety of Life at Sea" reaffirmed the basic concepts of the 1950 agreement, with a new provision, when ratified, requiring mandatory lane compliance by vessels in the converging areas. The present routes, consisting of tracks A, B, and C to and from U.S. ports and tracks D, E, F, and G for Canadian ports, together with the general instructions for their use are printed each year on the back of the North Atlantic Pilot Chart for April. The effective tracks each month appears on the face of the Pilot Chart for that month. Alterations to the effective tracks deemed advisable by the steamship companies composing the North Atlantic Track Agreement are published by the Hydrographic Office.

Radio Station NIK, Argentia

The Ice Patrol cooperates closely with the Canadian Department of Transport which, in conjunction with its Meteorological Branch, maintains an "Ice Central Office" at Halifax to support its ice-breaking operations and to assist shipping in Canadian waters, particularly in the Gulf of St. Lawrence and Straits of Bell Isle. Ice experts consolidate the information obtained by observers aboard the 10 Canadian Icebreakers, regular aerial reconnaissance, commercial shipping, and lighthouse keepers. Up-to-date charts depicting detailed ice conditions for the entire area of operation are maintained and a radio facsimile is broadcast to shipping and other interested parties. An ice forecasting service is also provided, and an ice information officer is stationed at Sydney, Nova Scotia to assist shipping and to act as a liaison between the shipping interests and the ice-charting and forecasting service.

Each year throughout the ice season, bulletins from the Commander, International Ice Patrol (NIK) are broadcast twice daily at 0048 and 1248 GMT by the U. S. Coast Guard Radio Argentia, Newfoundland (NIK). Broadcasts are preceded by the general call CQ on 500 kc. with instructions to shift to a receiving frequency usually either 155, 5320, or 8502 kc. The bulletins are transmitted at 15 words per minute and repeated at 25 words per minute. If necessary, special ice bulletins, preceded by the International Safety Signal TTT, may be broadcast in addition to those regularly scheduled. Normally, merchant ships call NIK on 500 kc. or 8 mc. Ships usually work 425, 448, 454, or 480 kc., or their assigned working frequencies, and NIK normally works 432, 8734, or 12718.5 kc. When on station the surface patrol vessels (NIDK) will relay messages between the ships and NIK if necessary.

All vessels are requested to report any ice sighted in the area between latitudes 39° and 49°N. and between longitudes 42° and 60°W. Also at 4-hour intervals, reports of the ship's position, course, speed, visibility, sea temperature, and weather conditions are desired. These reports by shipping are of the utmost importance to the International Ice Patrol during periods or reduced visibility when aerial ice observation is rendered ineffective. Reports aid the Ice Patrol in relocating drifting ice, effectively planning and concentrating ice observation flights in areas of suitable visibility, and constructing isotherm charts employed in estimating ice melting rates and detecting shifts in the branches of the Laborador Current. Weather conditions are useful in estimating set and drift of bergy bits and field ice and in determining the necessity for special warnings.

To facilitate the correct evaluation, ice reports to the Patrol should include (1) the type of ice sighted (Note.—If a radar target, report it as such.), (2) the position of the ice (not the position of the ship), (3) sea temperature at the closest point of approach to the ice, and (4) weather and visibility conditions. When impracticable to send reports promptly every 4 hours, vessels are requested to prepare the scheduled reports for later transmission as a late report is much better than no report.

Again this year, as in 1961, the International Ice Patrol contemplates regular daily transmissions of ice conditions by facsimile. The time and frequencies of the transmissions will be indicated in the regular ice bulletins. These facsimiles will represent true ice conditions and limits instead of the synoptic view offered by the ice bulletins.

Throughout the ice season the U. S. Navy Hydrographic Office repeats the ice information bulletins over Navy Radio Washington (NSS) on the twice daily Hydrolant Broadcast at 0430 and 1630 GMT. Before the commencement and after the termination of the International Ice Patrol, all reports of ice sightings should be addressed to the U. S. Navy Hydrographic Office, Washington, D.C. The information will then be broadcast to shipping on the Hydrolant schedule.

Fifty years have passed since that fateful night when the TITANIC went down with such an appalling loss of life. Today, thanks to the International Ice Patrol, thousands of ships annually traverse the Grand Banks region in perfect safety. Since the inception of the Patrol, not a passenger has lost his life in the area. Truly it can be said that those who lost their lives in the world's greatest maritime disaster, did not die in vain.

NATURAL PHENOMENA

G. E. Buckwalter
Maritime Safety Division
U. S. Naval Oceanographic Office

Mariners, by the very nature of their calling, have excellent opportunities for observing natural phenomena which may be of great value to the astronomer, oceanographer, and meteorologist. The scientist that delves into the secrets of nature depends upon accurate data obtained from all sources, but observations of phenomena from remote areas of the world add significantly to the sum of man's knowledge particularly when geographic distribution studies of the occurrences of such phenomena are made. Also, such observations may give the clues to unlocking the secrets of nature.

Observations of phenomena in the marine environs reported by mariners to the U. S. Naval Oceanographic Office are not only useful in studies made by this office but are forwarded to the various government agencies and institutions having related interests. Mariners are therefore encouraged to forward observations concerning natural phenomena, as well as other hydrographic observations.

The following are selected examples of natural phenomena to which mariners have contributed significant knowledge as well as being of general interest. Inquiries concerning them have been received from time to time.

ABNORMAL REFRACTION

Deceptions of vision at sea are produced by abnormal refraction of light which in the more extreme cases give rise to false images of land, ships, or other objects. Generally, abnormal refraction at sea is due to an inversion of temperature in a layer of air, the variations in density thus produced causing the light rays to be bent considerably in excess of normal conditions.

The most frequent and most favorable conditions for excess refraction, under which most of the more fantastic forms of mirage and distortion take place, occur when a layer of warm air is in contact with cooler water. The air next to the surface of the sea is cooled, and consequently the upper layers are warmer than the lower so that instead of the usual decrease there is an increase of temperature with height. Most refraction phenomena are formed at the boundary between this cold dense layer of air at the surface of the sea and the less dense warm air above. This condition is identical to that which is responsible for the formation of most sea fog; therefore, the presence of fog is an indication that excessive refraction is likely to be encountered.

Similar inversions may be caused by the presence of cold air over warm water. A marked difference between air and sea temperatures is therefore another guide to the presence of excessive refraction.

Although abnormal refraction is not restricted to particular geographical areas, certain regions of the globe are so situated with respect to general meteorological conditions as to be more favorable than others for the occurrence of abnormal refraction phenomena. The polar coasts are among the most favorable of these regions because of the frequently prevalent marked difference between sea and air temperatures. In polar regions excessive visibility or some form of mirage is often manifest when comparatively warm and light winds blow over the cold ice surfaces or when cold winds blow over open water. A milder temperature over open water than over the ice-clad adjacent shore also leads to refraction phenomena.

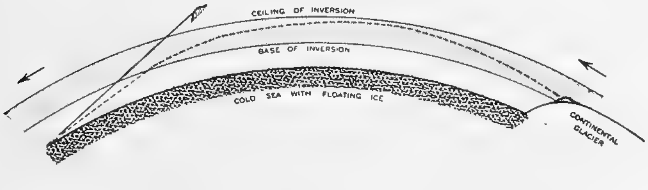


Figure 1 Mirage

DIAGRAM ILLUSTRATING THE CONDITIONS UNDER WHICH SUPERIOR MIRAGES MAY BE FORMED OFF LARGE ICE MASSES. THE INVERSION LAYER HAS BEEN WARMED ADIABATICALLY IN DESCENDING THE GLACIER SURFACE. THE DUST-FREE NATURE OF THE AIR LEADS TO GREAT UNDERESTIMATION OF THE DISTANCE OF THE COAST

In the polar regions the most common forms of abnormal refraction are *looming* and *superior mirage.* Looming is the apparent raising of an object above the horizon. It is quite common at sea especially in high and middle latitudes, and results in the appearance of distant objects which in many instances may actually be below the normal horizon at the time of observation. There are two types of looming. In one case, the object (island, iceberg, ship) is seemingly increased in elevation though not in size; in the other case, the object appears to be enlarged and brought much nearer to the point of observation.

The atmospheric condition that produces looming is one in which there is an abnormal decrease in the density of the air from the surface upward and hence a greater than normal downward curvature of the paths of light rays. The more rapidly the density decreases with elevation, the more unnatural and impressive becomes the phenomenon. If the rate of this decrease is variable at low elevation, the shape of the looming object is distorted, and strange bulging, thinning, flattening, or pointing may occur. Thus, a distant rounded peak might loom in its natural shape, appear with perfectly flat summit, or with a misshapen summit drawn much nearer the observer than the base. Likewise, the appearance from the masthead may be different from that at deck level.

Superior mirage is the apparent reflection from a more or less mirror-like atmospheric condition where there is a pronounced temperature inversion at a distance of several feet above the surface. This inversion introduces an abnormal change in density, and extraordinary refraction results. Its most frequent appearance is that of an inverted image above the object, but under suitable conditions a second mirage is seen erect, close above the inverted one. Sometimes the object is not observed directly and the inverted image or the upper erect image of an object below the horizon may be seen.

The formation of superior mirage is illustrated in figure 1. It is best and most frequent in Arctic and Antarctic regions but it may be observed down to middle latitudes. As with looming, the condition requisite for its formation is a warm layer of air existing over the sea at a suitable height, that is, an inversion of temperature. The only difference between this and the condition necessary for looming is that for superior mirage there must be a more sudden change from cooler to warmer air at a certain height.

The observer on a ship near land usually sees mirage as an unnatural image of the coastline, single, double, or triple, or as an appearance of the coast much nearer to him or farther from him than it actually is.

At sea, ships and icebergs are the mirage subjects more generally seen. Ocean fog is also associated with mirage since the temperature and humidity variations which favor condensation of moisture as fog in the air are often factors in causing mirage. An attendant mirage is, of course, not observable while dense fog actually obstructs the vision, but mock fog or the typical refraction band is often seen under such conditions and may lead to the recording of damp, or true, fog which does not exist.

The not uncommon phenomenon of mirage has been responsible for many false estimates of remoteness of newly discovered land features which have been seen by explorers within the polar regions, combined as it has been with the underestimates of distance due to the unusual clarity of the atmosphere. In many cases of snow-covered lands, there is not enough individual character in the coastal features to permit identification from different ship positions, and in such cases coasts have frequently been placed upon charts on the basis of the direction and estimated distance from positions offshore. These estimated distances are often as much as 40 to 50 miles too low because of atmospheric clarity alone, and can be as much as 300 miles too low as a result of the existence of a superior mirage.

As already indicated, abnormal refraction can be recognized only by its effect on the appearance of land, or such objects as ships, or icebergs. Temperature inversions may also give rise to abnormal dip of the horizon, which may seriously affect the accuracy of sextant observations. The navigator should therefore always be on guard against such a possibility whenever there is a chance that a temperature inversion may exist. If the motion of the ship permits use of a bubble sextant, it can be quickly determined whether the apparent horizon is appreciably displaced.

AURORAS

Auroras are caused by positively charged atoms, mainly hydrogen atoms, together with electrons emanating from the sun and entering the earth's atmosphere at speeds exceeding those of meteors. Auroras differ in color, form, motion, time of occurrence, and geographical distribution. They are associated with other phenomena, such as sunspots, magnetic storms, and ionospheric storms.

The auroras commonly occur only in high latitudes, both northern and southern. Occasionally they are visible from middle and low latitudes far beyond normal limits. They present a rare spectacle of great beauty and mystery to inhabitants of non-polar areas. Observations of these phenomena have been made in India (latitudes 19°N. to 36°N), in the West Indies, and Aden (latitudes 10°N. to 24°N.), as well as regions closer to the poles.

AURORAL FORMS (see Fig. 2).—The *Homogeneous Arc*, as the name indicates, appears as a segment of a circle across the sky, usually nearly at right angles to the meridian. The lower edge is more sharply defined than the upper, but there is no apparent fine structure. It may be high or low in the sky. The sky below the arc is sometimes very dark; this is called the dark segment. When several arcs appear they are closely parallel. The lower border, in most instances, becomes more luminous before the appearance of rays. Sometimes only short lengths of arcs appear. In this case, definite east-west motion may be apparent. Single narrow arcs, 1° to 2° in width, are sometimes about twice the usual height.

A more irregular form of arc with folds has been called a *Homogeneous Band*. It may move east-west with an undulating motion, or it may oscillate in a north-south direction. The arc may become very bright or have a red lower edge and may change suddenly into ray forms.

The *Rayed Arc* has the same elongated shape as the homogeneous arc, but it is composed of rays arranged side by side. Sometimes the homogeneous characteristic is retained; in others only the rays are present. When the rays are short and curves are present, they are commonly called *Rayed Bands*. Sometimes the rays become long and the rayed arc shows folds moving as though blown by wind; these have been called *Draperies*. They sometimes move as a whole and finally break up into groups of long rays. Whenever ray forms approach the magnetic zenith, they appear to converge to form a radiant crown or *Corona*. When a ray form moves over the magnetic zenith it appears as a thin band of light containing many bright points (rays seen end on). Rayed arcs are characterized by rays standing side by side in a pattern elongated at right angles to the individual rays.

A *Ray* is the term applied to isolated individual rays or narrow masses or bundles of rays. They may be present with other forms, but the rays do not appear connected. Observation of rays is important because they are usually high above the earth. Rays appear quite straight, like searchlight beams, and may be from 2° or 3° to over 60° in length. The width varies from a few minutes to many degrees of arc. The vertical edges are quite sharply defined. The brightness usually varies from a low value at the top to a maximum value about one third of the way from the bottom. Sometimes the rays are very bright at the bottom and decrease in intensity gradually upward.

The *Pulsating Arc* consists of a homogeneous arc or a part of a homogeneous arc which changes in light intensity, fading and brightening in a rhythmic fashion. Each pulsation may last from a few seconds to a few minutes. This form often drifts along slowly.

The *Pulsating Patches* or *Spots* are any diffuse patch or spot, not in arc form, which pulsates in brightness. They may be red in color.

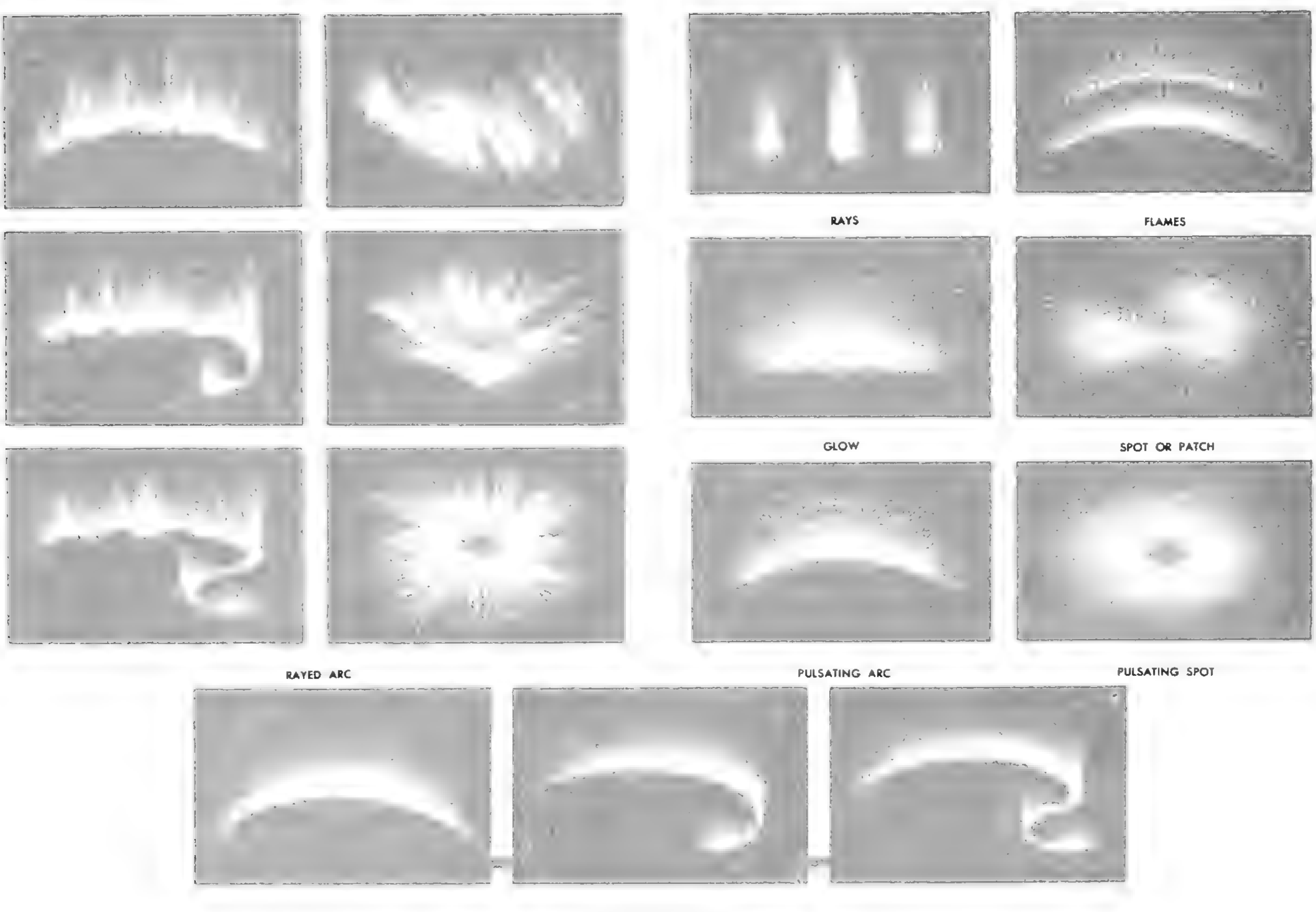


Figure 2 Auroral Forms

The *Flaming Aurora* comprise a quick moving form of waves of luminosity moving toward the zenith, or of invisible waves which cause segments of arc, bands, or patches to appear and disappear rhythmically but always with an upward motion. One form consists of arcs which extend upward out of a quiet arc. Another type occurs when these waves move up ray forms giving the impression of flames. They often appear near the peak of a display, though may be seen several times in one night.

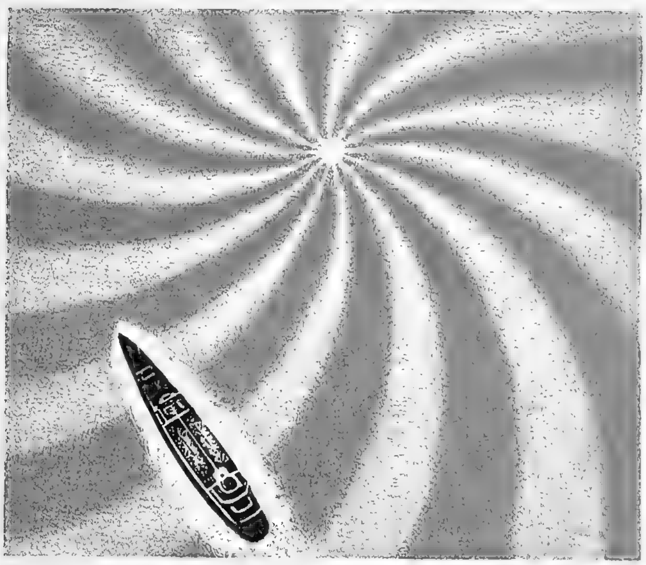
The *Glow* form is a faint luminosity, which, when seen near the north horizon, resembles dawn. When appearing high in the sky it resembles a translucent veil. It occurs alone only at the beginning and end of displays. However, after other forms become prominent it is easily overlooked. The activity of an auroral display often ends in a glow which may persist for several hours.

A *Patch* or *Spot* consists of patches or spots of diffuse light with the edges more well defined than the edge of a glow form. The patch or spot is usually whitish but may be a deep red in color.

BIOLUMINESCENCE

Bioluminescence, often incorrectly termed phosphorescence, is the production of light by living organisms in the sea. Bioluminescent displays must be triggered by some physical,chemical, or mechanical stimulus. Generally, these displays are stimulated by surface wave action, ship movement, fish and whale movement, subsurface waves, upwelling, eddies, physical changes in sea water, surfs, tide rips, and others.

In most cases bioluminescence is a reaction between luciferin and oxygen in the presence of luciferase. Luciferin is a heat stable, easily oxidized compound. Luciferase is an enzyme which accelerates the reaction. Bioluminescence may be produced by secretions of specialized glands, or by symbiotic bacteria.



Sketch of a phosphorescent wheel

Marine displays are generally grouped in three general categories: (1) sheet-type, often appearing as a sheet-like glow extending for several miles over the sea surface; these are caused by tiny one-celled animals, protozoans; (2) spark-type, observed as innumerable flickering points of light; these are caused by minute shrimplike crustaceans; (3) globe-type, observed as glowing balls of light produced by jellyfish and tunicates when drifted together in groups in the sea.

Numerous reports concerning these phenomena have been received from ships throughout the world. Some of the descriptive terms submitted by observers are as follows: "appeared as shoal water, low-lying fog bank, broad belts, narrow belts, ribbons, rivers, milky patches, bars moving at great speed, flashing spots, white water, beams of light, like a search light, patches resembling pack ice, pale blue—horizon to horizon, millions of electric lights, starry sky, round blobs, cloud-like patches, continuously changing form, large anti-clockwise pinwheels," and many others.

BURNING CLIFFS

Along the western shore of Franklin Bay, Northwest Territories, Canada, the coast is backed for several miles by a range of steep hills known as "Smoking Hills" or "Burning Cliffs". The cliffs range from about 300 to 500 feet in height and are in places composed of bituminous alum shale. Their name is from the burning mineral deposits which emit clouds of smoke and steam, particularly in spring and summer.

Some areas of the cliffs burn in places for years. At night the fires are visible a considerable distance to seaward and resemble numerous camp fires. The fires burn out in some places and start up in others. The burned out areas cause the cliffs to be washed and undercut by the sea in places.

The smoke has a sulphurous odor but the fires are reportedly not of volcanic origin. The water in the streams and ponds along this coast is mostly undrinkable because of the alum content and other mineral salts.

DESTRUCTIVE WAVES

Unusual sudden changes in water level can be caused by seismic sea waves or violent storms. These two types of destructive waves have become commonly known as tidal waves, a name which is technically incorrect as they are not the result of tide producing forces.

Seismic Sea Waves are set up by submarine earthquakes. Many seismic disturbances do not produce sea waves and often those produced are small, but occasional large waves can be very damaging to shore installations and dangerous to ships in harbors.

These waves travel great distances and can cause tremendous damage on coasts far from their source. In 1946, one originating in the Aleutian Trench caused $25,000,000 damage in the Hawaiian Islands 2,200 miles away.

The speed of seismic sea waves varies with the depth of water, reaching 300 to 500 knots in deep water of the open ocean. They cannot be detected in the open sea from a ship or from the air because their length is so great, sometimes a hundred miles, as compared to their height, which is usually only a few feet. Only on certain types of shelving coasts do they build up into waves of disastrous proportions.

There is usually a series of waves with crests 10 to 40 minutes apart, and the highest may occur several hours after the first wave. Sometimes the first noticeable part of the wave is the trough which causes a recession of the water from shore, and persons who have investigated this unusual exposure have been engulfed by the oncoming crest. Such an unexplained withdrawal of the sea should be considered as nature's warning of an approaching wave.

A warning system has been organized in the Pacific with its center in the Hawaiian Islands. Improvements for rapid determination and reporting of earthquake epicenters are being made, but no method has yet been developed for determining whether destructive waves will be generated.

Stormwaves.—A considerable rise or fall in the level of the sea may result from strong winds and a sharp change in barometric pressure. In cases where the water level is raised, higher waves can form with greater depth and the combination can be destructive to low regions, particularly at high stages of tide. Extreme low levels can result which are considerably less than those shown on nautical charts. This type of wave occurs especially in coastal regions bordering on shallow waters subject to tropical storms.

Seiche is a stationary vertical wave oscillation with a period varying from a few minutes to an hour or more, but somewhat less than tidal periods. It is usually attributed to external forces such as strong winds, changes in barometric pressure, swells or seismic sea waves disturbing the equilibrium of the water surface. Seiche occurs both in enclosed bodies of water and is superimposed upon the tides of the open ocean. When the external forces cause a short-period horizontal oscillation of the water, it is called *Surge.*

The combined effect of seiche and surge sometimes makes it difficult to maintain a ship at its berth alongside a pier even though the water may appear to be undisturbed. On occasion ships have incurred damage or caused damage to pier facilities after mooring lines have been parted repeatedly under such conditions.

Since prediction of this phenomenon is nearly impossible, mariners should be alert to the ship's behavior at all times especially in strange ports and should take measures to prevent damage to the ship or property.

Tide Bores.—The tide bore may be defined as a sudden rise of tide which rolls up certain rivers and bays in the form of a breaker. Bores form a hazard to shipping and generally occur in a shallow estuary where the range of tide is high. The high water moves inward at greater speed than the preceeding low water because of the greater depths at high water. When the high water overtakes the low water an abrupt front is formed.

An example of this phenomenon occurs in the Seine River, France, where it is known locally as a "mascaret". This wave takes the form of a fairly abrupt front the slope of which varies between 1/100 and 1/150, and the height from 3 to 6½ feet. This front travels upstream with a velocity of 22 to 25 feet per second and is followed by wave undulations of 2 to 3 feet high and a few score yards in length. This phenomenon is dependent on numerous factors and can be considerably lessened or even entirely suppressed by prevailing atmospheric conditions or hydrologic conditions of the river.

The impact of the mascaret on a ship at her mooring results in a more or less alternating force; generally, the maximum influence of this force takes place at the passage of the wave front and is directed upstream attaining a value nearly equal to the product of the displacement of the vessel by the slope of the wave (i.e. approx. 1/100 to 1/150 of the vessel's displacement). The following undulating and downstream forces, however, produce both upstream and downstream forces comparable to that produced by the initial wave front.

Thus the vessel experiences violent alternating forces attaining scores of tons with a period of some 10 to 20 seconds.

Moorings should therefore be such as to introduce opposing reactions to the movement of the vessel before any appreciable speed is obtained resulting in a considerable amount of kinetic energy. Mooring lines should also have the ability to stretch to allow for the lifting of the vessel as the tide rises.

Traditional mooring lines (wire hawsers, hemp ropes, etc.) are not suitable since they are not sufficiently elastic to be hove taut to limit the movement of the vessel at low tide and to subsequently undergo a rapid change of height. Furthermore, as it is not possible to balance the tension of each mooring line there is the risk of breaking one after the other when subjected to the forces generated by the mascaret.

The Port of Rouen Authority recommends employment of nylon springs shackled to customary mooring lines, particularly on wire hawsers. These nylon springs should be 26 to 32 feet in length and 3 to 4 inches in diameter. The lines are hove as taut as possible at low water. When conditions allow, both anchors should be laid out with slightly taut chains to increase the ship's resistance to the wave front. Ships should not use engines as this increases the downstream force. The nylon springs should not be in contact with bollards or bitts but should end in metal thimbles.

Glacial Wave.—Lituya Bay (58°38′N., 137°39′W.), on the southeast coast of Alaska, is a deep indentation with a narrow entrance. The shores are backed by high peaks from which glaciers descend to the water. This bay, on several occasions, has been subjected to waves and water movements of exceptional amplitude.

Discovered in 1786, by La Perouse, the bay then appeared to offer sheltered anchorage, but that explorer lost two small craft with crews sent to reconnoiter the area. The craft were lost from being thrown against the reefs by the strong tidal currents which attain rates of up to 12 knots at the entrance.

On the evening of July 9, 1958 an earthquake in Alaska caused an enormous mass of ice to break off Lituya Glacier and to fall into the bay. The resulting wave swept the shores to a considerable height. The few witnesses reported that the cataclysm caused the water to attain heights of 492 feet (150 meters) at certain points on the coast, more than twice that height southward of Lituya Glacier, and 164 feet (50 meters) on Cenetaph Island within the bay.

Such heights had remained an enigma for oceanographers; but several observations made by the U. S. Geological Survey and the U. S. Coast and Geodetic Survey, and taking into consideration similar phenomena, permitted the idea that such heights were not exaggerated.

The complete disappearance of two Indian villages, mentioned by La Perouse, were reported in 1853 or 1854 by hunters. A wave of great amplitude was reported in 1936; and prior to 1958 a geologist noticed that the trees around the bay shore grew according to the age of the trees with marked delineations or bands on the hillsides to a height of 393 feet (120 meters). The most recent boundary and age group corresponded with the wave of 1936, and the second age group corresponded to the winter of 1853-54.

Returning to the bay after July 9, 1958 the geologist discovered that the mountainsides he had previously observed as completely covered with trees, and the slopes descending to the shore were bare to heights of 1,640 feet (500 meters). He noted also that the rock fissures were clear of accumulated debris.

The observations were confirmed by aerial photographs taken after the quake. The photos indicated that some great masses of ice had fallen into the bay in addition to large avalanches. Photogrammetric measurements also indicated that the sea wave of 1958 exceeded the 1,280 foot (360 meter) level.

HISTORY OF A DISAPPEARING ISLAND

Falcon Island (Fonua F'ou).—This volcanic feature, located at 20°19′S., 175°25′W., in the Tonga Islands, has a history of appearance and submergence and has changed in size and form on several known occasions.

In 1865, the H.M.S. *Falcon*, from which it derives its name, observed it as a breaking reef. The H.M.S. *Sappho* observed smoke rising from the reef in 1877.

Birth of an island

In 1889, the H.M.S. *Egeria*, a surveying ship, surveyed the area and found an island 1¼ miles long north to south, one mile wide and wedge-shaped with a 153 foot-high hill at the southern part. The island was formed of loose volcanic ash and cinders which were constantly slipping down, as the sea action undermined it. It was estimated that two-thirds of the island had worked away since 1885. No growing coral was found. It soon dispersed entirely. The *Egeria* was able to anchor off all but the east side.

In April 1894, the area was observed at a distance of 2 miles and the only visible relief was a low streak of black rock. In December of the same year volcanic action and a new crater was observed to have formed with the resultant island 3 miles long and 1½ miles wide. It was 50 feet high with a hot surface. It was reported in July 1898, that Falcon Island had disappeared completely and that in its place was a shoal about 100 yards in extent with the sea breaking heavily on it. Discolored water was also observed about 1 mile southward of the breakers. Again in April 1900, it appeared above water and was estimated to be about 9 feet high at its northern end. The SS *Cormoran* could find no above-water features in the area in 1913.

The location of Falcon Island was examined by the H.M.S. *Veronica* in 1921. A very heavy swell, discolored water, rips, and a continuous breaker was observed at the southwest part of the area. The breaker was found to be caused by a rock about 15 yards in diameter, mottled green, covering and uncovering. The bottom was visible for some distance from the rock. It was estimated that in calm weather the rock would have had a depth of about 3 feet over it.

In October 1927, Falcon Island erupted again. It was examined by the H.M.S. *Laburnum* which cruised around it and found the island as it was originally charted in size but about 305 feet high. It was erupting once every 20 minutes. It commenced to erupt in the middle, then ejected smoke and vapor, then was enshrouded by a bank of smoke that billowed to over 4,000 feet in the sky. The Premier of Tonga landed on the island in June 1928, and hoisted the Tongan flag. In October of the same year the height of the island was observed to be 405 feet with steam emitting from the crater. In 1930, the height was again reported as 475 feet.

In 1936, the H.M.S. *Leith* steamed around the island about ½ mile off. The north side rose in a gradual slope to its 200-foot summit, falling in a perpendicular cliff at its southern end. Little volcanic activity was apparent, but eruptions were observed every 15 minutes from a submarine crater off the southeast end. The island was about 1½ miles long, north to south, and about ½ mile wide.

In 1937, the H.M.S. *Achilles* passed 1 mile northeastward of the island and reported no sign of volcanic activity. In June 1938, the H.M.S. *Leith* estimated the height to be about 30 feet about ½ mile from its southern end but with no activity. The MV *Maui Pomare* observed the island in March, 1941, emitting jets of steam.

Little is known of its activity during World War II. In February 1949, the H.M.N.Z.S. *Hawea* reported that the island had again disappeared, and that the least depth found in the vicinity was 9 fathoms.

In 1959, it was again reported that no above water features were visible in the vicinity of the island.

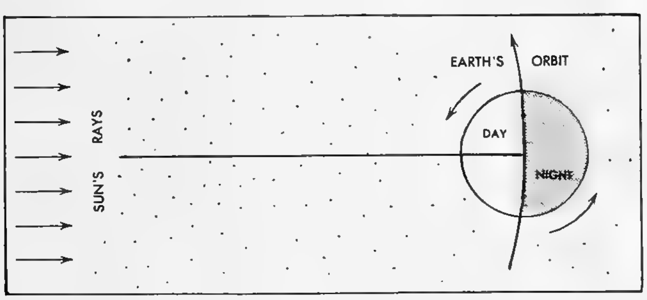
LOCUST RADAR TARGET

In July of 1959 at the Strait of Bab El Mandeb, at the southeastern entrance of the Red Sea, a ship observed a radar target at a distance of about 10 miles. Visually the target appeared as a sandstorm approaching from northwestward and to be about 8 miles long northeast to southwest, about 6 miles wide, and oval in shape. The target advanced until the ship was in the midst of a hugh swarm of locusts. The target moved southeastward until it disappeared at a distance of about 10 miles.

In the Middle East swarms of locusts are known to migrate from Africa into Asia Minor plaguing crops and other vegetation since Biblical days.

METEORS

Interplanetary space is by no means empty. As the earth revolves around the sun, it swims through an ocean of rarefied gas, thinly strewn with solid objects that range in size from dust specks to minor planets. Both the zodiacal light and the outermost part of the sun's corona are interplanetary solid particles illuminated by sunlight. But the most familiar indications that space between the planets is not empty are the meteors seen as the earth collides with small bodies.



Meteor Swarm

THE EARTH IS REPRESENTED MOVING IN ITS ORBIT AMONG THE PARTICLES IN SPACE. AN OBSERVER IS LOCATED ON THE FORWARD—MOVING SIDE OF THE GLOBE AFTER MIDNIGHT, AND THEREFORE ENCOUNTERS A GREATER NUMBER OF SPORADIC METEORS.

Astronomers have recently realized that the solid grains in our solar system are of two very different kinds. One variety consists of bits of stone and iron, which travel around the sun in nearly circular, low-inclination orbits, in the same direction as the earth. These are regarded as debris from collisions of asteroids, or perhaps material from a planet between Mars and Jupiter that long ago broke up (or failed to form). Any meteor observed brighter than Venus is probably the result of one of these asteroidal fragments passing at high speed through the earth's atmosphere.

The second kind of particles moving in orbits like those of comets. These include almost all the fainter meteors that we see. Several of the prominent annual meteor shows are caused by objects moving in the same orbits as known comets; thus it is definitely established that the Perseid meteors seen about August 12th each year are debris of Comet 1862 III. The fact that the Perseids appear every year means that fragments have spread out along the entire orbit, forming a ringlike stream that the earth cuts through each August.

At the height of the Perseid shower, a naked-eye observer may count a meteor per minute that is a member of the shower. All Perseid paths, if extended backward across the sky, originate in the same radiant (actually a small area rather than a point). This is a perspective effect; the Perseids are actually moving along widely separated parallel paths in space as they come into the earth's atmosphere.

The number of distinct showers is large but indefinite. Every gradation exists between conspicuous rich showers and others so sparse that they contribute less than one meteor an hour.

If we imagine the sporadic meteors to result from a random scattering of particles, moving at random in a swarm through which the earth is moving at an orbital speed of 62,000 miles per hour, then we can deduce that during the night the number of meteors visible per hour should increase steadily from dusk to dawn. At sunset we are on the trailing edge of the earth, and can see only those meteors moving fast enough to overtake our planet. But as night progresses, the earth's rotation carries us around until near sunrise, we are on the leading edge of the planet. Then the hourly rate of meteors becomes much greater because head on collisions occur, and slow moving meteors are overtaken by the earth.

This picture is valid even though the motions of sporadic meteors are not quite random. Those going around the sun in the same direction as the earth tend to have shorter periods and low inclinations; those traveling the other way have longer periods and high or low inclinations.

For many years astronomers debated whether these were visitors to our solar system from interstellar space. The practical criterion for recognizing such an intruder is high velocity. An object at the earth's distance from the sun is traveling in a hyperbolic (open) orbit only if its velocity exceeds 42 kilometers a second. Since we observe from the earth, which moves at 30 kilometers a second, a meteor found to move significantly faster than 72 kilometers a second must be an interloper in the solar system.

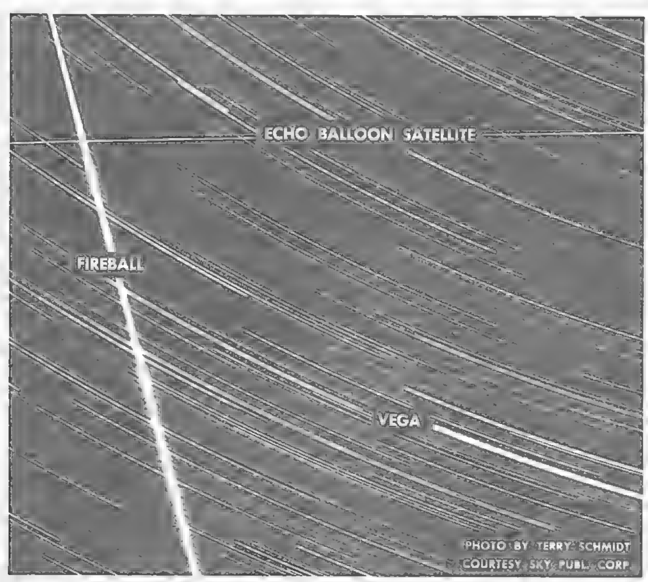


Photo of meteor trail

Accurate velocities for thousands of individual meteors have been obtained from modern photographic and radar observations, but so far not a single certainly hyperbolic case has been established. Interstellar meteors are extremely rare and are not within present ranges of detection. Less than 30 years ago it was widely believed on the basis of visual observations that most, if not all, sporadic meteors were of interstellar origin.

The development of photographic equipment has enabled astronomers to accurately compute the paths, entering velocities through the atmosphere, and the radiant points of meteors. In addition, the deceleration of meteors by air resistance can be evaluated accurately enough to indicate the density of the upper atmosphere.

Another breakthrough was scored soon after World War II, when radar observations began in England and Canada. When a meteoric object traverses the earth's atmosphere, a cylinderical column of ionized gas is produced which is a good reflector for radio waves. The echo is strongest from the point where the column is perpendicular to the line of sight. With a three-station system, it is possible to obtain excellent determinations of velocities and radiants of individual meteors.

Radar techniques can record meteors several magnitudes too faint to be photographed. Furthermore the radar observations can be continued around the clock, irrespective of daylight or clouds.

NATURE'S LIGHTHOUSES

On the island of Tofua, in the Tonga or Friendly Islands of the South Central Pacific Ocean, an area noted for its volcanic activity, is an extremely active volcano which is used as an aid to navigation. By day it emits smoke for 5 minutes out of every 10 and by night it displays flaring flames. Although there are other volcanic islands in that area that spew forth fire and smoke, none have the regularity of Tofua. Captain Bligh observed this phenomenon while adrift in the Bounty's longboat, and he recorded it in his logbook on April 28, 1789.

Another of nature's lighthouses in the Pacific has been used as an aid to navigation for years. This volcano's name is Izalco and its location El Salvador. Blazing regularly every eight minutes, it was once known as the "Lighthouse of the Pacific".

NATURE'S TOWBOAT

In the Dardanelles, below the surface current, a more dense subsurface counter-current enables fishermen to give their boats a tow against the surface current by lowering their nets into the deeper sub-surface current.

In the Black Sea the precipitation and runoff exceed the evaporation, thus giving rise to a low density, low salinity, surface layer. As a result, the surface waters of the Black Sea flow out through the Bosporus and the Dardanelles, whereas the Mediterranean waters flow into the Black Sea along the bottom, thus explaining the above phenomenon.

A REEF THAT EXPLODED

In Erin Bay, about 1½ miles off the southwest coast of Trinidad, a reef, known as Despatch Reef, has an interesting and explosive origin. On November 11, 1911, a submarine disturbance caused an island about 8 acres in extent to be raised 12 feet above sea level where there had previously been 6 to 10 feet of water. Fishermen who observed the phenomenon noticed that several days before the eruption the sea in the vicinity was churning violently and the air smelled of sulphur.

At 6 P.M. on the 11th a rumbling noise as of distant thunder was heard coming from a mound that had risen above the surface of the sea and which was emitting dense black clouds of smoke billowing skyward. The clouds were followed by a great blaze of flame rising 300 or more feet in the air. The color of the flame was reported blue to straw-colored and the duration was from 7 to 10 minutes. The flame was visible in Port-of-Spain more than 50 miles away where residents assumed there had been an explosion in developing oil fields of the area. The newly arisen island existed for several months, but the wind and eroding action of the the sea soon worked the apparently soft structure back into the sea. Today, on Oceanographic Office Chart No. 1963, there appears only the notation of a submerged reef in the vicinity of Despatch Reef.

Subsequent investigation of the phenomenon by Mr. Ralph Arnold, an American geologist and petroleum engineer, suggests the following sequence of events and theory of origin.

No recent volcanic rocks or other evidence of true volcanic activity are known on Trinidad. The porous sand beds and lenses containing petroleum gas, in many occurrences under enormous pressure, are associated with oil-bearing strata, especially along the anticlines or lines of disturbance. Mud volcanoes and pitch cones are found inland of Erin Bay and yield gas and muddy and oily water discharging continuously, intermittently, and occasionally, briefly and violently.

The appearance of the island was first heralded by an escape of gas from the apex of the anticline or line of disturbance coincident with the reef in Erin Bay. This was followed by the upwelling of the reef accompanied by a fracturing of the rocks and rapid ejectment of mud with minor amounts of fragmental material through a more or less well defined vent or crater. Two cones 20 to 30 feet high rose above the surface of the island and served as vents at the time of the explosion. During the height of the eruption when large quantities of hard rock fragments were being ejected, sparks were probably formed by the striking together of some of the rocks, and the petroleum gas thus ignited.

Following the destruction of the main cone several mud flows continued to be pushed upward from below the surface. Gas continued to escape from numerous small vents on the island but lessened as several days passed. This resembled large gas volcanoes in behavior which erupt periodically as the subterranean gas pressures build up, eject, and subside.

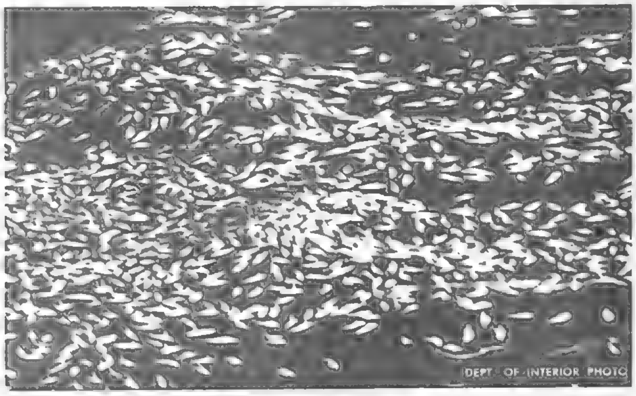
The presence of oil sand in the ejected material on the island and the presence of petroleum gas odor clearly demonstrated that source of gas was from the oil- and gas-bearing strata which underlies that area of Trinidad. In summary, the explosive origin of Despatch Reef was the result of a violent eruption of petroleum gas. The phenomenon was clearly non-volcanic in origin. The unusual features of this gas volcano were its large size as compared with similar cones of this character, its submarine origin, and the fact that the gas which caused the eruption ignited during its escape.

RED TIDE

In recent years this phenomenon has occurred off the coasts of several countries including India, Australia, Peru, and the United States. This scourge to sea life is caused by a small organism known as a dinoflagellate. Although classified among the algae, the power of movement places the creature between the animal and vegetable kingdoms.

Under suitable environment these organisms reproduce so rapidly that as many as 60 million may be contained in a quart of sea water, producing a deadly effect on other sea life. In vast numbers they give the water a reddish color but observations indicate other colors such as yellow, yellow-brown, or olive-green occur.

Scientists have advanced the theory that after heavy rains the run-offs in certain coastal regions contains phosphates and vitamin B^{12} which together with a lowering of the salinity and with favorable temperature enable the dinoflagellates to multiply at incredible rates.



Fish killed by red tide

It is suspected that these creatures secrete a poison as deadly as botulinum, which is claimed to be the most poisonous substance known. This secretion kills fish, turtles, and other marine life; causes inflamation of lungs and throats to humans swimming in such waters; and causes other unpleasant conditions at resort areas.

Research on this problem has added to knowledge of substances which attack the nervous system. New weapons against human disease may well be developed by medical science as a result of research in this phenomenon.

THE SARGASSO SEA

The central part of the Atlantic Ocean has remained the subject of myth and legend for a longer period than any other part of the ocean. The term "Sargasso Sea" is derived from the name given by the early Portuguese navigators. "Sargacao" so-called from the fact that the berries found on the weed resemble grapes *(sarga)*. It was traversed by Columbus as he sailed westward and the masses of weed, supposedly hampering the progress of the ships, nearly caused a mutiny among his crew.

Whether the Sargasso Sea was known prior to the discovery of America is still open to question. There are grounds for believing that the Phoenicians were acquainted with its presence. Before the beginning of the Christian era there are references to the sea west of the Pillars of Hercules (Gibraltar), and certain parts of the sea are represented as being unnavigable because of the seaweed. Also, there is a record of this fact that a Portuguese sailor told Columbus that one of the obstacles to be overcome in the westward voyage to India was weeds. To Columbus, however, must be credited its discovery and the first authentic record of the occurrence of gulf-weed in this area. On his first voyage westward he encountered Sargasso Weed for a number of days; and likewise on his return voyage. In his log, it is noted that Columbus carefully recorded the occurrence of this brown, floating weed.

Gulf Weed

Viewed from a small vessel, such as that used by Columbus and other mariners of his time, the patches of Sargassum undoubtedly looked vastly more formidable than they really were. This region is one of light winds; hence the sailing vessel made slow progress. It is therefore little wonder that stories developed of widespread distribution of the thickly-matted weed impeded the progress of the vessels. These stories, it is interesting to note, originated not with Columbus, but with his followers. Columbus himself records the occurrence in an accurate manner.

The increased knowledge of the ocean banished many of these myths concerning ships enmeshed in seaweed, being forced into the center of the mass, and gradually disappearing. With this increase in knowledge, many theories have been advanced to account for the existence of the Sargasso Sea. A Major Rennel observed "that the waters of the Atlantic have a greater tendency toward the middle of the ocean than otherwise and this seems to indicate a reduced level forming a kind of hollow space or depressed surface". Another theory, according to Findlay, was that it "Is the vortex of an immense eddy and which is caused by the influence of the trade winds and the Gulf Stream", while others maintain that it is a raised surface kept in position by the currents surrounding it.

A considerable portion of knowledge concerning the Sargasso Sea is to be found in the records of the *Challenger* Expedition of 1873. Many studies have been made since that date of the physical, chemical, and biological nature of this oceanic area. But that expedition undoubtedly gave the first systematic study of the region.

Following the work of the expedition, O. Krummel (1891), O. Wings (1923), and A. E. Parr (1939) wrote interesting and informative papers concerning the Sargasso Sea. The basis for Krummel's investigations was provided by the records of floating weeds observed from German ships crossing the North Atlantic and entered in their log books as required by "Deutsche Seewarte" over a period of many years. From these data regarding floating weeds, he plotted the frequency of observations and the boundaries of the Sargasso Sea and subdivided it into more or less concentric regions showing various degrees of frequency of the floating weed. Wing's material, on the other hand, consisted of actual samples collected by various Danish research and merchant ships. Parr also collected samples during hydrographic cruises to Central American waters. His very extensive work covering his observations of the Sargasso Weed is contained in the Bulletin of the Bingham Oceanographic Collection, Volume 6, Article 7, issued December 1939, in New Haven, Conn.

The Sargasso Sea is oval in shape and extends from about lat. 25°N. to 30°N., between long. 40°W. to 73°W. Isolated patches and streamers of weed are frequently encountered outside these limits, and the entire area shifts a few degrees to the north and south during yearly cycles. As can be seen from the charts, the Sargasso Sea is the center of the oceanic circulation and is an area of weak and variable currents. It is bounded on the south by the North Equatorial Current, flowing westward; on the west and north by the Florida Current and the Gulf Stream, flowing northward and eastward; and on the east by the North African Current.

The temperature of the sea water is high while the decrease in temperature is small compared with other parts of the ocean. Its position in the lower latitudes, coupled with the freedom from strong currents, permits the radiation from the sun to maintain a relatively high water temperature in the surface layers.

The waters of the Sargasso Sea are characterized by relatively high salinity, 36-37 parts per thousand, as compared to 35 parts per thousand in the South Atlantic. The area is situated at a considerable distance from any coast, thus there is no dilution by the less saline discharge from continental rivers. As this is a region of high temperature, conditions are favorable for evaporation and increased salinity. This latter factor is further augmented by the relatively high percentage of sunny days.

The waters of the Sargasso Sea are very transparent. Again this is a combination of factors such as lack of continental sediments reaching the region, and the relatively small quantity of plankton, the microscopic organisms, plants and animals, which abound in other parts of the sea. The color is a very deep blue contrasted to the green or greenish blue, characteristic of the open ocean.

Sargassum Weed, or "Gulf Weed" as it is commonly known to seamen, is not native to the Sargasso Sea, although for many years it was thought to be so; it being assumed that it grew on the bottom and then, becoming detached, floated to the surface. It is now well established, however, that Sargassum, a brown algae, grows along the coast and is loose, reaching the Sargasso Sea by way of the Florida Current and the Gulf Stream. These plants are kept afloat by air bladders and grow vegetatively, propagating by fragmentation, but apparently do not form fruiting bodies. These floating masses form a characteristic environment with numerous associations including other plants (algae) and animal forms.

The weed is generally found floating in little islands or bunches, not matted but with branches loosely intertwined, varying in size from 1 and 2 feet to 2 and 3 yards in diameter. When a wind of low force is blowing, the weed patches are usually formed into long lanes or streamers. The spacing of the lanes of wind-driven Sargassum is an indication of the depth of the mixed layer and isothermal water. The general color of the weed is olive, the younger branches being more golden olive with decaying parts dark brown.

One estimate of the quantity of Sargassum has been made. Nets were towed for a known length of time and distance and the resultant catch weighed. On the basis of these observations the aggregate amount of this weed in the Sargasso Sea is estimated to be about 20,000,000 tons.

Sargassum affords protection to swarms of minute crabs, fish, and other animals, not usually found in the open sea. These animals are an excellent example of "protective coloration". Their color allows them to blend in with the gulfweed in such a manner that only the closest scrutiny reveals their presence. The animals are very abundant, and represent a large number of species.

UPWARD-FLOWING WATERFALL

At Rathlin Island, off the north coast of Ireland, a small stream normally falls from bare cliffs into the sea. The source of the stream is a small lake on the island. With northerly winds of over 45 knots in force, this stream has been observed to be blown back from the cliffs toward its source. From 3 miles offshore under these wind conditions the water of the stream appears as cloudy mist billowing high in the air before drifting downward and settling in a turbulent mist.

WATERSPOUTS

Mariners have faithfully observed and reported waterspouts over the years, and oceanographers and meteorologists have a continuing interest and need for information concerning them.

Waterspouts are the result of meteorological conditions and do not affect them. Thunder and lightning, which often occur with this phenomenon, evidence the state of the atmosphere that is likely to generate electrical storms and waterspouts.

This phenomenon occurs more frequently in the tropic zones but also occurs in the temperate zones and have been observed off the coast of England.

Tornadoes and typhoons have their special seasons, and follow fairly stable patterns of activity. Waterspouts, however, are quite unpredictable. They are irregular in their occurrence, are generated in gales or calms, and form over warm and temperate waters. They move with, against, or across the winds, rotate both cyclonicly and anticyclonicly, and move with varying speeds from slow to rapid, and range from moderate to strong in force.

The size of waterspouts varies from high and narrow to low and wide. They have been observed from 10 to 5,000 feet in height and from 10 to 500 feet in width. Duration averages about 30 minutes but some lasting up to an hour have been observed.

A waterspout may be simply defined as a column of water over the sea sustained upright by a whirling circular wind movement. Shaped often like an inverted cone they appear to descend from heavy cumulonimbus clouds until they meet a cone of spray raised from the sea, forming a column or spout of water between the sea and cloud. The funnel point seems to descend slowly and at the point of contact with the sea appears agitated with a cloud of spray forming.

The occurrence of any waterspout depends to a large extent on local unstable atmospheric conditions. In many cases the cause is the importation of air of much lower temperature than the sea surface over which the air passes. It is believed that the interior and exterior parts of water spouts have opposite circulation, and that the descending central currents of rain precipitate around the virtually empty core of the spout.

Sometimes waterspouts dissipate quietly, but there is generally some agitation. The lower part breaks releasing a torrent of fresh and salt water accompanied by sleet, snow, or hail, the weight of which can cause considerable damage.

Waterspout

UNDERWATER DISTURBANCES

O. L. Martin Jr.
Maritime Safety Division
U. S. Naval Oceanographic Office

This article is being published to create a measure of seaquake consciousness in the minds of watch standers so that they will be in a position to recognize and therefore be more able to cope with the forces acting upon a ship during an underwater disturbance. The article is not intended to alarm the mariner about a natural phenomena which, although of considerable interest, may never be experienced to a degree which could cause distress.

INTRODUCTION

Slowly pacing the wing of the bridge, the mate watched the sun rise above the horizon as the ship steamed eastward in a slight southwesterly sea at a speed of 17 knots. Morning stars placed the ship approximately 20 miles off the southwest coast of Central America in 2,000 fathoms of water. Suddenly, there was a thunderous boom, the ship commenced to shake violently and seem to rise up in the water. Although the fathometer registered no bottom, the ensuing vibrations became so severe that the engines were stopped; the mate was certain the ship had grounded. An inspection of the hull, bilges, and machinery revealed no apparent damage. However, the master believed that the ship had at least struck a submerged object with such force that there must be underwater damage to the hull. Subsequently, the ship was drydocked, at considerable expense, only to find no evidence of underwater damage.

Later, an investigation of seismographic data provided by the U.S. Coast and Geodetic Survey disclosed that a few seconds before the vibrations commenced aboard the ship a strong earthquake occurred under the ocean floor about 35 miles southeast of the ship.

EARTHQUAKE HISTORY

Psychologically, an earthquake affects man in a rather strange and awesome manner. When the earth begins to lurch beneath his feet and he realizes that "terra firma" is a rather ambiguous term, his first impulse is usually to run. Often, this sudden undulation of the earth's surface subjects man to nausea and headache. Even the equilibrium mechanisms in his ears and eyes can be affected in such a manner that small vibrations in solid structures are magnified to the extent that if real the structures would be torn asunder. Broken columns and sheared arches of ancient ruins are majestic witnesses to catastrophic earthquakes of the past. Throughout recorded history, man has wondered about the cause and effect of the earthquakes that have continually plagued him. Two thousand years ago, the Chinese devised primitive instruments for detecting distant earthquakes. Other civilizations, particularly the Japanese, meticulously recorded the observed effects in the shaken area of each earthquake. These studies, although useful, revealed little of the geography, geology, and mechanics of earthquakes. Man did not begin to comprehend the nature of earthquakes until an English geologist and mining engineer named John Milne founded modern seismology.

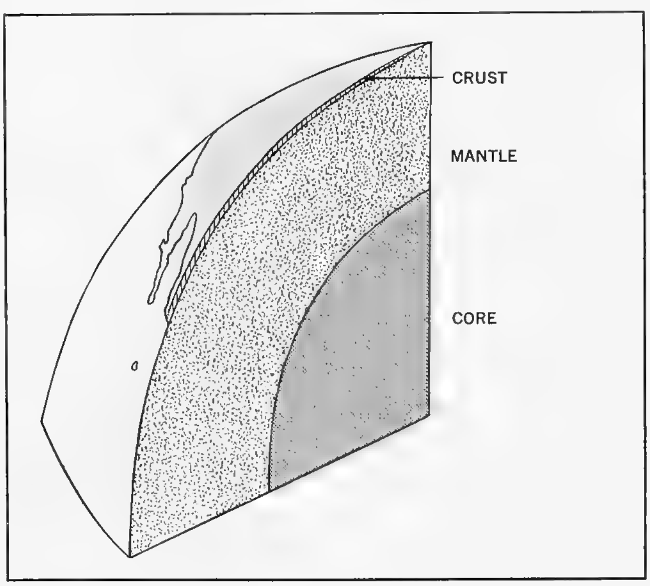
Milne, already an engineer of considerable renown, accepted in 1875 a position as professor of geology and mining at the Imperial College of Engineering in Tokyo. Immediately upon arrival in Japan he was greeted by an earthquake and at once became involved in earthquake research.

Literally, an earthquake is a shaking of the earth in which the ground surface moves back and forth, side to side, and up and down. If man could detach himself from the earth and remain suspended above the affected area, it would be simple to determine the relative magnitude and direction of ground motion during an earthquake. This is impossible. However, Newton's "First Law of Motion" states that a body at rest will remain at rest until acted upon by an external force. Thus, as with a pendulum, if the connection between a body and the earth is as loose as possible, the movement of the earth will exert a minimum external force on the body. Then, when an earthquake does occur, the body will tend to remain stationary while the earth moves beneath it. Milne incorporated this principle in the instrument he developed to scientifically detect and record local ground movements caused by the Japanese earthquakes. Basically, the instrument, firmly secured to the ground, consisted of the loosely connected body (pendulum) to which a marking pen was attached in such a manner that it lightly scribed a line on a continuously moving roll of paper powered by a clock mechanism. Thus, when earthquake vibrations moved the paper in relation to the marking pen, Milne was able not only to obtain a written record of these vibrations in the form of jagged lines, but he was also able to determine the time of the movements.

Normally, seismographic stations are equipped with 3 instruments—2 orientated at right angles, to record movements from east-west and north-south directions, and 1 to record the vertical movements. Thus, a record can be obtained of all 3 basic earthquake movements. Modern engineering and electronics have greatly improved todays' seismographs permitting even more detailed study of the phenomena. Each variation in the jagged lines as recorded on seismograms have meaning to the seismologist who can, by comparing the seismograms of a single distant earthquake from several stations, determine the location of its epicenter and the depth beneath the earth's surface (hypocenter) at which the original fracture occurred

Milne did not actually invent the seismograph, the principle and idea had been advanced about 1830, but he did develop and field test a very practical instrument by setting up a network of seismographic stations throughout Japan. Data obtained from the network enabled him to determine the geographic positions of the epicenters for 8,331 earthquakes in the next 8 years. When the earthquake epicenters were plotted, he discovered they fell in a relatively narrow belt along the East Coast of Japan, and that the interior of the Islands were relatively free of earthquakes. Upon returning to England, in 1885, Milne presented his findings to the Seismological Society, where they created such a great interest that a new science was launched—the study of earthquakes by an interpretation of the shock (seismic) waves they generate in the earth.

Milne proposed, and by the turn of the century had in operation, a world wide system of 34 seismographic stations. The information obtained from these stations enabled him to chart areas of earthquake activity throughout the world; basically the seismic zones he charted are unchanged today. Milne furnished the tools and established the methodology of the new science, but discoveries and advancements came fast as man began to seismically probe the interior of the earth. By 1907 the velocities of the seismic waves in the earth's mantle were accurately known and the existence of a core had been discovered. Soon Andrya Mohoroviac discovered that a discontinuity formed the lower boundary of the crust, and by 1913 Beno Gatenberg had determined the radius and nature of the core. Only in this century, with the aid of seismology, has man been able to investigate earth beneath its surface to study scientifically the nature of its interior.



OUR QUAKING EARTH

Today, scientists generally agree on the concept of the structure and nature of the earth as an elastic sphere slightly flattened at the poles with an equatorial radius of 3,444 miles. The mean rigidity of the earth is of about the same order as that of steel, and it consists of 3 principal parts—the crust, mantle, and core. The crust is an encircling outer shell of heterogenous rock varying in thickness from about 6 miles under the oceans to 15 or 20 miles beneath the continents, but increasing to as much as 30 miles under some mountain chains. The irregularity of the base of the crust is, possibly, the principal departure from the spherical symmetry in the physical properties of the earth. Below the crust is the mantle, believed to be a thick massive shell of dense fine-grained rock that has solidified from a hot molten condition. The thickness of the mantle is about 0.45 of the earth's radius and its volume accounts for approximately 85 percent of the earth's mass; for practical purposes, the mantle may be considered concentrically homogeneous. Inside of the mantle is the core, a hot dense molten sphere with a radius about 0.55 that of the earth's. Apparently, the core has no rigidity and its exact content is unknown, although it reacts to many investigations in the same manner as would a highly compressed ball of molten nickel-iron.

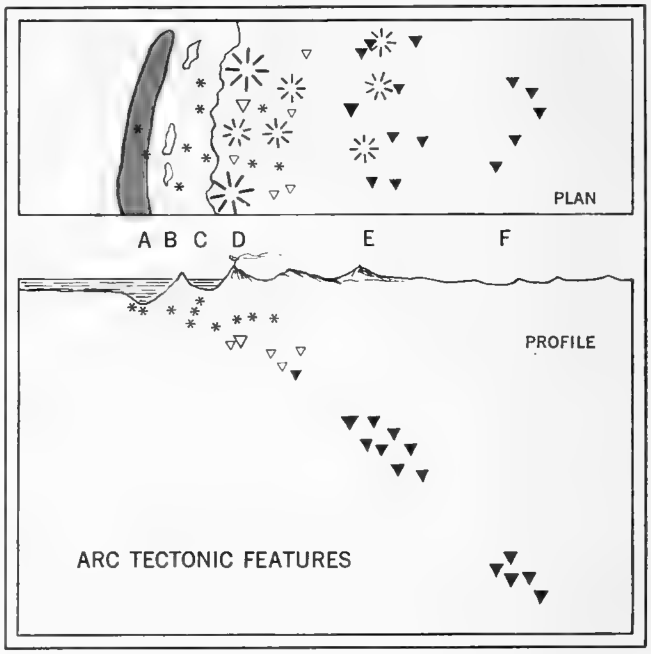
Over long periods of geological time, stresses build up within the rock structure of the crust and upper mantle. If the pressure increases slow enough, the confined rocks will bend and flow like plastic, and the rock structure will adjust itself to the changing stress. However, when pressure is applied too fast or the structure is rigid enough to resist slow deformation, the stress will accumulate until the elastic limit of the rock mass is reached. When this happens, somewhere the rock will break. The accumulated pressure will be released instantly and the energy transformed into shock (seismic) waves. This is the mechanics of an earthquake.

How the pressure originates is unknown. Many theories have been advanced but none satisfies the scientist completely. The pressure seems to be connected, in some manner, to the expansion and contraction of the rock mass due to differential heating. The weight of the material above induces another pressure, but this can be calculated. In the crust this pressure increases one atmosphere (14 psi) for approximately each 13 feet of depth. However, the rate of increase is more rapid at greater depths and the pressure at the center of the earth has been estimated to be as high as 57 million pounds per square inch. Under great pressure within the earth's mantle, the rocks seemingly become stronger and far more plastic, tending to distort rather than break. Although most of the earthquakes occur within 25 miles of the earth's surface, some have occurred as deep as 390 miles, which seems to be the floor of earthquake action. The pressure as this depth is estimated to be about 3½ million pounds per square inch, and possibly beyond this point the rock mantle becomes so plyable it will not fracture.

TECTONIC EARTHQUAKES

The majority of earthquakes involve a relative movement of rock masses along either side of a fracture or fault plane in the earth's crust. When this relative movement is in a vertical direction, there will be either an elevation or depression of one of the faces. Should an entire crustal block be defined by faults, the entire block may rise or fall as a unit. More often however, only one side of the crustal block will move, resulting in a tilting or folding of the crust. Frequently, the relative movement along the fault is in a horizontal direction resulting in a twisting effect or horizontal displacement. Earthquakes involving this sudden crustal movement are called tectonic because they are structural in nature. Normally, in a tectonic earthquake the area of greatest shock intensity lies along or parallel to a fault. Often tectonic earthquakes occur in groups with the epicenter of each subsequent quake migrating along parallel to the fault. The perceptible effect tends to travel great distances down the fault, but decreases rapidly as the perpendicular distance from the fault increases. Although tectonic earthquakes may occur in regions of volcanic activity there is no correlation between the two. The controlling factor determining the magnitude of a tectonic earthquake is the relation between the size of the rock mass and the relative distance of movement. In a tremor the displacement may be slight, but visible evidence on the surface have indicated abrupt displacements on the order of 50 feet after some major earthquakes.

During most earthquakes, the maximum intensity of observed vibrations occur in an elliptical area enclosing the epicenter, which normally lies along the major axis of the ellipse near one end. Usually, the orientation of this axis is parallel to major structural trends or faults in the area. The intensity of an earthquake is represented by a roman numeral rating (I to XII) on a descriptive scale that indicates the physically perceptible earthquake motion and is based solely on the effects observed on people and inanimate objects such as buildings and their contents. The area representing the highest intensity is called the meizoseimal area and outside this area, usually elliptical, the intensity falls off rapidly in a uniform manner. Each earthquake will have several intensity ratings from the highest in the meizoseimal area to the lowest rating where the motion is barely perceptible on the outer fringes. Scientifically, an earthquake is described by its magnitude which is derived instrumentally, from the seisomogram, and is a logarithmic measure of the total earthquake energy released at the focal point. There is only one magnitude for an earthquake.



Although the mechanics are similar, there are two distinct classes of tectonic earthquakes—the arc and block types. Arc tectonics constitute the majority group, but most of the knowledge of this type is derived from the analysis of instrumental findings recorded at great epicentral distances. However, on-the-spot observations of earthquake mechanics including studies of the visible results in the meizoseimal area are plentiful from regions of block tectonics. Therefore present earthquake theories are based primarily on information obtained from this type. Block tectonics are dominant in California and New Zealand and probably in most regions where only shallow earthquakes occur, as along the Mid-Atlantic Ridge. In sections of Japan, Peru, the Philippines, and North Island (New Zealand) both types occur. The remainder of the seismic activity throughout the world is predominantly arcuate. Arc tectonic are three-dimensional in scope and require a profile view as well as a plan for their study. Normally, they are associated with certain geological features usually found in the following order, beginning on the outside of an arc and traveling toward the center:

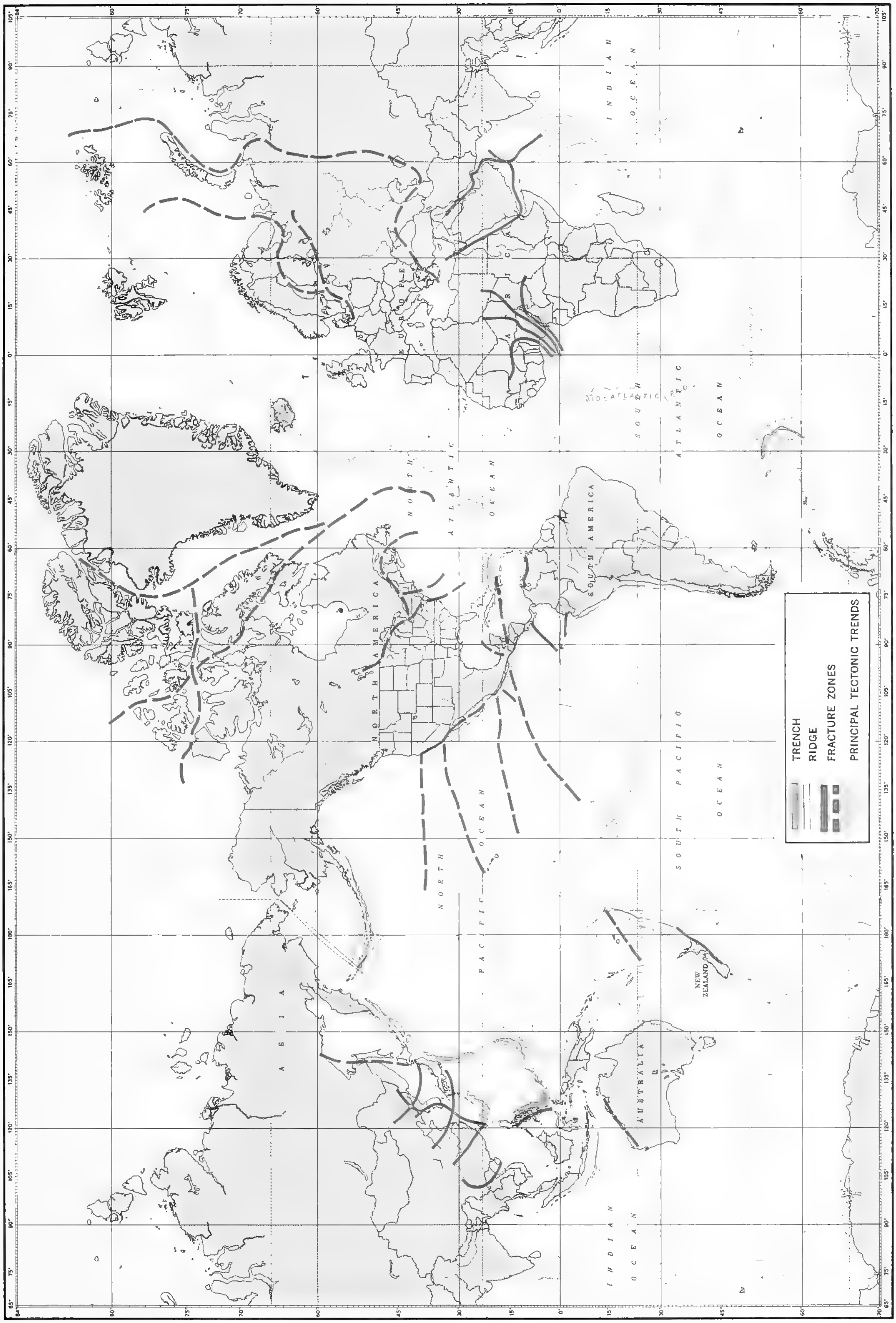
A. A deep oceanic trench or trough.

B. The principal tectonic line, with a narrow belt of shallow earthquake epicenters along a non-volcanic up-folding or rise of the earth's crust which may form a submarine ridge or possibly emerge as a chain of small islands.

C. A belt of earthquake originating at a depth of approximately 40 miles.

D. The principal structural arc, often consisting of large islands or even a coastal mountain range containing active volcanoes, and a belt of earthquakes originating at depths of 60 miles or more.

E. An inner structural arc of older mountains, extinct volcanoes, and earthquakes originating at depths between 120 and 180 miles.


TRENCH
RIDGE
FRACTURE ZONES
PRINCIPAL TECTONIC TRENDS
NORTH AMERICA
SOUTH AMERICA
ASIA
AUSTRALIA
NEW ZEALAND
NORTH ATLANTIC OCEAN
SOUTH ATLANTIC OCEAN
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
INDIAN OCEAN
MID-ATLANTIC RIDGE

F. A belt of deep focus earthquakes originating at depths between 200 and 400 miles.

When the associated hypocenters of a typically active arc system are plotted in profile on a cross sectional chart showing the relief, they seem to dip under the arc, frequently under a continent, at an angle of approximately 45 degrees. The epicenters of the large shallow earthquakes (B) are usually on the landward side of the foredeep, but the epicenters of the deep shocks (F) may fall hundreds of miles away. In South America the epicenters of many of the deep shocks are well to the east of the Andes.

The chief characteristics of block tectonics are frequent shallow quakes from which arc features are absent. The activity consist of relative displacements of blocks, separated by large faults which are often nearly straight and dip almost vertically into the earth.

DEEP FOCUS QUAKES

Most earthquakes occur in the earth's crust, but some originate in the rock mantle at depths as great as 390 miles, which seems to be the floor of earthquake activity. The mechanics of an earthquake are the same regardless of the focal depth, however, the surface affects in the meizoseismal areas differ greatly. A deep focusquake does not create a well-defined meizoseismal area, instead there may be several seemingly unrelated geographical areas of equal intensity at varying distances and bearings from the epicenters. Yet in areas closer to the epicenter the earthquake may be imperceptible. The instrumental magnitude of two earthquakes, one normal and one deep focus, may be the same, but the intensity in the meizoseismal area will decrease as the depth of the hypocenter increases.

VOLCANIC EARTHQUAKES

There is still another class of earthquakes whose mechanics are somewhat different. They are caused by the pressure of the confined gases or forces brought into play during the swelling and contraction of molten volcanic lava which may result in an explosion, tension fracture, or fault within the structure of the volcano itself. Therefore, volcanic earthquakes are dependent on volcanism and may be defined as the transient elastic vibrations caused by forces originating in the magma chamber and conduits of a volcano. The focal depth of this type earthquake is very shallow. Frequently, the hypocenter is within the volcanic cone structure itself. Volcanic earthquakes may be of considerable local intensity, often resulting in extensive damage to the flank of a volcano, but their total energy is slight and they are usually imperceptible a few miles away. A tectonic earthquake of equal epicentral intensity would be perceptible at great distances.

EARTHQUAKE GEOGRAPHY

The world chart showing the geographical distribution of seismic activity reveals that the earthquake epicenters fall in narrow belts and zones easily correlated with certain geological features as high mountain chains, oceanic trenches, ridges, and rises. Normally, where there is high-relief there is increased seismic activity, indicating that high seismic activity is related to crustal disturbances of the recent geological past. The highest mountains and deepest trenches are probably products of fairly recent geological time. Crustal irregularities as great as these would be equalized by geological processes within a single epoch if stress were not continually at work to maintain them. Earthquakes are indications of these stresses.

Possibly, the present world chart of the seismic zones, even though unchanged since Milne's time, merely represents a fleeting geological snapshot of temporary or unusual seismic conditions. Man's instrumental records span only a few short years of the hundreds of millions of years of geological time, and the evidence found in rocks indicate the tectonic geography of the earth has changed considerably during the past eons.

At present over 1 million perceptible earthquakes occur each year, of which at least 700 are strong enough to cause damage in their meizoseimal area. Fortunately, as the magnitude of earthquakes increase the relative frequency with which they occur decreases. Earthquakes as well as volcanoes are usually located close to large bodies of water. Therefore, it is not surprising that three-quarters of the world's earthquakes occur under the ocean floors. The Northern Hemisphere is more susceptible to seismic activity than the Southern Hemisphere. The area below 30° South Latitude represents one-fourth of the earth's surface, yet less than 10 percent of our earthquakes occur in this area. Earthquakes are unknown on the continent of Antarctica.

The Pacific Ocean is ringed by a system of active volcanic and seismic belts and has a branch that extends into the East Indies. Another branch extends eastward across Central America into the West Indies. This system accounts for four-fifths of the world's earthquakes. Another belt extends from the Mediterranean region of Southern Europe across Southern Asia and down the Himalayan Mountains into Southeast Asia. Active belts are also found in the oceans along the Tonga Trench, down the Mid-Atlantic Ridge, and southward from the Central Indian Ocean with a branch swinging westward across the South Atlantic towards the Sandwich Trench and another branch swinging eastward south of Australia.

PROPAGATION OF SEISMIC WAVES

When a rock mass fractures, the earth reacts to the resulting seismic waves as an elastic solid, propagating them to all parts of the earth, both through the interior and over the surface. Four elementary types of seismic waves are generated, each having its own characteristic type of motion and velocity that is easily distinguishable on seismograms.

The primary wave or P wave, sometimes called the longitudinal wave, is the faster of the two body waves that travel through the interior of the earth. Its velocity varies from about 4 to 7 knots per second, depending on the nature and density of the material traversed. Because of the variations in density, the path of the P wave through the earth is not a straight line cord but a concave curve bent toward the center of the earth, and it requires approximately 20 minutes for it to travel to the opposite side of the earth. The P wave has a period of about 1 second and travels through the earth in a manner similar to that of a sound wave. Thus as it radiates out from the focal point, the particles of earth immediately ahead of the wave front are compressed forward away from the hypocenter along the path of travel. Then as the wave front passes there is a slight dilation of the ground and the earth's particles move back along the path of travel toward the hypocenter.

The secondary body wave or S wave, commonly referred to as a sheer or distortional wave, travels through the earth at velocities about 0.6 that of the P wave and follows the same general path. However, there must be rigidity in the material through which the S wave travels, and there is no evidence that it penetrates the core. The propagation of the S wave is similar to that of a light wave or to the transverse vibrations of a taut string. Therefore the earth's particles are displaced in a direction that is perpendicular to the direction of travel from the focal point. Whenever a body wave traveling through the earth strikes a region of abrupt density changes, as at the earth's surface, the bottom of the crust, or even the surface of the core, part of the wave energy tends to be reflected in new and complex wave forms, or even transposed into waves of the opposite type. Thus a sheer wave may be changed into a longitudinal wave or vice versa.

The other 2 basic types of seismic waves are the Love and the Rayleigh surface waves which are created when the P wave reaches the earth's surface; they account for most of the visible ground movement in the immediate epicentral area. The speedier Love wave with a velocity of approximately 2½ knots per second is a sheer wave propagated in a horizontal plane in a manner similar to the way in which a wave travels down a garden hose when it is shaken from side to side. The velocity of the Rayleigh wave is only slightly lower than that of the Love wave and it creates a vertical wave motion on the earth's surface like the wave that travels down a carpet when one end is shaken up and down.

ENGINEERING SEISMOLOGY

Man's increasing knowledge of earthquakes and the specialized field of engineering seismology enables architects and engineers to design and build structures with inherently greater earthquake resistent qualities. Structures built to withstand great downward or gravitational forces with little thought of a vertical thrusting from beneath or the sheering effect of horizontal twisting may crumble during an earthquake, while properly designed structures closer to the epicenter escape relatively unscathed. Within a structure, the tempo of earthquake shaking in relation to the natural period of vibration of the structure is very important; if the frequency of the induced vibration happens to be the same as the natural frequency of the structure the resulting movement will be the sum of the two vibrations and create a greater amount of movement. This condition is called resonance, and the probability of damage from shaking is greater when this occurs than if the two components are completely out of phase. Another closely related phenomenon is when two adjacent structures having different natural periods of vibrations get out of step and tend to batter each other down when shaken by an earthquake.

SEAQUAKES

The mechanics of an earthquake are the same, regardless of whether occurring under a land mass or the ocean floor. Earthquakes ashore are sometimes called land quakes and the seismic vibrations frequently felt aboard ships are commonly referred to as seaquakes. Although the majority of the world's earthquakes occur under the ocean floors, the mariner is in a position far superior to his land bound brother. A ship built to withstand the rigors of the sea and remain a cohesive unit regardless of the direction from which an external force is applied becomes "earthquakewise" an engineering marvel. The intensity of shipboard seismic effects varies greatly, but an analysis of ship reports describing seaquakes in view of local geological conditions and available instrumental data reveals several interesting generalities that are in line with the facts associated with land quakes.

The principal seismic effect aboard ship is the jackhammering vibrations induced on the hull by the arrival of the P wave. Upon entering the less dense water from the sedimentary covering on the ocean floor this compressional-type wave is bent by refraction and deflected almost vertically to the sea surface at 0.8 knot per second. Frequently, the first P waves to arrive on the surface of the sea are not strong enough to be felt aboard ship, and will pass into the atmosphere above the sea to create a sound wave. When the frequency of the sound wave is high enough to be audible a loud bombbing noise will immediately preceed the actual vibrations. Sound is not heard in all earthquakes, and it is possible under certain conditions to have the sound without the vibrations.

The duration of these vibrations may vary from a fraction of a second to several minutes. Ship reports indicate a usual duration of between 15 and 60 seconds. When the P wave arrives at the sea surface its period is short and amplitude very low. Normally, the amplitude is so small there is no indication of a disturbance by the appearance of the sea surface. Yet this wave front simultaneously striking the complete under water portion of the hull produces enough energy to cause severe vibrations. Rarely have these vibrations damaged ships, but a report from a ship off Point San Telmo, Mexico, stated that on 15 April 1947 earthquake vibrations caused a well-secured deck cargo of heavy steel prefabricated construction sections to walk 6 inches.

The intensity of shipboard vibrations are determined by internal as well as external factors. Internal variables that affect this vibration include the type and construction of the ship, the nature and amount of cargo on board as well as the manner in which it is stowed, and under certain conditions the position in which the cargo-handling gear or other heavy equipment is secured. Among the external factors the magnitude of the earthquake, determining the amount of energy released, and the depth of the original fracture (hypocenter) are very important. Frequently, the perpendicular distance to the fault along which the original fracture occurred may be more important than the epicentral distance. Again at sea, as in a land quake, the earthquake energy tends to travel great distances down or parallel to the fault with little loss of intensity, but the perceptibility tends to fall off rather rapidly as the perpendicular distance from the fault increases. Although weather has no bearing on the origin of an earthquake, the effects (vibrations) on a ship may be magnified by unfavorable weather conditions.

Occasionally, there is a weaker but definitely distinguishable second set of vibrations closely following the original jolt. This is not a twin quake but the arrival of part of the energy from the slower S wave. When this sheer wave strikes the density discontinuity at the ocean floor part of the energy is reflected back into the earth and part of the energy is transformed into a compressional-type wave and deflected almost vertically into the less dense water. There is an energy loss in this transformation, but the arrival of the S wave under the hull is quite perceptible under proper conditions. If a vessel is in the immediate epicentral area of a shallow quake, the arrival of the second group will only tend to intensify the original vibrations and may not be detected. When the epicentral distance is too great the arrival of a weak second group may be imperceptible. However, there is a definite area between the two extremes in which the arrival of the S wave group is easily distinguishable.

MEXICAN EARTHQUAKE OF JUNE 1932

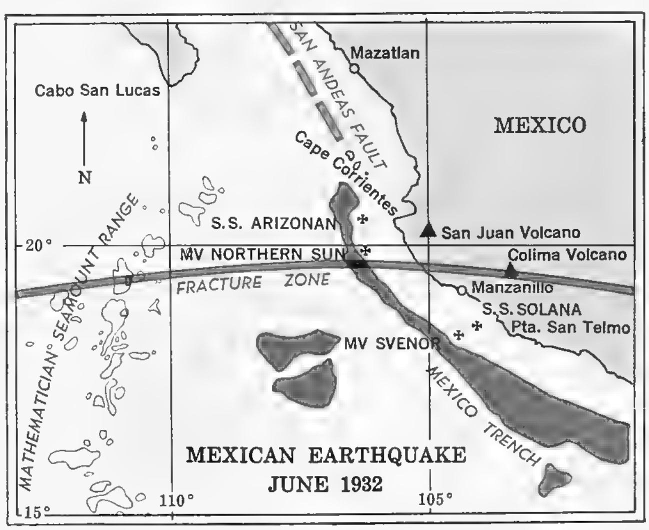
An excellent example of the varied manner in which individual ships, located at random, about the epicenter of an earthquake are affected is available from the review of the ship reports describing their experience during the large shallow Mexican earthquake of 3 June 1932. Although slight motions were felt throughout the early morning hours in the mountainous area behind Manzanillo, it was not until 10h 36m 50s GMT (03h 6m 50s Local Time) that the principal shock occurred. The epicenter, located about 30 miles inland near 19.5°N., 104.3°W. fell in the chain of volcanic mountains that traverse Mexico in an east - west trend and are, probably, a continental continuation of the long straight Clarion Fracture Zone that originates in the Central Pacific and passes through the volcanic Revilla Gigedo Islands before emerging on the Mexican Coast.

During the early morning hours of 3 June 1932, the *SS SOLANA* was steaming through a smooth sea with light variable winds in 18°30′N., 104°08′W., at 1037 GMT she was violently shaken for about 7 seconds. The ship was then about 60 miles 170° from the epicenter in approximately 800 fathoms of water and did not detect any change in the state of the sea. The perpendicular distance to the fault zone was also about 60 miles.

A few miles to the southwestward in 18°20′N., 104°32′W., the *MV SEVENOR* experienced at the same time less severe vibrations but of a longer duration (1 minute). The *SEVENOR* was approximately 70 miles 191° from the epicenter and the perpendicular distance to the fault zone was between 65 and 70 miles. The ship reported a calm sea and slight westerly swells and detected no noticeable change in the surface of the sea.

Conditions aboard the *MV NORTHERN SUN* in 19°56′ N., 106°14′ W. were entirely different. Although the vessel was 115 miles 285° from the epicenter the perpendicular distance to the probable fault zone was probably not more than 10 miles. Vibrations, commencing at 1039, continued for 3 minutes and became so violent that the engines were stopped. Before the earthquake, the sea had been smooth with a slight westerly swell, but by 1046 GMT the swell pattern had changed and the sea was confused.

Farther to the northward in 20°28′ N., 106°20′ W., the *SS ARIZONAN* commenced to vibrate at 1039 GMT and continued to do so for about 75 seconds. The ship was about 130 miles 297° from the epicenter with a slight southwesterly sea and did not notice any change in the state of the sea. The perpendicular distance to the fault was probably somewhat over 40 miles.



The after shocks continued for many days. Ship reports indicate that during the next 36 hours several strong underwater disturbances were experienced in the area. The *MV SILVERWILLOW* in 18°45′N., 104°34′W. began to vibrate dangerously in every part and at the same time partook an uneven short pitching motion followed by heavy rolling. The disturbances commenced at 0530 GMT on 4 June and the rolling continued for 15 minutes. Seven hours later at 1245 GMT in 19°31′N., 105°45′W. the crew aboard the *SS TALAMANCA* heard a loud noise like distant gunfire, then experienced severe vibrations, and at 1337 GMT 2 similar reports were heard about 10 seconds apart but there were no apparent vibrations. However, 20 minutes later the sea surface was littered for 5 or 6 miles with small white oval objects. Several hours later in 19°28′N., 106°06′W., the *SS HANOVER* reported at 1205 ship's time (probably 1905 GMT) 2 violent shocks that rocked the ship like a nearby explosion. Fifteen minutes later 2 more shocks were experienced with only slight vibrations.

The main quake created considerable damage throughout the country side behind Manzanillo and inundated the immediate coastal area with a minor tsunami. Tide gages in Hawaii recorded a 2½-foot wave and 12 hours after the earthquake the boxlike harbor of Pago Pago, over 4,400 miles southwestward of the epicenter, experienced a series of sea level fluctuations on the order of 8 feet for over an hour.

DOMINICAN EARTHQUAKE OF AUGUST 1946

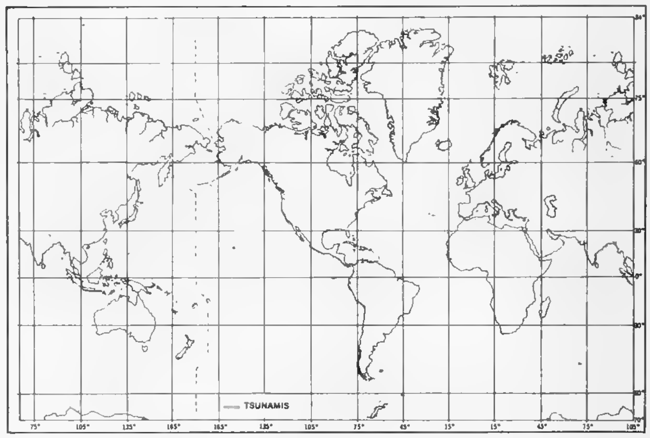
Another interesting earthquake occurred on 4 August 1946 when the northeast coast of the Dominican Republic was shaken by a destructive quake at 17h 51m 05s GMT. The epicenter was located in deep water about 9 miles eastward of Cape Samona. Forty miles westward of the epicenter in the bight of Escocesa Bay an 8-foot tsunami surged ashore destroying the town of Matanzas. Four miles northward of Cape Viejo Frances Light, or about 43 miles northwestward of the epicenter, the sea around *MS CAMCA* became confused at 1310 ship's time and commenced to boil violently, the ensuing vibrations aboard ship became so turbulent the engines were stopped and all machinery secured. The disturbance continued for 10 minutes, during which time an enourmous cloud of dust was observed rising from the shore behind Cape Viejo Frances. Approximately 30 minutes later the water was observed to be boiling again, but this time to the northward of the ship. Probably, there is no connection but it is interesting to note that approximately 2½ hours earlier, while steaming northward through the Yucatan Channel, the *SS SAMUEL F. DEWING* encountered similar areas of turbulent water in an otherwise calm sea at 0915 (local time) near 21°12′N., 86°16′W. The disturbance appeared close ahead and when the ship entered the area the bow took a 30 degree sheer to starboard despite attempts to check her. Although the fathometer was in constant operation no bottom trace was recorded, but in 1960 a ship did report 4½ fathoms in this general area.

During a seaquake the water mass in the ocean is seldom affected but areas of boiling water, seiches, and tsunamis have been started by earthquakes. Areas of boiling water that are occasionally sighted by ships during and after seaquakes could be of volcanic origin, but may have mechanics similar to earthquake fountains and sand blows that occur ashore during seismic disturbances. This phenomena can produce at great epicentral distances fountains 6 to 8 feet high that flow up to 3 hours after the earthquake. The alternate tension and compression applied to the ground during the passage of seismic waves may open fissures and suck all the ground water into the opening, then the same force closes the fissures and forces the water out. Under the ocean a related mechanism would create a boiling effect on the surface without an appreciable rise in water temperature, and the unlimited supply of sea water would allow for an earthquake fountain of staggering proportions.

Another unusual phenomenon is the seiche, a standing wave that has its crest at one end and its trough at the opposite end of an enclosed or partially confined body of water, and may even occur as lateral oscillations in rivers, canals, and ditches. It is only necessary that the limits of the enclosure define a natural period of oscillation. Earthquakes are a comparatively rare cause of seiches which are usually set up by prolonged winds, currents, or tides. Seiches in harbors have been started by the arrival of tsunamis. True earthquake seiches have been set up in graving docks and castle moats by the arrival of seismic waves through the interior of the earth. Regardless of the cause, it may become impossible to hold a ship alongside a dock during such a disturbance.

TSUNAMI

Many coasts of the world, notably those bordering the Pacific Ocean, have been swept by giant waves surging ashore as high as 60 feet above normal tide levels. Although often referred to as tidal waves, they are not associated with the tide in any manner but are somehow related to tectonic earthquakes and are actually seismic sea waves, commonly called tsunamis. The mechanics of a tsunami are not fully understood. These waves usually originate in the vicinity of deep ocean trenches after strong earthquakes, and often travel undetected across thousands of miles of open ocean before devastating an exposed coast, island, or harbor. Block tectonics ashore have produced vertical displacements of many feet over hundreds of square miles. Tectonics of this nature under the sea floor would produce an instantaneous movement of a tremendous mass of sea water which would immediately fan out from or pour into the epicentral area with great momentum, depending on whether the crustal block was raised or lowered. Occasionally, tsunamis are created by earthquakes whose epicenters are on shore. Possibly, the vibrations of the seismic wave passing through the sedimentary covering on the sides of trenches and continental slopes are great enough to create great submarine landslides which would again displace a tremendous amount of water in a relatively short time. There are also recorded instances where submarine volcanic explosions and glacier break-ups have created this type of wave in localized areas. There is some thought of the possibility of a tsunami being created by a mechanism related to the seiche being formed in deep trenches or troughs.



Once a tsunami is spawned it travels across the open seas at speeds approaching 400 knots and because of its low wave height (2 to 3 feet), tremendous distance between crest (100 miles or more), and unusually long period (12 to 40 minutes) is very inconspicuous. When a tsunami enters shoal water it conforms to the same physical laws that govern wind-driven waves, but because of its great forward speed in deep water, the slowing of bottom drag is relatively much greater than for a wind-driven wave. Therefore its forward speed rolls the wavefront over itself to greater heights than is possible with a wind-driven wave.

Usually, the first indication in a harbor or along an exposed coast of a tsunami is a slight, often unnoticeable, rise in the water level, only to be followed immediately by a noticeable withdrawal of the water, which returns several minutes later to a height well above normal tide level. The initial wave is seldom the highest, the crest is usually reached between the third and eighth wave. Once the crest is reached the wave begins to subside slowly, sometimes requiring a day or more. Because of a tsunami's long period and delayed crest, there is frequently enough time to take evasive action if it is initiated immediately upon noticing the first indications.

There are no known seismographic characteristics by which the seismologist can determine if a particular earthquake will create a tsunami; fortunately few do. However, once spawned these waves can be so destructive that a Seismic Sea Wave Warning System was organized and is now in operation in the Pacific Area. The system consists of strategically located seismographic stations, tidal stations, a communication system, and a Control Center. Each seismographic station is equipped with specially designed instruments and they are located throughout the Pacific in such a manner no really strong earthquake will go undetected. The tide stations are equipped with Seismic Sea Wave Detectors that produce an audible alarm on the arrival of waves with periods between 10 and 40 minutes. A high priority radio system permits rapid collection and dissemination of tsunami information by the Control Center at the Honolulu Magnetic Observatory. SEISMO is the characteristic identifying symbol for this type radio traffic.

UNCHARTED OBSTRUCTIONS

Since the advent of the fathometer the mushrooming supply of new sounding data adds daily to man's increasing knowledge of the topography of the ocean floors. No longer is the bottom of the ocean believed to be as monotonously void of irregularities as is its surface. Man realizes the magnitude and grandeur of many bottom irregularities are unmatched anywhere on earth. However, even today vast reaches of the ocean floors remain inadequately surveyed, averaging in some areas only one sounding to many square miles of ocean floor. Consequently, within these areas, particularly where irregularities exist, must lie countless uncharted shoals and banks. Today the increasing drafts of ships and operational depths of submarines greatly magnify the importance of these uncharted shoals as dangers to navigation.

Modern charts carry many doubtful shoals and reefs that mariners have encountered in the past. Many of these obstructions have been confirmed but others defy confirmation. Frequently, there is an astounding similarity between the reports of vessels encountering uncharted obstructions and the reports of vessels undergoing a seismic disturbance. A similarity also exists between ships reports describing distant reefs and rocks awash and vessels reporting early stages of submarine volcanics. A comparison of the chartlet showing the earthquake belts of the world and the chartlet showing concentrated areas of unconfirmed obstructions reveals a remarkable analogy. For this reason observers should always include the precise GMT of an observation when reporting a suspected obstruction.

SUMMARY

Psychologically, the mariner's sensation of grounding is common to most seaquake reports.

A seaquake will affect each ship differently. The type, construction, and amount of cargo are internal factors affecting the intensity of the vibrations.

Seaquake vibrations may become severe enough to warrant stopping the engine and securing machinery.

Frequently, there are two distinct series of closely related vibrations, representing the arrival under the ship of the P and S waves, respectively.

Usually shipboard vibrations cease with the terminaton of the seaquake, but, under unusual conditions, vessels have been known to undergo unexplained heavy rolling or pitching motions for several minutes after the original disturbance ceased.

Visibly, the state of the sea is unchanged during a seaquake. However, areas of turbulent water and locally confused seas are occasionally encountered during seismic disturbances, and this condition may exist for some time afterward.

Marine life can be destroyed by a seaquake.

There is no correlation between weather and earthquakes, but the condition of the sea at the time of a seaquake may have a bearing on the shipboard intensity of the vibrations.

Sound may precede the perceptible affects of a seaquake.

Although the epicenter of an earthquake is ashore the effects may be perceptible aboard ship.

Almost all seaquakes are the result of tectonic earthquakes.

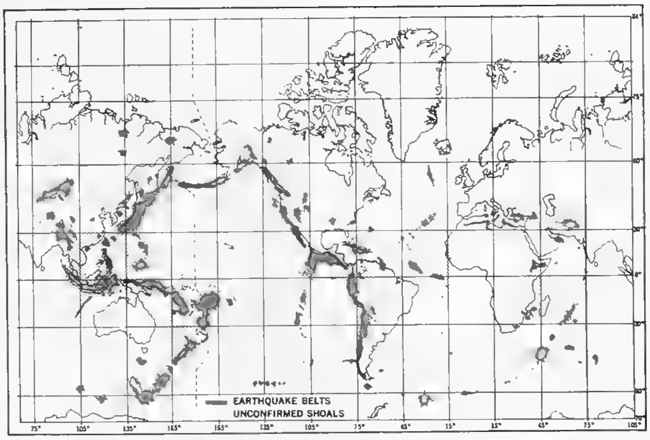
The mechanics of tectonic earthquakes are the same whether on land or under the sea. When the rock structure deep within the earth is rigid enough to resist slow deformation by changing stress patterns, the stress will accumulate until the elastic limit of the rock mass is reached, then somewhere along a fault plane the structure will snap, instantly readjusting itself to a condition of no stress.

Geologically, earthquakes are associated with high relief as mountain chains and deep oceanic trenches.

Exactly what triggers an earthquake is unknown and they cannot be predicted.

Tectonic earthquakes tend to occur in swarms, with the epicenter of each subsequent quake migrating parallel to a fault or major structural trend.

Earthquake energy at sea or ashore tends to travel considerable distances down or parallel to the fault with little loss of energy, but



the intensity tends to fall off uniformly, rather rapidly as the perpendicular distance to the fault increases.

A study of the chart showing, approximately, the fault zones in the earth's crust and earthquake epicenters for the world will give the mariner an indication of the areas in which he may expect to encounter seaquakes.

The tsunami chart depicting the coasts that have been inundated by these waves will also furnish the mariner an indication of the general areas in which tsunamis may be encountered.

Tsunamis tend to originate near deep ocean trenches and are somehow connected to tectonic earthquakes that usually have their epicenter on the landward side of deep oceanic trenches.

The most probable explanation of the creation of a tsunami calls for the vertical displacement of a block of the earth's crust under the sea. However, the epicenter of an earthquake does not have to be under the ocean to create a tsunami.

Fortunately, earthquakes rarely produce tsunamis, but there is no known method to foretell which earthquake will produce a tsunami.

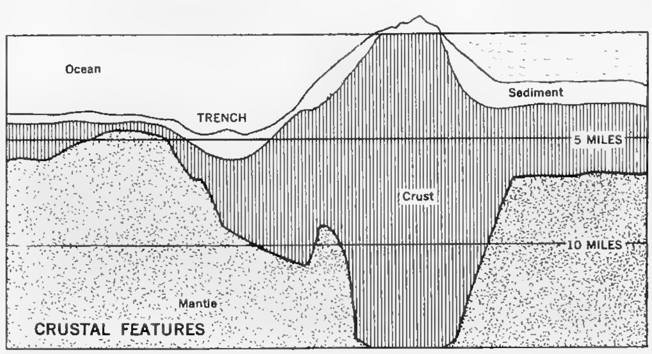
Usually, the first noticeable indication of an approaching tsunami is a lowering of the water level along an exposed beach or harbor.

At sea a tsunami is almost imperceptible, although thousands of miles from its origin a tsunami may surge ashore as high as 60 feet above normal tide level.

The period of a tsunami in deep water is between 12 and 40 minutes and its height is under 3 feet. The wave length or distance between successive tsunami wave crests may be 100 miles or more and it may reach forward speeds in excess of 400 knots.

The first wave of a tsunami is seldom the greatest. Usually, the crest is reached between the 3rd and 8th wave. Therefore, there is frequently enough time to take precautionary measures, if the action is initiated immediately.

Obey local tsunami warnings issued by competent authorities and work your vessel into deep water when possible.



SEAQUAKES

Seaman's Description	Shipboard Effect
Weak seaquake	Slight vibrations, normally felt in exceptionally fine weather only, as the vibrations would be lost in an easy roll.

Moderate seaquake	Noticeable vibrations and jolts resembling an anchor running out or a moored vessel bumping the dock. Squeaking of interior bulkheads.
Rather strong seaquake	Pronounced vibrations, sharp jolts as if a heavy lift was dropped on deck, a collision, a grounding, or casualty to the screw or tail shaft. Unusual jumping of suspended objects and pronounced squeaking throughout ship.
Strong seaquake	Severe vibrations, similar to a rather strong seaquake but much stronger and may require stopping the engines, steering may become difficult, wheel hard to hold, unsecured objects walk or topple over.
Very strong seaquake	Violent vibrations, crew may have difficulty in keeping their feet. Objects may jump out of their sockets; heavy and even well-secured objects may shift their position.
Damaging seaquake	The ship may be thrown about in the water with such force that mast, booms, superstructure and machinery as well as the hull may be damaged. It is possible for seams to be opened to such an extent that flooding cannot be contained and vessel sinks.

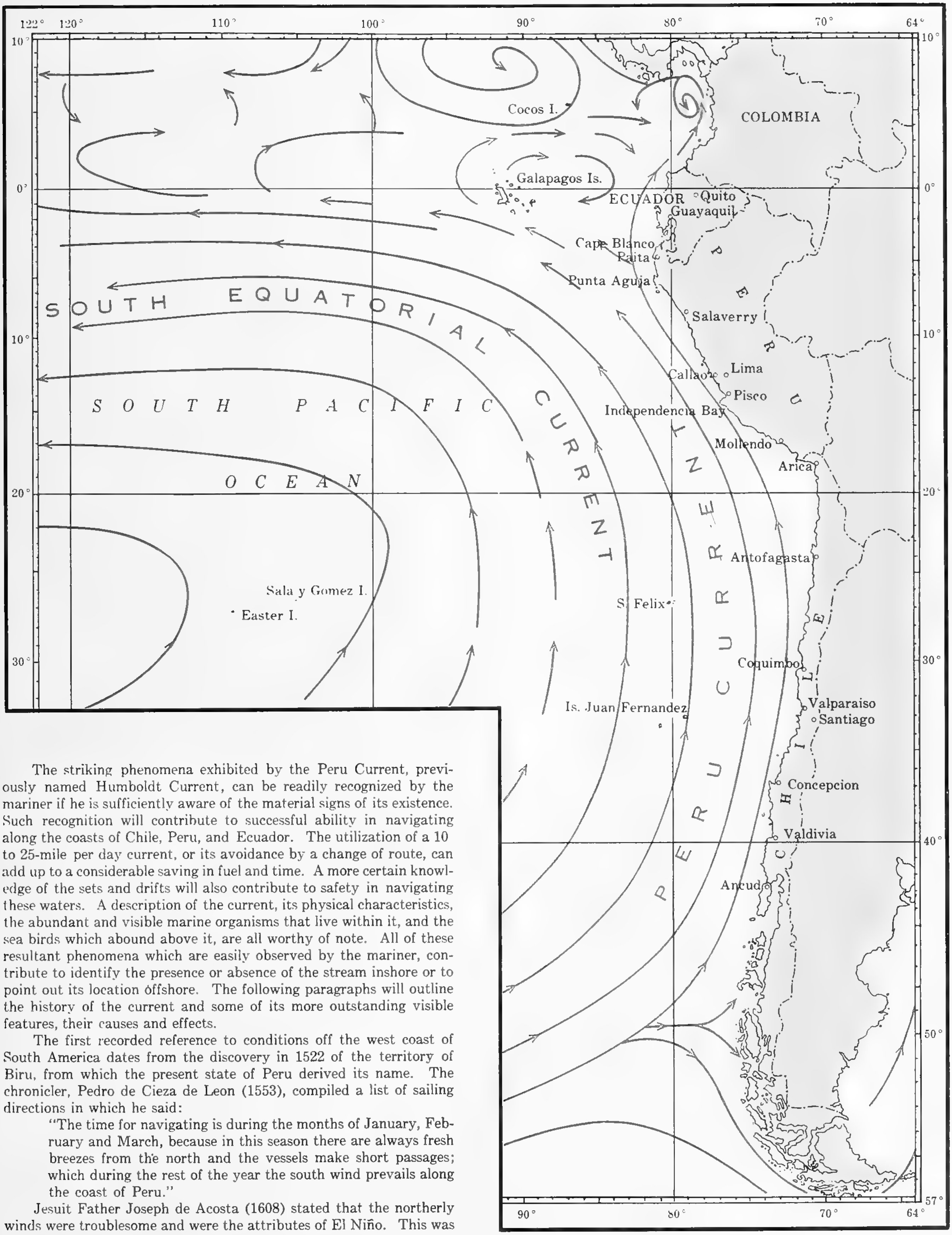
CONCLUSION

Although seaquakes are occasionally experienced by the mariner, factual information on the phenomenon readily available to him remains almost non-existent. Until recently, little had been done in this field since the German scientist E. Rudolph conducted a thorough study of hundreds of reports from ships encountering seaquakes. However, the value of his work decreased with the advance of seismology which enabled scientists to determine the epicenter of an earthquake regardless of its location. Instrumental locations and the precise GMT of strong shocks throughout the world are available from the Seismology Division of the U.S. Coast and Geodetic Survey. Today scientists are utilizing floating seismographs as well as instruments located on the ocean floor in their ceaseless search for knowledge.

Despite scientific advances, ship reports of seismic disturbances are still valuable even more so when analyzed in conjunction with instrumental data. The mariner's navigational ability and physical conditioning to the movement of his ship should allow him to observe and report accurately and objectively any seismic activity encountered. Include in the report the name, tonnage, type of vessel, and amount of cargo on board, the position, the GMT, and the duration of the disturbance. A brief description of the observed effects aboard the ship and on the surface of the sea together with the weather would complete the report. Reports received in the U.S. Navy Hydrographic Office will be forwarded to the cognizant authorities and, if requested, the mariner will be furnished the particulars of the quake he experienced.

PERU CURRENT

J. W. Lermond
Maritime Safety Division
U. S. Naval Oceanographic Office



The striking phenomena exhibited by the Peru Current, previously named Humboldt Current, can be readily recognized by the mariner if he is sufficiently aware of the material signs of its existence. Such recognition will contribute to successful ability in navigating along the coasts of Chile, Peru, and Ecuador. The utilization of a 10 to 25-mile per day current, or its avoidance by a change of route, can add up to a considerable saving in fuel and time. A more certain knowledge of the sets and drifts will also contribute to safety in navigating these waters. A description of the current, its physical characteristics, the abundant and visible marine organisms that live within it, and the sea birds which abound above it, are all worthy of note. All of these resultant phenomena which are easily observed by the mariner, contribute to identify the presence or absence of the stream inshore or to point out its location offshore. The following paragraphs will outline the history of the current and some of its more outstanding visible features, their causes and effects.

The first recorded reference to conditions off the west coast of South America dates from the discovery in 1522 of the territory of Biru, from which the present state of Peru derived its name. The chronicler, Pedro de Cieza de Leon (1553), compiled a list of sailing directions in which he said:

> "The time for navigating is during the months of January, February and March, because in this season there are always fresh breezes from the north and the vessels make short passages; which during the rest of the year the south wind prevails along the coast of Peru."

Jesuit Father Joseph de Acosta (1608) stated that the northerly winds were troublesome and were the attributes of El Niño. This was a first reference to the countercurrent. Augustine de Zarate, who was sent to Peru by the King of Spain soon after Pizarro's expeditions, gave a more complete report on conditions without however understanding their cause. Later accounts by early English voyagers were mostly concerned with piratical adventures. Frezier, an experienced observer, described a passage from Callao to Valparaiso (1717) as follows:

> "The Regularity of the Winds at E. S. E. and S. E. and the Breezes at S.W. along the coast of Peru, made the Navigation so tedious, before the Method was found of running out to sea, that Ships were six or seven months of sailing from Lima to La Conception, because they only advanced by the Help of some small Northern Blasts and the Land-Breezes, during the night, and some part of the morning. This shows that the Want of understanding Natural Philosophy among Sailors is a greater Evil than is imagined."

Alexander von Humboldt was the first (1802) to take the temperature of the coastal current and to make strictly scientific observations. He demonstrated that the temperature decreased approaching the coast from seaward and concluded that this represented a flow of cold water from high latitudes.

De Tessan (1844) partially solved the problem with his suggestion of an upwelling of the lower layers as an explanation of the low temperature. Many scientists have since contributed to the description and store of facts concerning the phenomenon now named the Peru Current, in accordance with modern usage and a more geographical designation.

Sailing directions and other manuals of navigation describe the Peru Current as part of the counterclockwise system of currents in the South Pacific. At a mean latitude of about 50°S. the surface water, encouraged by the west-wind drift of sub-antarctic latitudes moves eastward and later sets in an oblique northeast direction toward the west coast of South America and thence as a cold current northward along the coast to the Galapagos Islands. The current follows the trend of the coast in a general north and north-northeast direction, varying slightly under the influence of the wind. The width of this stream is about 120 miles at the latitude of Valparaiso. Temperatures in the current range from 39°F. in latitude 47° S. increasing to 52° F. off Valparaiso (Lat. 33° S.), 57° F. off Coquimbo (Lat. 30° S.), and 64° F. near Arica (Lat. 18°30′S.). The average velocity is about 15 miles per day. The drift along the Peruvian Coast is about one knot or less between Arica and Pisco (Lat. 13° 30′S.), with a westerly set felt at times. The greatest strength is attained between Paita (Lat. 5° S.) and the Galapagos Islands where vessels have occasionally been set 50 miles to the west-northwest in 24 hours. Seasonally under the influence of a northerly wind, a southerly set is experienced inshore in certain areas. This same northerly wind can bring torrential rains to an otherwise arid coast and can cause the inflow of warmer equatorial water as far south as Salaverry (Lat. 8° S.) with an accompanying widespread mortality of fish and birds. Curving westward near Cape Blanco the stream passes the Galapagos Islands and joins the South Equatorial Current.

The surface movements of sea water are due primarily to meteorological causes. Ocean currents are produced mostly by the agency of the wind. The center of the semi-permanent anticyclone in the South Pacific is located off the north coast of Chile near Lat. 30° S., Long. 90° W. Its position is relatively stable. On the southern side is the zone of westerlies, northward that of the Southeast Trade Winds; on the east and west are the coastwise winds, influenced by the usual offshore and onshore daily alternations. This ocean wind system tends to blow counterclockwise around a high pressure area of prevailing tranquility in which deep transparent blue water and a clear horizon are a marked characteristic. This is the "Great South Sea" named Pacific by Magellan because of the steady gentle winds that drove his fleet across the wide waters.

On the southern edge of this South Pacific expanse, the west wind drift along the edge of the sub-antarctic convergence, and the resulting effect of these cool waters on the greater part of the west coast of South America, determine the kind of climate that will prevail. The drift also determines what fish will exist in the waters and the kind of birds in the air above. It has also determined the economic circumstances of life ashore.

The surface waters in the Peru Current are relatively low in temperature close to shore, with progressively rising temperature offshore. There is a remarkable uniformity of low temperature extending northward through the greater length of the current, which is not ordinarily affected by latitude or season. This condition is made possible mostly by an upwelling from cooler intermediate layers of water and not to the northerly flow of surface waters. Otherwise these surface waters would gradually warm as they flowed northward. The inevitable result of the meteorological circumstances along the coast accelerates a flow of surface water offshore which results in a vertical circulation described as upwelling. One process in upwelling has been attributed to deviation, in which divergence of surface water offshore is a result of the earth's rotation. Another process would be the effect of offshore winds and ocean drift.

Upwelling along the coast is the cause of the varied marine life of this area. It brings to the well-illuminated upper layers the inexhaustible store of nutrient salts from the ocean depths, upon which the plant elements depend for life. This rich life gives to the coastal water its typical greenish color in contrast to the indigo or blue of the open ocean.

Recent current and temperature studies reveal the upwelling as practically limited to the upper 100 to 150 fathoms. Surface temperatures close to shore along the coast range between 58° F. and 64° F. and average about 18° F. lower than latitude alone would indicate. The atmospheric temperatures as a result are maintained at a similar unchanging low average all the way up the coast from about latitude 38° S. to the Gulf of Guayaquil.

The drift north, strong inshore and diminishing offshore, is the most evident feature of the Peru Current. The decrease in northerly set offshore is accompanied by an increasing westerly set. Upwelling off both Chile and Peru is the final evidence of the movement offshore of surface layers. Frequent observations of countercurrents close inshore are associated with the usual coastal eddies due to contours of the coast and variations with the season.

The Peru Current, off Punta Aguja (Lat. 6° S.), normally swings to the west and converges with the Equatorial Countercurrent running east. The line of convergence marked by a tide rip may run in an irregular line from Punta Aguja to the Galapagos Islands. The Equatorial Countercurrent normally turns northward along the coasts of Ecuador, Colombia, and Central America but seasonally it swings to the south during January to March and as a result a countercurrent of warm water moves down the coast of Peru, displacing the ordinarily cold water of the Peru Current. This influx of warm water named "El Nino" may reach as far south as Salaverry (Lat. 8° 13′S.). This is a drastic temperature reversal and is associated with widespread mortality in littoral invertebrates, fish, and birds. A common result of this disturbance to the planktonic life is observed in the extensive discoloration of the water. The phenomenon is always accompanied by marked changes in the fauna of the sea, including the disappearance of the typical cool water birds, and the invasion of the region by equatorial species.

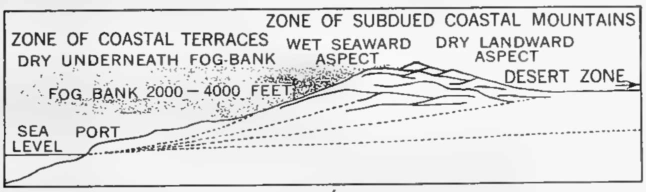
A similar current change occurring farther south in latitudes 8° S. to 13° S. during the months of April through June is called "Aguaje" and is caused by an inshore movement of outlying warmer water. After the occurrence of the "Aguaje", penetration and warming in shallow water by the sun, hastens decomposition of the plankton in such a manner as to discolor the ocean and produce hydrogen sulphide in a quantity sufficient to poison fish. This is but one of the several causes contributing to the widespread mortality.

Along the northwest extension of the current (Lat. 3° S.), towards the Galapagos Islands, maximum velocity is reached. The cool greenish water mixes with the warmer blue waters of the South Equatorial Current, often forming distinct bands or stripes. These mixing zones often prove very rich in sea life. Conditions are also favorable for sea birds. This is in marked contrast to the barren ocean areas offshore and northward.

The climate of the coastal region of Peru is arid with prevailing winds of small force from the southeast quadrant. Here, as on the northern coast of Chile, the cool waters of the Peru Current produce a stable condition of the atmosphere with considerable cloudiness but no rainfall of consequence. On the coast there are no storms and no sudden changes of temperature although the sky is frequently cloudy and threatening. The immediate coast of Peru has a regular alternating breeze locally called *virazón* which blows toward the land in the daytime, and *terral* which blows toward the sea at night. Farther offshore, the southeast trades always prevail.

Air temperature over the current is affected by the cool water from the upwelling. Conditioned by the hydrography of the submarine areas, the sharpest lowering of temperature corresponds in position with the ocean deeps close inshore or where the continental shelf is reduced in width. A marked similarity or uniformity of temperature exists from north to south. Temperature observations at Valparaiso and Paita with a difference of latitude of 28° show a temperature difference of less than 5° F. A comparison of temperatures between places on the shore and those a short distance inland also reveal the effect of the ocean on the climate.

The morning mists are the product of the abrupt cooling of air in contact with the sea at an hour when the land breeze still holds. These mists, or *Garúas* as they are known locally, extend all along the coast of Peru and northern Chile. The inability of the air to bring rain is explained by a lack of evaporation from cool water to cool air and also by the fact that the onshore breezes, which would be expected to bring rain, are deflected upward by the coastal mountains but sufficient change in temperature to cause condensation does not occur. It is estimated that air in this area at 65° F. may be warmed 25° F. by the land it is blown against. It would then take an ascent of nearly a mile to cool the air 25° F. thus leaving it at the same temperature at which it started and with no progress toward condensation. This arid condition persists for decades, with an appearance of rain, but no rain. It is amazing to encounter a pall of low cloud or an overcast sky, with ports hidden in fog, but at the same time encountering extreme evidences of aridity in the coastal areas. The coast appears like a desert under a humid sky. The fog forms over the upwelling stream of cold water and gathers on the seaward slopes of the coastal hills.



GARÚAS

Morning garúas are produced by the abrupt cooling of air in contact with the sea at an hour when the land breeze still holds. The air drifts landward with the onshore wind and mist gathers on the seaward slopes of the coastal hills. The garúas descend at night nearly to the surface and all but disappear during the day, or they may extend indefinitely westward.

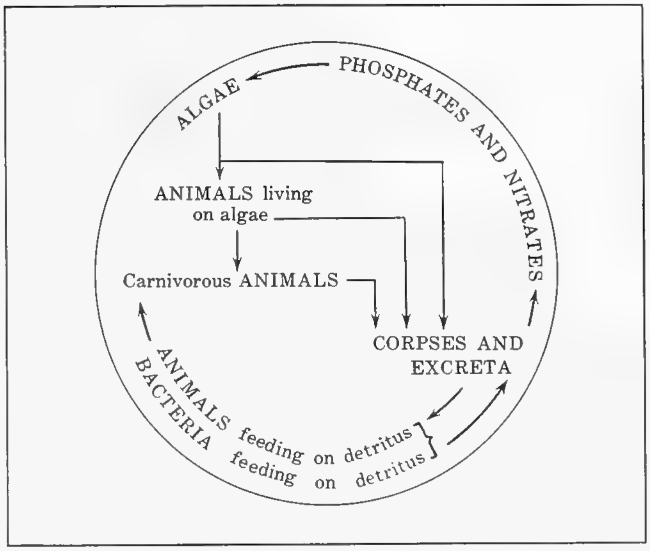
The rain making conditions in this area are in such fine balance that only a slight interference with the existing conditions might cause a deluge that could lay the coast in ruins. Mud-walled houses and sun-dried brick buildings would crumble in a heavy rain and the dry alluvial valley lands would become mighty rivers. Fertile tracts would be washed into the sea or be covered by sand.

Fortunately these conditions are infrequent and take place only in a small area along the north coast of Peru where tropical conditions temporarily blanket the area during the seasonal invasion by the countercurrent.

MARINE LIFE

The divisions controlling the distribution of animals in land areas are mountains, deserts, broad rivers and other abrupt lines governing changes in temperature or rainfall. The ranges of fish and marine invertebrates can likewise be correlated with the temperature and chemical content of the sea water. Ocean birds, like land birds, are bound in the same way to their own type of conditions, if not for their whole life then for at least a part of it. Few sea birds can long survive a marked change in sea temperatures and salinity. The unique and limited areas of change in the oceans provide barriers and invisible walls controlling bird existence.

Water temperature appears to be the principal limiting factor governing the distribution of sea birds. The control is bound up with a long sequence of conditions related to temperature, rather than a simple direct relationship. Temperature range is an important event in the life cycle beginning with the phenomena of sunlight and photosynthesis and ending with the nature and quantity of organisms upon which birds feed. Temperature is the most important factor of sea water in relation to sea life. Salinity and density factors as controlled by current and climate are only further complications in the relationships. Studies of conditions at the north end of the Peru Current have revealed some of the secrets in these relationships in which birds are adjusted and respond quickly to periodic changes in the character of sea water. Groups of birds retreat or advance with a change of conditions and areas are invaded by a different species.



SEA-LIFE CIRCUIT

The ultimate source of food for all marine life is the microscopic plant life obtaining sustenance from the nutrient elements in the sea water. Tissue thus built up then becomes food for small crustaceans and certain fishes which are in turn consumed by birds and other animals. Microscopic plants number tens and hundreds of thousands per quart of sea water. Existing principally within 50 fathoms of the surface, the dead remains settle and decompose in the lightless depths. The enriched water from the decomposition is then recirculated to the surface and made available for further profuse development.

Decomposition of animal and plant remains by bacteria brings derivatives of the body substances to a soluble condition in water, from which some may be removed for use by other advanced forms. An ordinary circuit in this chain of events would be: diatom—copepod—herring—cod (or bird)—bacterium—sea water—diatom. The diatoms are one of the basic connecting links and surpass a thousandfold in bulk the productiveness of all other aquatic plants. They may be likened to a pasture in the sea and, although available everywhere, are most profuse in waters of low temperature. They are an abundant source of food for all marine animals.

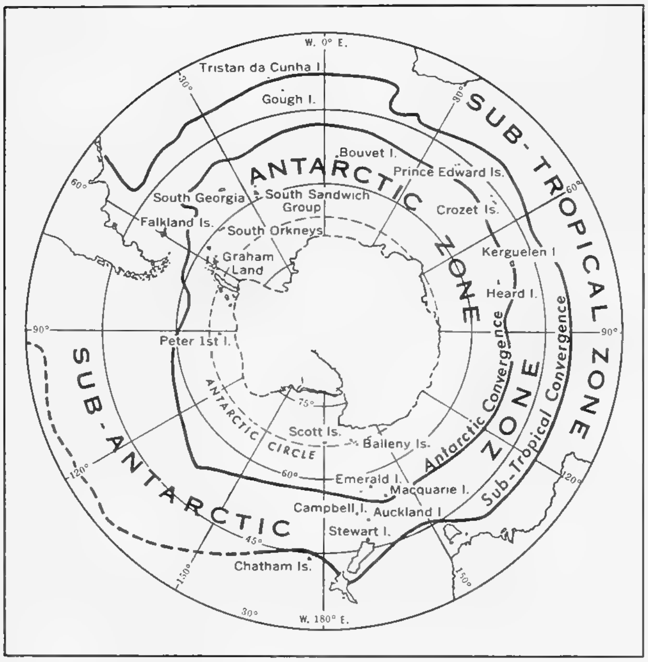
Low temperature and low salinity, usually associated with the southern oceans, create an abundance of life far in excess of that in warm sea water. The food substances of ocean life such as carbonic acid, nitrites and nitrates of calcium and magnesium, phosphates, silica and other elements, all exist in very small quantities everywhere. The living substances incessantly use up the elements. Sea water of low temperature, being more favorable to a high gas content and richer in mineral compounds, support a more abundant plankton growth. Co-existing generations in these low temperature areas assist in the creation of a more generous growth and aid in factors tending toward a longer life span leading to complete development.

Zones of distinctive conditions, each with a typical amplitude of temperature, salinity, and condition for the support of plant and animal life are defined geographically. These zones succeed one another from polar latitudes and are named Antarctic, Sub-Antarctic, Sub-Tropical, and Tropical. Hydrological circumstances within each zone bear an interesting relationship to the distribution of sea birds. The relationship of phosphate to plankton abundance, the distribution of plankton in general, and the color of sea water in relation to the contained life, are indicated by the number of sea birds.

Discontinuities of temperature and salinity in the open ocean behave more or less as though separated by a wall and are the physical basis for the zones of convergence. Surface layers of water are inhabited by organisms not characteristic of near-by zones. Parts of these convergencies are shaped and stretched as though by pressure, and although influenced by surface topography, these boundaries are seldom controlled by relationship to latitude alone. Such a diversion can be observed in the South Pacific where the Sub-Tropical convergence shapes northward in the vicinity of latitude 30°S., longitude

90° W. Bottom contours at great depth may assist the course of convergence. These are physical boundaries and can be detected with a thermometer by the sharp change in temperature. They can be as easily detected by the distinction of life within the water.

Within the Antarctic Zone, surface water temperatures 30° F. to 38° F., the food of birds, as well as of whales and some seals, consists mostly of "krill", the Norwegian whaleman's name for the euphausian crustaceans or oppossum shrimps. Although there are many kinds of euphausid, the species *Euphausia superba* has been found most abundant in the stomachs of penguins, petrels, seals and whales of the far south. The exclusive food of penguins is swarms of this form of "krill" which in turn subsist largely on diatoms, the predominant microplankton of the area. The body growth of the birds and whales are thus only one step removed from the organic fixation of the radiant energy of the sun by the phytoplankton.



ANTARCTIC CONVERGENCE

The Sub-Antarctic Zone, surface water temperatures 38° F. to 58° F. is almost entirely within the belt of westerly winds and is an area of much deeper and warmer surface water. Salinity and temperature decrease with depth in this area and there is a constant tendency toward upwelling and vertical mixing. The unstable conditions of rough weather tend toward less production of phytoplankton. *Munida*, known by the southern whalemen as "lobster krill", make up the predominant bird-whale-feed in this zone. These creatures occur in enormous abundance. *Munida gregaria* sometimes color the surface of the ocean a bright red. They appear in vast numbers far north in Peru Current waters and form a substantial part of the food of gulls, cormorants, petrels and penguins.

An impressive description of marine life in profusion living in nearly perfect conditions in the Peru Current has been recorded by R. E. Coker as follows:

> "In contrast to the barrenness of the coast [of Peru] there is a peculiar wealth of certain forms in the open ocean. The great red seas, formed sometimes, at least, of myriads of microscopic dinoflagellates, are of common occurrence........Sometimes, too, great areas of the surface of the sea are reddened by the vast numbers of small crustacea *(Munida)* which then play a part of great importance as food for the fishes and for the guano-producing birds. More striking still are the immense schools of small fishes, the "anchobetas" *(Engraulis ringens Jenyns)*, which are followed by numbers of bonitos and other fishes and by sea lions, while at the same time they are preyed upon by the flocks of cormorants, pelicans, gannets, and other abundant sea birds. It is these birds, however, that offer the most impressive sight. The long files of pelicans, the low moving black clouds of cormorants, or the rainstorms of plunging gannets probably cannot be equaled in any other part of the world. These birds feed chiefly, almost exclusively, upon the anchobetas. The anchobeta, then, is not only....the food of the larger fishes, but, as the food of the birds, it is the source from which is derived each year probably a score of thousands of tons of high-grade bird guano...No more forcible testimony to its abundance could be offered than the estimate, made roughly, but with not wide inaccuracy, that a single flock of cormorants observed at the Chincha Islands would consume each year a weight of these fish equal to one-fourth of the entire catch of the fisheries of the United States."

The Sub-Tropical Zone, surface water temperature 58° F. to 73° F., show an increase in salinity and a striking decrease in nutrients. Oxygen in the surface layers decreases from about 80 percent of saturation in 28° S. to about 40 percent at the Equator. These waters are not favorable for diatom growth except where replenished by upwelling such as exist along the Peruvian Coast where conditions remain constantly favorable. The volume of plankton diminishes under these adverse conditions in the Sub-Tropical Zone and the collective population of surface organisms may be no more than ten to each quart. The diatoms are replaced by less well known varieties and likewise the pelagic crustacea, so important to life in the southern zones, are replaced by copepods. Therefore the abundance, if available, becomes sporadic. The Portuguese man-o-war appears in this zone. Flying fishes and dolphins replace the immense schools of small fishes of the colder waters. The numbers and types of sea life near the surface diminish greatly.

The Tropical Zone of surface waters, temperatures 74° F. to 84° F., differs little with that of the Sub-Tropical. Salinity is at a minimum because of heavy rainfall and low evaporation. Waters of greater density and salinity are observable below the surface layer. There are no detectable phosphates and but minute quantities of nitrate nitrogen. Bird life in these climes is regarded as land bound rather than pelagic except for flock or single migrations.

Next to the extraordinary abundance of marine life in low southern latitudes, the most evident characteristic of the Peru Current is the unequalled northward distribution of Antarctic and Sub-Antarctic types of birds and mammals. Examples in this category are many Peruvian species with distinctly subpolar affinities such as:

(a) The Southern Kelp Gull *(Larus dominicanus)*, a Sub-Antarctic sea bird of circumpolar range, which breeds in numbers on Tierra del Fuego and upon other heavily-glaciated ice-covered islands, such as South Georgia and Kerguelen. This bird also extends its breeding range along the tropical western coast of South America practically as far as the Peru Current is in contact with the land. Its northernmost breeding station, on Lobos de Tierra (Lat. 6° 25′ S.) is one of its centers of maximum abundance.

(b) The White-breasted Cormorant, or Guanay *(Phalacrocorax bougainvillei)*, first in importance as the Peruvian guano bird, is a member of the well-defined Antarctic branch of the cormorant family. Its closest kin are the cormorants of the Strait of Magellan, New Zealand, Sub-Antarctic islands, and the shores of the Antarctic Continent, but its relationship with the other cormorants of South America or with those of the Northern Hemisphere is distant. The range of the Guanay extends along the west coast of South America from central Chile to within six degrees of the Equator.

(c) Diving Petrels *(Pelicanoididae)* are representatives of a typical Sub-Antarctic family of marine birds. They breed along the western coast of South America from Cape Horn to the northern islands off Peru (Lat. 6° 25′ S.). Diving Petrels do not breed north of about latitude 37° S. in any other part of the world.

(d) Penguins (genus *Spheniscus*) are found along the west coast of South America southward of latitude 6° S., and also an endemic species *(S. mendiculus)* resides on the Galapagos Islands at the Equator.

(e) The Southern Sea Lion *(Otaria byronia)* is a permanent resident along the west coast from Cape Horn to northern Peru, and again a representative of the same genus occurs at the Galapagos Islands.

(f) The rare Southern Fur Seal *(Arctocephalus australis)*, sometimes sighted at Independencia Bay (Lat. 14° 10′ S.),

Figure 3. PERUVIAN PENGUIN, *Spheniscus humboldti, "Pajaro Nino", walks upright with great dignity, standing about 27 inches high, weight about 9 pounds. The bird has gray feathers with a black band across a white breast and has a black bill and blackish brown feet. The penguin lacks any ability whatever in the air but exhibits incredible skill under water.*

Figure 1. WANDERING ALBATROSS, *Diomedea exulans, "Cape sheep", weighs about 13 pounds with a wing spread of eleven feet. The birds are white with slate brown wing tips and trim with a buff-yellow beak and blue-gray legs and feet. This is a southern hemisphere albatross which nests mostly on glacial Antarctic islands such as South Georgia. A gifted and beautiful aerial performer often seen far at sea. King of the air, the albatross is one of the largest sea birds, and also of all flying birds, the condor being heavier but with lesser wing-spread.*

Figure 2. PERUVIAN PELICAN, *Pelicanus occidentalis thagus, "Alcatraz", a large ungainly bird weighing about 16 pounds; has pearly gray plumage with a white head, black or orange-yellow pouch with greenish bill and lavender-gray legs. May hurtle into the water with a resounding splash or may swim and scoop while fishing. The bird gives the impression of being shy, stupid and at times awkward or impractical; is most conspicuous among the flock birds on the coast for its size as it is the largest. This bird does not stray out of sight of the coast and has never been sighted off the outlying islands.*

Figure 4. PIQUERO. *Sula variegata, "The lancer", weighs about 4 pounds, is white-headed and white-bodied with variegated white and brown wings and back, purple-blue bill and blue-gray legs. This bird is the noisiest and most numerous of the guano birds at the Peruvian islands and is a swift and active flyer and a powerful diver. The lancer descends straight from the blue, vanishes in a jet of foam in a spectacular plunge as he fishes for anchovies in the cool current.*

Figure 5. GUANAY. *Phalacrocorax bougainvillei, "Pato yeco", walks erect, about 20 inches high, weight about $4\frac{1}{2}$ pounds. A long-winged, long-billed, cormorant with glossy green and blue-black neck and back and glossy white breast, having pink feet. The bird has a conspicuous naked skin area about the eye. A very capable and strong flyer, feeding exclusively upon sea-surface organisms, the Guanay is ranked first in importance among the famuos guano birds of Peru*

formerly ranged from Cape Horn to northern Peru and the Galapagos Islands, or throughout the path of the Peru Current. This genus is one that has successfully jumped the northern barrier of tropical surface waters, as a related species *(Arctocephalus townsendi)* is now a resident of the lower California coast and inhabits Guadalupe and the San Benito Islands (beyond Lat. 28° N.).

The Peru Current is a narrow stream and the composite range of endemic marine fauna of the Peruvian Coast is likewise a narrow ribbon in the ocean, hugging the shore as it projects toward the Equator from the far south. A voyage offshore across the Peru Current reveals the change in fauna, which is closely correlated with the changes in surface temperatures. A few miles offshore the plankton, sea lions, penguins, cormorants, kelp gulls, and Sub-Antarctic petrels, with thousands of fish species, all disappear, and another oceanic region with a totally different fauna appears.

The following species are considered native to the Peru Current:

SOUTHERN DERIVATIVES

Peruvian Penguin	*(Spheniscus humboldti)*
Peruvian Storm Petrel	*(Oceanodroma tethys kelsalli)*
Eliot's Storm Petrel	*(Oceanites gracilis gracilis)*
Potoyunco	*(Pelicanoides garnotii)*
Guanay	*(Phalacrocorax bougainvillei)*

PAN-TROPICAL DERIVATIVES

Alcatráz	*(Pelicanus occidentalis thagus)*
Piquero	*(Sula variegata)*
Peruvian Tern	*(Sterna lorata)*

PROBABLE NORTHERN ORIGIN

Gray gull	*(Larus modestus)*

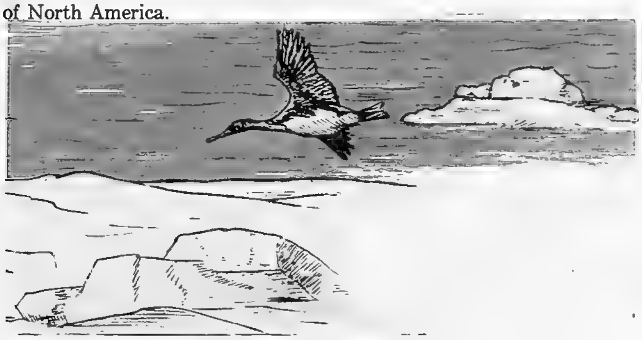
DOUBTFUL SOURCE

Markham's Storm Petrel	*(Oceanodroma markhami)*
Hornby's Petrel	*(Oceanodroma hornbyi)*
Belcher's Gull	*(Larus belcheri)*
Inca Tern	*(Larosterna inca)*

The birds of Sub-Antarctic affinities which extend their breeding ranges northward into the Peru Current are as follows:

Magellanie Penguin	*(Spheniscus magellanicus)*
Sooty Shearwater	*(Puffinus griseus)*
Frigate Petrels	*(Fregatta)*
Red-footed Cormorant	*(Phalacrocorax gaimardi)*
Tern	*(Sterna hirundinacea)*

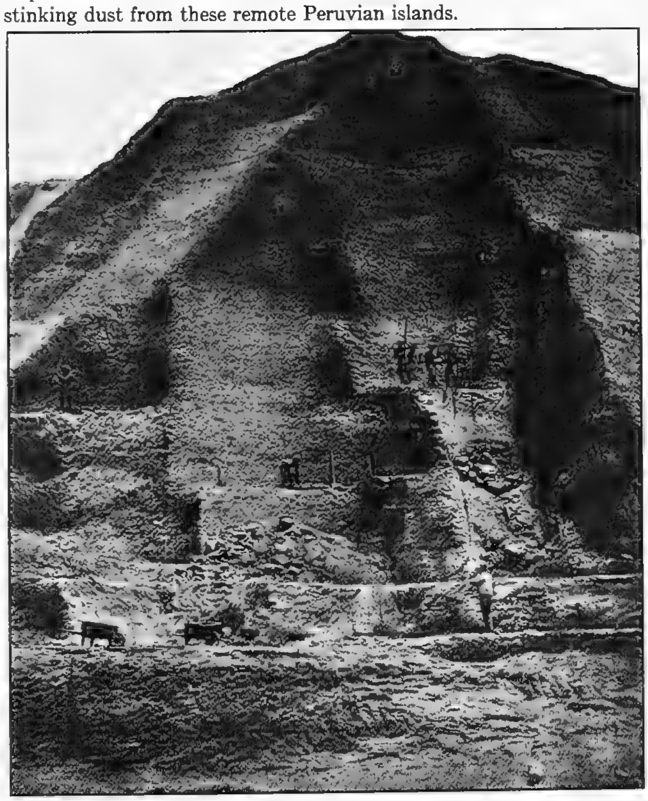
The area of the Peru Current is visited by many varieties of birds from distant parts of the Pacific during the various seasons, but the native species, found only in the waters off the coast between Ecuador and Chile, are more abundant and noticeable. Included among the migrants are certain species of Antarctic and Sub-Antarctic albatrosses, petrels such as *Daption, Priocella, Macronectes, Procellaria,* and *Oceanites oceanicus,* as well as forms of the skua *(Catharacta).* There are also seasonal migrants from the outer Pacific such as the Sooty Tern *(Sterna fuscata).* Migrants from the Galapagos Islands and tropical waters to the north are the albatross from Hood Island *(Diomedea irrorata),* a Gadfly Petrel *(Pterodroma phaeopygia),* the Blue-faced Booby *(Sula dactylatra),* the Swallow-tailed Gull *(Creagrus furcatus),* the Royal Tern *(Thalasseus maximus),* and at intervals a tropic bird *(Phaethon aethereus).* Casual visitors from the Northern Hemisphere include petrels such as *Loomelania melania,* gulls like *Larus pipixcan* and jaegers, and phalaropes from the Arctic interior of North America.



The Peru Current, besides being responsible for the dramatic distribution of cold Antarctic water, with a biologic cycle of its own, has yet another unique item of interest worthy of note. This is guano, a by-product of the cycle, the importance of which was long overlooked. Guano, although mentioned in the Royal Commentaries of the Inca and known by the early conquerors, was neglected as an item of world trade, until Humboldt advised its use as a fertilizer soon after 1800. Introduced into the United States by 1825 and England by 1840, the first users were fearful of its potency because of the astonishing results from its application as a fertilizer. After repeated experiments it came into general use as a safe and cheap fertilizer. Some early estimates describe guano as being 33 times more effective than any other equivalent.

Soon after 1847 it was a principal industry in Perú, amounting to nearly three quarters of Peru's annual income. By 1874, in spite of early predictions of an inexhaustible supply, most of the original accumulations had been removed. Less worthy deposits have been found around rocky islands in other parts of the world, but none compare with the quality or size of the Peruvian deposits. This is no doubt due to the peculiar aridity of the climate of Peru which preserved the deposits without loss.

Huge profits from the guano trade were realized in the early days. Profits from a single trip by a sailing vessel at this time amounted to as much as $10,000. Hundreds of vessels loaded at the coastal islands each year. Rapid exploitation with no attempt at conservation soon depleted first deposits. Four decades later, after implementation of a government program for conservation of both producing birds and deposits, the industry had become permanent. The Compania Administradora del Guano in Peru is the official agency controlling and operating the producing islands. The extraordinary commercial success of the company is no doubt due to the wisdom of the administrators who have conducted the industry with reference to the welfare and perpetuation of the valuable sea birds. A rotating extraction schedule is followed which provides for non-molestation of the birds and will in time restore the balance so blunderingly upset during the total exploitation era. Guano-fever burned as fiercely as gold-fever in the early days and the islands were a focus of greed and corruption that is now almost forgotten. Misery and slavery were attached to a commercial enterprise represented by the towering spars of sailing ships from the ends of the earth, whose skippers were greedy for the stinking dust from these remote Peruvian islands.



Excavating guano in the Chincha Islands about 1860. The layers here are nearly 800 feet thick.

Another interesting by-product of the Peru Current is the unusual nitrate wealth of the north Chile desert. Nitrate beds are found on the upland plain behind the coastal range between latitudes 19°S. and 26°S. One theory is that the substance owes its origin to ancient huge deposits of the guano of sea birds; later to be acted upon by water and sun in the presence of quantities of sea weed. Some of these beds are still the breeding grounds of many sea birds. Numerous petrel mummies are unearthed during present day mining operations. Geologic changes in the history of this unstable coast could well account for the present location of these inland beds far above the sea. Regardless of their origin the nitrate fields are the basis for an important industry in Chile. An average income of over twenty million dollars gold has been realized by Chile in export taxes alone from this source. For many years the nitrate trade accounted for half the total value of the export trade.

The foregoing is but a short description of the peculiar conditions found on this strange coast, with its odd interrelations of industry and nature, where a mountainous desert borders the ocean for 2,000 miles. Here rain threatens but never falls. Here the ocean current is cold and mostly vertically disposed. Here birds (penguins) fly under water instead of in the air.

The bird life and some of its spectacular features in this area have been aptly described by the talented Dr. Chapman as follows:

> "As for the birds, who can describe them in their incalculable myriads? Visible link in the chain of life that begins with diatoms nourished by the cool, highly oxygenized waters of the Humboldt Current, they animate both the air and the sea. No other coastline of similar extent can show an avian population equalling that of the waters off Peru.
>
> "Whichever way one looked from our anchorage at Salaverry, birds could be seen in countless numbers fishing in dense, excited flocks, passing in endless files from one fishing ground to another, or massed in great rafts on the sea. Toward the shore long, waving whip-like streamers and banners passed in endless undulating lines sharply silhouetted against the coast range.
>
> "Seaward, like aerial serpents, sinuous files crawled through the air in repeated curves lost in the distance, while low over the water processions passed rapidly, steadily, hour after hour, with rarely a break in their ranks during the entire day. At times the flocks were composed of Cormorants with, at intervals, a white-bodied, brown-winged Booby. At others, they were composed of Boobies accented, here and there, by a Cormorant.
>
> "When the birds stopped to feed, the scene commanded the untiring and often excited attention of every passenger aboard the ship. The Cormorants fished from the surface in a sea of small fry. Swimming and diving they gobbled voraciously until their storage capacity was reached. Then they floated in dense, black masses waiting for the processes of digestion to give space for further gorging.
>
> "The Boobies fished from the air, plunging into the water with great force from an average height of 50 feet, to disappear in a jet of spurting spray as they hit the surface. In endless cataracts they poured into the sea. It was a curtain of spearheads, a barrage of birds. The water bacame a mass of foam from which hundreds of fishers took wing at a low angle to return to the throng above and dive again; or their hunger satisfied, they flew by thousands to some distant resting place. It is difficult to understand why the birds near the surface were not impaled by their plunging comrades.
>
> "But the most amazing maneuver in all this astounding spectacle was the instantaneous disappearance from the air of flocks of 500 to 1,000 Boobies that chanced to pass over a school of fish. Then as one bird, they plunged seaward and the sky, which a moment before seemed full of rapidly flying birds, was left without a feather. This evolution, the most surprising I have ever seen in bird-life, was witnessed repeatedly during the day. When we left [Salaverry] late in the afternoon there was no apparent decrease in the numbers or activities of the winged fishers; but I could look at them no longer without a feeling of confusion and dizziness; for the first time in my life I had seen too many birds in one day!"

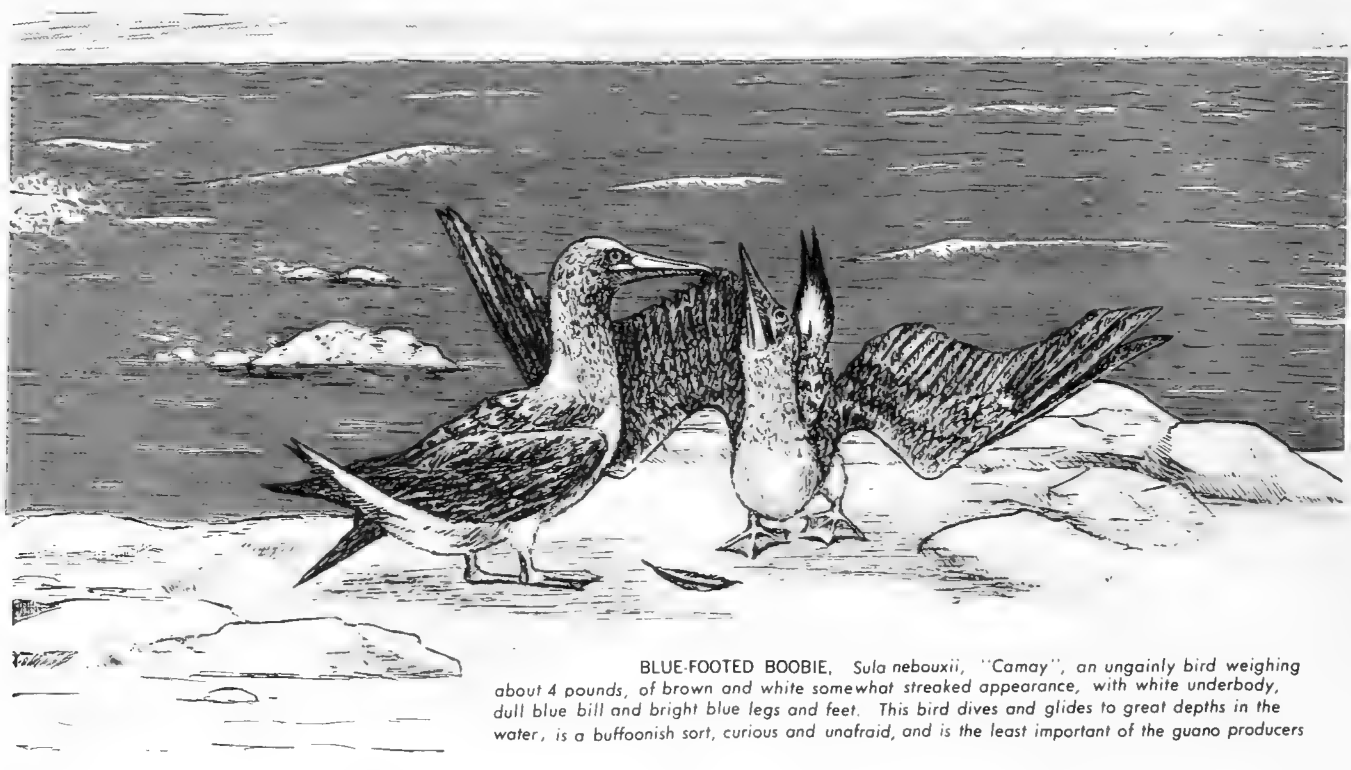
Sources of information include the following:

Ocean Birds of South America, 1936, Robert Cushman Murphy.

The Oceans, 1942, Sverdrup, Johnson and Fleming.

Variations in Behaviour of the Peru Coastal Current—with an Historical Introduction, 1936, E. R. Gunther, The Geographical Journal.

Notes on the Findings of the "William Scoresby" in the Peru Coastal Current, 1937, R.C. Murphy, The Geographical Review.



BLUE-FOOTED BOOBIE, *Sula nebouxii, "Camay", an ungainly bird weighing about 4 pounds, of brown and white somewhat streaked appearance, with white underbody, dull blue bill and bright blue legs and feet. This bird dives and glides to great depths in the water, is a buffoonish sort, curious and unafraid, and is the least important of the guano producers*

WATER DENSITY AND ITS APPLICATIONS

J. W. Chanslor
Maritime Safety Division
U. S. Naval Oceanographic Office

The sea is a wilderness full of secrets, upon which man has sailed since the earliest times. Even in these days of accelerated scientific achievement, mysticism of the sea remains. The purpose of this article is to touch upon one facet of the phenomena of nature—density of sea water and its applications to mariners.

Some of the complexities discussed include changes in draft, due to changes in density, currents affecting a voyage, causes of harbor siltation, and the explanation of certain related phenomena observed at sea.

The density of sea water depends upon three variables: salinity, temperature, and pressure. At constant temperature and pressure, density varies with salinity or, because of the relationship between this and chlorinity, with the chlorinity. Density and specific gravity are virtually identical numerically. A temperature of 32°F and atmospheric pressure are considered standard for density determination. The effects of thermal expansion and compressibility are used to determine the density at other temperatures and pressures. And, the density at a particular pressure is quite important in its relation to ocean currents.

The greatest changes in density of sea water occur near the surface where the water is subject to influences not present at depths. At the surface density is decreased by precipitation, runoff from land, melting of ice, or heating. When the surface water becomes less dense, it tends to float on top of the more dense water below. There is little tendency for the water to mix, so the condition is one of stability. The density of surface water is increased by evaporation, formation of sea ice, and cooling. If the surface water becomes more dense than that below, it sinks to the level at which other water has the same density. At that level it tends to spread out to form a layer or to increase the thickness of the layer below it. The less dense water rises to make room for it, and the surface water moves in to replace that which has descended. Thus, a convective circulation is established. It continues until the density becomes uniform from the surface to the depth at which a greater density occurs. If the surface water becomes sufficiently dense, it sinks all the way to the bottom. If this occurs in an area where horizontal flow is unobstructed, the water which has descended spreads to other regions, creating a dense bottom layer. Since the greatest increase in density occurs in polar regions, where the air is cold and great quantities of ice form, the cold dense polar water sinks to the bottom and then spreads to the lower latitudes. This process has continued for a sufficient length of time that the entire ocean floor is covered with this dense polar water, thus explaining the layer of cold water at great depths in all the oceans.

Changes in salt content of ocean waters, with position, depth, and time, are brought about in the main by greater evaporation taking place in subtropical latitudes and greater precipitation in the polar seas. In the equatorial region surface water increases in salinity because of evaporation but decreases in density because of rise in temperature.

As the density of sea water depends on temperature and salinity, all processes that alter the temperature or the salinity influence the density. The water of the greatest density is formed in high latitudes.

Generally, density is a physical property possessed by solids, liquids, and gases. It is defined as mass per unit volume. Although the quantities, temperature and pressure, have only small effects on density in the laboratory, these factors must be given close attention in oceanography. In the oceans density is further complicated by the effect of salinity.

The fact that density is an inverse function of volume indicates that an increase in volume will cause a corresponding decrease in density, whereas a decrease in volume will cause the density to increase. It logically follows that whatever factors cause the volume of some quantity to undergo a change will also cause density to undergo an inverse change, other factors being constant. The following explanations show how a change in pressure, temperature, or salinity bring about a change in density.

Pressure:—Though, as a general rule, liquids may be considered incompressible, such an assumption cannot be made when considering a unit volume of water at oceanic depths. Due to increase of pressure with increasing depths, a small volume of water carried from the surface down to some point beneath the surface will be compressed, or stated differently, will be caused to occupy a smaller volume. This decrease in volume causes an increase in density if the mass of the sample remains constant without a change in temperature. Thus, the effect of pressure is to bring about a change in volume and thereby influence the density as described.

Placing smoked glass slide in bathythermograph.

Smoked glass slide

Temperature:—Like pressure, the effect of changes in temperature changes the volume of a sample of water; however, unlike pressure, the variation of volume with temperature is direct, causing volume increases with increasing temperature. The net result of an increase in temperature causes a decrease in the density if other factors remain constant.

Salinity:—Salinity differs from the other factors in that its variation essentially involves a change in mass of a given volume. Increasing the salinity of a sample of water is much the same as adding mass to volume which increases the density.

DENSITY AT VARIOUS TEMPERATURES

For some practical uses of density, it is more important to know the density at the temperature apt to be encountered than at the standard temperature. Figure 1 provides for converting density at

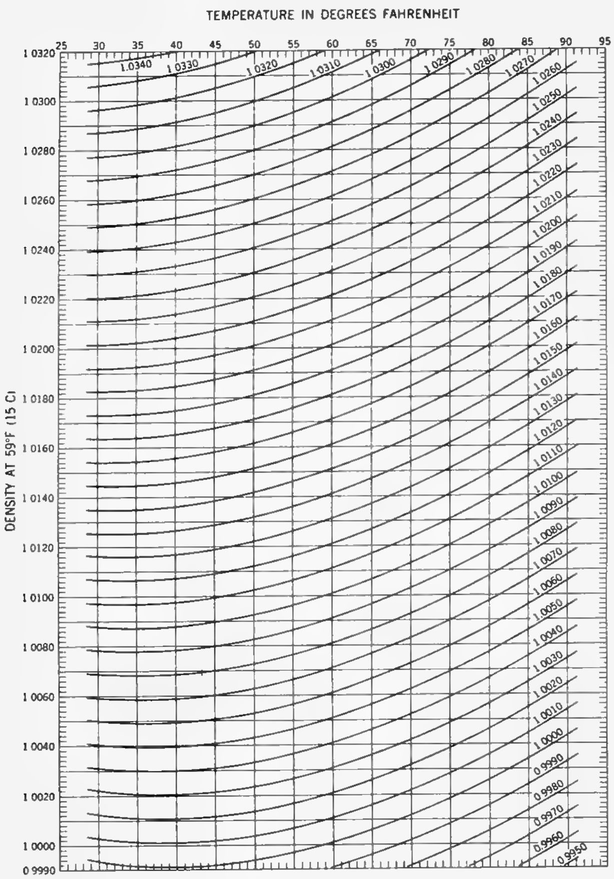


Figure 1. Sea water density at various temperatures.

59°F. (15°C.) as published in U. S. Coast and Geodetic Survey Publication Nos. 31-2 and 31-4 (Density of Sea Water, Atlantic Coast, North and South America, and Density of Sea Water, Pacific Coast, North and South America and Pacific Islands). As it is intended for use with true density rather than observed hydrometer readings, no glass correction was included.

To convert a density at 59°F. to density at another temperature, enter the graph horizontally from the left with the known density and downward from the top with the desired temperature; the position of the point of intersection of the curves gives the density at the desired temperature. Interpolate between curves when necessary.

Example: If certain water has a density of 1.0274 at 59°F. (15°C.) what would its density be at a temperature of 79°F.? Entering the graph from the side and top with these values, it is found that the point of intersection lies about 4/10 of the way between curves 1.0240 and 1.0250, so that the density at 79° F. is 1.0244.

DENSITY AND OCEAN CURRENTS

When the surface water in a particular area is heated until it is warmer than the water around and underneath it, the heated water expands so that the surface of the sea is slightly elevated in the center of the warm spot. Immediately, the water begins to flow downward in all directions away from the center. Cooler and denser water then presses up against the warmer and lighter water, buoying it up. Circulation therefore continues until there is an even distribution of density and pressure.

The rotation of the earth causes all these movements to be deflected to the right (in the Northern Hemisphere). This results in a whorl of clockwise water movements spreading out from the warm center. Under ordinary circumstances, this eddy of warm water can be expected to spread until the density differences are equalized. The process is retarded, however, by the tendency of the water particles to be deflected more and more to the right, so that at the edge of the eddy the movement follows very nearly a circular path.

The sinking of cold or saline water produces a somewhat similar current pattern, but in the opposite direction. If the surface water in a particular area is cooled sufficiently to make it denser than the water underneath, it will sink until it reaches a level of its own density. As it does, the sea surface is depressed, and warm surface water flows in from all sides to take its place.

All these factors are interrelated—the difference in density between the warm water above and the colder water below, the slope of the thermocline (as influenced by latitude), and the velocity of the current produced. The relationship can be expressed by a mathematical formula, so that by measuring the vertical density structure of ocean waters, it is possible to determine the direction and velocity of currents. Current systems are commonly studied in this way, for actual measurements of the currents are very inaccurate unless the vessel is equipped for anchoring in deep water, and even then measurements are difficult and laborious. The principle of determining ocean currents from the density structure of the sea, which is generally known as the Bjerknes Circulation Theory, is one of the most important contributions to modern oceanography.

While the mathematical relations of currents with the density structure of the water are always about the same, the casual relationships are often inextricably mixed. The wind may set up a current, and the transport of water that results will cause the density surfaces to slope. Contrariwise, density slopes that result from heating or cooling processes will cause a current to be formed. Often both processes are involved, and some of the most powerful ocean currents are those in which the prevailing winds and the density distribution work together.

In examining the currents it is worthwhile to compare them with the wind systems of the world which are similar in many respects and are, to a large degree, responsible for the general pattern of the currents. This is particularly true of the west wind drift in the Antarctic and of the North and South Equatorial Currents which lie in the trade wind belts. The latter currents form part of the great eddies centering in the mid-latitudes, clockwise in the Northern Hemisphere, and counterclockwise in the Southern, corresponding to the prevailing wind direction. As they are primarily

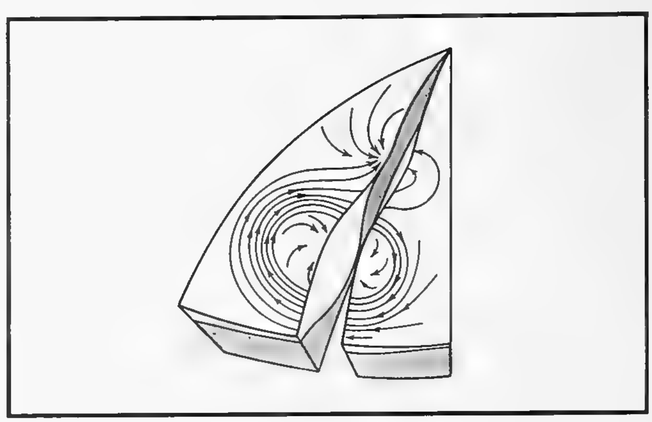


Figure 2. Diagram of typical circulation, wind driven eddy and subpolar convergence.

Recovering the bathythermograph.

wind-driven, they are swiftest at the surface. In the main thermocline and the upper part of the deep water layer, horizontal eddy-type motion gradually decreases with depth, giving way to slower deep water transport. These eddies, together with the sinking centers in higher latitudes, set the dominant pattern of the current systems of each ocean basin. Figure 2 is a diagrammatic representation of the scheme of circulation, showing the density structure and the direction of the currents in a combined wind-driven eddy and sinking center. In the eddy currents centering in mid-latitudes, the density surfaces slope downward toward the right in the Northern Hemisphere and to the left in the Southern. Thus, in the center of the eddies, layer depths are greater than around the outer edges of the currents. Hence, where these currents border on the equatorial doldrum belt the thermocline is shallow and echo ranging conditions are relatively poor. Sinking ordinarily occurs in a band a few yards wide and perhaps as much as several miles long. This phenomenon has been observed by surface vessels. It has the choppy appearance of a tide rip and may be full of seaweed and other debris brought into it by the converging surface currents. The downdrift is strong enough to carry down debris of slight buoyancy, and the surface currents may be strong enough to hold a drifting vessel in the convergence in spite of a crosswind.

Such convergences are probably important from the standpoint of diving operations. Submariners use the term *fresh pocket* for a place where the vessel suddenly and for no obvious reason begins to sink and requires reballasting. This can happen any time when a submarine goes too near the lower limit of a supporting density gradient. Varying thickness and amount of temperature change in the thermocline are no doubt responsible for some instances reported. On the other hand, sometimes the submarine sinks very rapidly and checks its descent with great difficulty and at a dangerous depth. In such a case it may have encountered a convergence in which there is no increase in density with depth, but also a downward current of water comparable to downdrafts in the air that cause airplanes to lose altitude. From what is known about the shape of these convergences, it seems likely that a submarine held in one for any length of time has come into it on a nearly parallel course and should therefore change course about 90 degrees to escape.

DENSITY AND COASTAL CURRENTS

Very marked currents are produced by the melting of ice in salt water. In the North Atlantic the arctic water of low salinity derived from melting ice flows southward as the Labrador current, hugging the right-hand shore. The deflection to the right owing to the earth's rotation causes it to set into the bays on the Canadian coast. On the south-east coast, so many wrecks have occurred near Cape Pine and St. Shots Cove that mariners have believed there was a local magnetic disturbance. Such is not the case however, because these disasters were mainly due to the effect of the density currents mentioned in the Sailing Directions for Newfoundland (Pub. No. 14).

Because of land drainage the density of coastal water is usually less than at corresponding depths offshore. Along any coast where there is a significant amount of freshening due to land drainage, there is a general tendency for the fresh water to move offshore on the surface and the denser (more saline) water to move in underneath. Thus, the salinity of the surface water increases from the shore seaward, and there is an increase in salinity from the surface downward. This is an unstable condition in that the density surfaces slope downward in an inshore direction; and the unequal pressure gives rise to currents which, in general, behave according to the principles of the circulation theory.

Since the density surfaces slope downward toward the shore, the directions of the currents are roughly parallel to the coast, with the coast on the right-hand side of the direction of flow in the Northern Hemisphere and on the left-hand side in the Southern Hemisphere. As a result of this prevailing condition, the Northern Hemisphere coastal currents on the west side of the oceans are

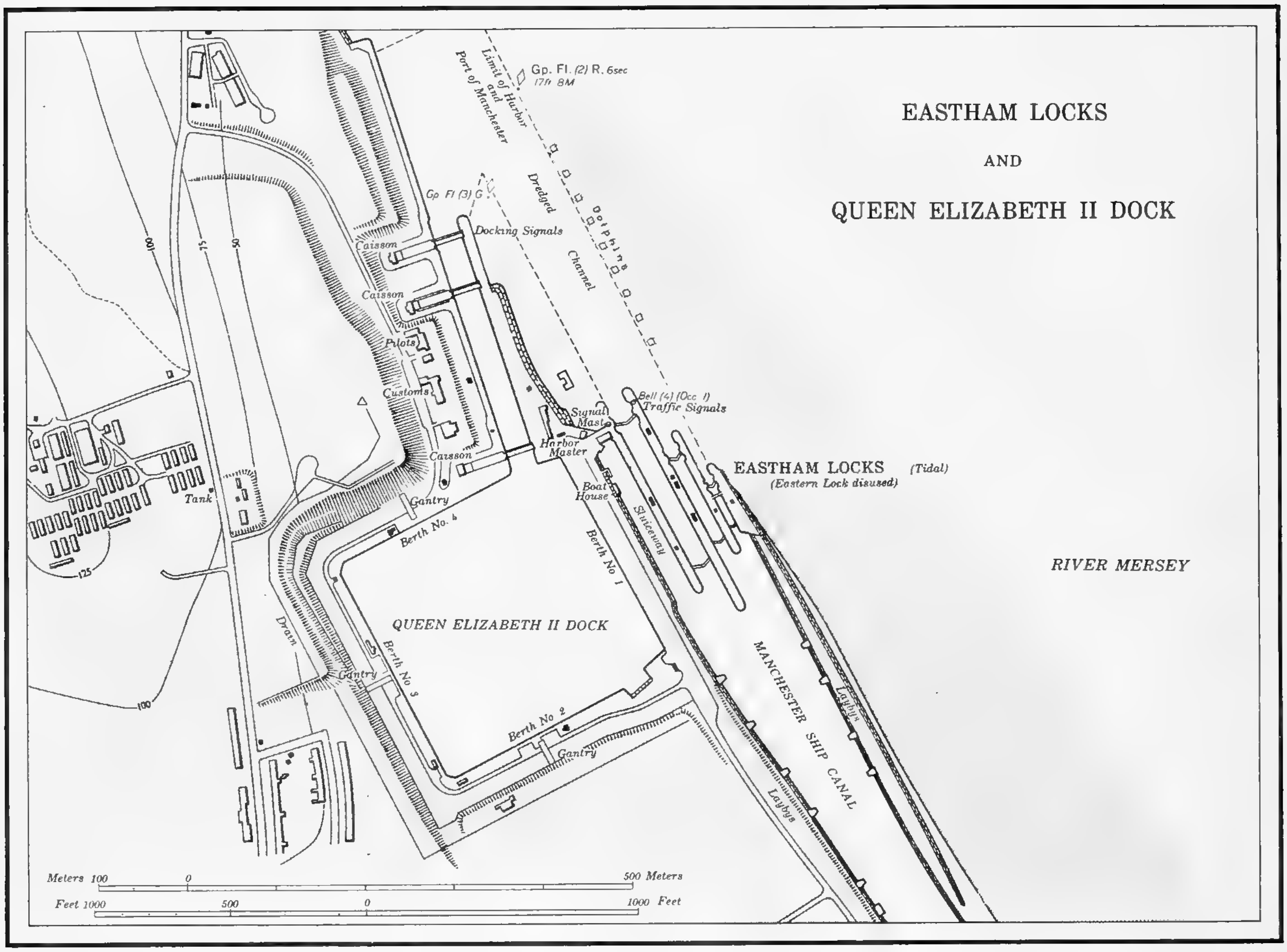


Figure 4.

usually south-flowing and relatively cold. Salinity is responsible for the density gradient that sets up the current, since, from the standpoint of temperature alone, the inshore water obviously would be heavier rather than lighter.

Along the east side of the oceans, coastal density currents generally flow northward and are warmer than the offshore water. Thus, both temperature and salinity contribute to the density gradient between inshore and offshore water.

Exceptions to the above occur where the Continental Shelf is narrow and where little river water is brought down to the sea. In such cases local winds and seasonal variations in rainfall are important in determining whether or not a typical coastal current will develop. For example, on the east coast of the United States there is a well-developed coastal current as far south as Fort Pierce, Florida. Beyond that point the shelf narrows rapidly and the coastal current, known as the Florida Countercurrent, becomes weak and sometimes nearly nonexistent. The coastal water off Miami is slightly cooler than the offshore north-flowing Florida Current. It is also slightly fresher, enough so that the countercurrent generally flows during the wetter months of the year. During the spring and summer months, however, steady southeasterly breezes carry the Florida Current close inshore and the coastal current is obliterated entirely or driven below the surface where it can be detected only by a subsurface method.

The extent to which a current parallels a coast depends, in considerable measure, on the difference in density between inshore and offshore water. When the density difference is slight, the current may frequently be set onshore or offshore. The directions that it takes will be dependent to a large degree on the bottom topography. Frictional retardation by bottom particles in contact with a current not only affect its velocity but also its direction. The tendency is for the normal twisting to the right (in the Northern Hemisphere) to be accentuated as the current moves over a shoaling bottom and to be lessened over a deepening bottom. Thus, when the water is relatively homogeneous, it is common to find an inshore set towards reefs and islets.

DENSITY AND SAFE CHANNEL DEPTHS

Density is an element which must be reckoned with when channel depths become a factor for entering port. The relation between salt water loaded draft and required channel depth is a problem not understood by all mariners. Several factors unite to increase the channel depth requirements over the salt water loaded draft, Figure 3.

As shown in the table, the salt water loaded draft for a 28,000 DWT vessel is approximately 33 feet 5 inches. Upon entering fresh water a ship of that tonnage will sink approximately one quarter inch for every foot of draft in salt water, or about 8 additional inches, due to water density variation. In addition, to improve steering characteristics she will be trimmed with a "drag" of approximately 3 inches for each hundred feet of length, or 1 foot 8 inches. A vessel sets at a depth determined by the relation between her average density and the density of the water she displaces. When underway, however, a "bow wave" is formed which starts moving away. The vessel itself moves forward steadily into the space previously occupied by the wave. Hence, a vessel underway moves in an artificial wave trough created by her own bow. She therefore rides somewhat lower than when at rest. This effect of depression varies with speed and form of the hull. The effect is accentuated in shallow water, and when the vessel occupies a considerable part of the channel cross-section the effect is greatly increased. When this is the case, the water velocities alongside and under the vessel are accelerated. The flow lines which this water follows interact with the channel bottom and cause a marked increase in the "squat" or "bottom effect". A 2-foot minimum bottom clearance is a requirement for safety. This is a precaution for avoidance of screw damage from sunken logs or other debris possibly carried into the channel. Further, it helps to minimize displacement of bottom sand by the propeller, which might easily scoop out a foot or two of sand and pile it up a short distance away to ground the next vessel passing. It can therefore be seen that a 28,000 DWT supertanker or bulk carrier with a 33-foot 5 inch sea water draft would require a 40-foot channel for safe navigation in fresh water.

In actual practice of seamanship, mariners usually use the hydrometer for measuring the specific gravity or density of waters to predict draft. The density of fresh water is 1000, and the average density of sea water is about 1025 ounces to the cubic foot. In some areas of exceedingly high salt content, such as the Suez Canal, the hydrometer will often float at 1040 or even higher. The water used for determining specific gravity should be drawn in a bucket from over the ship's side, well away from any overboard discharge pipes, and its temperature immediately observed and recorded. The instrument should be spun slightly in the center of the bucket so that the scale will quickly loose any vertical motion, and be read before the turning motion has entirely ceased.

Samples of the mechanics involved to determine draft frequently found on U. S. Coast Guard examinations follow:

Problem:—Find the draft to which a ship must be loaded alongside a pier where the density of the water is 1006, that she may float at a draft of 20 feet in sea water.

Average density of sea water.........		1025	
Draft at sea..........................		×20	
Density of water at pier........	1006)	20500	(20 feet
		2012	
		380	
Inches per foot......................		×12	
Density of water at pier........	1006)	4560	(4.5 inches
		4024	
		5360	
		5030	
		330	

Answer:—The ship must be loaded to draw 20 feet 4.5 inches. Hence, she would rise 4.5 inches on passing into sea water.

Problem:—A vessel's draft is 24 feet 6 inches at a dock where the hydrometer floats at 10. What will be her draft when she gets to sea where the hydrometer floats at 25?

Rule:—As the difference between salt water and fresh water is to the difference between salt water and the water in which the ship is being loaded, so is the allowance in fresh water to the required allowance.

Solution:—As 1025: 1010:: 24 ft. 6 in.: draft at sea.

$$\text{Draft at sea} = \frac{1010 \times 24.5}{1025}$$

Density at pier....................		1010	
Draft at pier.......................		×24.5	
Density of sea water........	1025)	24745	(24 ft.
		2050	
		4245	
		4100	
		145	
Inches per foot....................		×12	
Density of sea water........	1025)	1740	(1.7 inches
		1025	
		7150	
		7175	

Answer:—24 feet 1.7 inches

REQUIRED CHANNEL DEPTH	
1. Salt water loaded draft	33 feet 5 inches
2. Added draft in fresh water	8 inches
3. Drag (trim down at stern)	1 foot 8 inches
4. Open water "squat" at 10 knots	7 inches
5. Added "bottom effect squat"	1 foot 8 inches
6. Minimum safe bottom clearance	2 feet 0 inches
TOTAL CHANNEL DEPTH REQUIRED	40 feet 0 inches

Figure 3. Typical depth requirement.

DENSITY CURRENTS AND SILTATION

Density currents in relation to the siltation of docks are of prime importance in many areas. An example of this is the siltation problem in Queen Elizabeth II Dock on the River Mersey in England. As shown in Figure 4, the lock and dock are alongside the Manchester Ship Canal with the canal having separate entrance locks. The dock is designed for the use of oil tankers and will accomodate ships of 650 feet in length. The lock connecting the dock with the River Mersey is fitted with sliding caisson gates and prevents run-in at spring tides. A typical salinity at high water springs is 26 parts per thousand by weight (26 ‰) and the estuary tidal range at Eastham is approximately 30 feet. Water levels in the Queen Elizabeth II Dock as well as the Manchester Canal are maintained slightly above the average of high water spring tides. Fresh water tributaries constitute the primary source of water for the canal, supplemented to some extent by run-in at high spring tides through the locks at Eastham. Water level in the dock is maintained by the use of balancing culverts which supply water from the relatively fresh canal. An average salinity in the dock is 21 ‰, about 5 ‰ less than that in the estuary, but differences of up to 9 ‰ have been noted.

The origin of siltation has two possibilities: from the balancing culverts connected with the canal or through the lock connected with the River Mersey. Investigation has proved, however, that a negligible amount of silt enters from the canal.

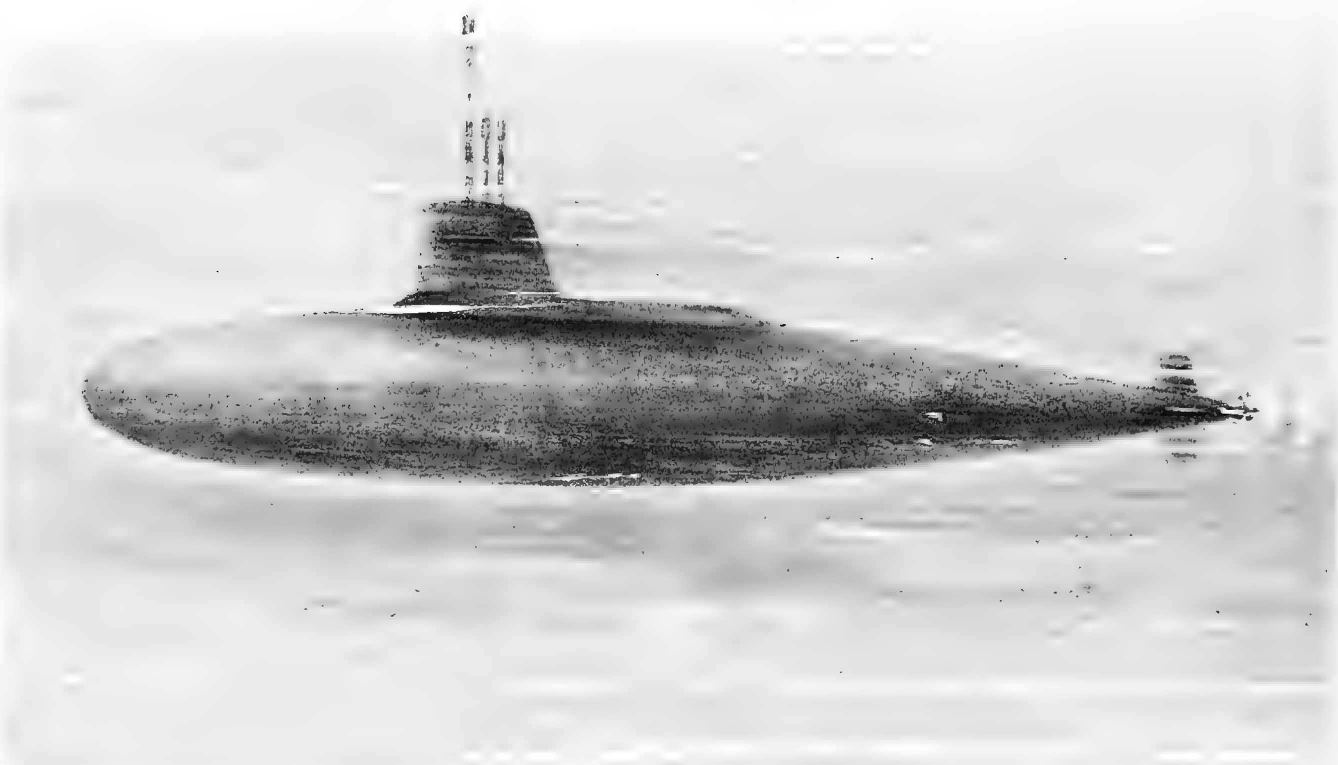
Conditions outside the lock are very favorable to continuous silt settlement from suspension. A mobile layer of unconsolidated silt with very high concentrations of solids has frequently been observed just outside the lock entrance. As the bed level of the estuary in this proximity is somewhat higher than that of the lock the mud layer gravitates, to some extent as a turbidity current, into the lock when it is opened. The effect of differences in salinity or density, however, is of somewhat greater interest. Locking operations are normally undertaken during the period of high water. However, this is also the time of the maximum difference in salinity between the lock and estuary.

When the outer lock gate is opened, denser and more saline water near the bed flows in carrying a large quantity of mud in high concentration. Consequently, there is a corresponding outflow of less saline and relatively clean water over the top of the more dense water and into the estuary. On completion of this process, the outer lock gate is closed and a similar condition develops when the inner lock gate is opened into the dock. That is, silt is carried into the dock by the strong in-flowing density current near the bed.

The rate of siltation in the dock varies from 3,000 to 8,000 cubic yards per week. This high rate of siltation is further complicated by the difficulties involved in using dredgers in an oil dock.

Several solutions have been suggested to help alleviate the situation. The most promising appears to be the use of vertical jets just outside the outer lock gate. These jets would be brought into action prior to the time the outer gate is opened. The mud lying in high concentrations near the bed would be carried in suspension in the upper layers of the water and, on opening the outer gate, would be carried away from the lock by the out-flowing surface current.

The fluctuation of water density is the prime factor in the siltation of tidal basins open to an estuary. Usually, the estuary water is heavy with silt in suspension, concentrations being particularly high in the lower layers during the early stages of flood tide.



Similar to the preceding example, the main in-flow takes place at the bed with heavily silt-laden water being carried into a relatively quiet basin, and deposition ensues naturally.

At sometime during the rising tide the salinity in the estuary exceeds that of the basin, with salinity increasing continuously until high water. This density difference tends to increase the inertia forces and thus strengthens the silt-bearing flow into the basin. Conversely, during the latter part of the ebb the salinity of the basin exceeds that of the estuary and the out-flowing density current assists the normal ebb flow from the basin. However, the total out-flowing current is not sufficient to remove the silt deposited during the rising tide.

DENSITY AND SUBMARINE APPLICATIONS

As an instrument designed for subsurface operation, submarines are required to dive from the surface into deeper layers of water. If the temperature and salinity of sea water were uniform from surface to bottom, these operations would be relatively simple. These two variables, however, change to cause varying densities which complicate subsurface operation. Such a complication is the decrease in buoyancy of a submarine at great depths, caused by hull compression. This must be compensated for by adjustments in ballast which the submarine must make under water. The presence of a density gradient serves to complicate this adjustment.

In addition to this, strong density gradients may hamper the ascent or descent of a submarine as well as impair the attempt to remain in balance or trim at a particular depth. The effect of density can very well be seen when one considers that a change in density of 0.001 changes the buoyancy of a fleet-type submarine by as much as 5,400 pounds. A change in salinity of one part per thousand alters the density by 0.00078 and thus changes the buoyancy of the submarine by 4,200 pounds. The role of density is of critical importance in certain phases of submarine operations.

Early investigations of sound conditions in the oceans led to the development of the bathythermograph, and it quickly became apparent that the whole problem of sound transmission in sea water was highly complex. Echo and listening ranges might be limited by any one of half a dozen or more factors. Much research was necessary before it was possible to devise a simple and accurate method of translating the basic temperature-depth curve of the bathythermograph into a practical prediction of sonar conditions.

Basically, bathythermograph literature is divided into two main groups, prediction manuals and charts.

Prediction manuals are designed so the probable limits of sonar ranges can be determined from any particular bathythermogram to enable efficient tactical operations. The submariner obtains information useful to him on the best depth for evasion, probable ping, listening ranges, and the most efficient diving procedure. Perhaps the most important use is for predicting ballast adjustments so that diving can be accomplished as quietly as possible and with a minimum of lost time.

The above-mentioned charts include sonar charts showing average echo ranging conditions, average diving conditions, and bottom sediment charts for shallow water sonar work. Charts on average conditions are of less tactical value than a bathythermogram obtained at the time and place needed because conditions are generally too variable to permit accurate predictions on the basis of averages. On the other hand, they provide a perspective unobtainable from a small number of bathythermograms and hence are useful not only to the observer for determining how often bathythermograph readings should be made but also for more strategic purposes. It is generally agreed that submarines can change depth more quickly and more silently if the diving officer understands the changes in density in the superficial layers of the ocean.

Maintaining efficient diving operations would be simple if the buoyancy of sea water was uniform. Since it is not, the variations in density that occur make each dive a separate problem requiring slightly different tactics. For example, if the submarine is in trim at periscope depth, its overall density is approximately the same as that of the surrounding sea water. Consequently, it has no great tendency either to rise or sink and such small movements as occur are readily corrected with slight changes in the angle of the diving planes. As the vessel travels at periscope depth it may move into water of greater or lesser density. An increase in temperature makes the water expand so that it is lighter. As density also depends on its salt content, changes in density require reballasting to bring the submarine back into trim. These lateral density changes are relatively slight in most cases, however, and it requires no great effort to keep the vessel on a horizontal course.

If a submarine in trim at periscope depth dives in water of uniform density it gradually gets out of trim because the increasing pressure at greater depths compresses the hull, making the submarine less buoyant. Therefore, under these conditions, a submarine must pump ballast during the dive in order to maintain trim. The amount of water to be discharged depends on the size of the submarine and on its compressibility, the latter varying with the type of construction and, to a lesser extent, with individual vessels.

As previously pointed out, temperature may decrease from the surface downward or in the water underlying a mixed surface layer. With decreasing temperature the density would increase downward. The sea may be thought of as a series of horizontal layers, one below another, in which the density is either uniform or increases downward by a greater or lesser amount.

A layer of increasing density gives a diving submarine more support and tends to counteract the compression effect. It is conceivable that the two effects may just balance, so that a diving submarine will remain in trim all the way down. On the submarine bathythermogram card, Figure 5, are printed isoballast lines, which show the amount of temperature change with depth that will, by its effect on the density of the water, exactly balance the compression effect of a submarine of the type for which the card was prepared. In any layer where the temperature-depth trace parallels the isoballast lines, the diving submarine will remain in the same state of trim throughout the layer. If the temperature is more nearly uniform, so that the trace crosses the isoballast lines toward the right, a diving submarine will get heavier and will have to discharge ballast to regain trim. In a strong gradient that crosses toward the left, it will be light and will have to flood ballast.

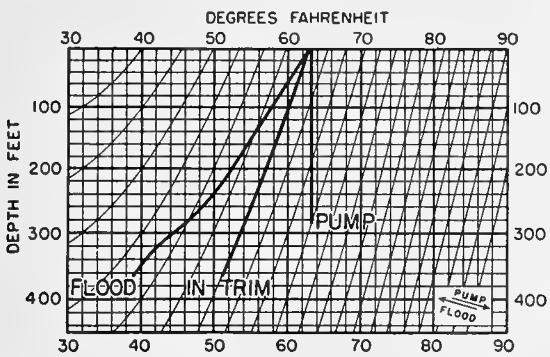


Figure 5. Submarine bathythermogram showing effect of temperature gradients on ballasting operations.

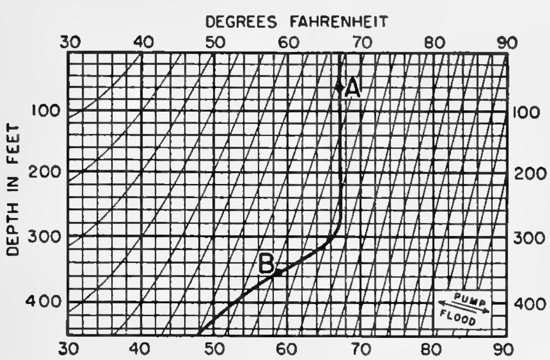


Figure 6. Submarine bathythermogram showing diving operations in a mixed layer with an underlying negative gradient.

It is common to find temperature conditions in the sea of the kind shown in Figure 6, in which there is a surface layer of mixed water and an underlying layer with a sharp decrease in temperature. Suppose a submarine is in trim at periscope depth (Position A) and makes a dive with no ballast changes. As it goes through the mixed layer it gets heavier and sinks more rapidly. But the temperature gradient below gives it more buoyancy again, and it finally comes to trim at Position B, where the temperature trace intersects the same isoballast line that passed through Position A. This is an example of a very quick and efficient dive that makes full use of temperature and density conditions. It would be much less efficient to dive in trim, discharging ballast while in the mixed layer, and flooding again below it. However, if there were no temperature gradient below the mixed layer, it would be more efficient, as well as safer, to remain more or less in trim all the way down. Thus, the correct diving procedure depends on knowledge of the vertical temperature structure of the water. The above example is simplified as it is not commonly possible to dive without making any ballast changes at all. Nevertheless, the general principle holds in almost any case. It is possible to dive more efficiently in water of known temperature structure than in an unknown situation, because when the diving officer knows the total amount of ballast change that will be needed, he can make the proper adjustments at an even rate through the entire operation. Hence, he will not be stopped by a sharp density gradient or forced to increase the noise output of the submarine in the effort to get through the layer. The time saved during such a dive may be as much as 10 or 15 minutes.

To obtain proper knowledge of the temperature structure of the water, it is necessary for the submarine to make frequent exploratory dives. Density conditions are best coped with in an emergency if a recent "BT" record is available. How often such dives are needed depends on the variability of temperature conditions where the submarine is operating.

The usefulness of density layers is too obvious to escape any submariner. For them it is a fortunate coincidence that from both the acoustic and diving standpoints density layers provide the best possible protection in evasion. The so-called "layer effect" reduces the echo and listening ranges. A submarine submerged well below the top of a density layer is more difficult to detect. It is also apparent that a submarine in the middle of such a layer requires little effort to maintain constant depth. If it rises it will be in water of less buoyancy and will tend to sink again. If it goes deeper it will encounter more buoyant water. Hence, it is not only easy to maintain quiet operation, creeping or balancing with the motor stopped, but it is also easier to maintain control of the ship.

THE GULF STREAM

E. E. Watson
Queen's University, Kingston, Ontario

Anyone who has sailed from the eastern coast of the United States to Bermuda or the West Indies will recall the startling transition from the cold, dull coastal water to the deep blue waters of the Gulf Stream. The air becomes warmer, and the breeze freshens; the roll of the ship has increased, but, above all, one is fascinated by the intense blue of the water. The white air-bubbles along the ship's sides and in its wake enhance the depth and purity of the color. Something yellow is floating on the surface, and as we come closer it turns out to be a stray bit of Sargassum weed. Soon we see more and more of this brightly colored weed, floating in patches or in long streaks. Columbus thought this weed grew on rocks or submarine ledges, and this idea persisted for a long time, but we know now that it is a pelagic perennial which grows fresh, greenish shoots at one end while withering to a brown color at the other. It is kept afloat by berry-like bladders which contain air. This Sargassum or gulf weed is found over a large area of the North Atlantic, but does not reach the North American coast. It is first noticed in any quantity as we approach the Gulf Stream. The most marked characteristic of the Stream is its blue color, flecked with the yellow of the weed, for there are no "landmarks" at sea to tell the casual observer that he is not only being driven through the water by the ship's engines or sails but is carried by the water itself in a northeasterly direction at a speed which may be as great as 4 knots. For a modern liner making 20 to 30 knots such a current is of no great importance, even though it may be about 60 miles wide, but for a sailing vessel it was, and is, a serious navigational influence.

Owing to its effect on the course of ships, considerable knowledge of the surface characteristics of the Stream has been accumulated, but it is only in recent years that we have learned much about its sources, the mechanism of its propulsion, and the transfer of moisture and heat to and from the atmosphere above it. Popular conceptions of the Gulf Stream are somewhat vague and often incorrect. Along the Atlantic seaboard any unusual weather condition is sure to be blamed on the Gulf Stream, especially a long hot spell such as was experienced in the summer of 1949. Since on the eastern side of a continent the weather moves from land to sea, the oceanic conditions are more likely to be influenced by the weather coming from the land than the other way round.

HISTORY AND THE GULF STREAM

Before describing the Gulf Stream and its problems according to modern oceanography, one may approach the subject from an historical point of view. On Columbus' first voyage in 1492, when nearing the Bahamas, he was influenced by the flight of birds (the fall migration by way of Bermuda to the West Indies) to change his course from west to west-southwest. Had he not done so his landfall would have been Eleuthera Island, and he would have sailed through Providence Channel straight into the Gulf Stream. He might then have made the coast of Florida or have been swept along the coast of Georgia and the Carolinas, if lucky enough to survive. There would have been no gold from Hispaniola, and the history of the Spanish conquistadors in the Caribbean might never have been written. It is a striking fact that the eastern coast of the present United States was not discovered by a direct voyage from Europe. In 1498 John Cabot discovered Newfoundland and pushed southward around Cape Breton. These explorations were continued by his son Sebastian, but how far down the coast he penetrated is uncertain. Even before the Cabots fishermen may have known the Nova Scotian and New England shores, but they would have been interested in the fishing banks rather than the shore, and hence disinclined to publish their knowledge. Probably the first thorough exploration of the coast was carried out by Giovanni Verrazzani, a Florentine, on behalf of Francis I of France. In considering the possible effect of the Gulf Stream on the early explorations, it is worth while to look at some of the details of Verrazzani's voyage. He left the isle of Madeira (which is almost at the same latitude as Bermuda) in January 1524, and sailed due west. By 20 February, a month later, he had traveled about 1,600 miles when he was "overtaken by a tempest." Unfortunately his account does not state the direction in which he was blown nor the duration of the tempest. After this he changed course to west by north, and 25 days and 1,300 miles later he discovered a new land. His landfall must have been near Charleston, S. C., or Savannah, Ga. This means that he must have crossed the Gulf Stream where the flow is rapid, so that he must have been carried north for "many leagues." It is hard to understand how he reached the coast at the same latitude as his starting point, Madeira, unless his mid-Atlantic storm carried him southward, though not so far as to land him on the Bahamas. Verrazzani sailed up the coast as far as Cape Breton, landing at many points. In 1562 Capt. John Ribault, again on behalf of the French, sailed directly from the Brittany coast to the west "to prove a new course which hath not been yet attempted." It was thought that this could not be done, for lack of favorable winds, but Ribault wished to avoid the more southerly route because of possible unpleasantness with the Spaniards. He succeeded in reaching the coast of northern Florida directly, but gives no details of his voyage. It is noteworthy that none of these explorers knew that he had crossed the Gulf Stream. No wonder the early maps of North America were distorted!

Not until two centuries later do we find what is probably the first scientific reference to the Gulf Stream. This occurs in a letter sent by Benjamin Franklin to the secretary of the British Post office,[1] much of which is quoted below:

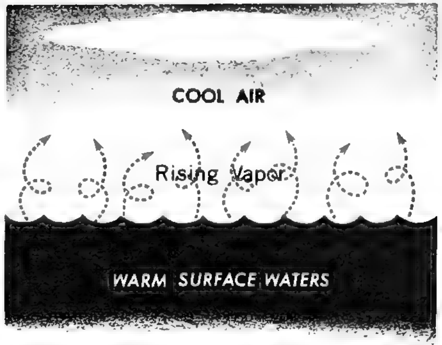
> Craven Street, October 29, 1769
>
> Sir: Discoursing with Captain Folger . . . I received from him the following information, viz.: . . . that the whales are found generally near the edges of the Gulph Stream, a strong current so called, which comes out of the Gulph of Florida, passing north-easterly along the coast of America, and then turning off most easterly, running at the rate of 4, 3½, 3 and 2½ miles an hour; that (people concerned in the whale fishery) . . . cruise along the edges of the stream in quest of whales . . . ; that they have opportunities of discovering the strength of it when their boats are out in pursuit of this fish, and happen to get into the stream while the ship is out of it, or out of the stream while the ship is in it, for then they are separated very fast, and would soon lose sight of each other if care were not taken; that . . . they frequently . . . speak with ships bound from England to New York, Virginia, etc., . . . and it is supposed that their fear of Cape Sable shoals, George's Banks, or Nantucket shoals, hath induced them to keep so far to the southward as unavoidably to engage them in the same Gulph Stream, which occasions the length of their voyages, since . . . the current being 60 or 70 miles a day, is so much subtracted from the way they make through the water.
>
> At my request Captain Folger hath been so obliging as to mark for me on a chart the dimensions, course, and swiftness of the stream from its first coming out of the Gulph . . .; and to give me withal some written directions whereby ships bound from the Banks of Newfoundland to New York may avoid the said stream, and yet be free of danger from the banks and shoals above mentioned . . . With much esteem, I am, etc. . . .

In a later paper, written in 1785, Franklin said that he had been prompted to write this letter by the observation that the mail packets from Falmouth to New York were generally a fortnight longer in their passages than merchant ships from London to Rhode Island. The chart referred to in his letter was "engraved and copies were sent down to Falmouth for the captains of the packets, who slighted it however." It is amusing to note that then, as now, sea captains were suspicious of any new scientific procedure or information, particularly when coming from a landsman, despite the fact that their navigation is entirely dependent on accurate scientific instruments and calculations.

---

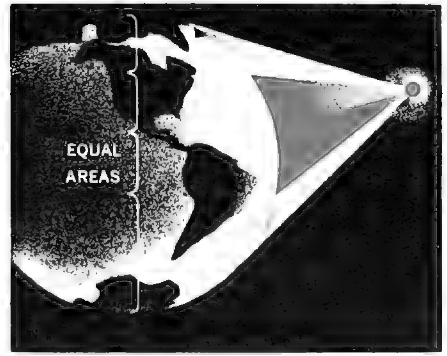
[1] Carl Van Doren, ed., *Benjamin Franklin's Autobiograhical Writings* (New York: The Viking Press, 1945), pp. 191–2.

TEMPERATURE AND SALINITY INFLUENCES AFFECTING DENSITY OF THE GULF STREAM

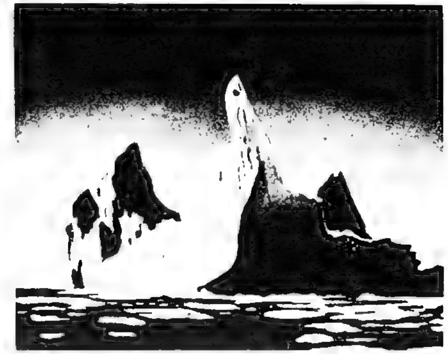


In the middle and higher latitudes evaporation is greatest in the winter.

Fresh water is added to the surface by great rivers.



More heat is absorbed from the sun in the tropics than in higher latitudes.



Fresh cold water from melting ice in Polar regions and winter cooling of surface waters along the coast.

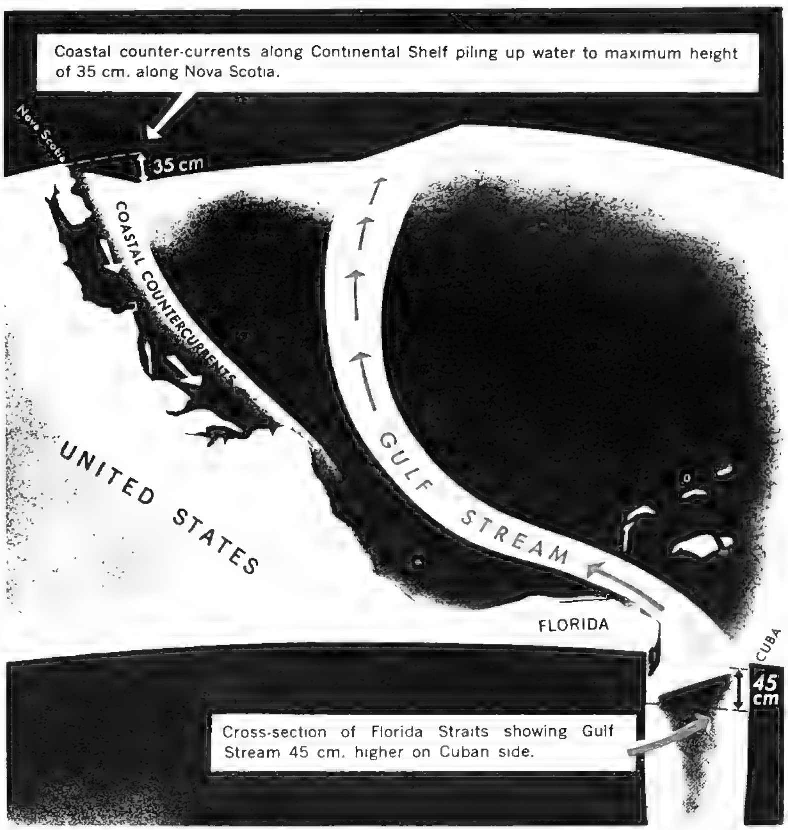
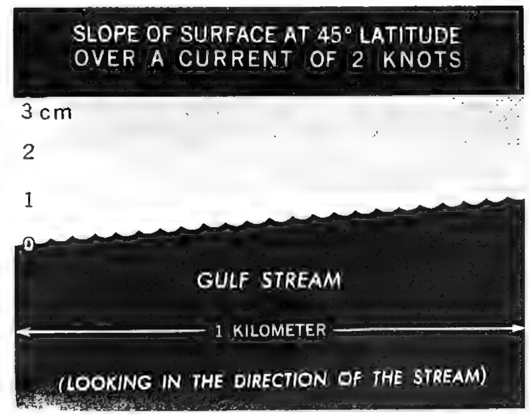
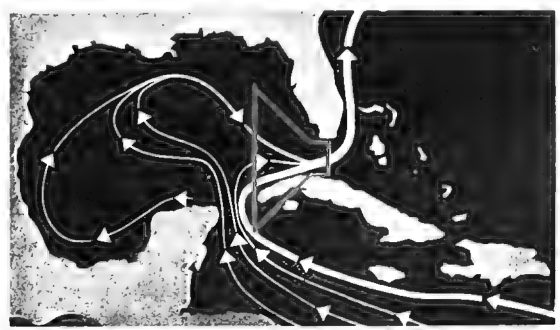


Illustration showing differences in elevation of the sea surfaces due to influences of the Gulf Stream and Coastal Counter Currents.

Red band represents 19 cm. difference in sea level between the Gulf and the Atlantic Coast.



The ocean surface above a current is not level. The water on the right is lighter and therefore higher than on the left. This provides a horizontal pressure-gradient to oppose the Coriolis Force.

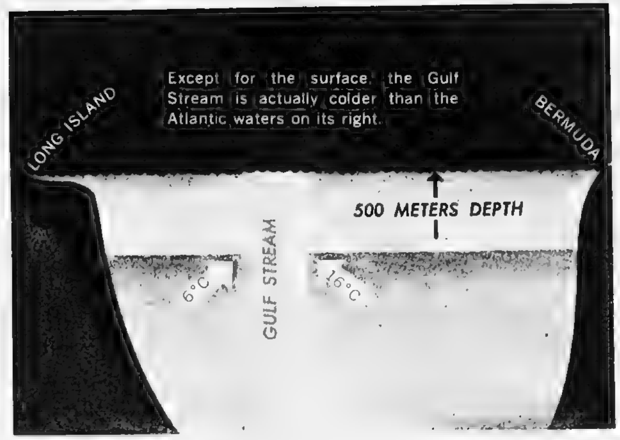


The current driven through the Yucatan Channel has only one outlet, be tween Florida and Cuba. This funnel is the genesis of the Gulf Stream.

THE CORIOLIS EFFECT

Owing to the rotation of the earth, there is an apparent force known as the "Coriolis Effect", which tends to deflect water, vehicles, projectiles and any other bodies moving over the surface of the earth to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

A steady state of flow is achieved when this Coriolis Force is balanced by a horizontal pressure-gradient due to the distribution of water density.



Cross section profile of the ocean from Long Island to Bermuda showing the rise in temperature below the surface across the Gulf Stream.

The Gulf Stream is by no means a surface current, its speed decreases from the surface downward, but it is still significant at a depth of 1,500 meters.

Friction from permanent wind systems seems to be the most important factor in determining the motion of the Gulf Stream in the North Atlantic Ocean, with northeast trade winds blowing across the southern part and prevailing westerlies across the northern part

About a century later, in 1860, a map was published by Matthew F. Maury, in his *Physical Geography of the Sea*, showing the current system of the North Atlantic. It contains gross errors, which must be attributed to his difficulty in obtaining information from those seafarers who would have it. For instance, the northern limit of the Gulf Stream is shown close to Cape Cod and the Nova Scotia shore and above the Grand Banks, whereas it never reaches George's Bank, which lies to the east and south of Cape Cod, nor does it ever flow onto the Grand Banks, a fact which even then would be known to all fishermen in those regions.

A more accurate knowledge of the Gulf Stream was not obtained until physical oceanography had been established as a science in the present century. The real beginning of oceanography was the *Challenger* expedition of 1872–76, but the cost of oceanographic research has made progress very slow. As in other branches of science a great impetus to development has come with each war. After 1920 the technique of sounding was revolutionized, with sonic depth finders replacing the old sounding wire. During the second World War the bathythermograph for temperature measurements became standard equipment for destroyers and submarines, and submarine warfare in general made it necessary to know what was happening within the ocean waters as well as on their surface. Scientific explorations of the Gulf Stream were initiated by the German and Norwegian oceanographers, but since the founding of the Woods Hole Oceanographic Institution in 1930 by a Rockefeller endowment much more information has been obtained about the Stream.

WHAT DRIVES THE GULF STREAM?

There are two major causes for the ocean currents in a large basin such as the North Atlantic—unequal distribution of density and the friction of the permanent wind systems. With the northeast trade winds blowing across the southern part and the prevailing westerlies across the northern part, one would expect that a large clockwise circulation of the water would develop, provided that no internal forces arose to prevent this motion. The friction of the wind seems to be the most important factor in determining the motion of this gigantic North Atlantic eddy, but the distribution of density complicates the details of the motion. Fresh water is added to the surface by the great rivers, and more heat is absorbed from the sun in the tropics than in higher latitudes. The process of evaporation influences both salinity and temperature. When the sea surface is warmer than the air above, it loses heat rapidly to the air and this air rises with turbulence, sometimes producing thunderstorms. But when the water is colder than the air the reverse process does not take place, because the air that is chilled does not rise and mix with that above it, so that heat transfer downward is very slow and inefficient. Evaporation utilizes heat while condensation releases heat. The greatest evaporation occurs, not when the air is hot, but when cold air flows over warm water. It may be surprising that in middle and higher latitudes, where the sea surface in winter is warmer than the air, the evaporation is greatest in the winter, not in the summer. This illustrates the intricate relationship between the physical conditions in the ocean waters and the meteorological conditions. Two seasonal factors that influence the oceanic circulation are the influx of cold but fresh water from the melting of ice in the polar regions, and the winter cooling of the surface waters along the coast, which so increases the density that the surface water sinks and the whole column of water is overturned and thoroughly mixed. To understand the structure of the Gulf Stream it is necessary to look briefly at the dynamics of ocean currents in general. Owing to the rotation of the earth, there is an apparent force which tends to deflect a moving mass of water to the right in the northern hemisphere. A steady state of flow can be achieved only if there is a horizontal pressure-gradient to oppose this, and in turn this pressure gradient can be produced only by a distribution of density such that the lighter water is on the right with the isobaric surfaces sloping upward to the right of an observer looking in the direction of the stream. This means that the ocean surface above a current is not level, but for a current of 2 knots in latitude 45° the slope is only a rise of 1 centimeter in a distance of 1 kilometer, or one in 100,000.

With this background we may examine the Gulf Stream system, first as regards its horizontal distribution and then its internal structure. The North Equatorial Current is driven by the northeast trades towards the Caribbean and joins a branch of the South Equatorial Current which has crossed the Equator. Thus the water entering the Caribbean contains some water of South Atlantic origin, while the water flowing north of the Greater Antilles is the same as that of the Sargasso Sea. The current driven through the Yucatan channel has only one outlet, between Florida and Cuba. This outflow is the genesis of the Gulf Stream system. Only a negligible portion originates in the Gulf itself. The term "Gulf Stream system" is now used to include the whole northward and eastward flow beginning at the Straits of Florida and including the various branches moving across the North Atlantic from the region south of the Newfoundland Banks. The system is subdivided into the following parts: (1) The Florida Current, from the Straits of Florida to Cape Hatteras, where the current swings outward from the continental slope. Beyond the straits the water from the Yucatan channel is joined by the Antilles Current, but the name Florida Current is retained up to the cape. (2) The Gulf Stream from Cape Hatteras to a point east of the Grand Banks at about longitude 45°, where the stream begins to fork. This terminology is a restricted use of the popular term, but is essential for clarity. (3) The North Atlantic Current, from this point east and north, including the several branches. In this region the main current is often masked by erratic wind-drift surface-movements, commonly known as the North Atlantic Drift. The major branches are the Irminger Current, flowing west below Iceland; the Norwegian Current flowing north through the Norwegian Sea into the Polar Sea; and an irregular branch which flows towards the Bay of Biscay. The Irminger Current joins the East Greenland Current and can be detected by its salinity (35 per mille[2]) as far south as Cape Farewell. The Norwegian Current is warm enough to keep the port of Hammerfest, though well within the Arctic Circle, from ever being closed by ice.

To return to the Florida Current: The energy of the flow is derived from the difference in sea level between the Gulf and the Atlantic coast, the difference being 19 centimeters between Cedar Keys and St. Augustine (on opposite sides of Florida). This difference of level is probably maintained by the trade winds. Because of the flow through the straits the lighter water must be found on the Cuban side and the sea surface there should be higher. It is in fact about 45 centimeters higher, and the possibility of direct measurement here corroborates our indirect methods of calculating velocities in the ocean from the distribution of density. The direct current measurements of Pillsbury, made from the survey vessel *Blake* in the years 1885–89, are among the classical data of physical oceanography, since they provide a test for indirect methods which can be applied elsewhere in the ocean. The transport of water through the Straits of Florida is about 26 million cubic meters per second. On its left the shallow coastal water is at rest and the transition to the blue water of the stream is so sharp that it appears as a line from horizon to horizon. The Antilles Current brings in about 12 million cubic meters per second, and as the current moves toward Hatteras more water is drawn in from the Sargasso on the right.

Beyond Hatteras the Gulf Stream swings away from the coast, and on its left are the coastal waters over the shelf and a slope water with temperatures of 4°–10° C. Here great seasonal variations occur, and eddies from the Gulf Stream intrude. Off Chesapeake Bay the transport of the stream has increased to about 75–90 million cubic meters per second, so that a great deal of Sargasso water and deep water has been added, but at the tail of the Grand Banks the transport has fallen off to less than 40 million cubic meters per second, showing that water has been discharged southward from the stream. The dynamics of this flow are not properly understood, though several theories have been propounded. An interesting point is that precise leveling along the eastern coast shows that sea-level increases from Florida to

[2] 35 parts of salt in a thousand by weight.

Nova Scotia by 35 centimeters. There is a discrepancy between the results of precise leveling and "oceanographic leveling" based on the current and mass distribution: The piling up of water along the coast takes place in the shallow coastal water only and does not extend beyond the continental slope. At the edge of the shelf the level sinks to the value suggested by the oceanographic data, and consequently a current flows to the south along the continental slope, following the contour lines. This current, flowing in the opposite direction to the Gulf Stream, lies between it and the coast. At the tail of the Grand Banks the Gulf Stream comes into close propinquity with the Labrador current, which flows south past Newfoundland and on to the banks. The warm moisture-laden air from over the Gulf Stream is chilled as it passes over the cold surface water of the Labrador current, thereby producing the abundance of fog for which the region is noted.

As to the internal structure of the Gulf Stream, the main characteristic is that the stream is by no means a surface current, but extends to great depths. The speed decreases from the surface downward, but it is still significant at a depth of 1,500 meters (nearly 5,000 feet). The flow of water in the surface layers is only a small part of the total transport of the stream, and this fact modifies the common concepts of the stream which are based on surface phenomena. If we examine a vertical section of the ocean from the eastern end of Long Island to Bermuda, we find that at any level except near the surface, the temperatures rise *as we go across the stream.* Thus at a depth of 500 meters (1,640 feet) the temperature rises from 6° to 16° C. This means that the water which is moving rapidly, and which therefore constitutes the stream, is on the average *colder* than the Atlantic water on its right. The oceanographer may be forgiven if he dislikes the popular concept of the Gulf Stream as a river of warm water running through the ocean.

Copyright Queen's Quarterly 1950

(Reprinted from Queen's Quarterly, Vol. LVII, No. 1, 1950).

U. S. GOVERNMENT PRINTING OFFICE : 1967 O - 272-494