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THE EFFECTS OF MARINE ORGANISMS ON ENGINEERING MATERIALS FOR DEEP-OCEAN USE.

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U. S. NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

THE EFFECTS OF MARINE ORGANISMS ON ENGINEERING MATERIALS FOR DEEP-OCEAN USE

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by

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OBJECT OF TASK

To determine the effects of pelagic and benthic marine organisms upon engineering materials for use in deep-ocean environments.

ABSTRACT

A literature survey was made of the effects of marine organisms on various types of engineering materials, particularly in deep-ocean environments. Numerous materials such as manila ropes, cotton fishing nets, petroleum hydrocarbons, rubber products, steel, submarine cables (telegraph and telephone), concrete, and cork (floats) have been attacked and destroyed by various marine organisms in various depths, from shallow protected waters to ocean depths exceeding 7,200 feet. Marine organisms which have been observed to be responsible for the destruction of these materials include species of wood- and rock-burrowing animals, purple sea urchins, sharks, fish, and microorganisms.

A proposed field and laboratory study to accumulate further biological and engineering data about the relative behaviors of various materials to marine biological deterioration is presented.

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INTRODUCTION

The sea covers over 70 percent of the earth's surface and is becoming increasingly recognized as an important new frontier to be conquered for man's use. The Bureau of Yards and Docks has responsibility for the design, construction, and maintenance of all naval shore bases and facilities. In recent years increased attention has been paid to the ocean in general and to the greater depths of the ocean in particular. BuDocks capabilities may therefore be expanded to include (1) construction of fixed undersea facilities deep within the ocean, and (2) servicing of ocean structures and equipments for both military and peaceful uses. Undersea facilities and recovery operations may be required for (1) underwater supply stations such as a fuel cache, (2) sonar stations for submarine detection, (3) mining the vast mineral resources at the ocean bottom, and (4) many other functions and activities yet to be established.

For any deep-sea construction program, novel applications of many conventional materials must be devised and basic and applied research for materials with new and unusual properties must be undertaken. However, before either conventional or newly developed materials are structurally integrated for long-term submergence in the little-known sea environment, the effects of biological organisms in this environment upon such materials should be studied and evaluated under both controlled laboratory and field tests.

There are wide varieties of marine organisms capable of causing serious destruction and fouling of all types of submerged engineering materials and equipment in shallow waters. Man's struggle against destructive marine animals is well documented in the literature, going back as far as Theophroastus in 350 B. C.[1] Because very little is known about the life cycle and ecology of many of these marine organisms, it is not known whether they are also capable of descending to great ocean depths and perhaps causing serious damage to various submerged materials. There are, however, reports of unspecified species of Teredo, Limnoria, and Xylophaga (marine borers) attacking submarine cables in deep waters. For this reason, the shallow-water species should not be neglected. Throughout this report, numerous references about materials attacked by marine organisms in shallow waters are cited in addition to references cited about materials attacked in deep waters.

The present study was undertaken to investigate, analyze, and evaluate the effects of marine organisms of the archibenthic and abyssal zones on various types of engineering materials such as elastomers, plastics, metals, portland-cement, concrete, and electrical wire conductors. The study places particular emphasis upon the biological deterioration of engineering materials exposed in the deep-ocean environment as well as in the marine sediments.

In the following pages a preliminary analysis of environmental variables is summarized, the results of a literature survey of the problem are presented, and a proposed field and laboratory study to accumulate further data on the effects of marine organisms on engineering materials is submitted.

PHYSICAL PROPERTIES OF SEA WATER

The environmental variables which are of immediate interest to marine biologists and oceanographers include salinity, temperature, density, viscosity, pressure, light penetration, suspended organic matter, dissolved gases, and hydrogen-ion concentration.[2, 3, 4] A brief summary for each of these variables follows.

Salinity

The salt concentration of sea water is known as salinity and is expressed as grams of salts per kilogram of sea water (parts per mille, o/oo). The salinity in the ocean is generally between 33 and 37 o/oo. Because the salinity range in the open oceans is rather small, an average value of 35 o/oo is used.

Temperature

The average surface temperatures for all the oceans range from about 27 C near the equator to (-) 1 C in the arctic and antarctic regions. However, with increasing depth not only does the temperature drop, but the seasonal variations become negligible below depths of about 600 feet. The temperature at 600 feet is about 20 C, at 4,000 feet it is about 5 C, and below this depth the temperature falls to a minimal value of 1 to 2 C in the abyssal regions.

Specific Gravity

The specific gravity of sea water is dependent upon salinity, temperature, and pressure. At atmospheric pressure and 0 C the specific gravity of sea water of average salinity 35 o/oo is about 1.028, and at 10 C it is about 1.027.

Viscosity

The viscosity of sea water is slightly greater than that of fresh water (0.0893 poises at 25 C) and increases gradually with an increase in salinity and to a much greater extent with a decrease in temperature. At a salinity of 35 o/oo, for example, the increase of viscosity is almost two-fold for a temperature drop from 25 to 0 centigrade.

Pressure

Hydrostatic pressure increases by about 1 atmosphere for each 32.8-foot increase in depth, and shows a range from zero at the surface to some 1,100 atmospheres at the greatest known depth of 36,000 feet. The mean ocean depth of all the oceans and adjacent seas is about 12,500 feet.

Light

Light is absorbed rapidly when passing through the surface waters of the sea and the intensity falls off with depth. In the clearest open ocean water, light is perceptible to a depth of 2,300 feet. In average open ocean water, light of selective wavelength bands is perceptible to a depth of 1,000 feet, and in turbid coastal waters to 200 feet.

Suspended Organic Matter

Sea water contains a small quantity (1.2 to 2.0 mg of carbon per liter) of dissolved and suspended organic matter, which is derived from the excreta of living organisms and their decomposed tissues after death.

Dissolved Gases

The dissolved gases of particular biological interest are oxygen and carbon dioxide. The dissolved oxygen content of ocean water varies from 0 to 8.5 ml/liter STP (standard temperature and pressure). It is greater in the surface layers where free exchange with the atmosphere can take place than in the subsurface waters, which obtain their oxygen through mixing, wind action, etc. In certain closed seas and basins in which there is deficient circulation, the bottom layers become stagnant and the oxygen concentration falls to zero. Hydrogen sulfide and other products of putrifactive decomposition such as methane may be present in such areas. The carbon-dioxide concentration in sea water varies from 34 to 56 ml/liter. It is present as free CO_2 and H_2CO_3, but the greater part of carbon dioxide is present as carbonates and bicarbonates; the content of free CO_2 and H_2CO_3 decreases with increasing temperature and salinity. In general, the carbon-dioxide content is higher in the deeper waters than at the surface layers.

Hydrogen-Ion Concentration

Sea water is normally alkaline in reaction, with a pH range of 8.0 to 8.4 in surface waters. In stagnant basins where large amounts of H_2S are present (anaerobic condition), the pH may approach 7.0.

MARINE ORGANISMS RESPONSIBLE FOR MATERIALS DAMAGE

The results of the literature survey on the biological deterioration of various engineering materials in the marine environment are tabulated in the Appendix. Materials attacked by biological organisms, the type of damage resulting from attack, the geographical location where the damage occurred, biological organisms responsible for the damage, and other pertinent information to the subject are listed and referenced. The following discussion is based on that data.

Crustaceans

Crustaceans responsible for extensive damage to materials in the sea include species of Limnoria also known as gribbles. Limnoria are related to the shrimps and lobsters and are world-wide in distribution. They are normally found attacking the surface of submerged wooden structures in shallow waters (harbors). However, materials other than wood, such as the gutta-percha coverings of submarine cables at a depth of about 360 feet in the ocean, have been penetrated by Limnoria lignorum. One species of Limnoria off the coast of Japan is known to inhabit depths of approximately 1,000 feet. It is suggested[5] that the absence of suitable edible materials in the deep-ocean environment may be one of the limiting factors which confine Limnoria to shallow water.

Species of Sphaeroma, also a crustacean, are found burrowing into sandstone in San Francisco Bay and into sea walls made of clay stone in Hawk Bay, New Zealand. Sphaeroma are less important economically than Limnoria in the amount of damage they cause to engineering materials.

Mollusks

The mollusks responsible for extensive damage to various types of engineering materials in the sea include species of Teredo, Bankia, Xylophaga, and Martesia. These mollusks are related to the clams and the oysters and are world-wide in distribution.

They are normally found attacking submerged wooden structures in harbors, or burrowing into rocks, coral, and mud on the ocean floor. Because of their ability to attack varied materials from soft wood to hard rocks, it is anticipated that undersea construction materials which serve as a source of food and shelter to these animals will be susceptible to attack and destruction.

One of the early engineering materials exposed in the deep-sea environment was the submarine cable. Numerous reports and articles have been published pertaining to damages inflicted upon these cables at various depths, and an extensive bibliography has been compiled by Clapp and Kenk.[6] Most of the attacks upon submarine cables were confined to the coverings of jute and hemp, although a few observers report attacks on the gutta-percha insulation of the cables by the mollusks belonging to the family Teredinidae. These attacks have occurred from depths of a few feet of water to a depth of 7,200 feet. Roch[7] in his paper on Mediterranean Teredos refers to Teredo utriculus obtained from a depth as great as 10,000 feet. A species of Xylophaga was found ranging from a few feet of water to 6,000 feet or more; some have been found burrowing into the insulation of submarine cables, causing physical damage and short circuits.

In a recent report,[8] mention is made of a species of Martesia boring through the outer solid-lead sheath and subadjacent insulation of an electrical conduit cable (off the coast of Florida), producing a blowout which seriously interrupted urban electrical service.

Martesia striata has been responsible for attacks and penetration of solid-lead sheathing of a submarine power cable (in Boca Ciega Bay, Florida) resulting in an electrical short. The exposed lead sheathing was riddled with holes. Some holes were about 6 mm in diameter and 2 mm in depth. In another instance, a 4-mm-thick solid-lead sheath covered with two layers of asphalt-impregnated jute which served as a bedding for a single layer of galvanized-steel armor wire was penetrated by Martesia striata and Barnea truncata 300 feet from shore in 3.5 feet of water where the bottom was muddy.

Even concrete has not been immune to attack by marine animals. Inspection of concrete-jacketed wooden piles in Los Angeles Harbor revealed the presence of 7 to 8 burrowing animals per square foot of concrete. Of 18 piles, 16 jackets were found to be attacked by rock-boring animals such as Pholadidae penita, Platyodon cancellata, Lithophaga plumula, and Botula falcata. Burrows in the concrete averaged 1-3/4 inches in diameter. The concrete jackets, which had an average thickness of 2-1/3 inches, consisted of cement mortar with no coarse aggregate.

The crushing strength of a 2-1/2-inch by 3-1/2-inch by 4-1/2-inch concrete specimen was 1,726 pounds per square inch. It is suggested[9] that a good concrete containing aggregates of gravel and broken stones would offer greater resistance to attack by these rock-boring animals.

Marble columns which were part of the cargo of a Roman ship wrecked in the Mediterranean Sea in the first century B. C. were found riddled by the rock-boring animals Lithophaga and Pholas, producing a spongy appearance.

Fiber mooring ropes which held buoys and mooring floats to anchors were damaged by Teredo morsei Bartsch, and some ropes were entirely severed mainly at the lower ends (near the attachments to the anchors).

Marine Bacteria

The marine bacteria's indispensible function in the biological cycle of the sea is primarily one concerned with transformation of organic and inorganic substances. The characteristics, distribution, and function of marine bacteria have been described in great detail by ZoBell.[10] Some are autotrophic bacteria and are able to build carbohydrate and protein out of simple substances such as carbon dioxide and inorganic salts. One group of autotrophes, the chemosynthetic bacteria, derive their energy from the oxidation of various inorganic compounds such as hydrogen sulfide, sulfur, or ammonia on the sea bottom where there is insufficient light for photosynthesis. However, the majority of marine bacteria are heterotrophic bacteria which obtain their energy and carbon source by the oxidation of organic compounds. During bacterial metabolism the organic substances in the sea water and sediments are transformed into carbon dioxide, water, ammonia, and minerals. These bacteria convert from 30 to 40 percent of the carbon of organic compounds into bacterial cell substances.[11] Other geochemical changes which take place during the bacterial metabolism include consumption of oxygen, production of heat and hydrogen sulfide, and changes in hydrogen-ion concentration.

Marine bacteria are found in sea water and in bottom sediments from shallow depths to the deepest portion of the sea. The greatest number have been found in coastal waters where the greatest abundance of plant and animal life is also produced; however, the greatest density by far of bacterial population is found on the bottom, where millions of cells per gram of wet mud may occur.[12] The aerobic bacteria, which require free oxygen for growth, are found in sea water and in the first few inches of bottom sediment. The anaerobic bacteria, which are able to grow in an environment where free oxygen is absent, are usually found in areas where relatively heavy accumulations of organic matters are found, such as in marine bottom sediments, under deteriorating organic coatings of various materials, and in minute pits found in corroding metal surfaces.

ZoBell and Morita found millions of viable bacteria per gram of sediments taken from depths exceeding 33,000 feet on the Danish Galathea Deep-Sea Expedition.[11] Many deep-sea species are able to grow well at a temperature as low as 0 centrigrade. The high hydrostatic pressures which prevail at great depths are not a deterrent to bacterial life; ZoBell found that some bacteria are actually barophillic or pressure-loving bacteria and reproduced only when subjected to 400 to 1,000 atmospheres.[13] (See Figure 1 for method of converting atmospheres to pounds per square inch.)

Because marine bacteria are able to live in various marine environments and can utilize various materials for growth, they are one of the major biological agents of deterioration and fouling of various organic and inorganic materials and equipment in sea water and in marine sediments. Marine bacteria play an important role in the fouling of submerged surfaces by (1) affording a foothold for other animals, (2) discoloring glazed or bright surfaces, (3) becoming a source of food for barnacles, etc., and (4) promoting the deposition of the carcareous cements of sessile animals.[10] The effect of fouling by marine organisms (including the bacteria) on the acoustic efficiency of submerged sonar equipment is extremely serious, resulting in an average attenuation of about three decibels per inch of fouling thickness.

Pits between 10 and 37 mils in depth were formed beneath the growth of fouling organisms (barnacles) on the surface of monel metal immersed in sea water at Port Hueneme, California. These pits may have resulted from localized oxygen-concentration cells due to barnacle growth. Bacterial film (produced as a result of abundant bacterial growth) may form a protective layer over an antifouling coating normally toxic to fouling animals, thereby affording these animals a foothold for growth.[14] It may be possible that a simple rapid test to determine the effectiveness of antifouling paints can be developed by testing antifouling paint against marine microorganisms.

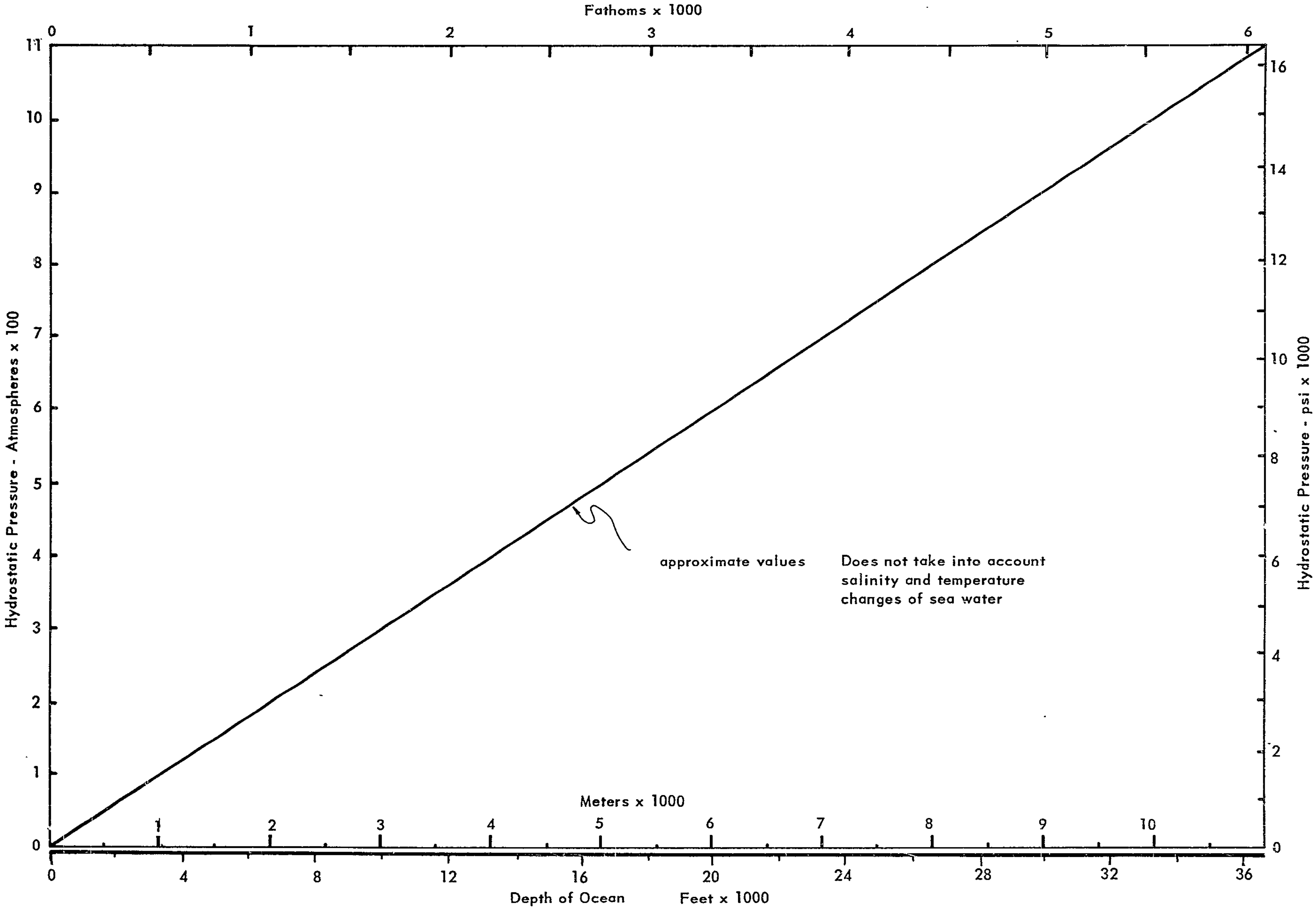
Marine cellulose-decomposing bacteria are responsible for millions of dollars worth of damage to fiber nets, seines, and lines used by commercial fishermen. The average useful life of this equipment is less than two years.[15] Manila ropes and cotton fishing nets have been destroyed after 14 months in sea water. Also present in the sea are cellulose-destroying fungi found infesting natural fibers and wood.[16, 17] Rubber products including rubber hoses, chlorinated rubber paints, rubber gaskets and similar materials used at sea, either submerged or subject to frequent wetting with salt water, are decomposed by the action of marine bacteria. Rubber is generally regarded as biologically inert, but highly purified rubber, both natural and synthetic, as well as various rubber products are susceptible to bacterial oxidation in the presence of mineral and moisture. Corks used at sea as floats by commercial fishermen and others also are decomposed by marine bacteria, which slowly destroy the buoyancy by rupturing the cell walls of the cork which is composed of lignocellulose suberin complex filled with air spaces. Petroleum hydrocarbons such as gasoline, kerosene, lubricating oil, crude oil, and other petroleum products are oxidized by microorganisms inhabiting sea water and marine bottom sediments as well as on land. In a laboratory test, samples of crude oil added to marine sediments were rapidly destroyed by the hydrocarbon-oxidizing bacteria of Proactinomyces, Actinomyces, Pseudomonas, Micromonospora, or Mycobacterium. Bacteria which utilize hydrocarbon might be instrumental in causing undesirable changes in petroleum products stored over water. Kerosene and gasoline in storage tanks were decomposed with the formation of methane and possibly ethane. When combined with air, these gases could form explosive mixtures which might account for spontaneous oil fires.[18] In a laboratory test, neither polyethylene plastic nor neoprene was affected by either aerobic or anaerobic marine bacteria; however, polyvinyl chloride plastics were susceptible to bacterial decomposition according to the way in which they were plasticized.

Sulfate-Reducing Bacteria

The sulfate-reducing bacteria are strict anaerobes which obtain their energy by the reduction of sulfates and sulfites in water in the absence of free oxygen. The end product of their metabolic process is hydrogen sulfide. These bacteria are widely distributed in the marine environment and have assumed particular significance since it was discovered that they are agents of deterioration of organic and inorganic materials.[19,20,21,22] ZoBell found from 10,000 to 1,000,000 sulfate-reducing bacteria per gram of bottom sediment from the Pacific coast of California.[10]

In the Black Sea, oxygenated water is found from the surface down to approximately 600 feet, and is inhabited by plants and animals. However, between 600 feet and the bottom at approximately 6,600 feet, the water contains large quantities of hydrogen sulfide (6.04 ml/liter at a depth of 3,300 feet), and only microorganisms inhabit this area.[3] The high content of the hydrogen sulfide does not visibly inhibit the capacity of microorganisms to use organic matter and other materials in their life process. They participate in the overturn of carbon, nitrogen, sulfur, and phosphorus in the sea. A bacteriological examination of one gram of mud taken from the deepest parts of the Black Sea floor produced 100,000 colonies of bacteria on a suitable medium. The large microbial population in the hydrogen-sulfide zone consists chiefly of filamentous purple-sulfur bacteria.[23]

The aqueous hydrogen-sulfide environment is detrimental to many materials; for example, it may produce the erratic behavior of steels known as "sulfide-stress cracking." This is the spontaneous fracturing of steel subjected simultaneously to a corrosive hydrogen-sulfide aqueous medium and a static stress less than the tensile strength of the metal.[24] Polyethylene insulating compounds used in ocean telephone cables are essentially impervious to sea water and oxygen; however, they can be permeated by hydrogen sulfide found in ocean-bottom sediments.[25]



Does not take into account salinity and temperature changes of sea water

Figure 1. Rapid method for determining pressures at various ocean depths.

Sulfate-reducing bacteria were found to be responsible for a severe external anaerobic corrosion of a ship's hull which laid on mud banks of a river estuary for several months after launching. Pitting and black corrosion products were observed on rivet points and plates. The liquid extracted from inside the paint blisters on the ship's hull have been reported to contain sulfate-reducers, and their deleterious action is considered to be more widespread in marine corrosion than has been previously suspected.[26] Anaerobic corrosion is one of the several important types of corrosion which cause metal loss estimated at between 5 and 6 billion dollars annually in the United States.[27] In studies[28] wherein steel test samples were immersed in sterile sea water (bacteria-free) for 6 months, the corrosion rate was 0.0294, 0.0397, and 0.066 gram per square meter per hour; however, samples of steel exposed to the action of natural marine bacterial populations in the North Sea showed a 20 to 25 percent increase in the deterioration rates. This increase was attributed to increased acidity of the liquid medium and changed electric potential of the metal due to the metabolic activity of marine bacteria. It was demonstrated that microorganisms isolated from corroding steel samples attacked newly submerged steel samples more aggressively than those bacteria normally found in sea water.

Concrete sewer pipes and buried iron conduits are severely damaged by sulfur bacteria (genus Thiobacillus). These bacteria utilize elemental sulfur, thiosulfates, and hydrogen sulfide as sources of hydrogen or energy, oxidizing these substances eventually to sulfuric acid. The acid attacks concrete and iron conduits, causing severe deterioration.

Fish, Sharks, and Sea Urchins

Certain varieties of marine fish are attracted to white polyethylene-covered cables and lines. Nibbling by these fish has caused considerable damage to insulations. It is suggested[29] that the use of black polyetheylene-covered cables in the sea is advantageous since they do not attract fish. There is a report about sharks which like to test their teeth and jaws on submarine cable sheathings, often leaving their teeth embedded clear through the copper core.

The purple sea urchins, Strongylocentrotus purpuratus, were blamed for the destruction of steel H-beam piles in 30 feet of water about 1,500 feet from shore. Of the 42 steel piles (oil-well pier) pulled, about half were damaged by these urchins. The abrasive action of the sea urchins kept the rust cleared, leaving the bare metal continuously exposed to the corroding action of sea water. The adjoining pits made by the urchins became large holes; as these holes merged, the damaged isolated sections of the steel piling finally fell before the forces of the surging sea.

DEEP-SEA ANIMALS

The knowledge of the existence of animal life in the deep sea was first provided by a broken submarine cable that was brought up for repairs from a depth of over 6,600 feet in the Mediterranean in 1860. Attached to this cable were bivalve mollusks, gastropods, hydroids, alcyonanians, and worms. Recently the Danish Deep-Sea Expedition (1950-52) in the research ship Galathea obtained living animals of several phyla, in addition to viable bacteria, from a depth of greater than 33,000 feet in the Philippine Trench. The animals obtained at this great depth included about 40 actinians, 5 echiurid worms, 80 myriotrochus, 1 elasipod holothurian, 5 bivalves, and species of amphipods and tanaids.[30]

Much of the animal life in the deep sea is truly endemic, as shown by the presence of vast numbers of species and genera found consistently in the deep zones. However, many deep-sea species are eurybathic; that is, they endure great ranges of depth. These animals are of great biological interest because of their adaptability to conditions of depths. Some of the more outstanding eurybathic forms which are able to inhabit the ocean from shallow to great depths are: (1) pennatularians — to 11,900 feet, (2) polychaetes — to 16,500 feet, (3) bivalves — to 14,500 feet, (4) snails — to 9,900 feet, (5) starfish — to 8,000 feet, and (6) sea urchins — to 16,000 feet.[3]

Species of marine fish are also capable of inhabiting the environment of total darkness, low temperature, and high hydrostatic pressures which prevails in deep waters. In this area of very little or no light penetration, there is a marked increase in reddish and dark-colored animals. Abyssal fishes are characterized by strange and weird anatomical adaptations. These adaptations are concerned with structural modifications fitting the animals better to survive in faintest light or in utter and perpetual darkness. They are mainly along three lines: (1) tactile structures, (2) food-procuring contrivances, and (3) light production. The following are a few of the deep-sea fishes that were obtained on various deep-sea expeditions: (1) Macropharynx longicaudatus, length 15.1 cm, from 11,500 feet, (2) Gigantactis macronema, length 13.3 cm, from 8,250 feet, (3) Linophryne macrodon, length 5.3 cm, from 5,000 feet, (4) Malacostus indicus, length 8 cm, from 3,000 to 8,250 feet.[3, 31]

PROPOSED FIELD AND LABORATORY INVESTIGATIONS

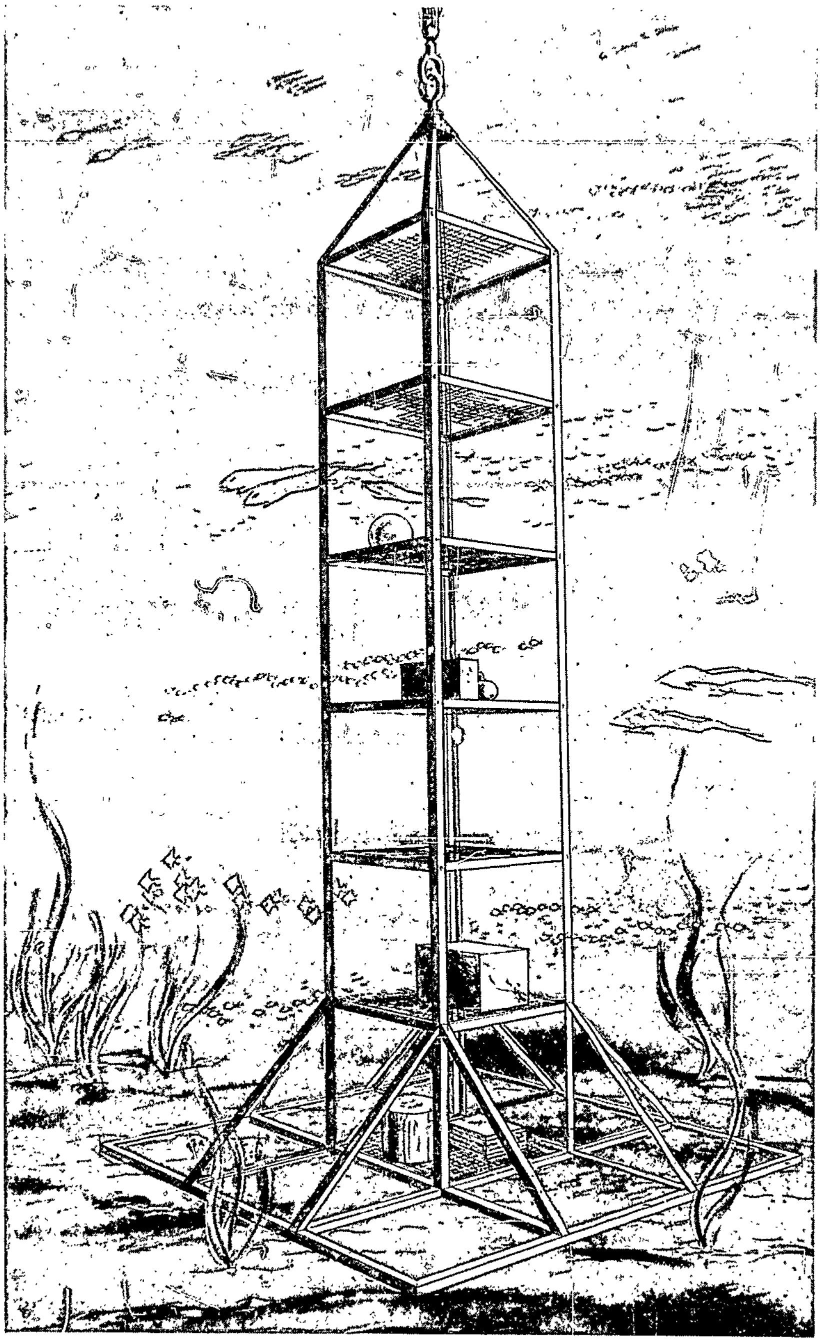
The ocean environment is so broad and complex with so many factors involved, such as marine life, depths, pressure, temperature, salinity, dissolved oxygen concentration, and bottom sediments, that a single test procedure cannot be expected to yield all the necessary information on the problem of biological deterioration of materials in the deep ocean. Field, as well as laboratory, studies are essential. The data obtained from these two approaches can then be compared and correlated, and a more useful body of information on the behavior of each engineering material to biological deterioration can be accumulated. This information would provide marine engineers and designers with valuable data on the merits of each material for use in the deep-sea environment.

As a part of its total program of deep-ocean studies, the Laboratory is planning a series of investigations along the following lines.

Exposure of Materials in the Natural Sea Environment

Deep-Ocean Exposure Test. Selected engineering materials to be exposed will be secured aboard a Submersible Test Unit (STU), shown in Figure 2, and placed on the bottom of the sea off Port Hueneme, California, at a depth of approximately 6,000 feet. For example, commercially available plastic rods and tubes will be assembled in a rack as shown in Figure 3. A portion of each rod will be wrapped with jute fiber and coal tar, another portion will be taped, and the remaining area will be left smooth. At the midpoint of the rods, an untreated piece of pine wood will be fitted around the test samples to act as bait to lure marine organisms into direct contact with the specimens and thus determine whether or not they will attack the plastic rods directly from the water. The assembled rack will be attached to the STU in such a way that the lower ends of the rods will be buried in the bottom sediments and the upper portions exposed to the sea water. This is to determine the effect of mud dwellers, including bacteria, on plastics buried in the sediments, and the effect of other marine organisms on plastic rods exposed above the mud line. Various materials such as concrete, metals, rubber, electrical wire cables, and coral concrete will also be placed aboard three STU's. The first STU will be retrieved after 6 months, the second after 12 months, and the third after 24 months' exposure in the deep ocean. The biological effects, if any, upon these materials then will be carefully inspected and evaluated. Materials and devices placed on the STU by other engineers and scientists for exposure to the effects of the deep-ocean environment will also be inspected for biological deterioration and any live specimens found attached to these materials will be preserved for later biological study.

Shallow-Water Exposure Test. Because of the wide differences in water temperature, hydrostatic pressure, etc., between shallow and deep-ocean depths, it is expected that the number, activity, and species of marine animals found will be quite different in the two environments. However, it is possible that some species which attack materials in shallow water may be eurybathic. A comparison of species found deleterious to submerged materials (other than wood) in these two environments will be made and the rates of deterioration due to biological action will be determined. No further investigation other than the exposure test is planned in this environment.



Height: 14 ft

Cross section: 2-1/2 x 2-1/2 ft

Base: 13 x 13 ft

Weight: about 3,000 lb

Capacity: about 2,000 lb of mtls and test equip.

Figure 2. Sketch of Submersible Test Unit (STU) designed to test the behaviors of engineering materials in deep-ocean environments.

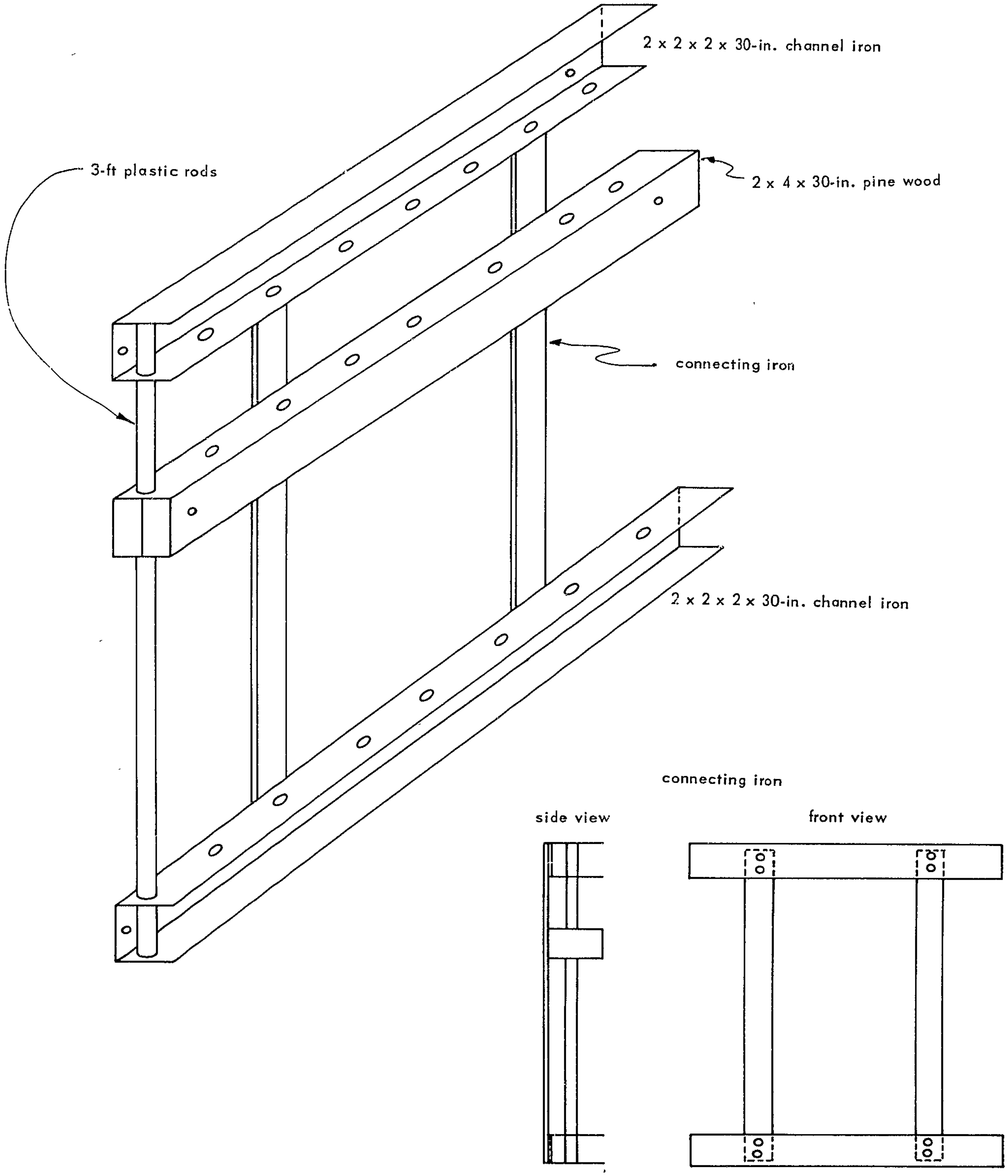


Figure 3. Sketch of special metal rack to hold plastic rods and tubes for deep-ocean exposure.

The preferred location for the shallow-water exposure test would be in tropical waters such as at Pearl Harbor, Hawaii, where the biological activity is intense. In addition to the species of Teredo and Limnoria, a pholad, Martesia striata, is present in these waters. Martesia striata is found throughout the world in nearly all temperate and tropical regions and this invertebrate may prove to be the most destructive and difficult to control of all the biological agents, especially since it is able to attack various chemically preserved woods, hard tropical woods, and even solid lead sheaths of submarine cables. Species of Martesia have been found in waters around the coasts of North Carolina, Florida, Texas, Cuba, the Hawaiian Islands, Japan, the Philippine Islands, and Australia.

Commercially available plastic rods and tubes and other selected materials will be exposed in the sea. The plastic rods will be assembled in a rack very similar to the ones assembled for the deep-ocean exposure test. The lower ends of the rods will be in marine sediments and the upper portions will be exposed to the sea water. The rack with the test materials will be raised and inspected for any biological deterioration after 6, 12, and 24 months' exposure in relatively shallow water. Other selected engineering materials will also be exposed in this environment.

Laboratory Investigations

The Effects of Hydrostatic Pressure on Materials and their Resistance to Biological Action. It is anticipated that some materials may undergo structural changes under the influence of high hydrostatic pressure; i.e., changes in permeability, density, elasticity, etc. Some materials which are normally resistant to biological deterioration may become highly susceptible to biological action when these changes take place.

Hydrostatic pressures (up to 15,000 psi) will be applied to various organic materials in a high-pressure test vessel. The biological-deterioration studies upon these materials will take place in standard BOD bottles containing sea water and bottom sediments and utilizing marine microorganisms as biological agents. This laboratory test is essentially a biochemical oxygen demand (BOD) type of test in which the ability of marine bacteria to utilize organic compounds as the only source of carbon for growth is determined. It is considered primarily a screening test. The BOD-type test consists of two separate bioassay procedures. In one method, the oxygen consumed by the aerobic bacteria is measured; in the other, a metabolic by-product (hydrogen sulfide) resulting from anaerobic bacterial activity is measured. With minor changes, the BOD-type test follows the procedures employed by Snoke[32] in biological-deterioration tests of various organic materials and elastomers utilizing marine microorganisms.

A Conductor Test to Determine Biological Deterioration of Organic Coatings and Insulations. Various organic coatings and insulations for wire conductors designed for use in shallow and deep water will be evaluated for biological deterioration. Hydrostatic pressures (up to 15,000 psi) will be applied in a high-pressure test vessel to organic insulating materials coated on a wire conductor and to commercially available insulated wire conductors. Coils of pressure-applied and nonpressure-applied test materials will be placed in separate covered glass jars containing sea water and marine sediments, and results will be compared and evaluated. This medium will also contain species of viable microorganisms normally found in sea water and bottom sediments. Insulation resistance measurements will be taken periodically to indicate any changes in dielectric strength. Microscopic examinations of the insulations will be performed when electrical failure has occurred, and it will be determined if breakdown of wire coatings occurred in the sediment or in the water. Conductors will be placed in sterile sea water and sediments to serve as controls. It is believed that valuable and readily applicable engineering data can be obtained by using this test technique.

Studies on Deterioration of Metals by Marine Microorganisms. This investigation will consist of basic research on the effects of marine microorganisms on the corrosion of various metals. Because bacteria are capable of inhabiting varied marine environments and are able to utilize various organic and inorganic materials from the sea for growth, it is expected that marine bacteria (including the sulfate-reducers) would be one of the major biological agents of deterioration of various engineering materials in sea water and in marine sediments.

The marine anaerobic sulfate-reducing bacteria which reduce sulfates and sulfites to hydrogen sulfide during their metabolic process have assumed particular significance since it was discovered that they are agents of severe deterioration of iron and steel in the sea. It is felt that any information obtained from this study on the mechanism of corrosion of metal due to bacterial action or its metabolic by-products will aid researchers in developing methods of prevention and control of deterioration of various organic and inorganic materials for use in the sea environment.

CONCLUSIONS

1. Extensive field and laboratory studies have been performed and considerable published information exists about the deteriorating effects of marine wood-boring animals upon wooden structures in shallow protected waters. However, there have been very few controlled field or laboratory studies made about the biological deterioration of materials other than wood in either the shallow or the deep-ocean environments. Thus there is virtually no published data on the behavior of materials

such as plastics, concrete, coating resins, wire insulation, elastomers, ceramics, metals, and other nonligneous materials exposed to the natural biological population of the sea and its bottom sediments.

2. Materials such as lead sheaths of submarine cables, concrete, rocks, and steel pilings have been penetrated by marine animals at various depths; therefore, it is highly possible that other engineering materials will also be susceptible to attack if they were available as a source of food or shelter for these animals in the deep-ocean environment.

3. The marine microorganisms capable of inhabiting extreme sea environments can be expected to be important agents of deterioration of materials in the ocean. The sulfate-reducing bacteria which produce hydrogen sulfide under anaerobic conditions have assumed particular significance as agents of deterioration of various engineering materials.

4. The inadequacy of the information obtained from the literature survey to meet the requirements of the Navy's accelerated interest in deep-ocean developments points up the need for more intensive investigations of the effects of marine organisms on engineering materials in deep-ocean environments.

REFERENCES

1. Turner, Ruth D. "The Status of Systematic Work in the Teredinidae," in Marine Boring and Fouling Organisms, edited by Dixy Lee Ray. Friday Harbor Symposium, University of Washington Press, Seattle, 1959.

2. Forsythe, W. E. Smithsonian Physical Tables, Smithsonian Miscellaneous Collections, 9th Ed., Vol. 120. Smithsonian Institution, New York, 1954.

3. Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. The Oceans. Their Physics, Chemistry and General Biology. Prentice Hall, New Jersey, 1942.

4. Nicol, J. A. C. The Biology of Marine Animals. Interstate Publishers, New York, 1960.

5. Menzies, R. J., and Ruth D. Turner. "The Distribution and Importance of Marine Wood Borers in the United States." ASTM Special Technical Publication No. 200. American Society for Testing Materials, Philadelphia, September 1956, pp 3-21.

6. Clapp, W. F., and R. Kenk. Marine Borers, a Preliminary Bibliography, Parts I and II. Library of Congress, Technical Information Division, Washington, D. C., 1956 and 1957.

7. Roch, F. "Die Teredinidae de Mittelmeeres," Thalassia, Vol. 4, 1940, pp 1-147.

8. Bartsch, P., and H. A. Rehder. "The West Atlantic Boring Mollusks of the Genus Martesia." Publs. Misc. Coll. No. 104. Smithsonian Institution, New York, 1945.

9. Atwood, W. G., and A. A. Johnson. Marine Structures, Their Deterioration and Preservation. National Research Council, Washington, D. C., 1924.

10. ZoBell, C. E. Marine Microbiology. A Monograph on Hydrobacteriology. Chronica Botanica Co., Waltham, Mass., 1946.

11. Morita, R. Y., and C. E. ZoBell. "Occurrence of Bacteria in Pelagic Sediments Collected During the Mid-Pacific Expedition." Deep Sea Research, Vol. 3, 1955, pp 63-73.

12. ZoBell, C. E. "Studies on the Bacterial Flora of Marine Bottom Sediments." Jour. of Sedimentary Petr., Vol. 8, April 1938, pp 10-18.

13. ZoBell, C. E. "Hydrostatic Pressure as a Factor Affecting the Viability and Activities of Bacteria in the Sea." Int. Congr. Microbiol. Rept. Proc. 6th Congr., Vol. 7, September 1953, pp 372-373.

14. ZoBell, C. E., and Esther C. Allen. "The Significance of Marine Bacteria in the Fouling of Submerged Surfaces." Jour. of Bact., Vol. 29, 1935, pp 239-251.

15. Robertson, A. C. "Preservation of Textile Fish Nets." Ind. Engr. Chem., Vol. 23, 1931, pp 1093-1098.

16. Barghoorn, E. S. "The Occurrence and Significance of Marine Cellulose-Destroying Fungi." Science, Vol. 96, 1942, pp 358-359.

17. Myers, S. P. "Marine Fungi in Biscayne Bay, Florida." Bull. of Marine Sci. of the Gulf and Caribbean, Vol. 2, 1953, pp 590-601.

18. Thaysen, A. C. "Gas Evolution in Gasoline Storage Tanks Caused by the Activity of Microorganisms." Jour. Inst. Petrol. Tech., Vol. 25, 1939, pp 411-415.

19. Starkey, R. L. "The Relationship of Sulfate-Reducing Bacteria to Iron Corrosion in the Marine Environment." Int. Congr. Microbiol. Rept. Proc. 6th Congr., Vol. 7, September 1953, pp 326-327.

20. Scott, W. R. "Some New Concepts of Corrosion from Bacterial Action in Water Floods." A Seminar on Water Flood Problems, presented in Los Angeles, California, by Magna Products, Inc., Santa Fe Springs, California, January 1960, pp 3-38.

21. Wood, F. E. J. "Marine Bacteria in Relation to Economic Processes." Int. Congr. Microbiol. Rept. Proc. 6th Congr., Vol. 7, September 1953, pp 350-357.

22. Starkey, R. L. "Sulfate-Reducing Bacteria — Physiology and Practical Significance." Lecture presented at University of Maryland, College Park, October 1960.

23. Kriss, A. E. "Microbiology and the Chief Problems in the Black Sea." Deep Sea Research, Vol. 5, 1959, pp 193-200.

24. Vollmer, L. W. "The Behavior of Steels in Hydrogen Sulfide Environment." Corrosion, Vol. 14, July 1958, pp 37-42.

25. Hazzard, Peggy M. "How Environment Affects Ocean Cables." Bell Laboratory Record, March 1961.

26. Patterson, W. S. "External Ship Corrosion Due to Bacterial Action." Trans. North East Coast Inst. Engr. and Shipbuilders, Vol. 68, December 1951, pp 93-106.

27. Uhlig, H. H. "The Cost of Corrosion to the United States." Chem. Engr. News, Vol. 27, 1949, pp 2764-2767.

28. Nikitina, N. S., and I. B. Ulanovskii. "Some Data on the Microbiological Factors of the Corrosion of Steel in Sea Waters." (In Russian.) Akad. Nauk SSR. Murmanskaia Biologicheskaia Stantsiia, Dal'niye elentsy, Trudy No. 3, 1957, pp 190-200.

29. Pauli, D. C., W. M. Ellsworth, and J. Richards. "A Survey of the Effect of Ocean Environment on the MONOB Array." Cleveland Pneumatic Industries, Inc., Washington, D. C., August 1960.

30. Bruun, A. Fr. "The Philippine Trench and Its Bottom Fauna." Nature, Vol. 168, October 1951, pp 692-693.

31. Marshall, N. B. Aspects of Deep-Sea Biology. Hutchinson and Co., London, 1958.

32. Snoke, L. R. "Resistance of Organic Materials and Cable Structures to Marine Biological Attack." The Bell System Tech. Jour., Vol. 36, 1957, pp 1095-1127.

33. Chilton, C. "Destructive Boring Crustacea in New Zealand." New Zealand Jour. Sci. Technol., Vol. 2(1), 1919, pp 3-15.

34. Anderson, J. "Statistics of Telegraphy. Appendix I. An Account of Marine Cables Laid." Jour. Statistics Soc. London, Vol. 35(3), 1872, pp 313-321.

35. Mance, H. "Experiments Conducted for the Purpose of Ascertaining Whether the Teredo Borer Prefers Gutta-percha to India Rubber." Teleg. Jour. and Elect. Rev., Vol. 3(68), 1875, p 278.

36. Preece, G. E. "On Cable-Borers." Teleg. Jour. and Elect. Rev., Vol. 3(69), 1875, pp 296-297.

37. Bontemps, C. "Telegraphic Sous-Marine: la Destruction des Cables." Nature (Paris), Vol. 5, Part 2(233), November 1877, pp 387-389.

38. Rivera, V. "Osservazioni e Rilievi Sopra Alcuni Xilofagi Marini Rinvenuti nell Interno dei Cavi Telegrafici." R. Comitato Talassografico Italiano, Bollettino Bimestriale, Vol. 5 (1-3), 1951, pp 34-48.

39. Siemens, C. W. "On the Outer Covering of Deep-Sea Cables." Rep. Brit. Assoc. Adv. Sci. Meeting, Vol. 35 (1865), Trans. 1866, pp 187-190.

40. Andrews, A. "*Limnoria terebrans* Attacking Telegraph Cable Exhibited." Quart. Jour. Microsc. Sci. (n.s.), Vol. 15(59), 1875, p 332.

41. Springer, V. G., and E. R. Beeman. "Penetration of Lead by the Wood Piddock, *Martesia striata*." Science, Vol. 131, 6 May 1960, pp 1378-1379.

42. Snoke, L. R., and A. P. Richards. "Marine Borer Attack on Lead Cable Sheath." Science, Vol. 124, 7 September 1956.

43. Kelly, R. A. "Toughest Splicing Job of All." Popular Mechanics, February 1961, pp 154-156, 258-259.

44. Johnson, M. W. "Deterioration Due to Marine Borers." Marine Corrosion and Fouling Conference, Scripps Institution of Oceanography, April 18-20, 1956.

45. Sadler, W. R., and D. E. Hughes. "Observations on Rock-Boring Mollusks in Concrete." Engineering News Record, Vol. 93(26), 1924, pp 1027-28.

46. Ludlow, J. W. "Developments in Connection with Concrete Piling." World Ports, Vol. 12(6), 1924, pp 34-44.

47. Rigdon, J. H., and C. W. Beardsley. "Corrosion of Concrete by Autotrophes." Corrosion, Vol. 14, April 1958, pp 206t-208t.

48. Summer, W. "Microbially Induced Corrosion." Corrosion Tech., Vol. 7, September 1960, pp 287-288.

49. Oppenheimer, C. H. "Marine Microbiology." Naval Research Review, April 1961, pp 11-14.

50. Starky, R. L. "Transformation of Iron by Bacteria in Water." Jour. of the Amer. Water Works Assoc., Part II, Vol. 37, July-December 1945, pp 963-983.

51. Caldwell, J. A., and M. L. Lytle. "Bacterial Corrosion of Offshore Structures." Corrosion, Vol. 9, June 1953, pp 192-196.

52. Nikitina, N. S., and I. B. Ulanovskii. "Growth of Bacteria on Steel Surface in Sea Water." (In Russian.) Doklady Akad. Nauk SSSR, Vol. 98, 1954, pp 841-844.

53. Irwin, Margaret. "Steel Boring Sea Urchins." Pacific Discovery, Vol. 6, March-April 1953, pp 26-27.

54. Brouillette, C. V. "Corrosion Rates in Port Hueneme Harbor." Corrosion, Vol. 14, August 1958, pp 352t-356t.

55. Mendizza, A. "Corrosion — The Constant Enemy of Metal." Bell Laboratory Record, Vol. 34, December 1956, pp 451-455.

56. Ulanovskii, I. B., and N. S. Nikitina. "The Influence of Putrifying Aerobic Bacteria on the Corrosion of Steel in Sea Water." (In Russian.) Microbiologiya, Vol. 25, January-February 1956, pp 66-71.

57. Atkins, W. R. G., and F. J. Warren. "The Preservation of Fish Nets, Trawl Twines, and Fiber Ropes for Use in Sea Water." Jour. Marine Biol. Assoc., Vol. 25, 1941, pp 97-107.

58. ZoBell, C. E., and Josephine D. Beckwith. "The Deterioration of Rubber Products by Microorganisms." Jour. Amer. Water Works Assoc., Vol. 36, 1944, pp 439-453.

59. ZoBell, C. E., C. W. Grant, and H. F. Haas. "Marine Microorganisms Which Oxidize Petroleum Hydrocarbons." Bull. of the Amer. Assoc. of Petr. Geol., Vol. 27, September 1943, pp 1175-1193.

60. Coe, W. R. "Destruction of Mooring Ropes by Teredo: Growth and Habits in an Unusual Environment." Science (New York), Vol. 77, 12 May 1933, pp 447-449.

61. Kodota, Hajime. "A Study of the Marine Cellulose-Decomposing Bacteria." Fisheries Series (Japan), Vol. 6, 1956.

62. Defense Research Laboratories. Report No. 192, The Preservation of Ropes Against Deterioration in Sea Water, by W. R. Hindson. Dept. of Supply, Australia, May 1953.

63. U. S. Fish and Wildlife Service. Report No. 22, Fishing Gear Preservatives for Philippine Waters, 1950.

64. Naval Research Laboratory. Report No. S2477, Corrosion and Fouling of Sonar Equipment, Part I, by J. W. Fitzgerald, M. S. Davis, and B. G. Hurdle. Office of Naval Research, Washington, D. C., March 1947.

65. Kalinenko, V. O., and N. A. Mefedova. "Bacterial Fouling of the Submerged Parts of Ships." (In Russian with English Summary.) Microbiologiya, Vol. 25, 1956, pp 191-194.

66. Ragg, M. "The Biological Rapid-Testing of Ship-Bottom Paints." (In German.) Farbe U. Lack, Vol. 57, July-August 1951, pp 287-291, 352-356.

67. Marine Fouling and its Prevention, prepared for Bureau of Ships, Navy Department, by Woods Hole Oceanographic Institution, Woods Hole, Mass. Contribution No. 580. Copyright by United States Naval Institute, Annapolis, Md., 1952.

68. Woods Hole Oceanographic Institution. Technical Report No. 5, Fouling in the Western Pacific, by L. W. Hutchins under Office of Naval Research Contract N5 ori-195. Woods Hole, Mass., March 1949.

69. Turner, Ruth D. "The Family Pholadidae in the Western Atlantic and the Eastern Pacific." Johnsonia, Vol. 3, Parts I and II, May 1954 and March 1955.

70. Schmitt, W. L. Crustaceans in Smithsonian Scientific Series, Vol. 10, Washington, D. C., 1931, pp 85-248.

71. MacGinitie, G. E. "Ecological Aspects of a California Marine Estuary." Amer. Midland Naturalist, Vol. 16, 1935, pp 639-765.

72. Yonge, C. M. The Sea Shore. Wm. Collins Sons and Co., London, 1949.

73. Yonge, C. M. "Marine Boring Organisms." Research (London), Vol. 4, 1951, pp 162-167.

74. U. S. Naval Civil Engineering Laboratory. Technical Report 147, Harbor Screening Tests of Marine Borer Inhibitors — III, by H. Hochman and T. Roe, Jr. Port Hueneme, California, 16 May 1961.

75. U. S. Naval Civil Engineering Laboratory. Technical Report 048, The Toxicity of Chemical Agents to Marine Borers — I, by H. Vind and H. Hochman. Port Hueneme, California, 29 June 1960.

76. Vind, H., H. Hochman, J. Muraoka, and J. Casey. "Relationship Between Limnoria Species and Service Life of Creosoted Piling." ASTM Special Technical Publication No. 200. Amer. Soc. Test. Mat., Philadelphia, September 1956, pp 35-50.

77. Ray, Dixy Lee. "An Integrated Approach to Some Problems of Marine Biological Deterioration: Destruction of Wood in Sea Water," in Marine Biology, edited by Ivan Pratt and James E. McCauley. Biology Colloquium, Oregon State College, Corvallis, 1959, pp 70-87.

Appendix

LITERATURE-SURVEY DATA

MATERIALS	LOCALITY	BIOLOGICAL ORGANISMS RESPONSIBLE	DAMAGE & OTHER PERTINENT INFORMATION	REF.
Submarine cable	Cook Strait, New Zealand	Limnoria lignorum	Damaged the gutta-percha covering of cables at a depth of about 360 ft.	33
Submarine cable	Mediterranean Sea	"Teredo of all kinds"	One kind of Teredo bored through the core of a cable in shallow water. Damaged cables have been recovered from depths of 7,200 ft with all the hemp eaten away and the cores filled with Teredo.	34
Submarine cable	Karachi Harbor (Karachi, W. Pakistan)	Marine borers	A cable exposure test. About 600 ft each of (a) bare gutta-percha core, (b) bare india-rubber core, (c) Persian Gulf gutta-percha cable, and (d) Persian Gulf india-rubber cable was placed in a harbor. After 10 months the gutta-percha cable was riddled by borers; the bare gutta-percha core had 5 borer holes; the india-rubber cable and the india-rubber core had no penetrations to the conductor.	35
Submarine cable	Mediterranean Sea; Coast of Norway; English Channel; Brest (W. France); Coast of Valentia, Ireland; Key West and Punta Rassa, Florida	Xylophaga, Limnoria lignorum	Hemp between the steel wires was eaten away and the gutta-percha core was penetrated to various depths by Xylophaga.	36
Submarine cable	Persian Gulf; Indian Ocean; Irish Coast	Teredo, Xylophaga, Limnoria lignorum	Teredo and Xylophaga entered the hemp covering and penetrated to the gutta-percha wherever the interstices of the wires of the exterior envelope afford them an opening. Limnoria also caused similar damage.	37

MATERIALS	LOCALITY	BIOLOGICAL ORGANISMS RESPONSIBLE	DAMAGE & OTHER PERTINENT INFORMATION	REF.
Submarine cable	Western part of Mediterranean Sea; English Channel; Irish Sea; Coast of Brazil; Persian Gulf; Malay Archipelago	Teredo navalis, Xylophaga, Limnoria lignorum	Teredo and Xylophaga attack only the hemp layer of the cable while Limnoria destroys the gutta-percha.	6
Submarine cable	From Otranto, Italy, to Valona, Albania, and Palermo, Sicily; from Marseilles, France, to Algeria	Chelura terebrans, Limnoria lignorum, Xylophaga dorsalis, Teredo norvegica	These marine animals have attacked and damaged cables located in shallow waters to 1, 350 ft in depth.	6
Submarine cable	Between Stromboli and Panarea (Tyrrhenian Sea, North of Sicily); between Elba and Pianosa (Tyrrhenian Sea, between Italy and Corsica)	Teredo utriculus Gmelin	Teredo may bore into the jute and gutta-percha coverings of the cables in any direction. Teredo are found in shallow as well as great ocean depths. For the protection of cables, the author recommends the insertion of a brass sheath between the jute and gutta-percha layers of the cable.	38
Submarine cable	Black Sea and Mediterranean Sea; between Toulon, France, and Algiers	Xylophaga	The cables failed after 6 to 9 months' operation. Xylophaga penetrated and destroyed the hemp and had entered the gutta-percha. Attacks upon cable occurred at depths of 1, 800 to 3, 000 ft.	39
Submarine cable	Between Ireland and Holyhead	Limnoria lignorum	Destroyed the gutta-percha covering of the cable.	40
Submarine cable	Between Port Darwin (Australia) and Singapore, via Java	Species of Teredo	The galvanized iron-wire sheathing of the cable was penetrated in a short period of time and the insulation of the copper core was destroyed.	6

MATERIALS	LOCALITY	BIOLOGICAL ORGANISMS RESPONSIBLE	DAMAGE & OTHER PERTINENT INFORMATION	REF.
Submarine cable	Extending 1,060 ft across Boca Ciega Bay beside the Treasure Island Causeway, St. Petersburg, Florida, approximately 200 ft from the west shore of the bay	*Martesia striata* Linnaeus	Attack was upon the lead sheathing of power cable which resulted in a short. Diameters of borer damage about 6 mm; depths about 2 mm. The exposed lead sheathing was riddled with holes.	41
Submarine cable	Jacksonville, Florida, 300 ft from shore at a depth of 3.5 ft where the bottom was muddy	*Pholadidae*; *Barnea truncata* and *Martesia striata* are suspected	A 4-mm-thick solid lead sheath covered with 2 layers of asphalt-impregnated jute which served as a bedding for a single layer of galvanized steel armor wire was penetrated by marine borers. Hole diameters varied from 2.5 to 3.5 mm. At a depth of about 2 mm the diameters increased to 5 and 6 mm.	42
Submarine cable	West Palm Beach, Florida	*Martesia* (Diploplax) *americana*	This species is normally a marine wood borer. It drilled through the outer solid-lead coat and the sub-adjacent insulation of an electrical conduit cable, producing a blowout which seriously interrupted electrical service.	8
Submarine cable	Coast of China	Sharks	Serious damage to cables occurs rather often along the coast of China. Sharks like to test their teeth and jaws on the cable sheathing and often leave their teeth embedded clear through the copper core.	43

MATERIALS	LOCALITY	BIOLOGICAL ORGANISMS RESPONSIBLE	DAMAGE & OTHER PERTINENT INFORMATION	REF.
Concrete	La Boca Dock in the Panama Canal Zone	Lithophaga aristata Dillwyn; others include Carditamera affinis Brod., genus Saxicava and Petricola	Cylinder piers 16.4 ft in diameter encased in a metal coffer dam was built by a French Company in 1898. There is no record of material used or construction method. The concrete was attacked by the borers after the metal casing corroded.	9 44 45 46
	Los Angeles Harbor, California	Pholadidae penita Conrad, Platyodon cancellata Conrad Lithophaga plumula, Botula falcata	The concrete piles were inspected in 1922. Burrows 1-3/4 in. in diameter were found, with an average of 7 to 8 borers to a sq ft of concrete. Of the 18 piles jacketed with concrete, 16 were found to be more or less attacked. The jacket consisted of cement mortar with no coarse aggregate (avg 2-1/2 in. thick). The crushing strength of a specimen 2-1/2 x 3-1/2 x 4-1/2 in. was 1,726 lb per sq in. Good concrete containing an aggregate of gravel, broken stone or silica may resist attack by rock-borers.	
Concrete conduit Iron water pipes	Sewer system Water mains Marine sediments	Sulfur bacteria, Thiobacillus thiooxidans	The sulfur bacteria derive their energy from the oxidation of reduced sulfur compounds with the production of acid. The bacteria can be cultivated in a media at a reaction close to a pH of O and have been known to produce acidity as high as 10% sulfuric acid. The acid attacks iron pipes and concrete, causing disintegration.	47 48 49
		Sulfate-reducing bacteria, Desulfovibrio desulfuricans	During the metabolic process, the sulfate in water is reduced to sulfide. It reacts with dissolved iron or metallic iron to form black	50

MATERIALS	LOCALITY	BIOLOGICAL ORGANISMS RESPONSIBLE	DAMAGE & OTHER PERTINENT INFORMATION	REF.
			insoluble iron sulfide. Most of the sulfide in the black muds of ocean sediments and tidal basins comes from the reduction of sulfate under anaerobic conditions. The sulfate-reducing bacteria can serve as a depolarizing agent in increasing the rate of corrosion of metal.	
Steel	Laboratory and field studies. Marine platform 7 miles off Grand Isle, La.; coast of La Port, Texas, and Galveston, Texas	Marine microorganisms	In a laboratory test, the corrosion rate of steel coupons under anaerobic conditions was 0.001 in. per year. Sulfate-reducing marine bacteria were used as biological agents. Similar test samples exposed for 85 and 496 days in marine environments (above and below mud line) showed a corrosion rate of 0.002 to 0.0054 in. per year. The corrosion rates of cathodically protected test coupons were negligible.	51
Steel	Field studies, Barents Sea	Marine microorganisms	Steel samples, 200 x 150 x 3 mm were immersed along the coast of the Barents Sea. Bacterial growth appeared on the first day of immersion. After 150 days, a total of 310 million bacteria (aerobic and anaerobic) were collected from the surface of a steel sample, and these samples had a 3-mm-thick corrosion layer on their surfaces.	52
Steel piling	Ellwood, California, 11 miles north of Santa Barbara, 1,500 ft from shore in 25 to 30 ft of water (open sea)	A purple sea urchin, *Strongylocentrotus purpuratus*	Abrasive action of the sea urchins combined with corrosion made a lacework of the steel H-beam piles. Of the 42 piles pulled, about half were damaged by sea urchins.	53

MATERIALS	LOCALITY	BIOLOGICAL ORGANISMS RESPONSIBLE	DAMAGE & OTHER PERTINENT INFORMATION	REF.
Monel (Ni 66.5%, Ca 29.4%)	Port Hueneme, California	Barnacles and other fouling organisms	The corrosion rates of 16 metals and alloys were determined over a period of 30 months total immersion in the sea water at Port Hueneme. Pits 10 and 37 mils in depth were formed beneath fouling organisms by the end of 24 months. Pitting may result from localized oxygen-concentration cells formed on the surface of the metal beneath marine growth, especially barnacles.	54
Iron	Field and laboratory tests	Sulfate-reducing marine microorganisms	Sulfate-reducing bacteria are widely distributed in the ocean. Formation of H_2S is their principal contribution to corrosion. Metal samples in sea water were coated with fouling organisms and corrosion products were pitted, while samples buried in marine sediment corroded evenly without pitting.	19
Copper	Marine environment	*Desulfovibrios*, sulfate-reducing bacteria	Submarine telephone cables are protected by galvanized-steel armor wire and copper. Copper is used as protection against *Teredo* borers. The H_2S produced by sulfate-reducers during the metabolic process attacks copper.	55
Steel	Laboratory and field studies, North Sea	Marine microorganisms	The corrosion rate of steel in sterile sea water was 0.0294, 0.0379, and 0.066 per sq meter per hr. Steel samples exposed to sea water containing bacteria showed a 20 to 25% increase in corrosion rate (6-month period). Bacteria from corroding metal were found to be more aggressive in their activity than bacteria from sea water.	28 56

MATERIALS	LOCALITY	BIOLOGICAL ORGANISMS RESPONSIBLE	DAMAGE & OTHER PERTINENT INFORMATION	REF.
External ship hull corrosion	Laboratory and field studies	Sulfate-reducing bacteria	The nature, mechanism, and prevention of an unusual, severe case of ship corrosion are discussed. Pitting and black corrosion products were observed especially on rivet points and plates of a hull which had laid on mud banks for several months after launching. Laboratory tests showed steel and iron plates suffered negligible corrosion in sterilized mud compared to unsterilized mud. Deterioration of paint film was also caused by sulfate-reducing marine bacteria.	26
Silicone rubber and lucite rods	Laboratory and field tests, Wrightsville Beach, North Carolina; Daytona Beach, Florida	Pholad, a marine borer	Molluscan borers penetrated into solid rods, 1 in. diameter, during marine exposure tests.	32
Polyvinyl chloride plastics, GR-S rubber, neoprene		Marine microorganisms	Plastics are attacked according to the way in which they are plasticized. Neoprene was the most resistant to bacterial action.	
Cellulose acetate yarn, jute fiber		Marine bacteria and fungi	Deteriorated badly in 6 months.	
Polyvinal chloride plastic containing basic lead stabilizers		Sulfate-reducing marine bacteria	Plastic blackened as a result of hydrogen sulfide produced by this bacteria reacting with the lead salts to give black lead sulfide.	
Cordage and net (fish net, manila rope, traps, hemp, jute)	Marine environment	Cellulose-decomposing marine bacteria and fungi	These were found to be destroyed after 14 months in sea water. Treatment with copper naphtanate prolonged useful life by 40 percent.	15 57

MATERIALS	LOCALITY	BIOLOGICAL ORGANISMS RESPONSIBLE	DAMAGE & OTHER PERTINENT INFORMATION	REF.
Cork (floats)	Marine environment	Marine microorganisms	Cork is a lignocellulose suberin complex filled with air spaces which give it buoyancy. Cork is decomposed by marine bacteria which slowly destroy its buoyancy by rupturing the cell walls of the cork.	10
Rubber products (hoses, conductors, bumpers, certain chlorinated rubber paints, rubber gaskets)	Marine environment	Marine microorganisms: Species of *Actinomyces*, *Microbacterium*, *Micrococcus*, *Micromonospora*, *Nocardia*, *Pseudomonas*, and *Bacillus*	Rubber is generally regarded as biologically inert; however, highly purified rubber, both natural and synthetic as well as various rubber products, are susceptible to bacterial oxidation in the presence of mineral and moisture. Unsaturated hydrocarbon (C_5H_8) is quite susceptible to bacterial oxidation.	58
Petroleum hydrocarbons (gasoline, kerosene, lubricating oils, crude oils, paraffin wax, mineral oil, petroleum ether, methane	Marine environment Laboratory tests	Marine microorganisms: Species of *Proactinomyces*, *Actinomyces*, *Pseudomonas*, *Micromonospora*, and *Mycobacterium*	Microorganisms capable of oxidizing petroleum hydrocarbons are rather widespread in sea water and marine sediments as well as on land. From 100 to 100,000 hydrocarbon-oxidizing bacteria have been demonstrated per gram of marine sediment (wet basis). Samples of crude oil added to marine sediments were rapidly destroyed under aerobic conditions.	59
Mooring ropes	New Haven, Connecticut	*Teredo morsei* Bartsch	Molluscan borers attacked ropes which held buoys and mooring floats at anchor. Only ropes which had been continuously submerged for several weeks or longer were damaged, mainly in the lower ends near the attachment to anchors. Some ropes were entirely severed.	60

MATERIALS	LOCALITY	BIOLOGICAL ORGANISMS RESPONSIBLE	DAMAGE & OTHER PERTINENT INFORMATION	REF.
Commercial fishing gear (cotton fishing net)	Maizuru Bay and Hiroshima Bay, Japan	Cellulose-decomposing marine bacteria: Species of Psuedomonas, Vibrio, and Cytophaga; Vibrio purpureus and Vibrio marino-flavescens responsible for deterioration of cotton fishing nets	Mercury chloride was the most effective bacteriocide. Cellulose acetate yarn which acetylated from 26.6 to 61.5%, remained completely resistant to the activities of marine bacteria.	61
Commercial fishing gear (sisal ropes, manila ropes, coir ropes, trawl twines, nets)	Marine environment	Marine animals, fouling organisms, microorganisms, etc.	Methods of preserving these materials in sea water are presented. Satisfactory treatment was a mixture of copper naphthenate (0.5 to 1% copper by weight of the rope) and coal tar or creosote (to give a 10 to 15% retention on the rope). Copper compounds give best protection against marine growth.	62 63
Sonar equipment	Marine environment	Fouling organisms: Barnacles, annelids, tunicates, bryozoa, hydroides, mollusks, bacteria, etc.	The mechanism of fouling and the controlling factors in the production of corrosion and fouling are discussed. The effect of fouling on the acoustic efficiency of sonar equipment is extremely serious, resulting in an average attenuation of about 3 decibels per inch of fouling thickness.	64
Ships' hulls	Laboratory and field studies	Fouling organisms: Marine microorganisms, barnacles, mollusks, tunicates, hydroids, bryozoans, etc.	Fouling growth on ships' hulls studied. Bacteria settled first on submerged painted layers. Mucous protein membrane formed by the bacteria protected larvae of marine organisms such as barnacles, mollusks, etc., from the	65 66 67

MATERIALS	LOCALITY	BIOLOGICAL ORGANISMS RESPONSIBLE	DAMAGE & OTHER PERTINENT INFORMATION	REF.
			toxic action of the paint. It is possible that only paints which will prevent bacteria from settling and forming mucous layers will protect ship bottoms from fouling. Use of bacteria to screen antifouling paints is suggested. Studies show that microorganisms merit considerable attention in investigating the exact cause and ultimate prevention of fouling.	
Ships' hulls, mines, nets, buoys, test panels	Western Pacific Ocean from Hawaii to Japan and Korea, and south to New Guinea, the Solomons, and adjacent islands	Fouling organisms: Tube worms, barnacles, tunicates, hydroids, algae, mollusks, bryozoa, oysters, sponges, flatworms, bacteria, etc.	Available information on fouling in the Western Pacific are compiled and analyzed. Recommendations for further field research designed to fulfill Navy requirements are presented. Fouling results in deterioration of submerged materials, and loss in performance of marine equipments.	68
Stiff blue clay, sand-stone, cement	Range from Bering Island, Siberia, to Baja California	Penitella penita, a molluscan rock-borer	The Pholadidae, a family of highly specialized bivalve mollusks adapted for boring into wood, soft rock, shells, peat, hard clay and mud, are presented. Life history and ecologic notes on other borers are included.	69
Soft shale rock	Range from Santa Cruz, California, to Baja California	Chaceia ovoidea, Penitella penita, P. gabbi, Parapholas californica		
Coral reefs	Tropical waters	Sponges, polychaetes, worms, sea urchins, mollusks, including Lithophaga, Gastrochaena, and Petricola	Many marine species bore into dead coral or coral limestone. Living coral colonies are not attacked by the burrowing animals to the same extent as dead coral masses.	4

MATERIALS	LOCALITY	BIOLOGICAL ORGANISMS RESPONSIBLE	DAMAGE & OTHER PERTINENT INFORMATION	REF.
San Pablo sandstone, Pinole tufa	San Francisco Bay, California	Sphaeroma pentodon	These crustacean borers honeycombed sandstone with burrows.	70
Sea wall made of clay stone	Hawkes Bay, New Zealand	Sphaeroma quoyana	Sea wall damaged by burrows.	
Marble rocks, hard blue mud, hard clay, hard rocks, solid granite rocks	Elkhorn Slough, a tributary of Monterey Bay, California	Lithophaga plumula Hanley, Saxicava artica Linnaeus, Zirfaea gabbi Leach, Penitella penita Conrad, Chaceia ovoidea Gould	All are rock-borers. Lithophaga burrows by means of an acid, and the others burrow into rocks by mechanical means.	71
Carara marble	Saint-Tropez (S.E. France)	Lithophaga, Pholas	Remains of a Roman ship wrecked in the first century B. C. were discovered at a depth of 130 ft. Marble columns were part of the cargo and the exposed surfaces of the columns were heavily attacked by marine rock-borers, producing a spongy appearance.	6
Marble columns	Mahdia (E. Tunisia, Mediterranean)			
Rocks	Marine environment — sea shores of Britain	Sea urchin, Paracentroutus lividus (deepens shallow depressions by means of its spines and teeth)	The boring activities of various marine animals are reviewed.	72 73
Limestones and mollusk shells		Boring sponge, Cliona celata (burrows into calcareous rocks and honeycombs them)		
Limestone and sandstone		Hiatella (Saxicava gallicana), a rock-borer		
Soft rock, sandstone, shales, slate, chalk		Molluscan rock-borers: Pholas dactylus, Pholadidae loscombiana, Barnea parva, Zirfaea, Petricola pholadiformis, Lithophaga (acid borer)		
Mudstone	Coast of California	Botula, Platyodon cancellatus		
Wooden structures (treated and untreated wood)	In harbors throughout the world	Species of Bankia, Limnoria, Teredo, Martesia, Sphaeroma	Considerable published information exists today on the effects of marine organisms on wood and methods of protecting wood against marine animals.	1 5 6 73 74 75 76 77

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