NELC / REPORT 1593

EFFECTS OF DEEP- AND SHALLOW-OCEAN ENVIRONMENTS ON CONSTRUCTION MATERIALS

Comparison of fouling and corrosion produced by prolonged submergence of selected materials, with and without protective coatings

J.C. Thompson and R.K. Logan

Research and Development Report

14 November 1968

NAVAL ELECTRONICS LABORATORY CENTER
San Diego, California 92152

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THE PROBLEM

Investigate methods for protecting materials used in naval equipments from damaging effects of underwater environment.

RESULTS

1. Test specimens of several construction materials, with and without protective coatings, were submerged in both shallow (10 fathoms) and open-ocean (35 fathoms) environments. Some open-ocean specimens were recovered after 21 months; the remainder were left for continued exposure and evaluation over a longer period. Those from the shallow water were recovered after 18 months. Effects of the submergence and the effectiveness of the various coatings were compared.

2. Fouling in the shallower environment was much more severe than in the open ocean.

3. Corrosion-resistant steel was found to be more subject to corrosion and fouling than is generally believed.

4. The specimens protected with cuprous materials exhibited the least fouling.

5. Shallow water (depths to 15 fathoms) yields satisfactory results in testing materials for underwater construction, with the least expenditure of time, effort, and money.

RECOMMENDATIONS

1. Continue to investigate the corrosive and fouling effects of the marine environment on material used in underwater constructions, and the protective coatings which will inhibit such effects.

2. Make further studies of the tri-butyl-tin oxide compounds for protective coatings.

ADMINISTRATIVE INFORMATION

Work was performed by members of the Materials Sciences Group. The report covers work from December 1965 to September 1967 and was approved for publication 14 November 1968.

The authors wish to express their appreciation to Dr. Eric Barham and W. Farmer, who identified the fouling organisms; and to W.J. Bunton and J.R. Houchen, who performed the necessary diving to submerge and retrieve the test assemblies.

INTRODUCTION

The tests described here are part of a continuing effort to find methods for protecting the various materials used in constructing naval equipments from the damaging effects of the ocean environments.[1,2] Such tests, because of the equipments and procedures they involve, must be scheduled when dock and pier areas are available and, often, when assistance may be provided by ships and by the divers and photographers who work in support of underwater research activities.

About two years ago, we were informed, with very short notice, that the hull of the submarine USS SQUAW would be available to us for submerging samples for underwater testing. To take advantage of this opportunity, we prepared test specimens from the limited number of materials and protective coatings at hand. Ten assemblies of these specimens were submerged aboard the submarine hull approximately 20 miles at sea. Two similar assemblies were submerged in the Pacific Ocean in the vicinity of the NELC Oceanographic Research Tower about 1 mile off Mission Beach, California.

This report is a record of the results obtained with the two assemblies submerged near the Oceanographic Tower and three of the ten submerged aboard the SQUAW. The other seven are to be periodically retrieved and examined over a period of 10 years.

TEST PROCEDURE

Each test package consisted of eleven panels of various materials, measuring 12 by 12 inches, joined at the sides in a ladder-like arrangement by lengths of ¼-inch polypropylene line (fig. 1). The panels were attached 1 foot apart, with the lines extending continuously to about 10 feet below the last sample. Heavy, reinforced rubber hose was used for chafing guards at the holes where the line passed through the samples. The samples were stacked, with a glass-ball float attached at the top and a ¾-inch-thick board at the bottom. The float was covered with cotton mesh which had been further reinforced by 2x2x⅛-inch nylon netting. Attached at the top of the glass ball was a coil, or "halo," of polypropylene cord. A line was laced up and down from the board to the halo, all around the sandwich, with the 10 feet of line below the last panel left free for use in securing the assembly at the desired location (figs. 2 and 3). Cutting the coil would then release the float, which would pull the entire ladder upright and so expose each individual test specimen to the seawater.

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[1]Navy Electronics Laboratory Report 1026, *Investigation of Sonar Diaphragm Coatings*, by J.C. Thompson, R.K. Logan, and R.B. Nehrich, 17 March 1961

[2]Navy Electronics Laboratory Report 1199, *Wire Cables for Oceanographic Operations*, by J.C. Thompson and R.K. Logan, 13 November 1963

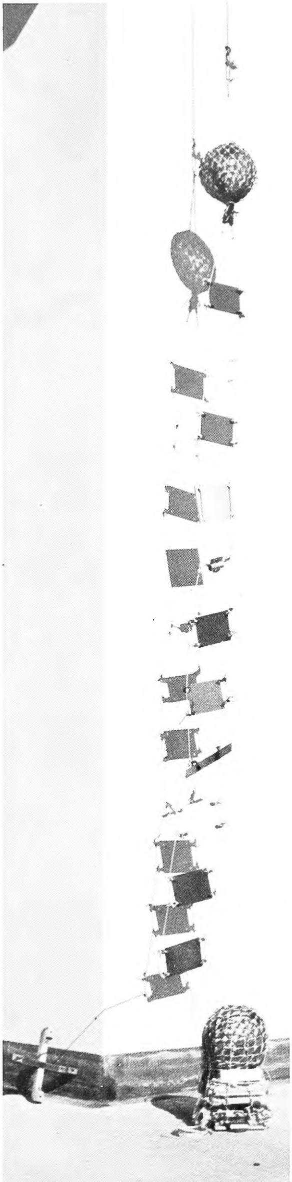

Figure 1. Test assembly pulled into upright position.

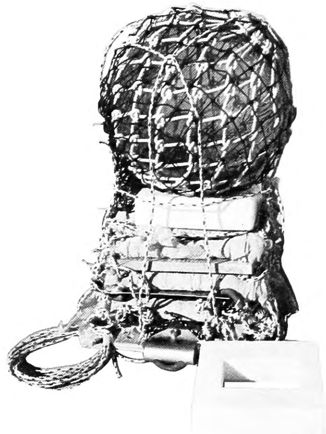

Figure 2. Test assembly in sandwich arrangement.

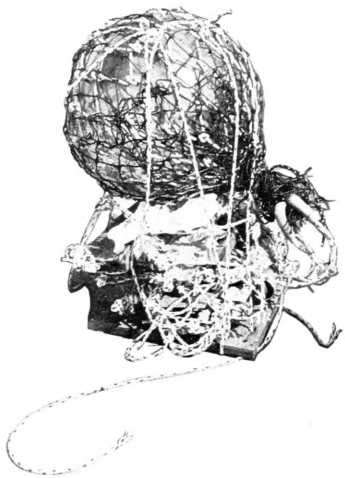

Figure 3. Test assembly in original sandwich arrangement, as retrieved from USS SQUAW after three months of submergence.

A total of twelve such test assemblies were constructed. In December 1965, ten of these were submerged by attaching them to the hull of the submarine USS SQUAW, which was suspended about 35 fathoms below the surface in water over 500 fathoms deep. To compare the effects of shallow-water environment with those of the open ocean, the remaining two assemblies were taken to the area of the NELC Oceanographic Research Tower off Mission Beach, where they were attached to tripods anchored approximately 100 yards seaward from the Tower at a depth of 60 feet. They were left for 18 months, during which time the installations were inspected periodically by divers working at the Tower.

Only five assemblies are discussed here, and these were not exposed to their environments over the total planned test period. One of the packages anchored in the Tower area became loosened from the tripod, drifted to shore, and was returned by a lifeguard. The test specimens aboard the SQUAW were not positioned successfully, because of some misunderstanding. The coils had not been cut when the assemblies were attached to the hull of the SQUAW and the panels, in their original sandwich form, were left floating about 2 fathoms above the hull, so that the individual panels were not properly exposed. It was not until 10 March 1966 that one coil was cut. A package still in sandwich form was retrieved at this time (fig. 3). Scheduling difficulties and bad weather prevented cutting the other coils until September 1967, when another sandwich assembly and the ladder that had been cut loose were retrieved. The five test assemblies examined did, however, yield useful information.

DISCUSSION OF RESULTS

Results of the tests are summarized in table 1. When the assemblies were recovered, the glass floats were found to be completely covered with 1-inch-deep fouling. The original cotton mesh had completely disintegrated, but the nylon netting was still intact. The polypropylene line was completely fouled, as were its attachment points to the samples and the rubber chafing guards. In no case had the antifoulant coatings used on the panels protected the adjoining areas. The rubber tubing had attracted more mussels than any other material in the assembly.

The panels which had been torn away from the tripod had been roughened by the action of the sand and surf, but the condition of the samples corresponded, in general, to that of the set which remained undisturbed for the entire 18 months. Variations in depth in this shallow-ocean test were small (20 to 45 feet), and could not have contributed significantly to the differences in the results. These differences can only be attributed to the varying effectiveness of the coatings used.

At both locations there were considerable differences among the unprotected panels as well as among those which had been treated with protective materials. As had been expected, fouling proceeded rapidly on the acrylic plates; differences in fouling between the plates at the two locations can be attributed to the types and population densities of biological life at the different depths.

TABLE 1. SUMMARY OF SUBMERGENCE TEST RESULTS

Sample No.	1	2	3	4	5
Material	Steel	Acrylic, ¼ in. thick	Steel	Douglas Fir	Corrosion-Resistant Steel
Treatment	Corrosion-resistant coatings with copper-organotin antifoulant.	None.	Corrosion-resistant coatings with cuprous oxide antifoulant.	None.	Uncoated. Bent to induce stress, fastened with CRES nut and bolt.
Oceanographic Tower Installation (18 months at 10-fm depth)	Coatings were chipped off edges of sample and anti-fouling coating was washed off along the sides and some areas in the center of the panel. Hydroid and bryozoan foulants attached along the bare edges and a tight scum of bacterial and proto-zoan colonies covered approximately 80% of the surface of the sample.	Heavily fouled over 90% of the surface. Large percentage of encrusting bryozoa with the balance matted with branching bryo-zoa. Other foulants were mussels (mostly on the chafing tubes), limpets, balanus, and corynactus.	Thin layer of green algal-fouling growth over entire surface. Scratch in coating permitted another type of fouling to propagate. Too small to identify without a micro-scope. One edge of panel was chipped to bare metal. A slight feathering of branching bryozoa had started in this area.	Heavy branching bryozoa over entire surface. Some kelp, tun-icates, balanus, limpets, etc., including, for the first time, large clumps of white sponge (see fig. 4).	Completely fouled. Large clumps of bran-ching bryozoa and white sponge were predominant. Small scattering of filamentous green algae and jingle shells were found. Some corrosion around the bolt and nut.
SQUAW Installation (21 months at 35-fm depth)	Panel seemed to have been damaged during installation on SQUAW or release of coil. Undamaged areas were clean. Damaged area was badly corroded. No fouling.	Approximately 25% of surface covered by jingles and 15% by hydroids. A number of red and pink sea anemones were also attached.	One corrosion eruption approximate-ly 1½ to 2 inches across was located in the central area of the panel. Scrape marks across the corroded area provided a starting place for the oxida-tion. The panel was clean of all biologi-cal growth.	Wood was about 30% eaten away by borers. There were a few jingle shells and tube worms on the board. 15% of the remainder of the panel was covered with hydroids (fig. 5).	Extensive corrosion around bolt head. One jingle and approximately a dozen sea anemones were attached.

6	7	8	9	10	11	Remarks
Steel	2024T3 Aluminum Alloy	Corrosion-Resistant Steel	Steel	Steel	Steel	Panels of mild steel except as noted
Corrosion-resistant and cuprous oxide antifouling coatings.	None.	Uncoated. Flat plates bolted together with a CRES bolt and nut.	Corrosion-resistant coatings with tri-butyl-tin oxide antifouling.	Corrosion-resistant coatings with tri-butyl-tin oxide antifouling.	Corrosion-resistant coating with copper oxide antifouling.	All antifouling coatings were different standard commerical or Navy standard.
Edges were fouled slightly. General condition good. Very little fouling, away from the edges, and that too small to be identified without a microscope (fig. 6).	Heavily burdened with branching bryozoa, minor infestations of yellow sponge and crustose bryozoa. Some tunicates, jingles, and tube worms were in evidence.	Similar to panel 7 with a greater concentration of yellow sponge. Corrosion in bolt area (fig. 8).	Relatively light fouling over 92% of the surface. Jingles started the procedure with branching and crustose bryozoa generally over the surface (fig. 10).	Surface was covered with variegated combination of filamentous algae, dotted with Balanus tintinnabulum from very small to approximately 1½ inches across. These were fairly numerous: 10 to 15 on one side.	Coating turned from red to apple green. The panel was fouled over the surface in clumps of filamentous algae. These were small and randomly scattered over the face of the panel. Approximately 60% of the plate was covered with either this or a silt-like filth.	
Panel was clean except for a brown stain covering about 75% of the area (fig. 7).	Heavy corrosion. Hydroids over 50% of the surface. Algal fouling approximately 10% and a few sea anemones.	Heavy corrosion of bolt and immediate area. Several small jingle shells. Sea anemones and hydroids attached lightly over the surface. There appeared to be crustose bryozoa over about 20% of the panel (fig. 9).	3 jingles attached; traces of several others having been attached and fallen off. Also attached were 25 or so sea anemones, a starfish, and large flat worm (see fig. 11).	Corrosion area about 1 inch long on one edge. The panel was free of fouling.	Bad corrosion on edge, with blisters. Apparent lack of adhesion of coating. No fouling, but a creeping corrosion.	

The Douglas fir panels differed in their ability to resist biological borers. The shallow-water panel maintained its entire outline, while the deep-water sample was almost destroyed. It may be that the fouling elements at the shallower location, finding lodgement and rapid growth possible on the bare wood, grew so rapidly that they made penetration by the borers more difficult. A corresponding effect was noted on the aluminum plates; the deep-water panel was severely corroded over its entire surface, while that from the shallow water had apparently been protected by the heavy growth of fouling organisms.

The ''corrosion resistant'' steel proved to be more subject to corrosion and fouling than is generally believed. The more severe corrosion of the sample from the SQUAW might indicate the effect of pressure at greater depth or, possibly, as in the case of the wood and aluminum panels, the heavier biological fouling in the shallower environment protected the sample there from corrosion.

The panels showing the least fouling were those protected with coatings containing cuprous oxide. Steel panel #6 was the cleanest of all tested, with #3 second best; panels #11 and #1 were slightly more fouled. Steel panels #9 and #10, coated with tri-butyl-tin oxide compound, were considerably fouled by the shallow ocean water, but only #9 was fouled in the deep water. The absence of fouling on #10 in the SQUAW installation cannot be explained. The tin compounds should be investigated further, as they are relatively new, whereas the copper materials have an extensive history as antifoulants.

The anticorrosion coatings functioned as expected, except for panel #11 from the SQUAW. There are several possible causes for this failure, none of which can be accepted definitely until the remaining samples have been retrieved and inspected.

The expense and effort involved in deep-water testing are not justified, since the more rapid fouling of materials in shallow water expedites evaluation of corrosion-resistant and antifoulant coatings.

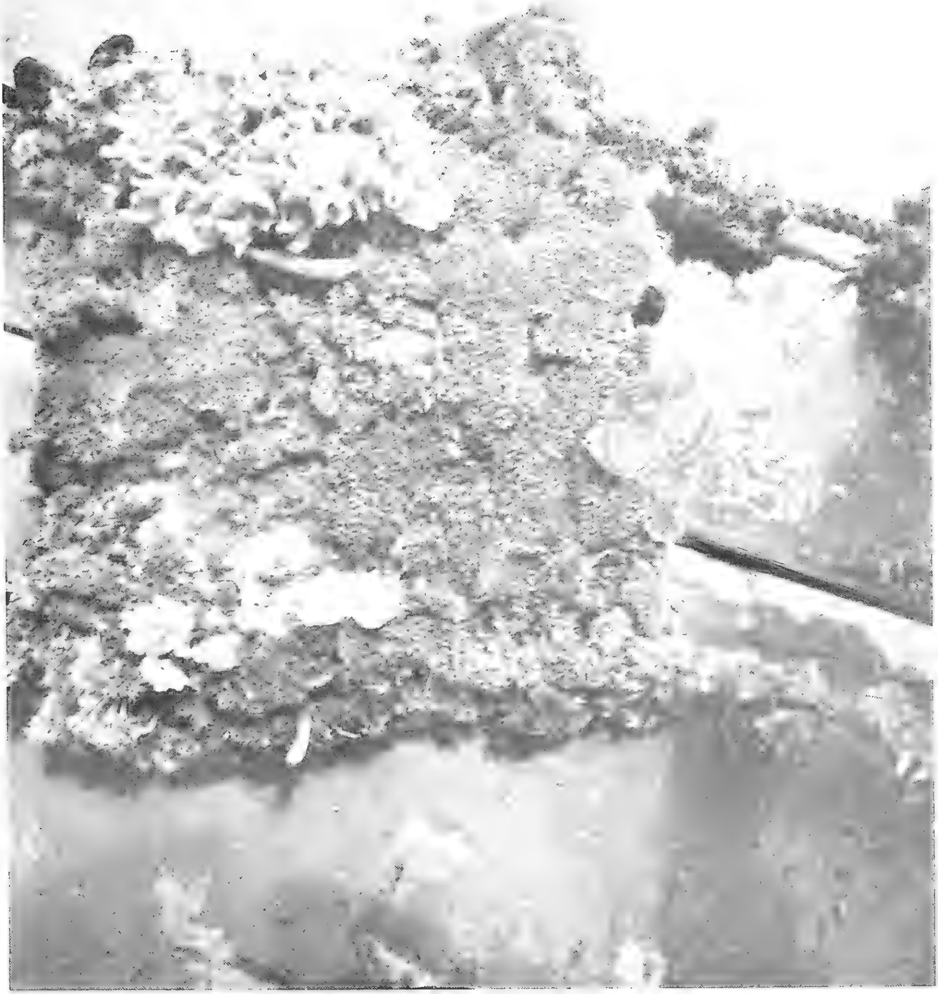

Figure 4. Douglas fir panel after submergence in Tower installation.

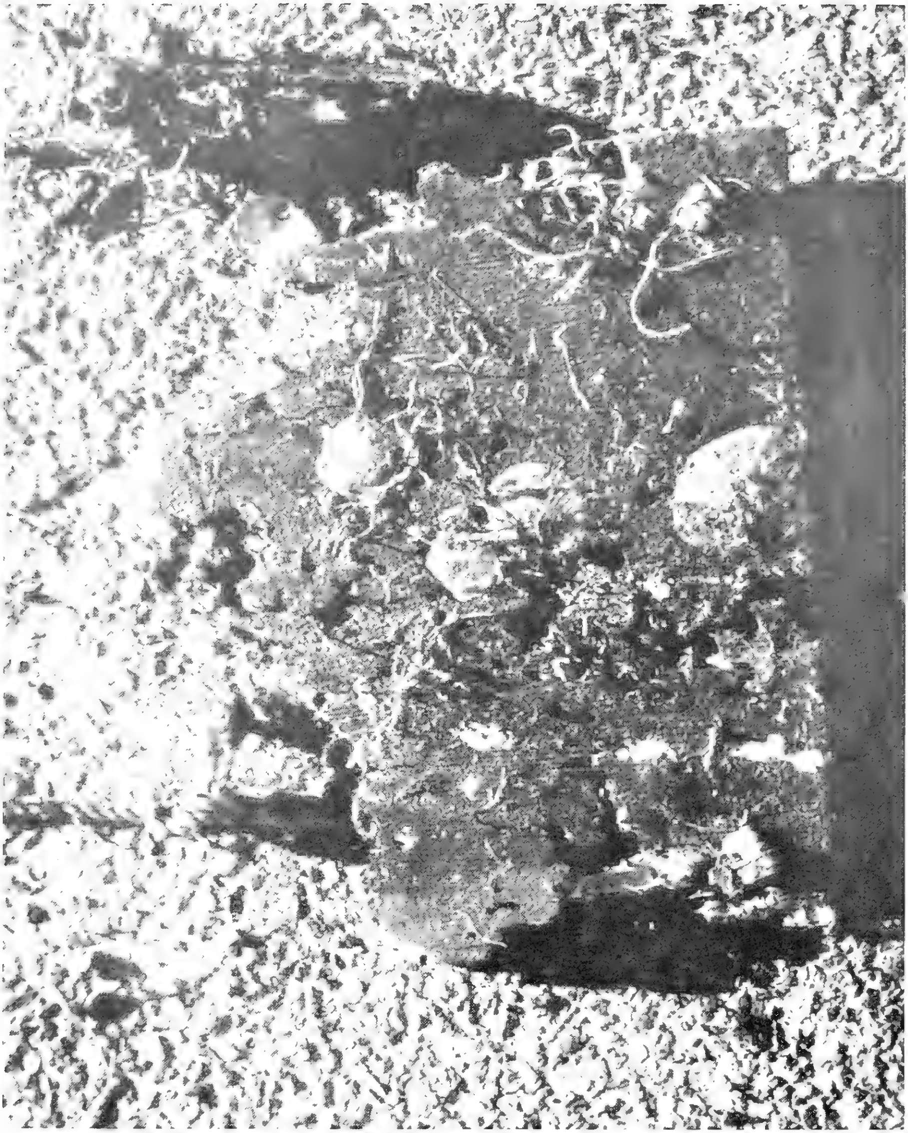

Figure 5. Douglas fir panel after submergence in SQUAW installation.

Figure 6. Steel panel (#6), coated with cuprous oxide antifoulants, after submergence in Tower installation.

Figure 7. Steel panel (#6), coated with cuprous oxide antifoulants, after submergence in SQUAW installation.

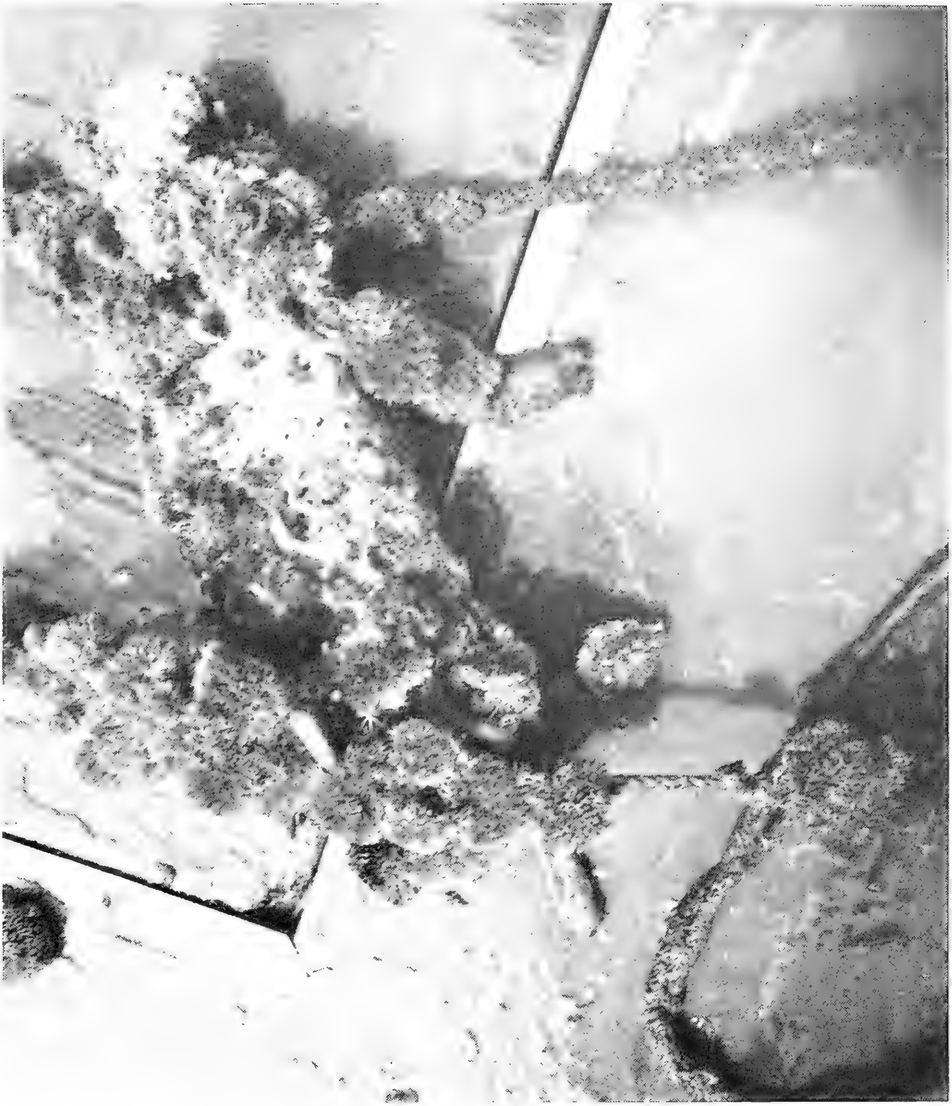

Figure 8. Corrosion-resistant steel panel (#8), uncoated, after submergence in Tower installation.

Figure 9. Corrosion-resistant steel panel (#8), uncoated, after submergence in SQUAW installation.

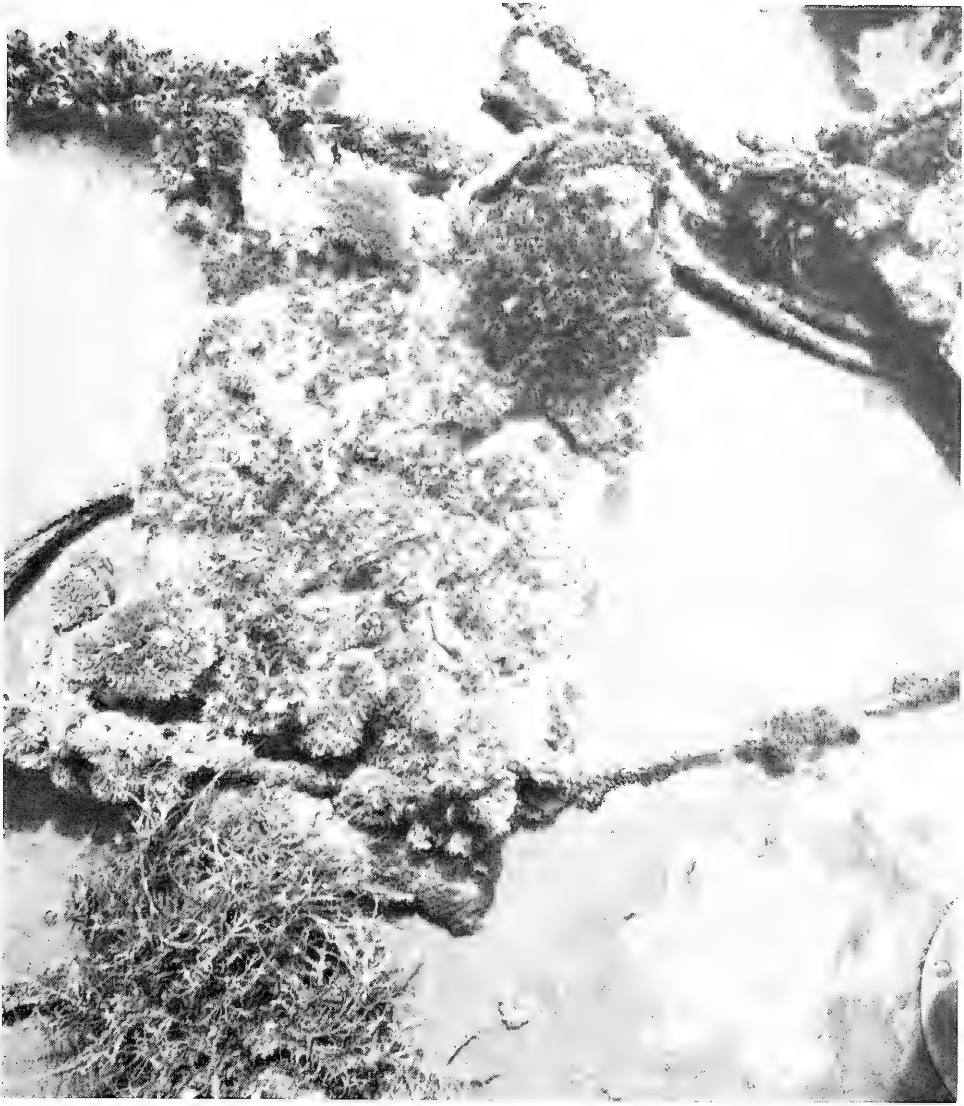

Figure 10. Steel panel (#9), coated with corrosion-resistant and tri-butyl-tin oxide antifoulant, after submergence in Tower installation.

Figure 11. Steel panel (#9), coated with corrosion-resistant and tri-butyl-tin oxide antifoulant, after submergence in SQUAW installation.

CONCLUDING REMARKS

The tests described here are only a fragmentary contribution to the overall study of the effects of the ocean environment on materials used in underwater equipments and of how to inhibit these effects. These studies must be continued, in view of the increasing need for protection of underwater military installations.

Future investigations should be directed not only towards obtaining protective coatings to retard the corrosive and fouling effects of the ocean environment, but also towards the development of structural materials that are inherently resistant to such effects.

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13. ABSTRACT

Test assemblies, each containing 11 specimens of various construction materials, with and without protective coatings, were submerged at depths of 10 and 35 fathoms for periods of 18 and 21 months, to determine the fouling and corrosion caused by exposure to these environments. Fouling in the shallower environment was much more severe than in the deeper ocean. Corrosion-resistant steel was found to be more subject to corrosion and fouling than is generally believed. The tri-butyl-tin oxide compounds show promise as protective coatings. Seven test assemblies were left in the deep ocean; they will be periodically retrieved and evaluated over a 10-year period.

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