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PROJECT MICHAEL

CONTRACT N6-ONR-27135

COLUMBIA UNIVERSITY

HUDSON LABORATORIES

DOBBS FERRY, N. Y.

[illegible]is document has been reviewed in accordance with [illegible]AVINST 5510.17, paragraph 5. The security [illegible]ification assigned hereto is correct.

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COLUMBIA UNIVERSITY

Hudson Laboratories

Dobbs Ferry, N. Y.

PROJECT MICHAEL

Contract N6-ONR-27135

STATUS REPORT

April 1 - September 30, 1953

W. A. Nierenberg
Director

Research Sponsored by
Office of Naval Research

SECRET — October 1, 1953

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This report consists of 27 pages.

53AA-19987

CONTENTS

LIST OF FIGURES

SUMMARY

1. East-west soundings at San Juan, Puerto Rico, with a modified Edo sonic sounder, indicated a series of canyons 50-100 fathoms deep and about 2 miles apart extend seaward from the 100 fathom curve.

2. Two sets of refraction profiles have been shot across the San Juan hydrophones.

3. Analysis of shot range data at Puerto Rico has led to the following conclusions:

   (a) Propagation beyond the 3° slope at Puerto Rico is characterized by deep water focussed transmission with 35 mile peaking.

   (b) From the deep hydrophone out to the end of the 3° slope, the sound intensity undergoes inverse square spreading due to the geometry of the slope and an additional loss of several db due to imperfect bottom reflections.

   (c) The intensity change down the initial slope can be matched fairly well with the function A x $(\text{Range})^{-2.26}$. A bottom velocity of 6625 ft/sec, in excellent agreement with that from refraction data, and a density of 2, give a bottom reflectivity yielding this intensity-range law.

   (d) The intensities for the shallow hydrophone are 3 db below those for the deep hydrophone.

   (e) A comparison of the Puerto Rico intensities with those from Eleuthera indicates the latter are 3-4 db above those at the Puerto Rico 35 mile peaks.

4. The sound propagation pattern out to 7000 yds was determined at 15 and 30 cps for a point east of Ambrose Lightship at the harbor approaches to New York City. From the data, it was found:

   (a) The sound pressure at 15 and 30 cps falls off as $(\text{Range})^{-1}$.

   (b) Both the 15 and 30 cps sound level vs range curves show pronounced maxima and minima for all azimuths,

although within a given range there are about three times as many extrema in the 15 cps case as in the 30 cps case.

(c) There is good evidence for azimuthal symmetry at 15 cps.

(d) The maxima and minima structure of the 30 cps curves is markedly different from that observed earlier at the two locations in Long Island Sound.

5. Additional ambient noise data have been collected at three locations: Puerto Rico, Byram Lake, and in northern European waters.

6. Experiments designed to detect a submarine by the diffraction of 30 cps sound continued but no effect above background was found.

7. The facilities of the San Juan, Puerto Rico installation have been used to record the noise characteristics of two submarines: USS SEA OWL and USS GRAMPUS.

8. Tests of redesigned "Yo-Yo" listening units were made during August. No mechanical or electronic difficulties were encountered.

9. A device designed to eliminate long expensive armored cables used at permanent listening stations has been built. In a preliminary test at San Juan, the electronic parts operated satisfactorily but no hydrophone signal was detected.

INTRODUCTION

The primary problems of Hudson Laboratories are those involving the propagation of low frequency sound in the ocean. During the period from April 1 to September 30, 1953, considerable progress was made toward solving some of these problems. Sound transmission in both deep and shallow water was investigated and the development of instruments useful in these studies continued.

A major part of the research of these laboratories centers around the San Juan, Puerto Rico installation. To use the installation most effectively, it is essential that the physical parameters of the ocean and the bottom near the station be known. From shot refraction profiles, taken across the hydrophones during April and September, 1953, the thicknesses of the layers underlying the bottom and their velocities were determined. Depth contour information was obtained from a sonic sounding survey within 10 miles of the Puerto Rico shore and the ambient noise background at the station was recorded on the hydrophones and "Duckling" detectors. Shot-range run data analyzed during the April-September period established the sound transmission behavior of the ocean near the installation.

Since the sound transmission properties of the San Juan area are now well known, the station may be used both for experimental work and Naval service jobs. At the request of the Navy, a routine program of determining noise patterns for submarines under various operational conditions has been initiated. Tapes have been taken on the first two ships in the program: USS SEA OWL, May 12-16, 1953, and USS GRAMPUS, August 24-27, 1953. Experiments in the active detection of submarines continued also with modified A Mark 6 (b) minesweeping equipment and shots as sources. The laboratory ship USS ALLEGHENY was present for all Puerto Rico operations except those involving the SEA OWL.

A combined approach for minesweeping and shallow water listening led to a limited investigation of shallow water propagation. An extensive and successful study of 15 and 30 cps sound propagation was conducted during June and July, 1953, at the approaches to New York Harbor. With A Mark 6(b) sound sources carried by the ALLEGHENY, and listening hydrophones carried by two small boats, intensity-range data were obtained for all azimuths around a fixed point.

During the August, 1953, Puerto Rico exercises, tests were made of six redesigned Yo-Yo's and of a device, designated as the anchored buoy, designed to eliminate long, expensive hydrophone cables at permanent installations.

SOUND PROPAGATION STUDIES - SAN JUAN STATION

As one of the few deep water listening stations available for experimentation, the San Juan, Puerto Rico installation of the Hudson Laboratories is of ever-increasing importance. If the station is to be used efficiently, it is essential that the properties of sound transmission to the hydrophones be understood. Since the sound transmission pattern can be predicted theoretically if the physical characteristics of the water and bottom are known, an intensive program to gather the required information has been undertaken.

The Edo sonic sounder has been modified to record on a scale giving ten times the detail of the original equipment. East-west traverses made by the USS ALLEGHENY within 10 miles of shore, using the modified Edo, obtained soundings that indicate a series of submarine canyons extending seaward from the 100 fathom curve. The canyons are from 50-100 fathoms deep, about 2 miles apart, some V-shaped and some flat bottomed. All of these canyons do not extend headward into enbayments of river mouths but seem to be independent of terrestrial geomorphology. Some of the canyons extend 40 miles seaward and emerge onto the 4150 fathom flat plain which runs roughly east-west 50 miles offshore. This basin is separated from the Puerto Rico Trench by a series of uncharted sea mounts, except near longitude 66°20'W, where an overflow into the 4350 fathom trench is apparent. The presence of calcareous sediment in the Puerto Rico Trench shows the canyon's turbidity currents must reach the abyssal floor of the trench and are not seriously ponded in the intervening 4150 fathom plain.

To determine the sound velocities and thicknesses of the layers underlying the bottom, refraction profiles have been shot across the San Juan hydrophones. A preliminary survey was made in April, 1953, with the ATLANTIS and VEMA firing shots which were received by the shore-based hydrophones. A much more detailed experiment was carried out during September, 1953. The data are being analyzed.

Analysis of the shot range data taken at Puerto Rico during March and April, 1953 is in progress. For sound propagated in plane waves, the total energy crossing unit area of the listening hydrophone is

$$E \frac{1}{\rho c} \int_0^T p^2 dt$$

A quantity closely related to this, $10 \log \int_0^T p^2 dt$, has actually been used in studying the data. The preliminary experimental results have been compared with theoretical energy-range curves found by ray tracing. A few statements can be made for sound propagation within the 53-106 cps band as a function of range along azimuth 000°T from San Juan.

1. Propagation beyond the 3° slope at Puerto Rico is characterized by deep water focussed transmission with 35 mile peaking (Fig. 1).

2. From the deep hydrophone out to the end of the 3° slope (a distance of 20-25 miles), the sound intensity undergoes inverse square spreading due to the geometry of the slope and an additional loss of several db due to imperfect bottom reflections.

3. The intensity change down the initial slope can be matched fairly well with the function $A\ (\text{Range})^{-2.26}$. A bottom velocity of 6625 ft/sec and a density of 2 give a bottom reflectivity yielding this intensity-range law. This velocity is in excellent agreement with that calculated from seismic refraction shots.

4. The intensities for the shallow hydrophone are 3 db below those for the deep hydrophone, presumedly because of further attenuation of the sound in multiple reflections on the slope.

5. A comparison of the Puerto Rico intensities with those measured on the "good" azimuth at Eleuthera indicates that the latter intensities are 3-4 db above those at the Puerto Rico 35 mile peaks. The shot data for other azimuths are being analyzed.

During Operation 19, August and September, 1953, shots were fired out to a range of 90 miles along azimuth 000°T and recorded on the deep hydrophones. These data will be used to check the relative calibrations of the hydrophones.

PROPAGATION OF SOUND IN SHALLOW WATER

Sound propagation in shallow water depends critically upon the properties of the ocean bottom in the area being studied. Since these properties remain largely unknown, Hudson Laboratories has conducted experiments designed to obtain empirical data which could be compared with the existing theoretical predictions. These experiments are important for all problems connected with shallow water propagation. The first work was done during August, 1952, in Long Island Sound. The program has been extended and expanded by extensive investigations carried out in Operation 18 during June and July, 1953, east of Ambrose Lightship at the harbor approaches of New York City.

The area chosen for Operation 18 has a relatively flat bottom covered by shallow water of 80 foot depth. A point designated as X-Ray, about which the experiments were centered, was marked by a USCG anchored buoy and the velocities and thicknesses of the layers underlying the bottom determined by shooting two mutually perpendicular refraction profiles across X-Ray. In agreement with results found by previous investigators, three layers were identified: unconsolidated sediment, semi-consolidated sediment and rock basement.

Sound level as a function of range was measured at 15 cps and 30 cps using A Mark 6(b) minesweeping equipment as sources. The sources were carried at a depth of 42 feet by the USS ALLEGHENY, anchored each day within 200 yards of X-Ray, and the sound was monitored by two 40 foot boats dragging listening hydrophones at 42 feet or 63 feet. The monitoring boats, driven by currents and winds, covered a wide range of azimuths for distances up to 7000 yards. Speeds of more than one knot could not be tolerated because of hydrophone strumming. The curves of Fig. 2 are for sound level as a function of range for all the data averaged by eye.

The important results are as follows:

1. The sound pressure at 15 and 30 cps falls off as $(\text{Range})^{-1}$, corresponding to spherical spreading loss.

2. Both the 15 and 30 cps sound level vs range curves show pronounced maxima and minima for all azimuths, although within a given range there are about three times as many minima in the 15 cps case as in the 30 cps case.

3. There is good evidence of azimuthal symmetry at 15 cps. Not enough runs were made at 30 cps to warrant a conclusion.

4. The maxima and minima structure of the 30 cps curves is markedly different from that observed for the two locations in Long Island Sound. The differences may be attributed to differences in physical conditions, especially depth to basement rock.

AMBIENT NOISE

The ambient noise level is a basic design factor in passive and active listening in the ocean. At this laboratory the ambient noise spectrum has been determined for a variety of locations and conditions. During the past six months data reported previously have been augmented by four additional sets of measurements taken at Puerto Rico, in Byram Lake, New York, and on an extended cruise in northern European waters.

From April 1 to April 17, a series of ambient noise measurements were made using both the Duckling and the shore based hydrophones of the San Juan, Puerto Rico Station. One set of observations was obtained from the sampling unit which records two minutes of ambient noise every hour. Another set consisted of simultaneous recordings from one of the hydrophones and the Duckling. The Duckling was operated from the USCG 83-400 which was hove-to during the measurement as nearly as possible over either the shallow (200 fathom) or the deep (460 fathom) hydrophone. A third set of observations was made with the Ducklings alone, again from the USCG 83-400, at a point offshore about due north of El Yunque Mountain. Although analysis of the data obtained in this operation is not complete, the results thus far indicate no major differences between the ambient noise spectrum observed with the Duckling 200-300 feet below the surface and with the hydrophone on the bottom. Additional data were taken with the sampling unit in September but they have not been analyzed as yet.

During July, observations were made at Byram Lake in Westchester County, New York. The spectrum obtained differs markedly from a typical ambient noise ocean spectrum.

At the invitation of the US Navy Hydrographic Office, two members of these laboratories conducted ambient noise measurements aboard the USS REHOBOTH in August during Amos Cruise No. 13-C. The results will be contained in a special report to the Hydrographic Office.

Several pieces of equipment are under development at present. A five-channel amplitude distribution analyzer and three Ducklings designed to operate at depths of 4500 feet are completed and the analyzer is being tested. Design studies on arrays are proceeding. A twenty-channel mechanical delay consisting of twenty loops of recording tape with individual adjustable heads is being built. It will be used to steer the array during studies of the directional properties of ambient noise.

SOUND PROPAGATION STUDIES-MISCELLANEOUS

Cape Sable, Nova Scotia

The information furnished by Sonic soundings is invaluable in predicting the sound propagation properties of a particular part of the ocean. In addition to using data obtained by Hudson Laboratories' operations in drawing bottom contour maps, these laboratories gather and utilize soundings collected by other organizations. Soundings taken by the US Navy Hydrographic Office and by the Woods Hole Oceanographic Institution have been analyzed to give a picture of the bottom near Cape Sable Island, Nova Scotia.

The Hydrographic Office data show the continental shelf to extend 60 miles offshore from Cape Sable Island. The seaward edge of the continental shelf corresponds to the 100 fathom curve, which is indented by numerous canyons. These submarine canyons have been traced seaward for 200 miles into 2500 fathoms of water by Woods Hole Institution ships, equipped with the Edo sonic sounder modified to record on a scale which gives ten times the detail provided in the original equipment. A study of their records has shown that the canyons are from 5 to 10 miles apart and 300 to 400 fathoms deep where they incise into the continental slope. Beyond the 700 fathom curve the gradient of the continental slope decreases and the canyon vertical relief is only 10 to 15 fathoms. They become flat bottomed, vary from 1 to 4 miles wide and some exhibit natural levees. Sediment samples obtained in the area contain glacial material overlain by a maximum of 10 feet of recent sands and clays which show evidence of turbidity current deposition and slumping.

Montauk Point, New York

The analysis of transmission data taken in December, 1952, on the continental slope south of Montauk Point is now substantially completed. Fig. 3 shows some of the results of the analysis. The pressure levels have been corrected for cylindrical spreading and water absorption by the addition respectively of 10 log R and 0.01 $\overline{f^2}$ R, where R is the range in kiloyards and $\overline{f^2}$ is the mean square of the frequency of the band in kc/sec. There are differences of two to three db between the pressure levels recorded by the listening stations at 480 fathoms and 284 fathoms as a result of loss in reflection from ocean bottom and surface of the sound traveling up the continental slope approximately nine kiloyards between the deeper and shallower stations. The corresponding differences in pressure level for the 480 fathom and 180 fathom stations, which are 16.5 kiloyards apart, is seven to eight db for the 30-60 cps frequency band and 10 to 11 db for the 1000-2000 cps band.

The curves of Fig. 3 show a sharp drop in pressure level, especially for the 1000-2000 cps bands, as the temperature of the surface water rises. Rays originating in a higher temperature, and thus a higher velocity, layer are bent more sharply downward and strike the bottom at steeper angles, resulting in a greater loss in the bottom. The temperatures plotted in the upper curves are from bathythermographic records.

Theoretical Studies

A preliminary evaluation of acoustic transmission at what has been designated as the "Old Fox" site has been completed and a report transmitted to the Propagation Committee. A similar examination of the "New Fox" site is half completed.

In connection with the shallow water experiments, extensive computations are under way using the normal mode theory, both as originally developed by Pekeris and as reworked by Stone and by members of this laboratory.

A system for the machine computing of rays using the IBM CPC has been developed. The programming in this system is wired into the boards of the machine, only the velocity and bottom profiles and input data being punched on cards. The CPC can compute a complete ray to 200 miles, including 10 bottom reflections in about 50 minutes. This is to be compared with a minimum time of half a day by hand computation alone.

Ambient noise data taken by these laboratories are being carefully examined with a view toward determining its statistical properties, in particular the distribution of amplitudes in various frequency bands.

REFLECTIONS FROM A SUBMARINE

To avoid the limitation of short ranges inherent in present sonar equipment, it is necessary to use lower frequencies than the 24 kc/sec common today. Low frequency sound propagates great distances in the ocean with little but geometrical losses and also penetrates farther into the shadow zones. In view of these facts, Hudson Laboratories have investigated the active detection of submarines with 30 cps continuous waves and high-energy pulses from shots. The work was done at the San Juan, Puerto Rico, Station.

An attempt to detect reflections from the USS DIABLO, March, 1953, using A Mark 6(b) minesweeping equipment, modified to generate constant 30 cps waves, failed. Because of difficulties with sound source synchronism, uncertainties in the submarine and sound source positions and the availability of only three of the filters needed in the Doppler-shift detection method, it was impossible to determine if the effect sought was present. The experiment was repeated with the USS GRAMPUS during August, 1953. Although all of the difficulties encountered in March had been corrected, no evidence of a reflected signal above the backgrounds of the filter outputs was found.

A series of shots also were fired near the submarine USS DIABLO and detected on the 460 fathom hydrophone 30 miles from the shot point, but when the tapes were analyzed, it was not possible to distinguish the expected reflections from the noise. To avoid reflections from the bottom and eliminate signal attenuation in transmission to the hydrophone, a similar experiment was carried out in deep water during the USS GRAMPUS operation. Yo-Yo hydrophones near the submarine were used as detectors. However, since the sea was rough and the Yo-Yo transmitting antennas frequently dipped beneath the waves, it is doubtful if much useful information was obtained.

SHIP NOISE PROGRAM

The San Juan, Puerto Rico installation of the Hudson Laboratories is in many respects an ideal station at which to determine ship noises. The hydrophones are located in deep water which simplifies the analysis of the data and the transmission characteristics of the area are well known from extensive 30 cps source and shot work. At the request of the Navy, a program designed to determine the characteristic noises emitted by various submarines has been initiated. In contrast to most measurements of this type, the experiments are conducted in such a way that the results can be presented quantitatively as a radiation pattern of the vessel.

The first measurements of this program were made on the USS SEA OWL, May 12-16, 1953. The exercises consisted of surfaced, submerged, and snorkeling runs over a prescribed course and under specified engineering conditions near the deep (460 fathom) barium titanate hydrophone. Frequencies from 5-1000 cps were recorded. Similar experiments were conducted with the USS GRAMPUS in August.

For purposes of analysis, the frequencies recorded have been divided into 5-30 cps and 30-1000 cps bands. Both broad band and line analyses are being made-- the broad band, with a Bruel & Kjaer spectrum analyzer which uses 1/3 octave filters; the lines, with a Vibralyzer. To use the B & K over the 5-30 cps range, the tape speed must be increased by a factor of ten. The analysis is proceeding.

THEORETICAL STUDIES-MISCELLANEOUS

In the long range detection of submarines by passive listening, a very weak signal must be separated from a strong noise background. The problem of the improvement of signal-to-noise by various methods is being investigated and the particular case of improvement by the use of a linear filtered array has been examined in detail. The principal conclusion is that the effect of filtering is independent of the array effect, the signal-to-noise improvement of the two operations being multiplicative. Formulae for the signal-to-noise ratio of an array in several interesting regions of size have been derived.

THE YO-YO HYDROPHONE

While fixed underwater listening stations may be made very efficient, they are extremely expensive to establish and are rather inflexible. For many applications it would be desirable to use a simple, inexpensive device which has a limited listening range and can be dropped from an airplane. The Yo-Yo represents one version of such an instrument being developed by Hudson Laboratories. In its present stage, it is essentially a sonobuoy modified to avoid surface disturbances and strumming of the hydrophone cable.

The hydrophone of the Yo-Yo unit is connected to a long coil of plastic coated wire which pays out freely and acts as a low frequency, spring-like suspension as the hydrophone descends in the water. In previous tests (see Progress Report, January - March, 1953), the Yo-Yo's were able to detect a submarine as far away as 22 miles but the instruments suffered from leaky cases and numerous transmitter tube failures, and the antenna insulators were frequently submerged. Six of the units were redesigned extensively and taken to San Juan, Puerto Rico for the August, 1953, exercises with the USS GRAMPUS.

No mechanical or electronic difficulties were found with the redesigned Yo-Yo's. After the cases had been loaded with lead at the lower end and buoyed with a small rubber ring at the water level, the units seldom submerged, even in a state 3 or 4 sea.

Recordings of the submarine noises and of shots were made aboard the USS ALLEGHENY. Reliable radio range was short, presumedly because of waves coming between the Yo-Yo and the ship's receiving antenna. During these tests, three hydrophone assemblies were lost, two to sharks and one in retrieving the Yo-Yo from the water. Records from one test were analyzed by Lofar. It was found that three of the five units used were operating but no lines from the snorkeling submarine were visible.

THE ANCHORED BUOY

The purchase of the special cable required to link the hydrophones to shore represents a major expense in establishing undersea listening stations. At the price of more than a dollar per foot, a fifteen-mile cable costs approximately $100,000 and, as a heavy investment, is expected to last for years. A great part of the high price per foot pays for armor designed to resist abrasion by the bottom and biological activity. Such destruction, however, occurs in relatively shallow water near shore. If a method could be devised to eliminate the near-shore section of the cable, it is possible that simple, inexpensive wire could be used at a great overall saving. The anchored buoy is being developed by Hudson Laboratories for this purpose.

The anchor buoy (Fig. 4) consists essentially of three parts: hydrophone, anchor and buoy. The anchor is dropped in water deep enough to be beyond the zone marked by a rough bottom and biological destruction. From the anchor, several miles of inexpensive, unarmored wire stretches seaward along the bottom toward the hydrophone preamplifier assembly. A second connection, this time a short section of galvanized armored cable, leads upward from the anchor to a buoy floating on the surface. The buoy contains a postamplifier and a frequency modulated radio transmitter which relays to a receiver on shore sounds detected by the hydrophone.

In the first unit built, the buoy was a cylindrical can 2 feet in diameter and 4 feet long, topped by a 9 foot mast and antenna. The batteries required were sealed in a second can hung on a rigid pipe below the buoy. The buoy was stabilized by the battery can acting as a keel and floated with an inflated truck tube strapped just above the water line.

In connection with Operation 19, during August, 1953, the anchor buoy was taken to Puerto Rico and anchored in 600 feet of water. Nine miles of Signal Corps wire were used between the anchor and hydrophone, which rested on the bottom at 4000 feet. The buoy rode the waves very satisfactorily for a period of three weeks, during which the sea states ranged up to state 4 but disappeared after this period. It is presumed it was torn from its mooring in high seas generated by nearby tropical storms.

During the period in which the buoy was observed to be anchored, checks were made that indicated the radio link was operating but no signal was recorded from the hydrophone. The reason for this failure is unknown.

PERSONNEL

During the six months ending September 30, 1953, the total personnel employed on Contract N6-ONR-27135, including five part-time people, has increased from 114 to 151. With only a few minor increases planned in the near future, it appears that the personnel figure should stabilize at approximately 160 to 165. Listed below is a breakdown of the present staff.

Research Scientists (full time)			19
Research Scientists (part time)			5
Research Assistants			4
Analysts			5
Computers			9
Engineers -	Mechanical	6	
	Electrical & Electronic	16	
	Associate	3	25
Engineering Technicians			3
Draftsmen -	Mechanical	5	
	Electronic	3	8
Electronic Technicians			17
Machinists			13
Administrative (including librarians, secretaries, purchasing, stockroom, etc.)			24
Building maintenance & operation			15
Security (guards)			4
		TOTAL	151

PUBLICATIONS

During this period the following reports were issued:

Technical Report No. 9

30 cps Sound Propagation in Shallow Water, by G. E. Becker, R. O. Carlson, R. A. Frosch and H. L. Poss.

April 15, 1953 — 34 p.
CONFIDENTIAL

Technical Report No. 10

Signal-to-Noise Improvement From a Filtered Linear Array, by Franklin Pollock.

June 26, 1953 — 22 p.
CONFIDENTIAL

Technical Report No. 11

A Preliminary Ray Computation for the Ocean South of Sable Island, by R. A. Frosch

July 15, 1953 — 11 p.
SECRET

Technical Report No. 12

A Preliminary Report on Sound Transmission at San Juan, Puerto Rico, by R. A. Frosch, A. N. Guthrie, H. H. Loar, and H. L. Poss.

October 1, 1953 — 39 p.
SECRET

Progress Report, January 1 - March 31, 1953.

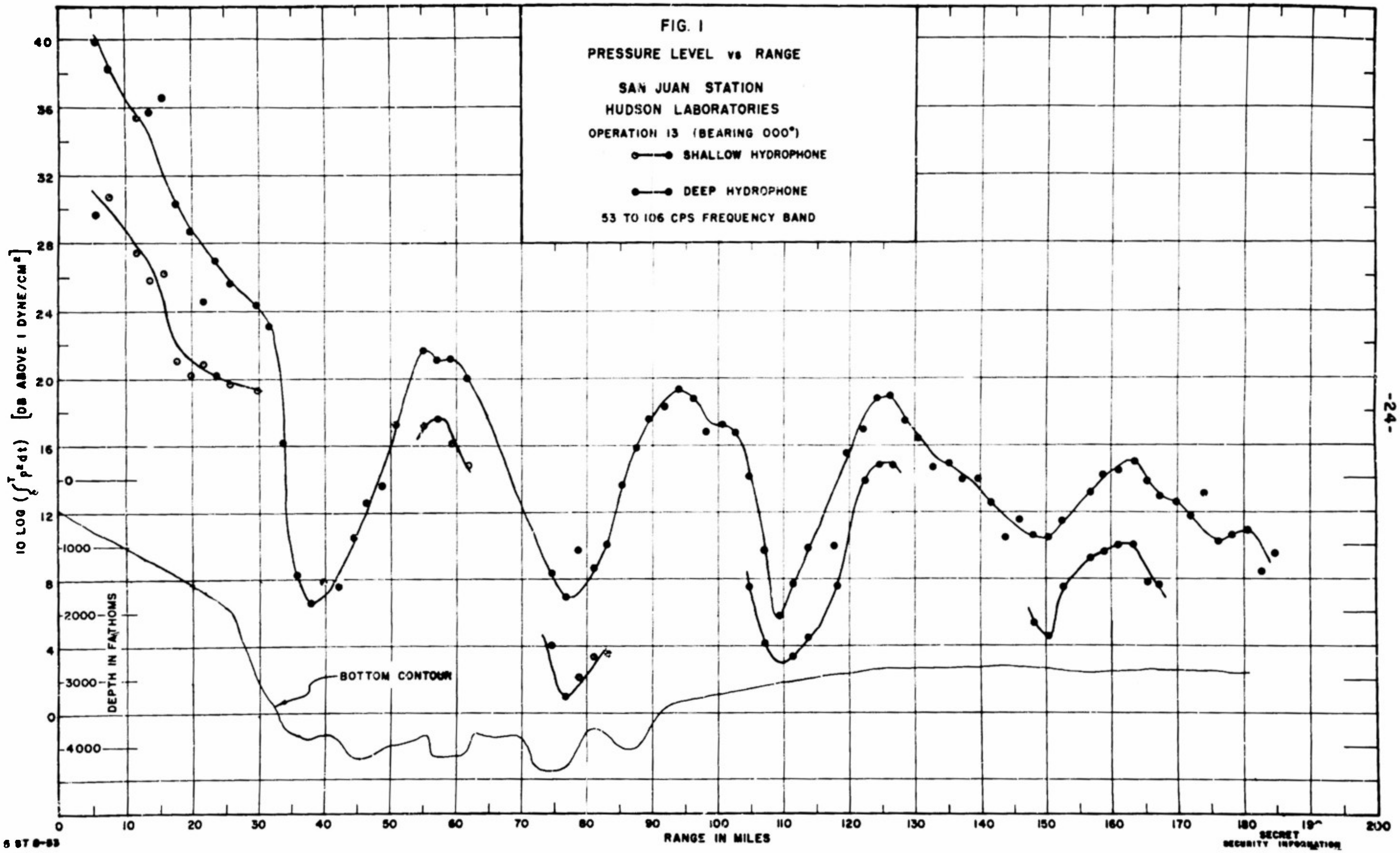
April 30, 1953 27 p.
SECRET

These papers were accepted for publication as noted.

Northrop, John, A Bathymetric Profile Across the Hudson Submarine Canyon and its Tributaries. Journal of Marine Research. In press.

Northrop, John, Bathymetry of the Puerto Rico Trench, American Geophysical Union, Transactions. In press.

SECRET



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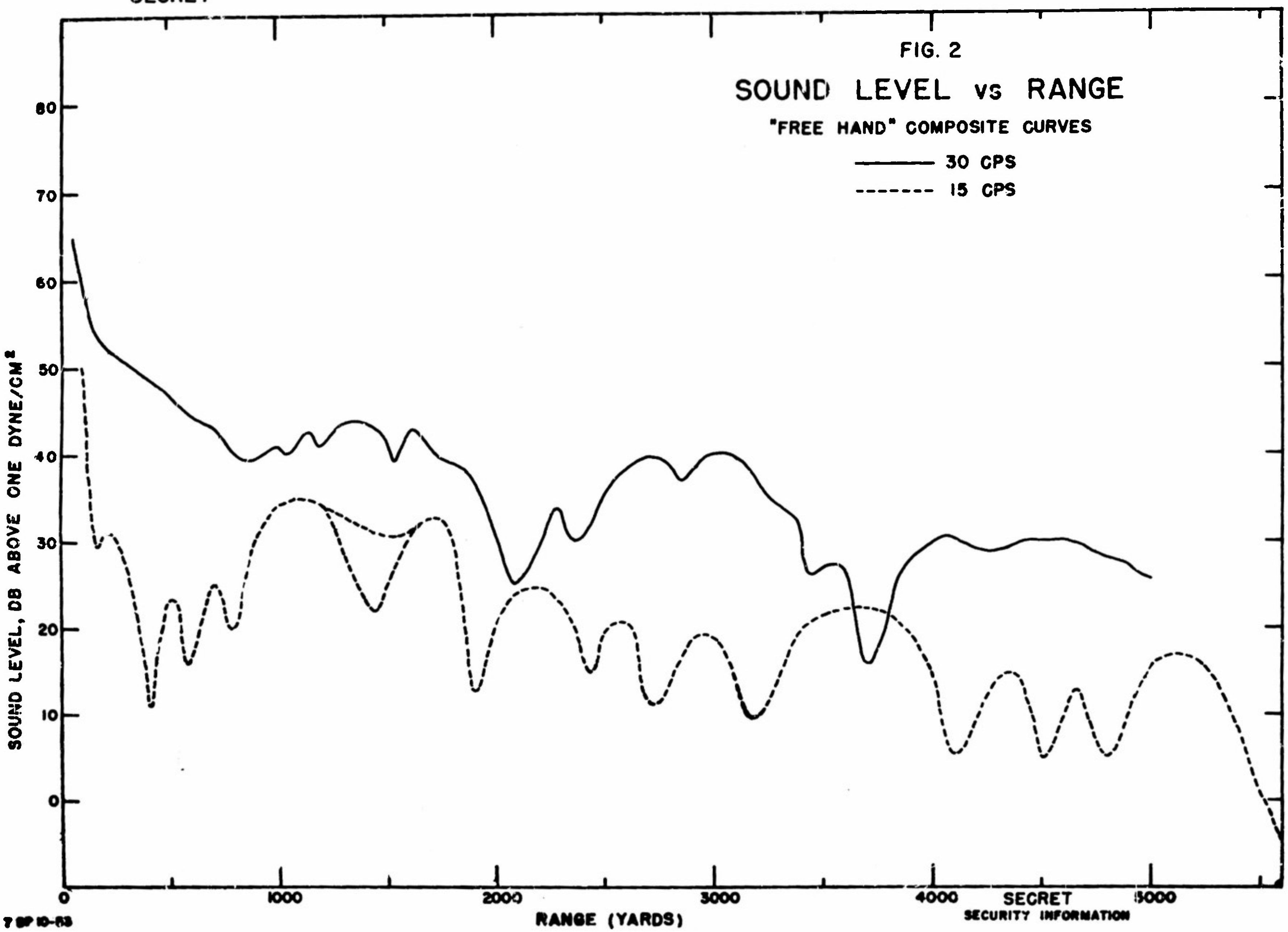

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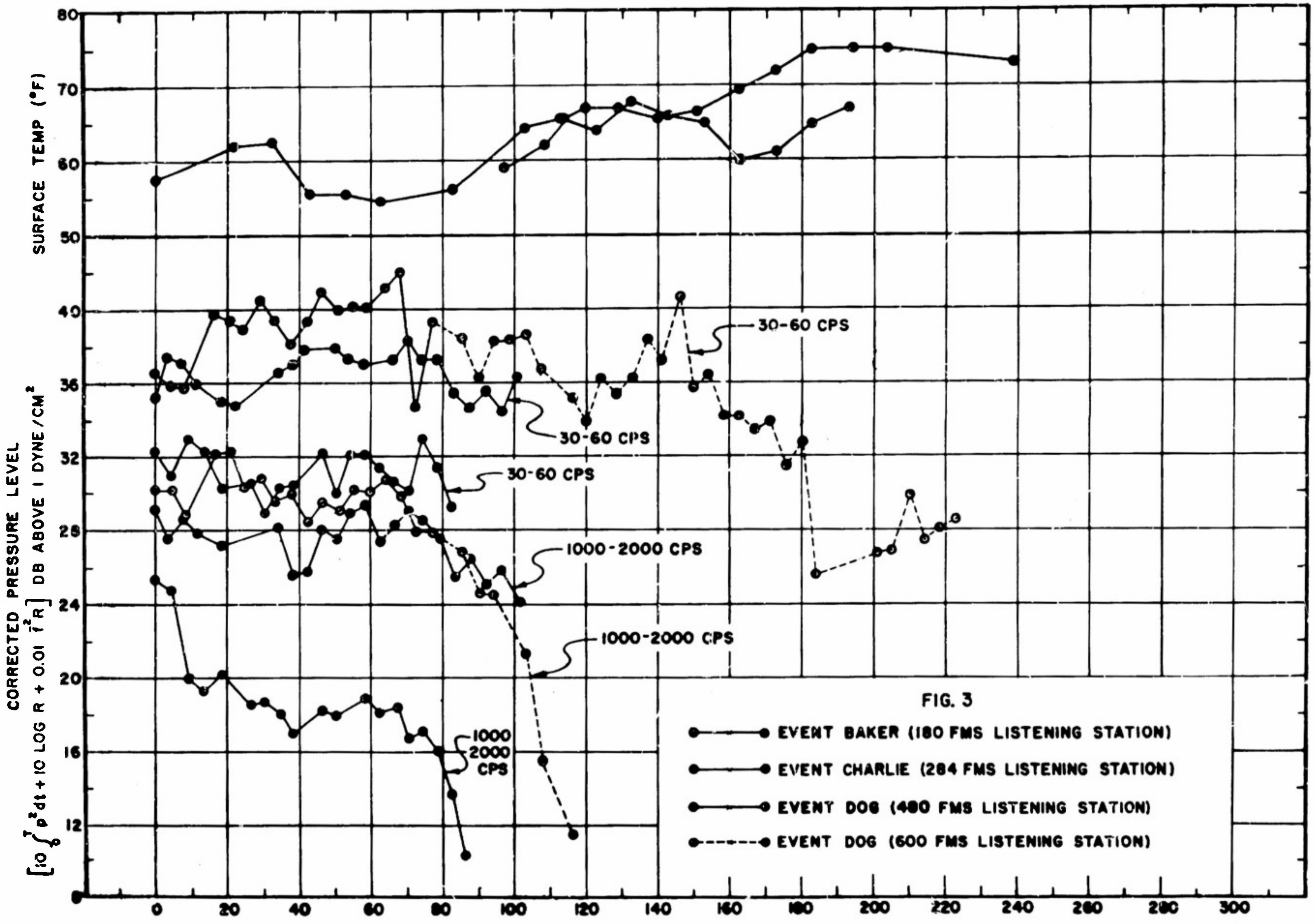
80
70
60
50
40
36
32
28
24
20
16
12
SURFACE TEMP (°F)
CORRECTED PRESSURE LEVEL
$\left[10 \int_0^T p^2 dt + 10 \log R + 0.01\ \bar{r}^2 R\right]$ DB ABOVE 1 DYNE/CM²
30-60 CPS
30-60 CPS
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1000-2000 CPS
1000 2000 CPS
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
DISTANCE FROM POINT BAKER (KILOYARDS)
EVENT BAKER (180 FMS LISTENING STATION)
EVENT CHARLIE (284 FMS LISTENING STATION)
EVENT DOG (480 FMS LISTENING STATION)
EVENT DOG (600 FMS LISTENING STATION)

FIG. 3

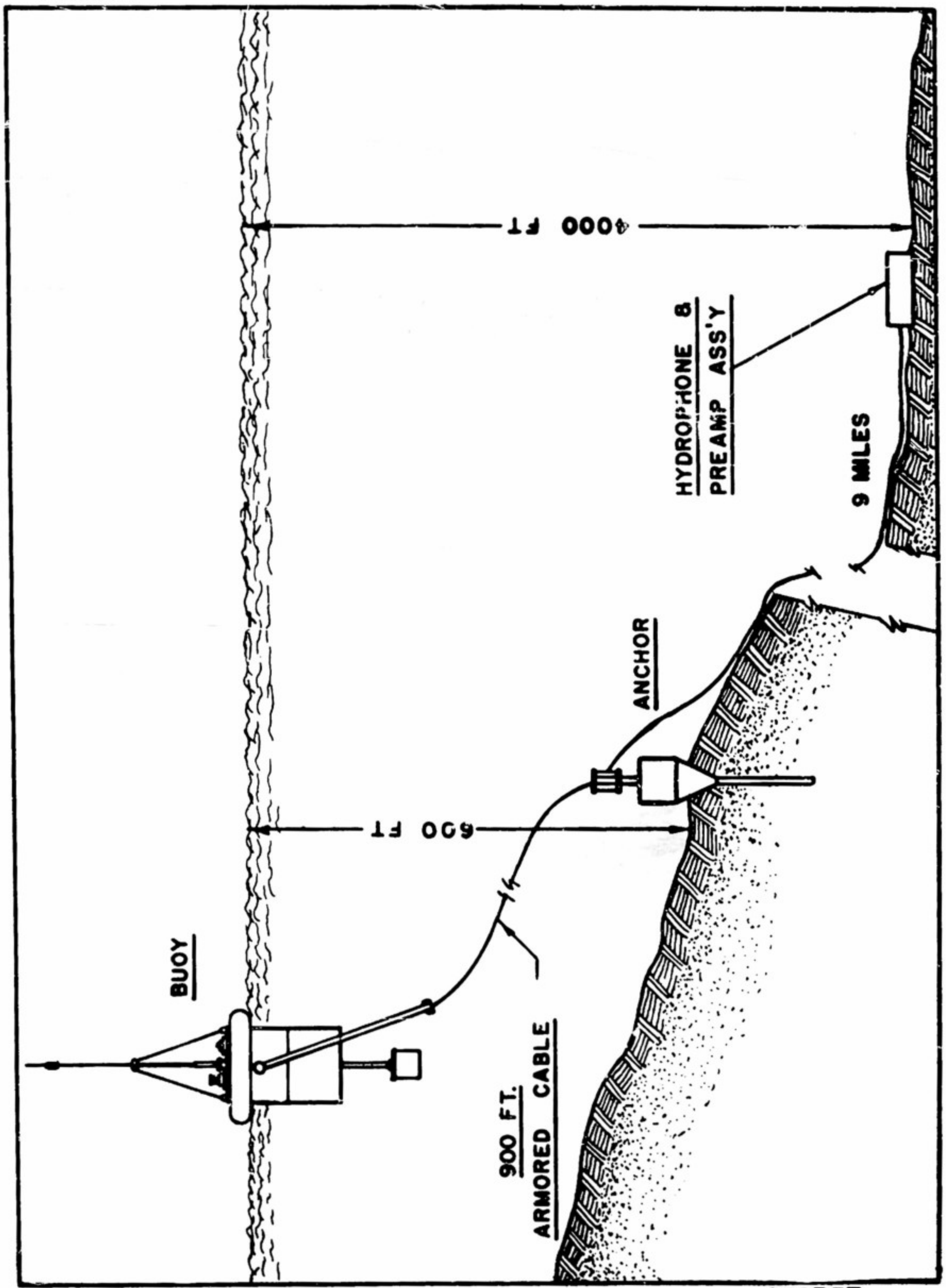
BUOY
900 FT.
ARMORED CABLE
600 FT
ANCHOR
4000 FT
HYDROPHONE &
PREAMP ASS'Y
9 MILES

FIG. 4