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DEEP SEA NORTH OF ST. CROIX, VIRGIN ISLANDS

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Naval Ordnance Laboratory
White Oak, Maryland

14 August 1972

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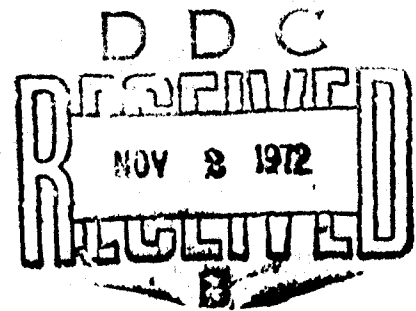
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NAVAL ORDNANCE LABORATORY, WHITE OAK, SILVER SPRING, MARYLAND

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Prepared by:

R.J. Urick, G.R. Lund and T.J. Tulko

ABSTRACT: The deep sea appears to be quieter at mid-depth than at greater or lesser depths. This was found in a series of measurements of the ambient noise background at a location north of St. Croix, V.I., using hydrophones suspended from a cable at intervals of 2000 ft down to 8100 ft. The noise profiles show a sharp decrease of noise from the surface down to 6100 ft and a reversal of the profile below. The measurement site is an active, dynamic one, and shows a large variability in noise level from hour to hour.

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THE DEPTH PROFILE OF AMBIENT NOISE IN THE DEEP SEA NORTH OF
ST. CROIX, VIRGIN ISLANDS

This report describes how the natural underwater noise background at a deep water location varies with depth. It will be of interest to anyone contemplating the use of deep sound sources and receivers in sonar applications. The work was done as Project MARLIN for the Naval Air Systems Command under Task No. A370-370A/WF11-121-707, Problem 202.

ROBERT WILLIAMSON II
Captain, USN
Commander

Z.I. Slawsky
Z.I. SLAWSKY
By direction

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THE DEPTH PROFILE OF AMBIENT NOISE IN
THE DEEP SEA NORTH OF ST. CROIX, VIRGIN ISLANDS

INTRODUCTION

1. The ambient noise of the sea has been measured and reported for many of the world's ocean areas. A relatively abundant literature is extant, and the noise level to be expected under given conditions of wind, shipping and biological activity is well defined (1). Yet, nearly all of this work has involved measurements made relatively near the sea surface. At depths in the body of the sea, the noise has not been greatly studied, partly because of experimental difficulty and partly because of a lack of practical application to which the information could be related.
2. The earliest attempt to determine the variation of noise with depth was made - as one of many "firsts" - by the Hudson Laboratories of Columbia University, using a slowly-sinking recording package aptly called the "Diving Duck" (2). Later, the bathyscaphe TRIESTE was employed for the purpose (3), and, more recently, the depth variation of noise was reported by Perrone (4) from measurements made with different bottom-mounted hydrophones at various depths in an area south of Bermuda.
3. Within the last few years an awakening of interest in this hitherto neglected subject has been brought about by the possibility of using deep propagation paths in long-range passive sonars. Recently, a number of novel instrumental approaches have been taken, and the results are beginning to appear in the literature.
4. However, the data obtained in these recent and current field studies is discordant, and no clear picture of the effect of depth on the noise background has been obtained. One reason for this lack of agreement is the difficulty of sampling a variable noise environment. For if the noise samples at different depths are not obtained simultaneously, many samples are required to smooth out the constantly occurring variations of the background. Another problem is how to avoid, or allow for, changes in hydrophone calibration with depth and temperature. In short, the average depth profile of the noise background of the deep sea is difficult to determine, and requires special experimental measurement techniques.

5. We have avoided the difficulties just mentioned by a method which permits taking data simultaneously at different depths, along with an on-the-spot calibration of the various hydrophones by means of a standard sound source located near the surface. The results show a distinct depth variation of the ambient background at the active, dynamic location where the observations were made.

MEASUREMENT METHOD

6. A string of five hydrophones at depths of 100, 2100, 4100, 6100 and 8100 ft was used for recording the noise background at regular intervals over a period of several days. Fig. 1 shows the hydrophone string called MARLIN (Multiple Array Line) suspended from an anchored instrumentation barge maintained and operated for the Naval Air Systems Command by TRACOR/MAS, Inc. The barge was located just north of the island of St. Croix, V.I., at the location of the cross in Fig. 2 on the side of a basin some 10 miles wide and 60 miles long. This area is one of frequent commercial ship traffic traveling between the Panama Canal and European ports. It is also popular with sports fishermen operating out of the near-by islands. Sources of ship noise are numerous and are relatively close-by the measurement site, and therefore may be expected to be highly variable in their contributions to the noise environment. Although a total length of 12,000 ft of cable was available, it could not all be deployed because of the limited water depth and an electrical fault discovered in the upper portion of the cable.

7. A frequency-modulated multiplexing-demultiplexing system was employed to transmit the output of the five hydrophones up the common coaxial cable. Each hydrophone modulated its own carrier frequency between 120 and 480 kHz; demodulation took place just before analog recording on a Precision Instrument 7-channel FM magnetic tape recorder. Noise samples 1 1/2 minutes long were recorded at hourly intervals during two 2 1/2 day periods separated by an interval of a few days (for battery charging) during March, 1972. A total of 114 hourly samples were recorded.

8. Calibration was accomplished by transmitting to the hydrophones the CW output of a standard Navy J-9 sound source placed at a depth of 50 ft. The response of this projector was checked at the NOL Brighton Dam calibration facility. Tones of known intensity were tape-recorded over each hydrophone channel and were used to convert the recorded data to acoustic levels.

9. Wind speeds during the data-taking period ranged from 0 to 17 knots. A sound velocity profile was not obtained. However, a historical sound velocity profile for the same month of the year at a location a few miles away is given in Fig. 3; a 900-ft bathythermogram taken during the data period showed a 400 foot layer above a thermocline.

10. Analysis of the field tapes was made with a General Radio Model 1921 Real Time Analyzer yielding one-third octave band levels. Four one-third octave bands (50, 160, 500, 3150 Hz) were selected for playback of the hourly recordings. The over-all analysis band extended from 12 to 8,000 Hz; the upper frequency limit was imposed by the tape speed (30 ips) used in recording.

THIRD-OCTAVE SPECTRA

11. Fig. 4 shows three analyses, over the above frequency range, of individual noise samples taken under different conditions of wind and shipping. The upper group of spectra (Fig. 4a), one for each of the five hydrophones depths, was obtained for a single 4-second noise sample recorded during an exceptionally quiet period of nearly calm wind and inaudible ship noise. Two additional curves are superimposed on the measured spectra: The solid curve shows the Knudsen-Wenz spectrum (5) for conditions of light shipping and a 4 to 6 knot wind; the dashed curve is the system electronic noise level recorded when one of the hydrophones was replaced by an equivalent capacitor. The other two groups of spectra (Figs. 4b, 4c) were obtained on samples taken under other combinations of ship traffic and wind speed.

12. We observe from these spectra that, except for the 100 ft hydrophone depth, the measured levels agree well with the Knudsen-Wenz levels for the same noise conditions. Also, the measured levels are well above system noise, except for the 8100 foot hydrophone at high and low frequencies under quiet conditions. The noise level apparently falls off with depth at all frequencies; the deepest (8100 ft) hydrophone is appreciably quieter than the shallowest (100 ft).

STATISTICAL DATA

13. Fig. 5 gives the cumulative distribution of the levels of the 114 hourly samples in the four one-third octave bands centered at 50, 160, 500, and 3150 Hz. These plots show the spread of the 1 1/2-minute average levels at each hydrophone. The standard deviation (σ) of the samples, based on straight lines drawn by eye through the points, ranges from 3.8 to 7.6 db, with an average σ of 6.0 db. A similar statistical spread was found by Wenz (6) in the levels of Pacific Ocean ambient noise over a two-year period.

14. The levels at the 50% points on these figures are the median noise levels equalled or exceeded by half of the noise samples. For three hydrophones depths, these median levels are compared with the Knudsen-Wenz curves in Fig. 6. We observe that, again with the exception of the 100 foot depth, the measured median levels agree with the curves for the conditions of moderate-to-heavy shipping and a 9-knot wind. The median wind speed during the two 2 1/2 day data periods was 7 knots.

DEPTH PROFILES

15. The measured median levels are plotted against depth in Fig. 7. These noise profiles show a rapid decrease of noise with depth from 100 to 2100 ft, followed by a slower decrease down to 6100 ft and a suggestion of a reversal below. The noise profile is roughly the same for all four frequency bands. This result is contradictory to the findings of Perrone (4) in an area south of Bermuda, where the noise at four hydrophones located on the bottom in different water depths down to 2500 fathoms was found to decrease with depth at high frequencies and to increase with depth at low frequencies. However, in the present data the similarity of the depth profile at all frequencies is both reasonable and expectable, since the noise sources at both high and low frequencies, whether due to shipping or the wind, are numerous and are located near the sea surface.

LEVELS AT THE 100-FT DEPTH

16. The profiles show levels at 100 feet to be some 5 to 10 db higher than those at greater depths. These high levels at 100 ft will at once be suspected to be the result of proximity to the measurement barge, where a generator was running to provide 60 cycle a.c. power and where wave slap and human activity aboard the barge might be suspected to overwhelm the ambient sea background only 100 ft away. Indeed, narrow-band sound spectrograms of the noise picked up by the 100-foot hydrophones did show the presence of line components at 60, 90, and 120 Hz originating in the barge power supply.

17. However, various pieces of evidence indicate that the recorded noise at this depth is in large part valid ambient sea noise in nearly all third-octave bands. First, the levels of the power supply line components just mentioned were not high enough to affect the third-octave band levels, except under very quiet noise conditions. Second, the levels are high in all bands, from the lowest to the highest; a barge-proximity effect would be expected to occur principally at low-frequencies. Third, distant shipping (faint screw beats) could be heard much better on the 100-foot hydrophone than on the deeper hydrophones. Fourth, a computed noise-depth profile (Fig. 16) shows a strong near-surface decrease of noise. Finally, higher noise levels at a shallow depth were observed 6 months earlier at the same location with another experimental arrangement: two hydrophones at depths of 55 and 305 ft floated 2000 ft away from the barge (7). Typical one-third octave spectra under these conditions are shown in Fig. 8. A difference of 5 db or more between the two depths appears to exist at frequencies above about 800 Hz. This frequency is about equal to the lowest frequency trapped in the mixed-layer duct 120 ft thick that existed during the earlier data period; the corresponding frequency for the 400-ft duct existing for the present MARLIN data is 120 Hz.

18. From all of these bits of evidence it appears likely that, for frequencies above 100 Hz at least, the high noise levels at 100 ft are those of the natural ambient background at the measurement site.

One possible cause of high noise levels at shallow depths is propagation in the surface duct of the noise from distant sources. Still and all, no such strong layer effect appears to have been reported in the past. Indeed, it is contrary to the notion that at frequencies above a few hundred cycles, the background of surface noise originates in the vicinity of the receiving hydrophone, rather than at ranges great enough for ducting to be effective. Further investigation is required.

SHIP SPOTTING

19. A Navy aircraft, together with radar services of the Atlantic Fleet Weapons Range, enabled ship spotting to be done on two consecutive days. During the exercise, the locations of major ships in an area around the measurement site, together with the type, speed, and course of each ship, was determined. The results of this exercise are shown in Fig. 9. Fig. 10 shows the one-third octave spectra of noise samples recorded at the times the shipping was identified. It will be noted that higher noise levels at low frequencies occurred on the second day (open circles) than on the first (closed circles), in keeping with the larger number of ships observed on the second day.

VARIABILITY

20. It has already been noted that the 1 1/2 minute noise samples are variable in level from hour-to-hour, and have a fluctuation expressed by a standard deviation of about 6 db. Since in Fig. 5 the data points fall on straight lines, the levels in db are roughly normally distributed.

21. This variability is demonstrated in Fig. 11. This is a series of 1 1/2 minute playouts recorded hourly during an overnight period between 1530 hours local time and 1730 hours the next morning. The levels at all hydrophones in the one-third octave band at 160 Hz are seen on close inspection to change in the same way from hour to hour, though not by the same amount. It follows that the depth profile of the noise level must be variable, and so change its shape from hour to hour.

22. This variability in the depth profile is illustrated by the consecutive hourly profiles at two frequencies plotted Fig. 12. Here we see that although the general shape of the profile is preserved from hour to hour to hour, there are considerable variations in detail; for example, at 3150 Hz, where the noise tends to be dominated by the wind, the difference in level at 0630 hours between the 100 ft and 8100 ft hydrophones is 20 db, but is only 6 db an hour later. Similar, though smaller, differences occur regularly throughout the sequence of profiles. In other words, while the level variations of the hourly samples tend to be correlated between hydrophones, the correlation is not perfect.

23. By contrast, short-term, short-period variations do not correlate at all. This is shown by Fig. 13, where, over a total record length

of 19 seconds, we observe noise transients on individual hydrophones that do not appear on others. In short, long period changes tend to occur at all depths in a generally similar way, while short period changes do not.

24. At low frequencies, changes in the location and type of ship pattern are doubtless the cause of much of the variability of the background. This is illustrated by the sound spectrograms of Fig. 14 corresponding to the same series of hourly samples as Fig. 11. Here we note the variability in the line component structure of the low frequency noise, both from hour-to-hour at a single hydrophone, and in the relative strength of the lines from hydrophone to hydrophone at any one time. Although the changing distribution of shipping produces changes in the pattern of the tonal structure from hour to hour, any one instant of time interference effects produced by propagation cause differences to appear in the tonal components from hydrophone to hydrophone.

25. At the higher frequencies, changes in wind speed are a cause of noise variability. This is illustrated by Fig. 14, where the levels of the hourly samples are plotted against the wind speed at the time the sample was taken. It is evident that there is an absence of dependence on wind speed, along with considerable scatter of the data points, at 50 and 160 Hz; on the other hand, there is a strong dependence on wind speed, with little scatter, at 3150 Hz. This behavior with frequency is caused by the increasing dominance of wind noise with increasing frequency, and has been repeatedly observed in the past, in both deep (1), (8), and shallow (9) water.

COMPARISON WITH A COMPUTER MODEL

26. An ambient noise computer model has been developed by the Naval Air Development Center (10). This model assumes an infinite uniform distribution of equal noise sources over the sea surface, and sums up the contributions of sources in different range increments by the use of a ray trace intensity program based on a given velocity profile.

27. Fig. 16 is a comparison of the computed noise profile, using the velocity profile at the right, with the median profile observed at 3150 Hz (Fig. 7). There is reasonable agreement between model and data; the principal features of the noise profile occur similarly in the model and the observations.

SUMMARY

28. We may summarize the results of this field study of the noise background throughout the water column at the St. Croix site by the following statements:

1. It is feasible to observe the ambient noise background at a depth by means of hydrophones suspended from an armored cable provided vibration isolation is used between hydrophones and cable.

2. At St. Croix, the sea becomes quieter with increasing depth down to about 6000 ft, with a suggestion of a reversal between 6100 and 8100 ft.

3. The noise background is variable over hourly intervals. One-minute noise samples have a standard deviation of about 6 db.

4. Although long-period changes in level tend to occur at all depths in a similar way, short period changes do not, and remain uncorrelated between depths 2000 ft apart.

5. The noise near the surface (100 ft) is higher at all frequencies than at greater depths. This effect appears to be inherent in the noise background at the measurement site, but is difficult to explain.

6. A computer model assuming a uniform distribution of ship sources over an ocean of constant depth gives a depth profile reasonably close to that observed.

ACKNOWLEDGEMENTS

29. The authors wish to acknowledge their indebtedness to the personnel of TRACOR/MAS, Inc. for their fine assistance in all phases of the field work, and to W.A. Fisher of the Atlantic Fleet Weapons Range for arranging aircraft and range services during the ship spotting exercise.

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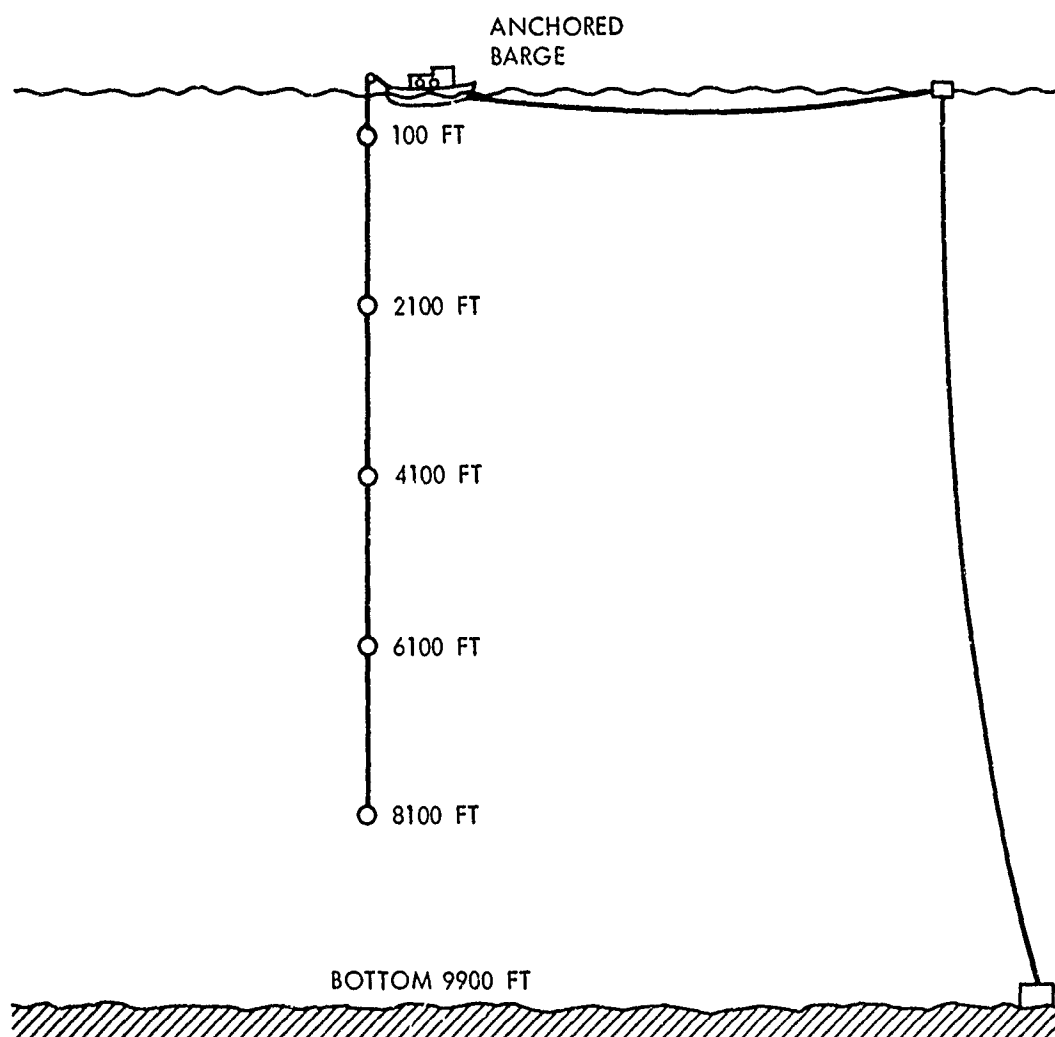


FIG. 1 MARLIN HYDROPHONE STRING



FIG. 2 CHART SHOWING MEASUREMENT SITE NORTH OF ST. CROIX.
SITE IS AT THE CROSS. BOTTOM CONTOURS IN FATHOMS.

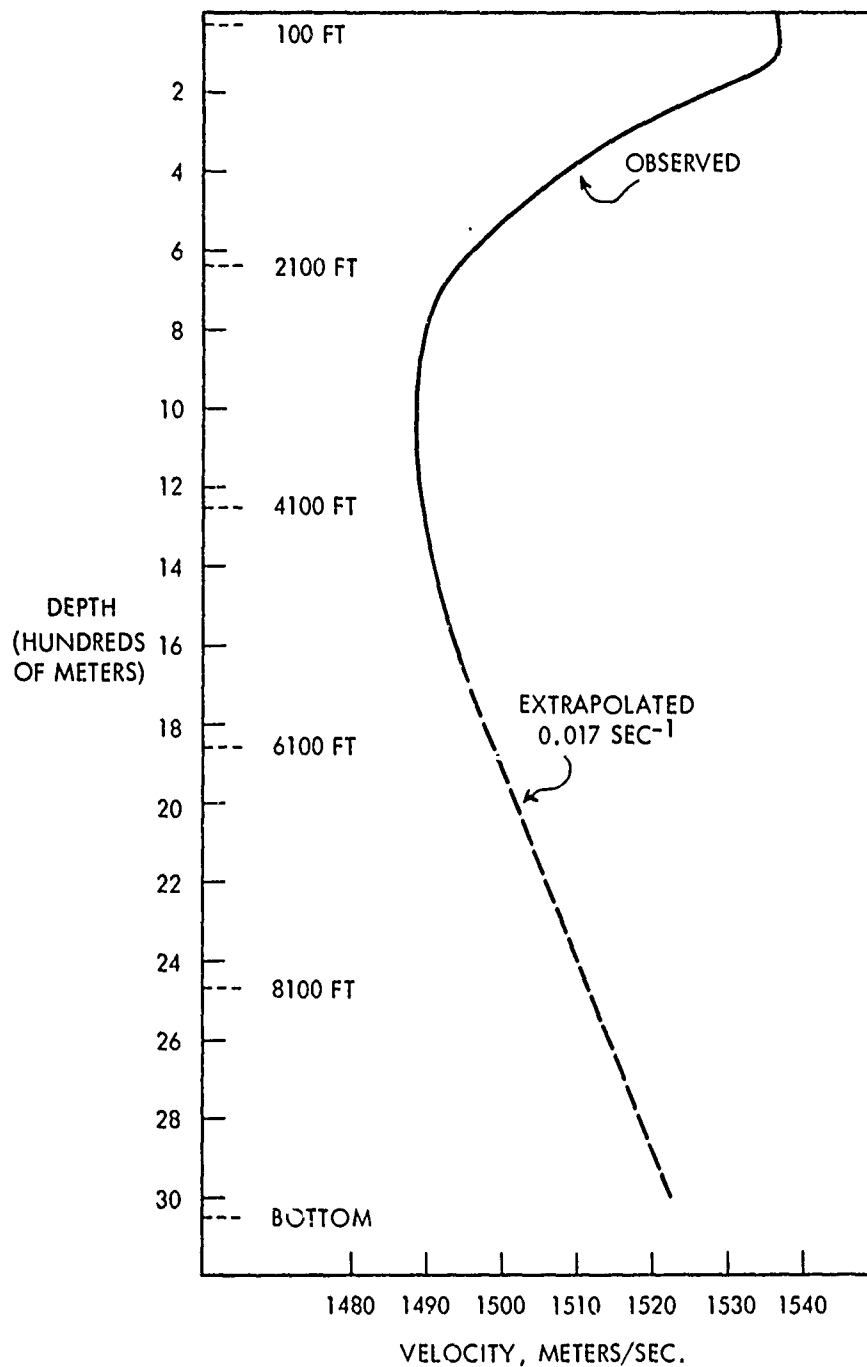


FIG. 3 VELOCITY PROFILE, NODC REF. 31-302 AT CONSES. STA. 460, PROVIDED BY D.F. FENNER AND W. RANDLETT, NAVOCEANO. EXTRAPOLATED BELOW 1637 METERS AT THE RATE OF 0.017 SEC⁻¹. LAT 17° 55' N, LONG 64° 31' W, 12 MARCH, YEAR UNKNOWN.

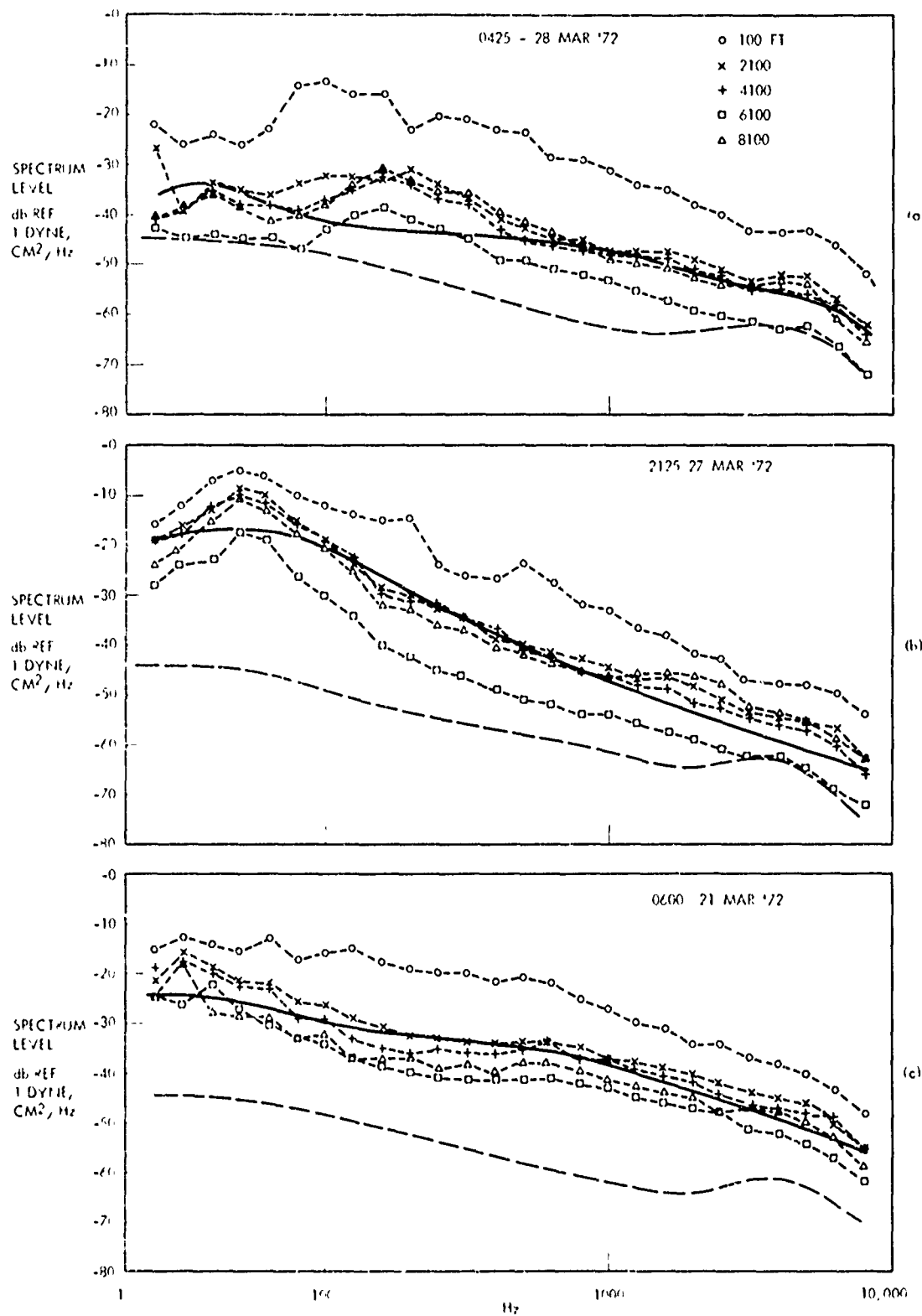


FIG. 4 ONE-THIRD OCTAVE ANALYSES OF SIMULTANEOUS FOUR-SECOND NOISE SAMPLES UNDER THREE DIFFERENT CONDITIONS OF SHIPPING AND WIND. SOLID CURVE, KNUDSEN-WENZ SPECTRUM; DASHED CURVE, SYSTEM NOISE LEVEL. (a) WIND CALM, SHIPPING IN-AUDIBLE (b) WIND CALM, STRONG SHIPPING (c) WIND 16 KNOTS, MODERATE SHIPPING.

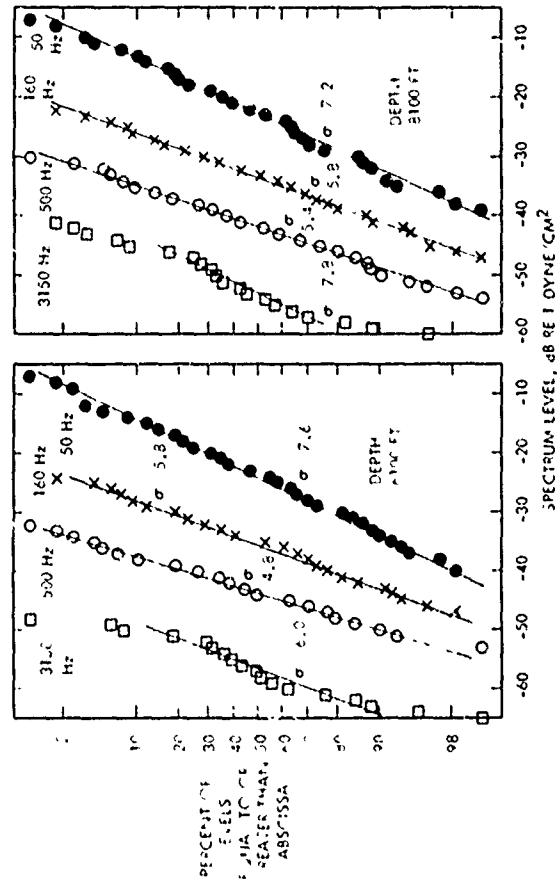


FIG. 5 CUMULATIVE DISTRIBUTION OF THE SPECTRUM LEVELS OF 114 NOISE SAMPLES, MEASURED IN FOUR ONE-THIRD OCTAVE BANDS. VALUES OF STANDARD DEVIATION (σ) ARE GIVEN FOR THE STRAIGHT LINES DRAWN THROUGH THE POINTS.

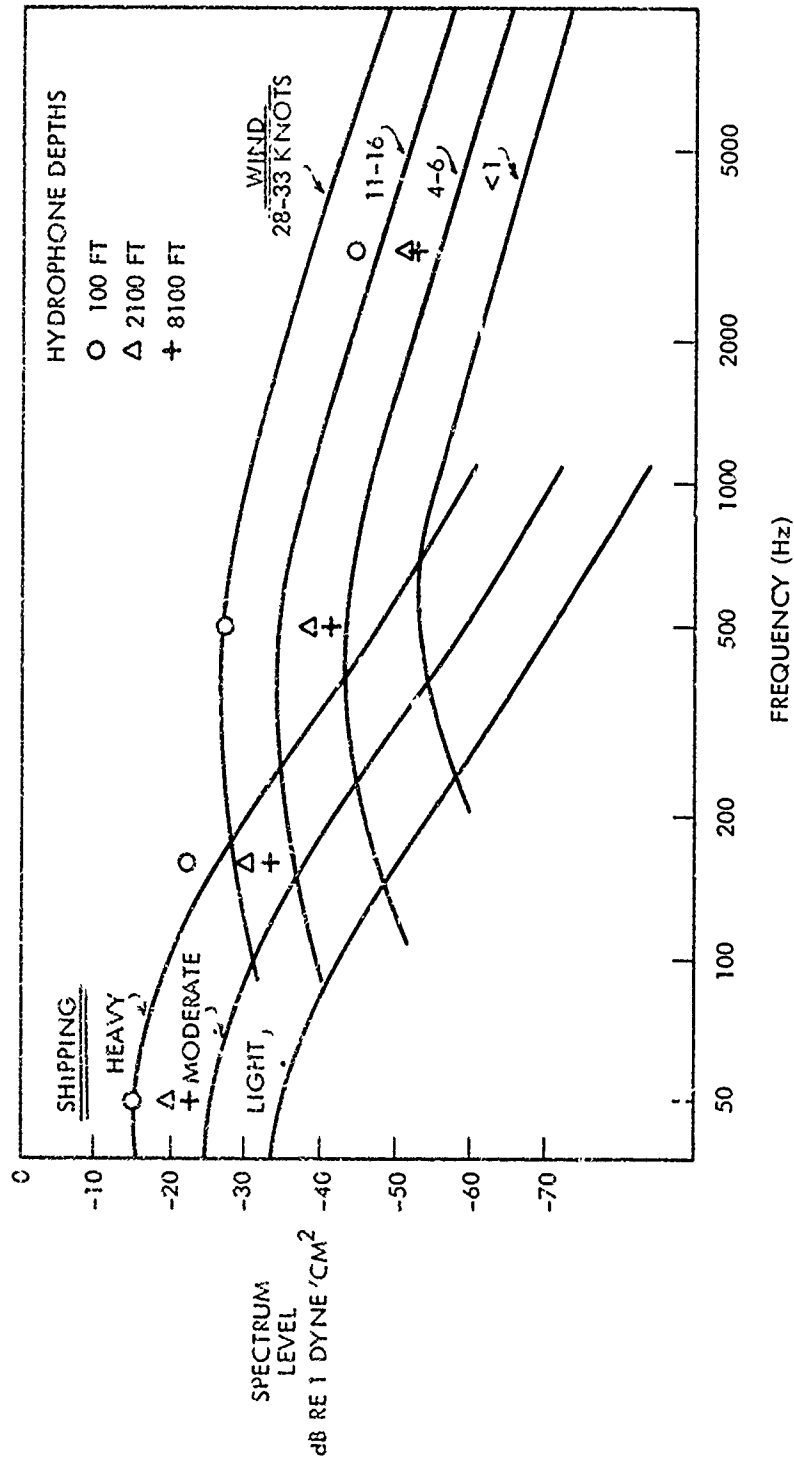


FIG. 6 MEDIAN NOISE LEVELS AT THREE DEPTHS COMPARED WITH KNUDSEN-WENZ CURVES, USING THE 50% LEVELS OF FIG. 5

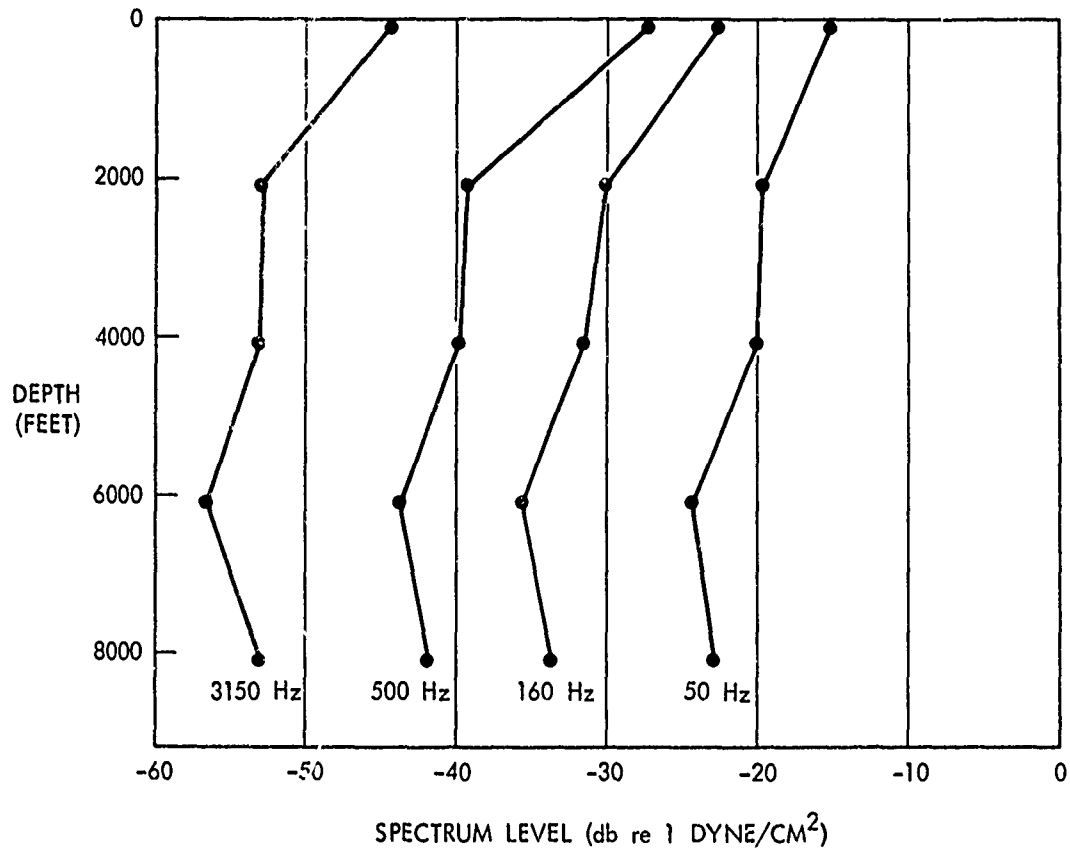


FIG. 7 MEDIAN NOISE PROFILES, USING THE 50% LEVELS OF FIG. 5

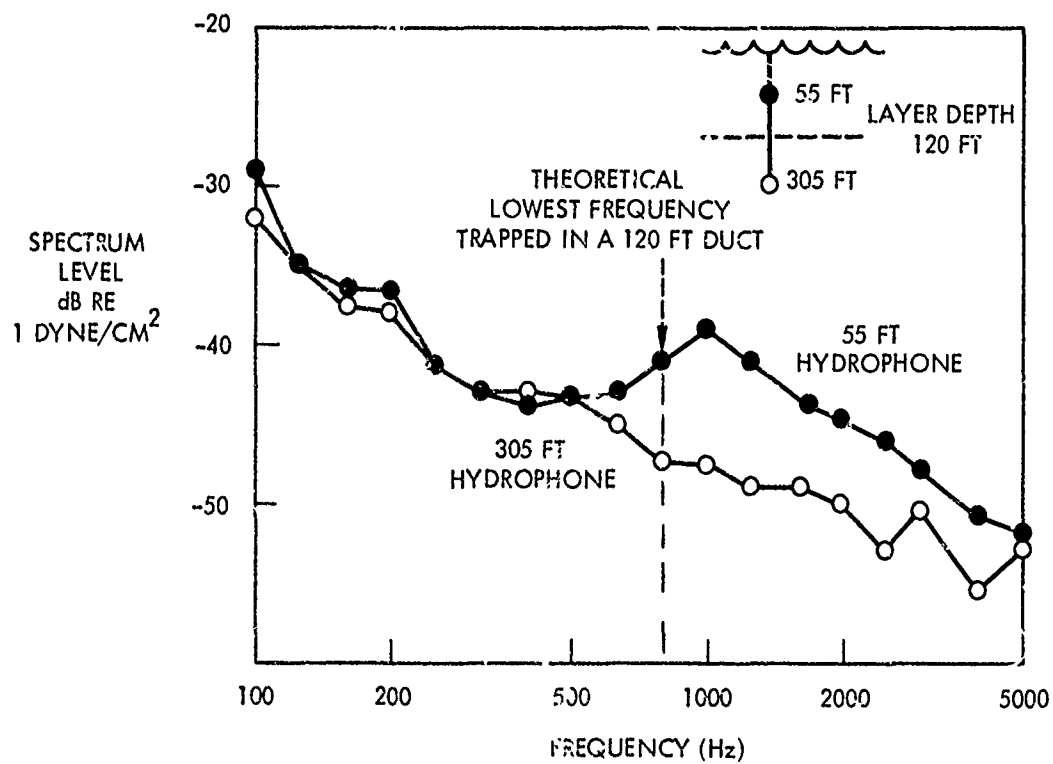


FIG. 8 NOISE SPECTRA OBSERVED AT DEPTHS OF 55 AND 305 FEET
SIX MONTHS EARLIER AT THE SAME LOCATION.

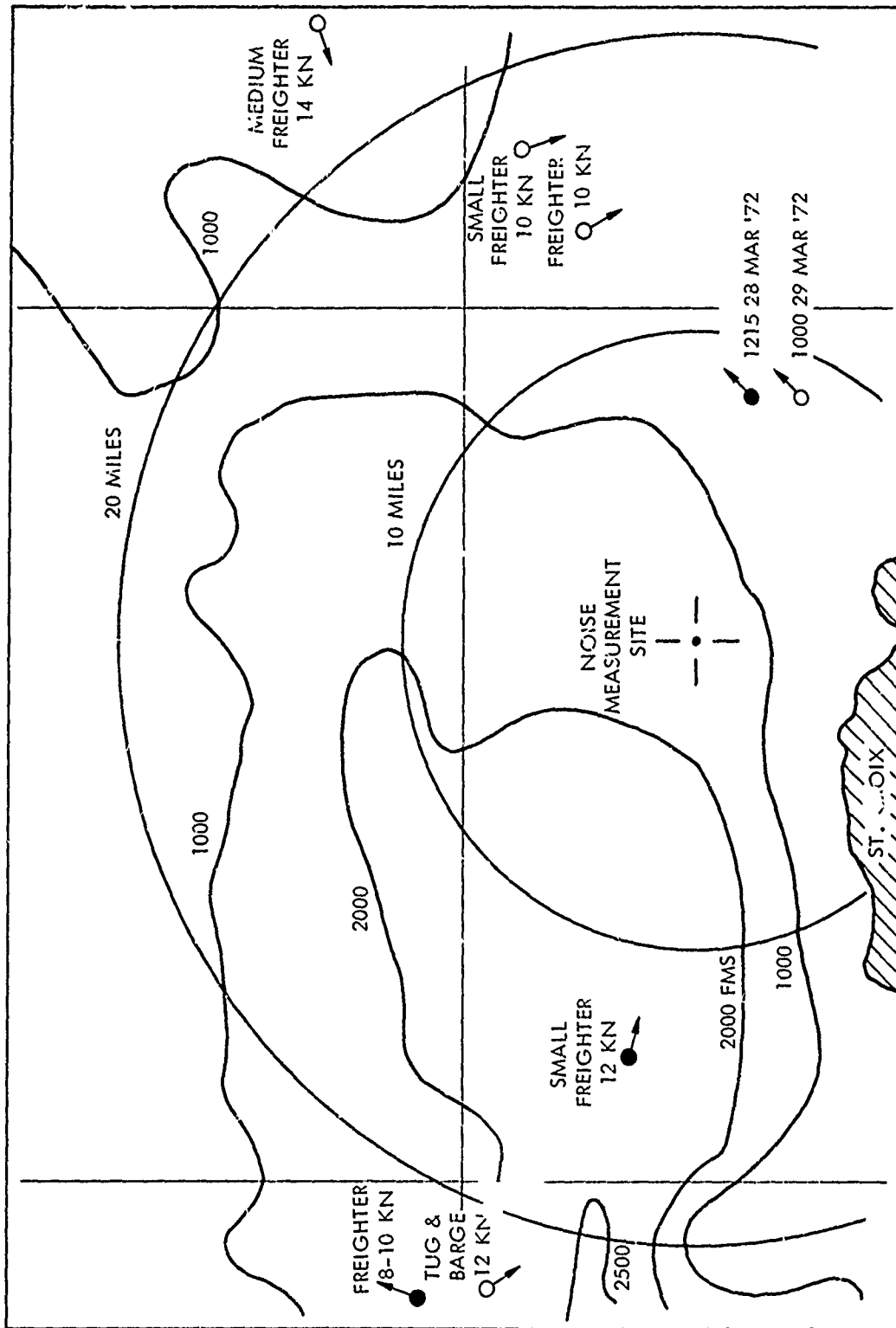


FIG. 9 PLOT OF MAJOR SHIP LOCATIONS ON TWO DAYS, AS OBSERVED BY AN AIRCRAFT.

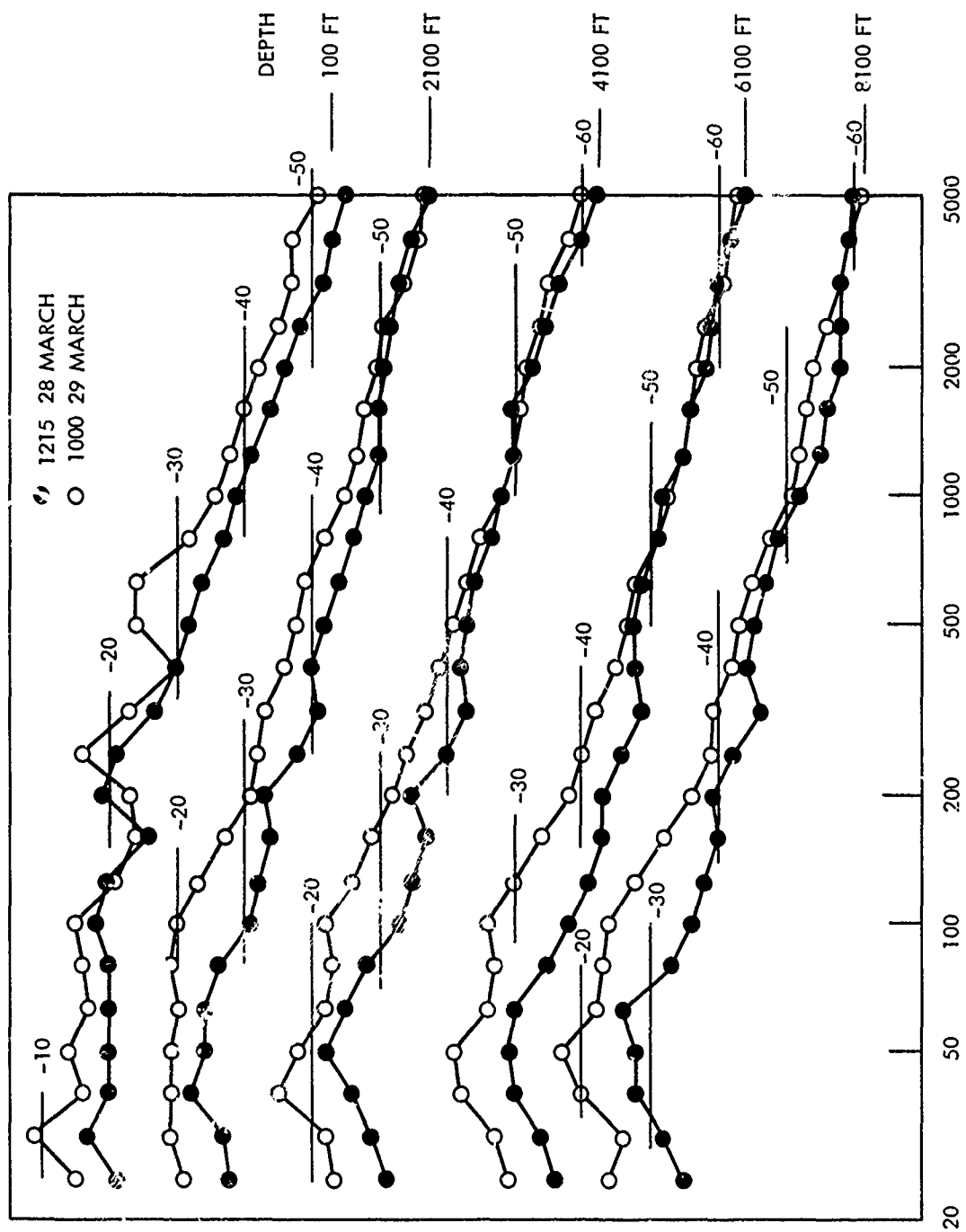


FIG. 10 SPECTRUM LEVELS AT THE DIFFERENT DEPTHS AT THE TIMES OF SHIP SPOTTING. THE SPECTRUM LEVELS ASSOCIATED WITH EACH PLOT ARE INDICATED AT 10 db INTERVALS.

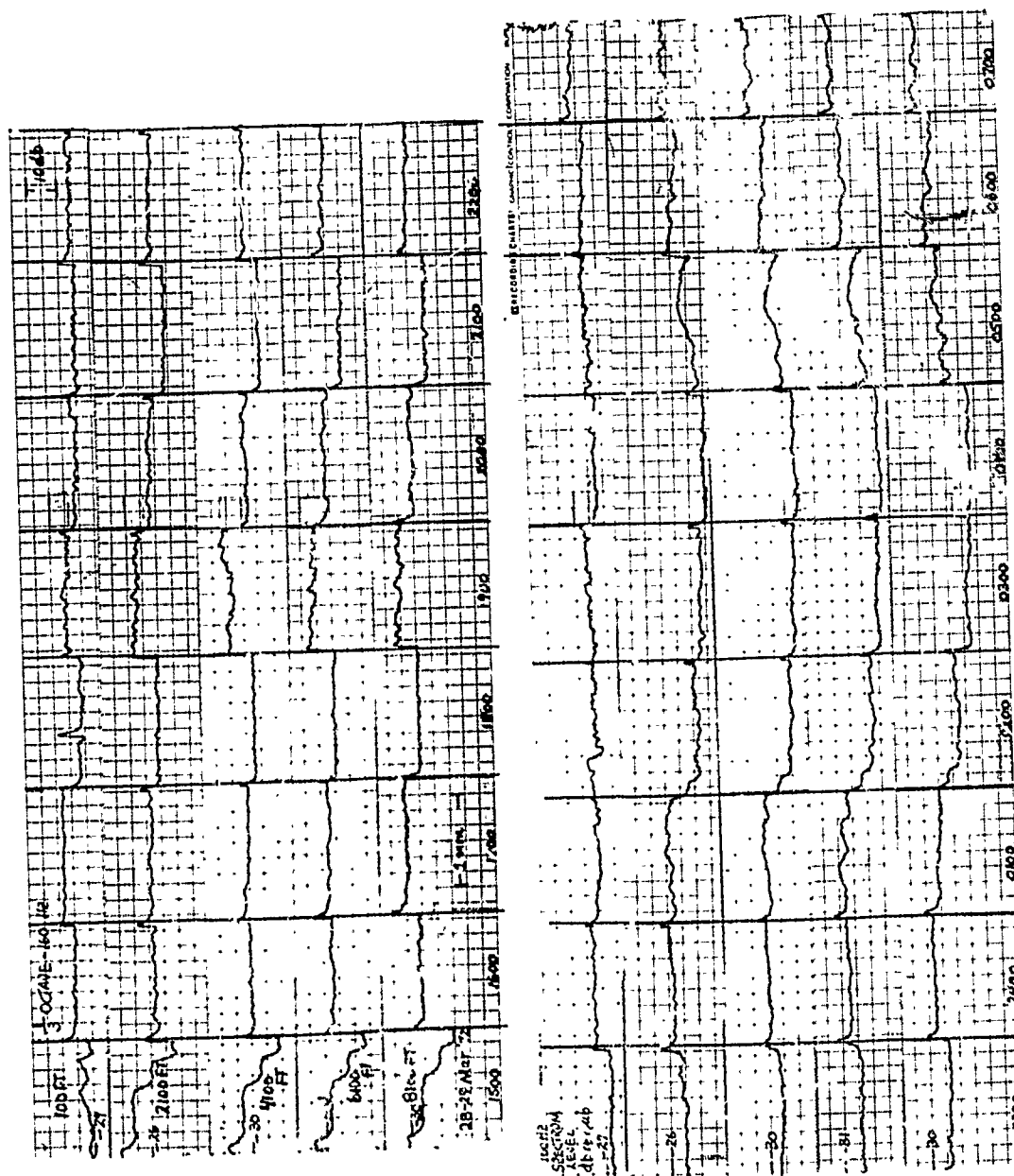


FIG. 11. PLAYOUTS OF CONSECUTIVE 1, - MINUTE SAMPLES TAKEN HOURLY DURING AN OVERNIGHT PERIOD. THIRD-OCTAVE BAND AT 160 Hz, 1530-0730 HOURS, 28-29 MAR 1972.

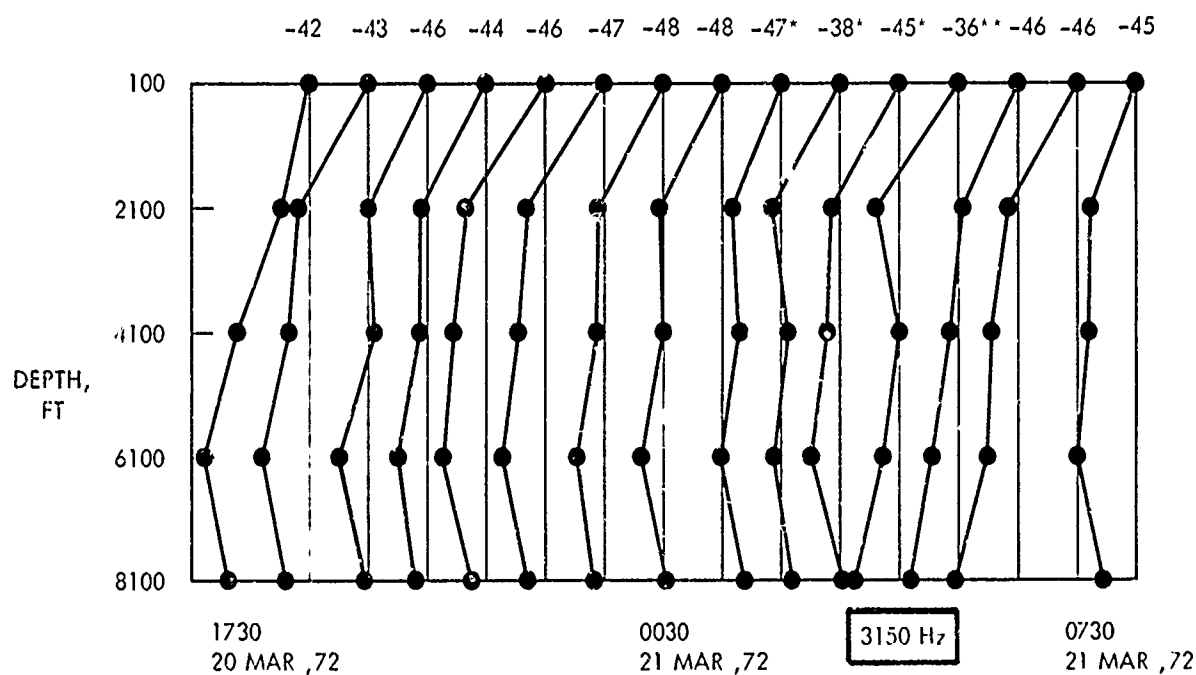
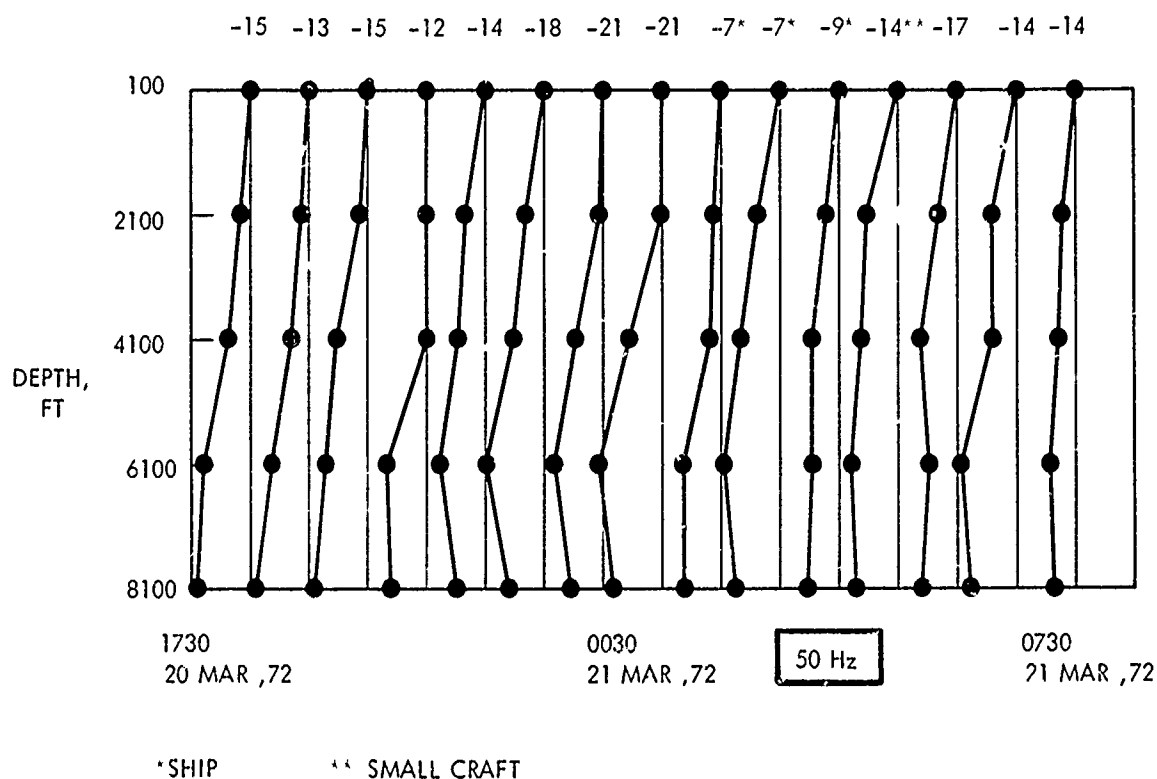


FIG. 12 CONSECUTIVE HOURLY PROFILES AT TWO FREQUENCIES, SHOWING THE VARIABILITY OF THE PROFILE FROM HOUR-TO-HOUR

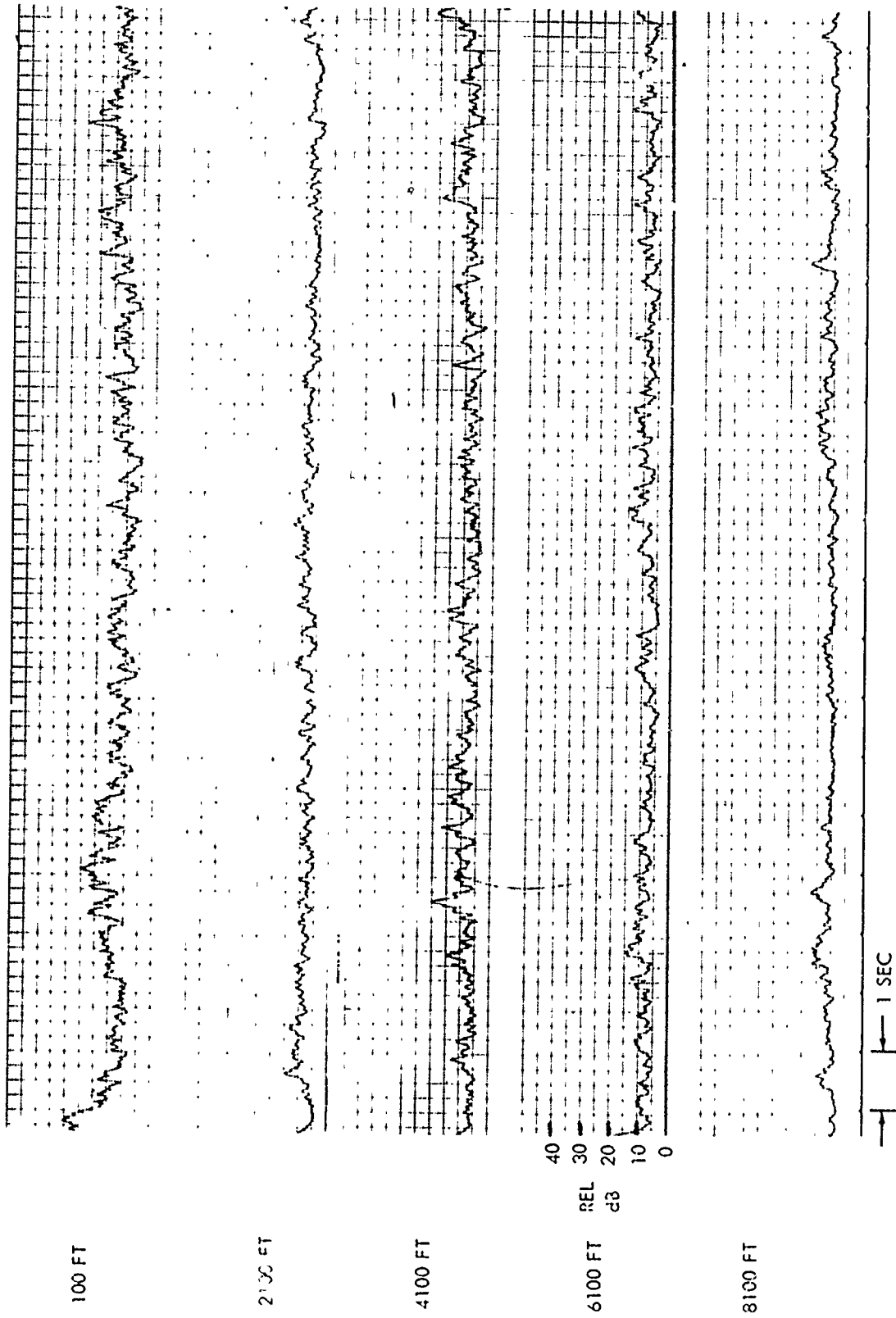


FIG. 13 SHORT-PERIOD VARIABILITY OF NOISE AT DIFFERENT DEPTHS.
ONE-SECOND TIME TICKS ARE SHOWN AT BOTTOM.

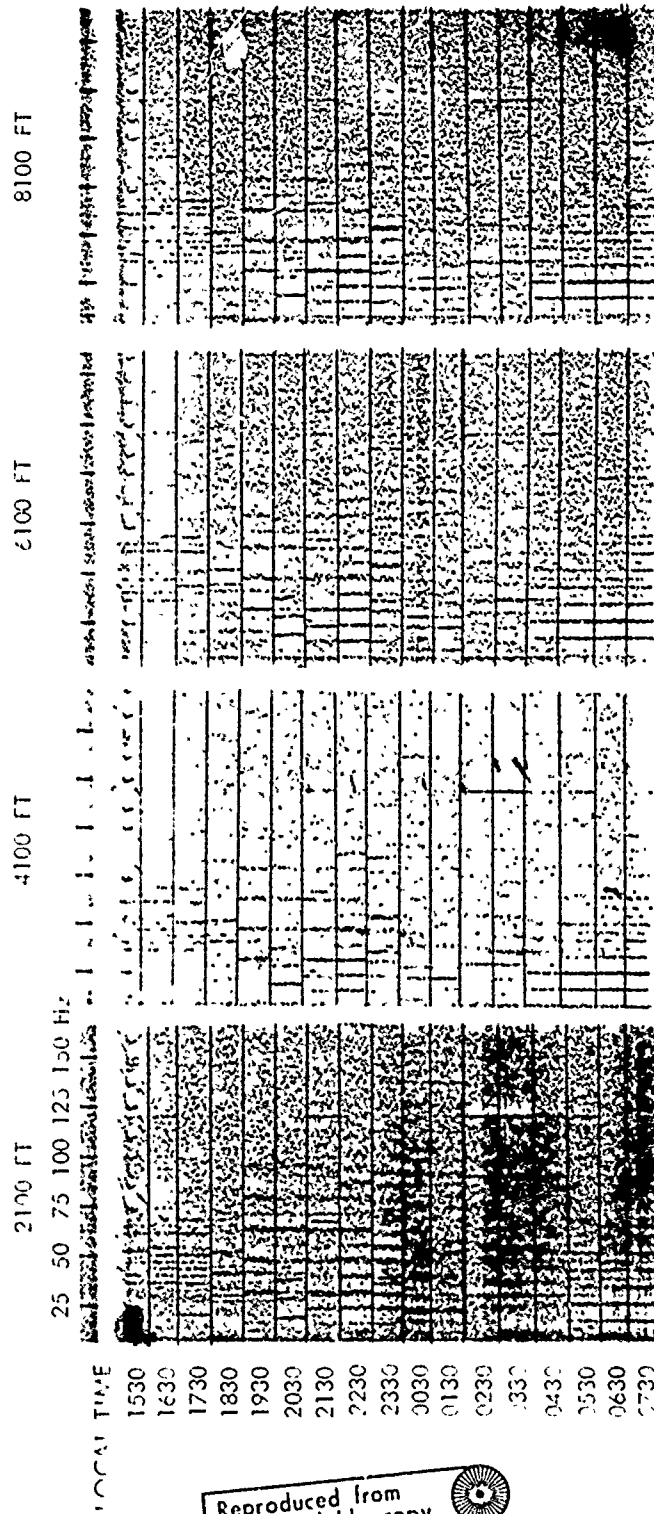


FIG. 14 SOUND SPECTROGRAMS AT HOURLY INTERVALS DURING AN OVERNIGHT PERIOD.

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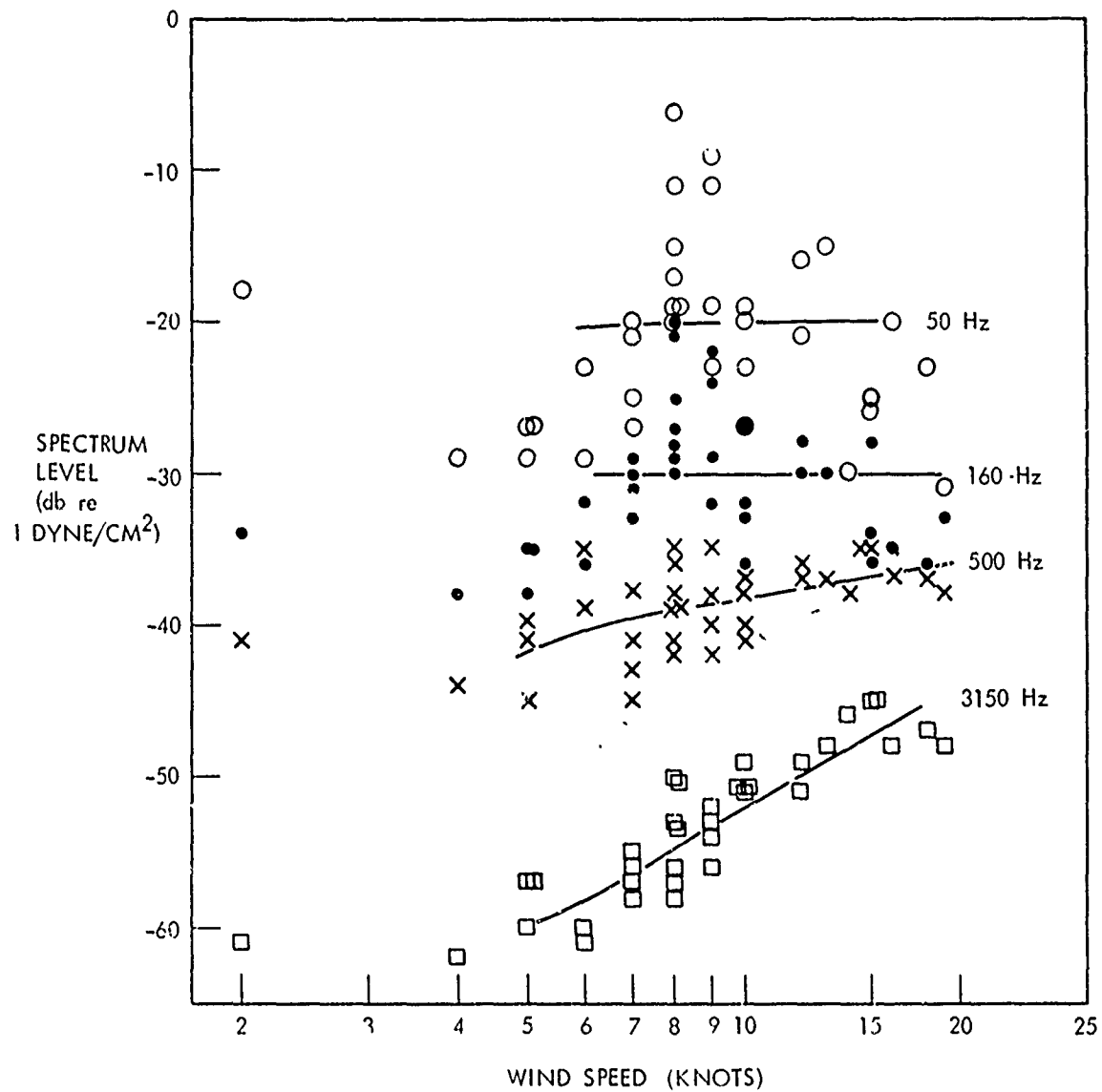


FIG. 15 NOISE LEVEL IN FOUR BANDS PLOTTED AGAINST WIND SPEED FOR A HYDROPHONE DEPTH OF 2100 FEET.

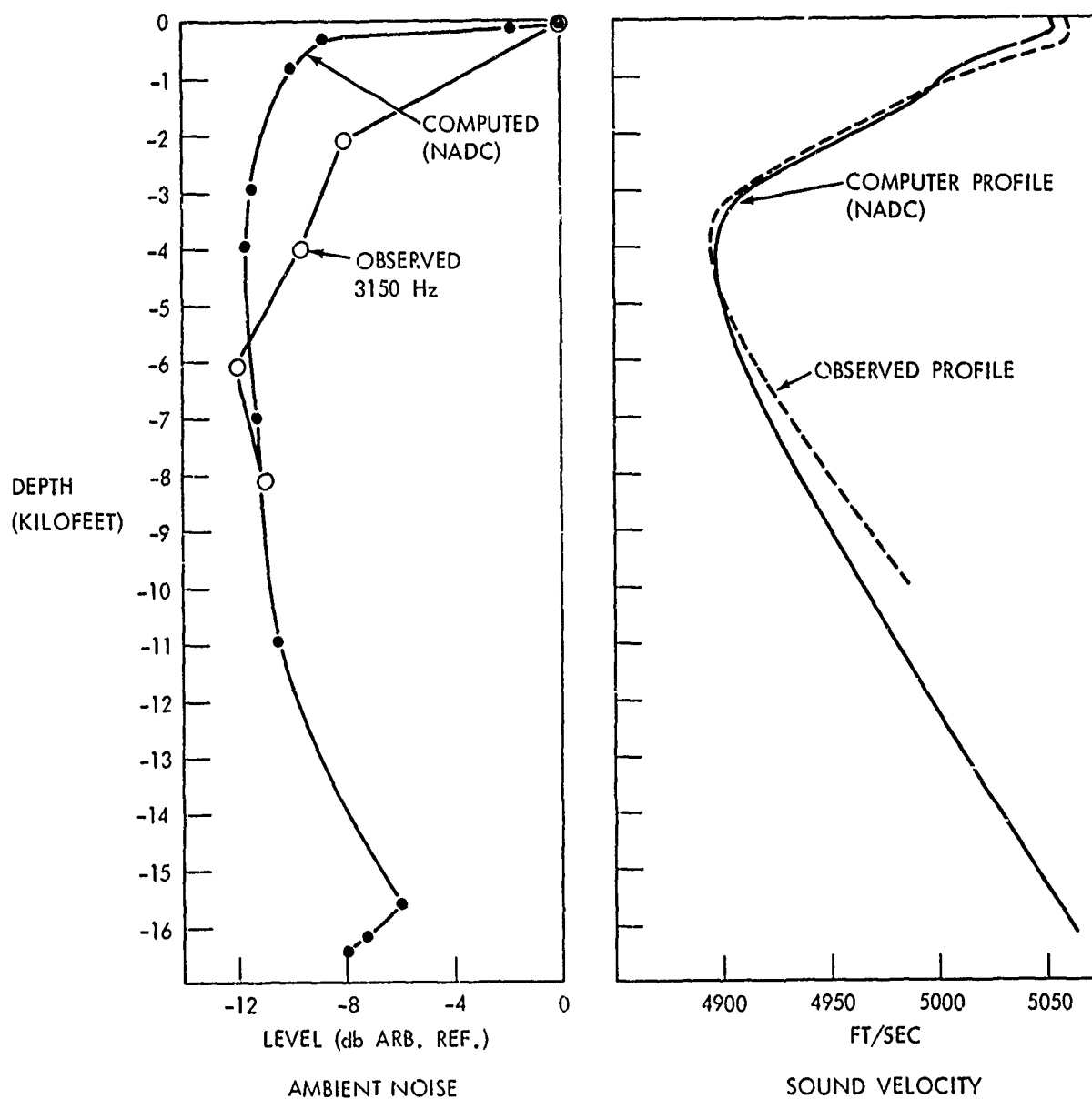


FIG. 16 COMPARISON OF THE OBSERVED MEDIAN PROFILE AT 3150 Hz WITH A PROFILE COMPUTED BY THE NAVAL AIR DEVELOPMENT CENTER. AT THE RIGHT IS SHOWN THE VELOCITY PROFILE USED IN THE COMPUTER PROGRAM ALONG WITH THE PROFILE OF FIG. 3. THE WATER DEPTH ASSUMED IN THE MODEL WAS 16,500 FEET. COMPUTED AND OBSERVED PROFILES ARE MATCHED AT THE SURFACE.