NOISE SOURCES IN THE OCEAN
(Part I)

by

P. Wille
Forschungsanstalt der Bw für Wasserschall -
und Geophysik
Kiel, Germany

ABSTRACT

Following a brief historical survey of the development of our knowledge of the origins and characteristics of ambient noise in the ocean, the principal known sources of noise are described. These are: environmental origin, biological origin and man-made. The combination of these sources leads to the modified Knudsen curves which are variable both in time and space. Methods of measurement of noise are reviewed. A state-of-the-art tabulation of the geographic, frequency and time dependence of various sources of noise is presented as a starting point for discussion. The text is in two parts, of which this is the first.

Five centuries ago , a native son of this country gave the first hint on a sound source in the sea we know of (Fig.1). Up to now it is still far from being sufficiently understood, though it is one of the most important. By this text passage in mirror writing Leonardo da Vinci has moreover symbolized our twofold interest in marine sound sources.

First: There is the acoustical image of the ocean environment as an analogy to the visible image we get from the surroundings above the sea surface. While we receive the optical information mainly in the space domain, the acoustical image is governed by the frequency domain, strongly coloured by 3 decades of audible frequency range against only one visible octave but at the price of low angular resolution.

This is the field of acoustical remote sensing: passive detection of vehicles up to remote recognition of physical and biological properties of the ocean environment.

Secondly: we have to deal with the marine sound sources as unwanted noise which limits the range of transmitted signals for many applications. Since we cannot escape from sea noise we have to predict it as a crucial component of sonar range prediction. How far this can already be achieved for practical purpose is the only aspect of noise we want to mention in this short review. This aspect is the reason why we accepted the invitation to present this paper, because in our establishment we have to apply the knowledge on noise more than to contribute novel results.

The official definition of noise (Fig. 2,3) distinguish between separate groups of noise sources: sea noise plus technical noise gives ambient noise and this together with self noise gives background noise which we want to deal with in this review.
Fig. 4 is a catalogue of background noise sources. Even in this incomplete list there are several situations which have not been investigated. All these sources contribute to the frequency range of practical interest (Fig. 5) and the level range so far observed. Keeping in mind, that we have to predict SONAR-range after all, which means predicting signal-to-noise-ratio, the problem obviously covers

about the same order of magnitude for both quantities. In this figure Wenz has associated known and possible sources with overlapping frequency intervals. There is little doubt about the existence of three main types of sources which are nearly always and everywhere present: turbulent pressure up 10^2 Hz; traffic noise up to 10^3 Hz; and noise from surface agitation up to some 10^4 Hz. There are several temporary and local sources - a few of them will be discussed later. At first sight the picture looks rather complete. Indeed, the amount of literature on background noise is impressive (Fig. 6). From the thirties till now there are more than 1400 citations, even if the initial "exponential" increase has now come into saturation. It is interesting to look a little into these statistics, because it illuminates a problem which we feel to be even more serious than the scientific problem itself.

40% of the papers are classified - they deal mainly with most important geographical and operational contributions. 40% of the unclassified literature is biological and one third of the rest are abstracts only. Theoretical models - descriptive or physical - are extremely rare: perhaps one or two percent.

Fig. 7 shows the main noise properties which are items of the investigations. Besides spectrum level there are directionality, depth- and time-dependence and, what is indispensable for practical prediction, the statistical properties and the geographical variation. In the mechanism of noise production the environment contributes both as source and as propagationpath filter.

To demonstrate the distribution of the main activities on these items the symbolized matrix of figure 8 gives some insight for the group of geophysical sources. For clearness sake it is restricted to four main properties and so to speak five steps of knowledge. Although strongly simplified, the table cannot conceal the lack of available statistical and geographical data, both for shallow and deep water.

Before giving a few examples of the state of the art, let us anticipate a conclusion:
background noise will presumably remain an empirical science within the surveyable future. As a consequence a universal noise model cannot be expected. Any empirical or parameterized prediction model has to be

tailored to the sea area and application of interest. Detailed regional prediction is probably impracticable. Though the costs for noise measurement are as a rule less than those for propagation (which is also a regional problem) we are convinced that the aim of SONAR-range prediction and therefore noise prediction throughout the NATO waters of primary interest cannot be achieved without systematic and coordinated cooperation of the NATO partners. MILOC surveys are perhaps encouraging but no substitute. We cannot present a map with the blank areas here but-without any doubt- the smaller countries could contribute much more to fill in the gaps if they could participate in the classified knowledge of their larger partners instead of perhaps reinventing the wheel. In the very last years economic urgency has been added to scientific insight and gained ground for coordinated cooperation also in the field of research. Perhaps today a reinforced appeal to the responsible authorities can at least improve the necessary flow of information.

The review must begin with self noise (Fig. 9) which is a problem of suppression more than of prediction. From the hydrodynamic branch of this self noise tree we take the perhaps most important example of turbulence induced noise which is present even at bottom mounted receivers and is strongly influenced by flow and shape parameters (Fig. 10).

The origin of the usually observed low frequency noise component between 1 Hz and some 20 Hz with a steep spectrum slope about - 10 db was controversial for years and discovered more or less by accident. During a slack cable condition of a ship connected hydophone the spectrum level within this interval was reduced by more than 20 db. Similar noise reductions have been achieved with bottom mounted receivers and streamlined hulls (1,2).

The theoretical pressure fluctuations in a turbulent field (Fig.11), which are not radiated sound but pseudosound, give spectra of the right order but in practice the configuration of the boundaries and even their surface treatment (Fig. 12) govern the flow noise level.

Recent experiments on hull orientation and cable fins (Fig. 13) demonstrate that even a slight flow disturbance or deviation from the axial orientation may increase the level to more than 20 db above the empirical optimum. Further investigations for optimising hulls and hydrophone supports (3) are obviously necessary, although the limits of the technical possibilities seem to be almost exhausted.

Returning to sea noise (Fig. 8), the lowest end of the spectrum given by hydrostatic pressure can be completely described by theory (Fig. 14). The first order pressure field of a surface wave is a non-radiating nearfield too, which has a sharp frequency and depth decrease and contributes only in extreme shallow water cases and/or low frequencies. In fact the waves do induce noise through their currents but this is a problem of self noise (4).

The next source group is seismic activity (Fig. 15). Spontaneus unpredictable earthquakes may raise the noise level by 30 dB within the frequency interval normally occupied by turbulent noise (5-8). Of course there are preferred geographical regions for frequent occurrence but the range of such signals has the order of hundreds to thousand nautical miles - the acoustic energy can achieve the equivalent for 1 kt TNT - explosions.

The so-called microseism which is not of geological origin (Fig. 16) has to do with the movement of the sea surface. Longuet Higgins (9) explains this by surface wave components travelling in opposite directions and therefore raising and lowering the center of gravity of the surface by twice the frequency. This second order effect can explain the frequency maximum of the microseism (the swell is plotted versus twice the frequency) although not the structure of the spectrum. Since the second order effect is producing radiated sound instead of pseudosound, it has been supposed (10,11) to be the origin of the famous Knudson spectra too (Fig. 17). This facsimile of the historical diagram shows the standarised spectrum slope of - 5 db per octave and the seastate or wind dependence respectively. These standard curves mainly extracted from deep water data have been verified and modified by numerous authors.

The Knudson results lie somewhere between recent pure deep water data (12,13) which tend to be a few db lower and pure shallow water levels like those of Piggott (Fig. 18) which are higher in general, the difference depending on frequency and sea state (4). The spectrum shape near a few hundred Hz is given by distant traffic and is highly variable (13-15). There have been a few model computations for traffic noise but we are still far away from the aim of prediction. One of the reasons is the lack of available regional traffic statistics.

Though we have empirical functions to describe the high frequency wind dependent noise level, the mechanism of its production is still unclear. There are several possibilities (Fig. 19) which have been discussed but none of them offers a sufficient explanation for the full range of frequency and wind speed (4,13,16). At high wind speeds there are very likely contributions of mechanisms 3-6 of figure 19, and at low frequencies mechanism 2 is quite probable. But at very low wind speeds where white caps and capillaries are absent the mechanism of noise production remains a mystery. Fig. 20 presents the theory of Marsh for the second order effect. He postulates different slopes for gravity and capillary wave noise. Though in the FWG the existence of capillary waves in the open sea up to a few hundreds Hz has been proved recently, there are serious arguments against Marsh's hypothesis (11,17).

Trustworthy and useful for prediction is the empirical law of a linear dependence of the sound level and the logarithm of wind speed. Fig. 21 shows this linear coefficient which itself follows perhaps a simple frequency law but is nevertheless unexplained.

The situation is similar with the directionality (Fig. 22). Indeed, nearly all observations (19 - 26) show a preferred direction of the noise from the vertical at frequencies in the kHz region and high wind speed, and preferred horizontal direction at lower frequencies where the contribution from distant traffic will as a rule increase. There is no explanation, however, why the low frequency directionality can be fitted best with omnidirectional sources though only dipoles would be physically allowed (and have indeed been verified at higher frequencies).

Also the depth dependence of the noise level (27 - 29) is only partly and qualitatively understood. Fig. 23 presents a mixture of the dependence of the noise level on both receiver depth and water depth, since the measurement was performed at a steep coastal slope(where in any event equilibrium conditions are not very likely). One would expect a decrease of the high frequency components with depth because of absorption which is often found though with different laws. The amount however by which low frequency components increase with depth may depend on SOFAR-trapping of traffic noise and will therefore be an additional problem of oceanographic stratification.

An extreme situation of receiver depth dependence as a consequence of stratification is found in the Baltic (Fig. 24) where a strong salinity increase near the bottom acts as a shield against noise from horizontal directions. We found a decrease of level with receiver depth which is at least 100 times steeper than in deep water. Beyond the halocline there seem to be moreover quite different spectrum slopes. The agreement with the Pigott curve at the upper frequency limit is only by accident: the traffic density was about 10^3 times higher than in the Atlantic, for example.

With respect to time dependence there are only a few inconsistent results for the hourly and daily variations (14, 30 - 33). The only confirmed variation is seasonal (Fig. 25) and at low frequencies (13, 14, 34, 35). Deep water low frequency noise levels are about 6 db lower in summer than in winter. Different propagation loss of traffic noise during summer and winter may be an explanation. The example demonstrates, however, that the geographical variation is even greater and needs interpretation.

Very encouraging are the observed standard deviations of figure 26: at higher wind speeds and lower frequencies the deviations are surprisingly small. If they were found to hold for other areas we would have at hand one of the primary prerequisites for successful prediction.

We should not forget that corresponding observations of high frequency noise level for different areas differ by more than 10 dB and for the lower frequencies in the traffic range there is more than 20 dB difference. The geographical variation is certainly greater than the variation with depth, with direction or often even with time. These facts underline once more the urgent demand for coordinated cooperation and data exchange within NATO.

List of literature

(1) FRANKLIN, J.B.; JOYE, J.R.
"Mobile hydrophone suspension system for the measurement of low-frequency sound".
Jasa, Vol. 44, No. 1, 394, July 1968.

(2) BARDYSHEV, V.I.; VELIKANOV, A.M.; GERSHMAN, S.G.
"Experimental studies of underwater noise in the ocean".
Soviet physics-acoustics, Vol. 16 Nr. 4, 512-153, April - June 1971.

(3) LEEHEY, P.
"Flow-noise research related to the sonar self-noise problem".
Jasa, Vol .40, (1966) 1265.

(4) PIGGOTT, C.L.
"Ambient sea noise at low frequencies in shallow water of the Scotian shelf".
Jasa, Vol. 36, No. 11, 2152-2163, Nov. 1964.

(5) BRADNER, Hugh; DOODS, James G.
"Comperative seismic noise on the ocean bottom and on land".
JGR, Vol. 69, No. 20, 4339 - 4348, 15 Oct 1964.

(6) BRADNER, H.; DOODS, J.G.; FOULKS, R.E.
"Investigation of microseism sources with ocean-bottom seismometers".
Geophysics, Vol. 30, No. 4, 511 - 526, Aug 1965.

(7) KIBBLEWHITE, A, C.
"Detection and location of new underwater volcano".
Nature, Vol. 210, No. 5039, 938 - 939, 28 May 1966.

(8) LATHAM, Gary V.; ANDERSON, ROCKNE, S.; EWING, Maurice.
"Pressure variations produced at the ocean bottom by hurricanes".
JGR, Vol. 72, No. 22, 5693 - 5704, 15 Nov 1967.

(9) LONGUET-HIGGINS, M.S.
"A theory of the origin of micro seism".
Phil - Transact. Royal Soc. Lond.
Vol. 243 No. 857 Ser. A., Math. and Phys. Sc. 1950, 1 - 35.

(10) MARSH, H.W.
"Origin of the Knudsen spectra".
Jasa, Vol. 35, No. 3, 409 - 410, March 1963.

(11) BREKHOVSKIKH, L.M.
"Generation of Sound Waves in a liquid by Surface Waves".
Soviet Physics-Acoustics, Vol. 12, No. 3, 323 - 325,
Jan.-Mar. 1967.

(12) PERRONE, Anthony J.
"Deep-ocean ambient-noise spectra in the north-west atlantic".
Jasa, Vol. 46, No. 3 (part 2), 762 - 770, Sept 1969.

(13) WENZ, Gordon M.
"Acoustic ambient noise in the ocean: spectra and sources".
Jasa, Vol. 34, No. 12, 1936 - 1956, Dez 1962.

(14) WENZ, Gordon M.
"Review of underwater acoustics research noise".
Jasa, Vol. 51, No. 3 (part 2), 1010 - 1024, March 1972.

(15) DYER, IRA.
"Statistics of distant shipping Noise".
Jasa, Vol. 53, No. 2, 564 - 570, Feb 1973.

(16) PENHALLOW, W.S.; DIETZ, F.T.
"Correlation of 630-CPS shallow-water ambient noise with wind speed and waveheight".
Jasa, Vol. 36, No. 11, 2149 - 2151, Nov 1964.

(17) ISAKOVICH, M.A.; KURYANOV, B.F.
"Theory of low-frequency noise in the ocean".
Soviet physics-acoustics, Vol. 16, No. 1, 49 - 58, July-Sept 1970.

(18) DIETZ, F.T.; KAHN, J.S.; BIRCH, W.B.
"Effect of Wind on shallow water ambient Noise".
Jasa, Vol. 32, No. 7, 915, July 1960.

(19) ARASE, T,; ARASE, E.M.
"Mapping of the space-time correlation of ambient sea noise".
Jasa, Vol. 40, 499 - 1966.

(20) AXELROD, E.H.; SCHOOMER, B.A.; VON WINKLE, W.A.
"Vertical directionality of ambient noise in the deep ocean at a site near Bermuda".
Jasa, Vol. 37, 77 - 1965.

(21) ARASE, T.; ARASE, E.M.
"Correlation of ambient sea noise".
Jasa, Vol. 40, 205 - 1966.

(22) ARASE, T.; ARASE, E.M.
"Time variability of ambient-noise directionality",
Jasa, Vol. 36, No. 5, 1015 - 1016, May 1964.

(23) FOX, G.R.
"Ambient-noise directivity measurements".
Jasa, Vol. 36, 1537 - 1964.

(24) HUGGINS, G.G.; BURROUGHS, C.H.
"A simplified description of windgenerated noise for sonar response application".
Jasa, Vol. 53, No. 1, 353, Jan 1973.

(25) TALHAM, R.J.
"Ambient-sea-noise model".
Jasa, Vol. 36, No. 8, 1541 - 1544, Aug 1964.

(26) URICK, R.J.
"Correlative properties of deep-Water ambient noise at Bermuda".
Jasa, Vol. 39, 1217 - 1966.

(27) KING, L.A.
"Comparative study of deep-ocean ambient noise".
Jasa, Vol. 39, No. 6, 1217, June 1966.

(28) LOMASK, M.R.
"Acoustic measurements in deep water using the bathyscaphe".
Jasa, Vol. 31, No. 1, 837, Jan 1959.

(29) PERRONE, A.J.
"Ambient-noise-spectrum levels as a function of water depth".
Jasa, Vol. 48, No. 1, (part 2), 362 - 370, July 1970.

(30) DIETZ, F.T.
"Suggested Sampling Procedure of Estimating shallow water ambient Noise".
Jasa, Vol. 32, No. 11, 1497, Nov 1960.

(31) WENZ, G.M.
"Some periodic variations in low-frequency acoustic ambient noise levels in the ocean".
Jasa, Vol. 33, No. 1, 64 - 74, Jan 1961.

(32) WILLIS, J.
"Effect of tidal currents on 25 CPS shallow water ambient noise measurements".
Jasa, Vol. 33, No. 11, 1659, Nov 1961.

(33) WILLIS, J.; DIETZ, F.T.
"Some characteristics of 25-CPS shallow-water ambient noise".
Jasa, Vol. 37, No. 1, 125 - 130, Jan 1965.

(34) SCRIMGER, J.A.
"Seasonal variation in underwater noise in north-east pacific".
Nature, Vol. 243, No. 5402, 79 - 81, 11 May 1973.

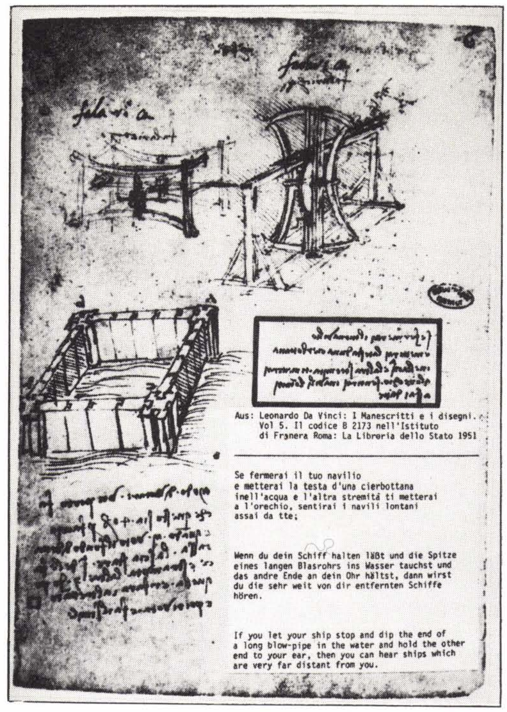
(35) WALKONSHAW, H.M.
"Low-frequency spectrum of deep ocean ambient noise".
Jasa, Vol. 32, No. 11, 1497, Nov 1960.

(36) SKUDRZYK, E.J.; HADDLE, G.P.
"Noise production in a turbulent boundary layer by smooth and rough surfaces".
Jasa, Vol. 32, No. 1, 19 - 34, Jan 1960.

(37) SCHNEIDER, N.A. et al.
Geophysics, 29 (1964), 745.

(38) KNUDSEN, V.O. et al.
Journ. Mar. Res., 7 (1948), 410.

FIG. 1



(1) IEC-Vocabulary Dok 29 (IEV-08) (secretariat) 100

(2) Handbook of mil. oceanogr. information and service in NATO.

Noise (2)	"Any unwanted background sounds within a useful frequency band"
Sea noise (1)	"Noise in the sea created by natural causes such as wind, rain, water waves, currents, thermal agitation"
Ambient noise (2)	The naturally occurring noise background in the sea combined with commercial and industrial noise but excluding self noise and reverberation

FIG. 2
DEFINITIONS OF NOISE IN THE SEA (Part 1)

(1) IEC-Vocabulary Dok 29 (IEV-08) (secretariat) 100

(2) Handbook of mil. oceanogr. information and service in NATO.

Background noise (2)	All unwanted noise, other than reverberation; it includes ambient noise and self noise
Radiated noise (1)	Sound radiated into water by surface ships and submarines
Self noise (1)	Noise in the output of a sonar receiving system, not including useful signal, that is caused by the sonar and machines and movement of the ship or platform on which the sonar is located

FIG. 3
DEFINITIONS OF NOISE IN THE SEA (Part 2)

Geophysical origin	Hydrostatic (tides, swell) Seismic activity SEA STATE / WIND Precipitation Ice Cover Thermal
Technical origin	DISTANT SHIP TRAFFIC Industry / land traffic Drilling / prospective platforms Aircraft
Biological origin	Fish MARINE MAMMALS Crustacean
Self noise	HYDRODYNAMIC (TURBULENCE) CAVITATION Machinery Density structure

FIG. 4
SOURCES OF NOISE IN THE SEA

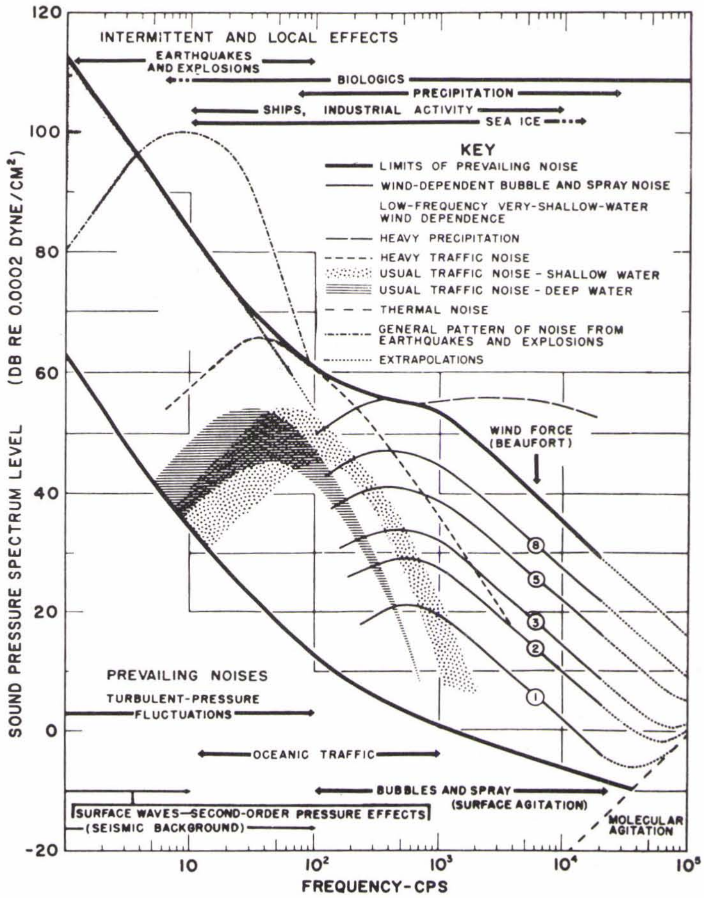


FIG. 5
COMPOSITE OF AMBIENT NOISE SPECTRA BETWEEN 1 Hz AND 100 kHz. PROBABLE SOURCES AND MECHANISMS TOGETHER WITH SPECTRUM SHAPE AND LEVEL (Results and conclusions) (Ref. 13)

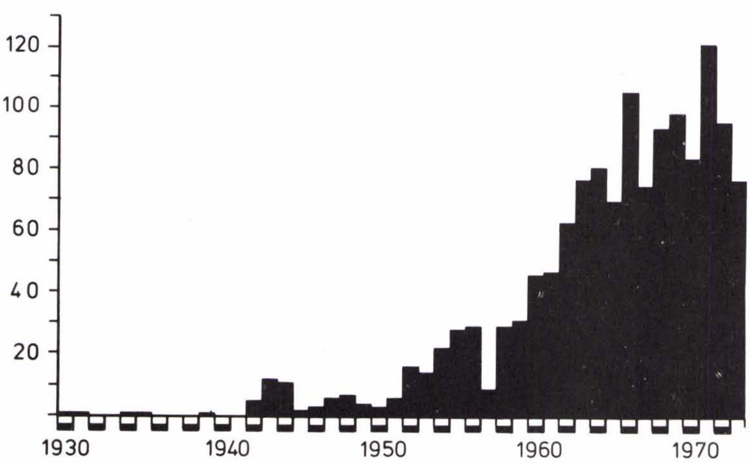


FIG. 6
NUMBER OF PAPERS CONCERNING NOISE IN THE SEA

FIG. 7
PROPERTIES OF NOISE

Descriptive noise properties

Spectrum level

Directionality (spatial correlation, vertical, horizontal)

depth dependence

time variability (hourly, dayly, seasonal)

statistical properties (standard deviation, type of distribution)

geographical variation

Relations to origin

connection with environmental parameters contributing as source

connection with environmental parameters contributing as propagation path (water depth, stratification)

direct observation of mechanisms (biological source, vehicles)

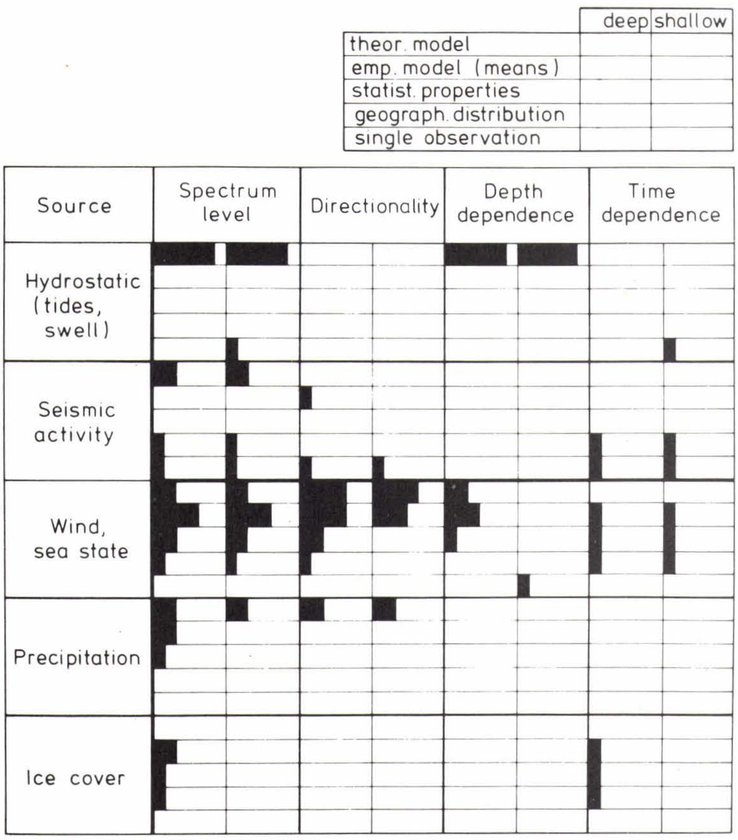


FIG. 8
NOISE SOURCES OF GEOPHYSICAL ORIGIN

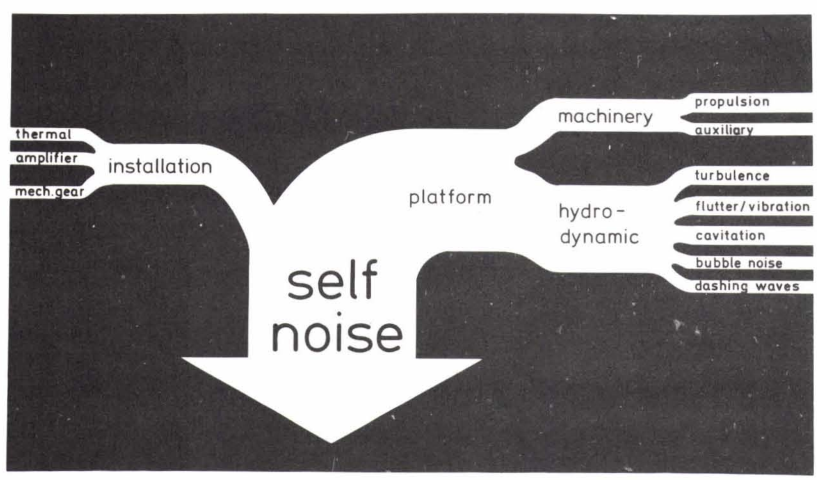


FIG. 9
SOURCES OF SELF NOISE

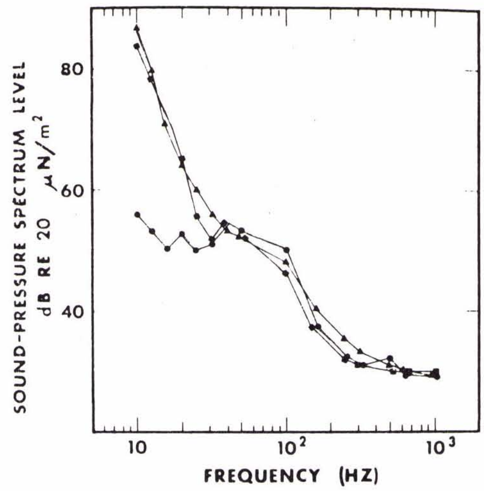
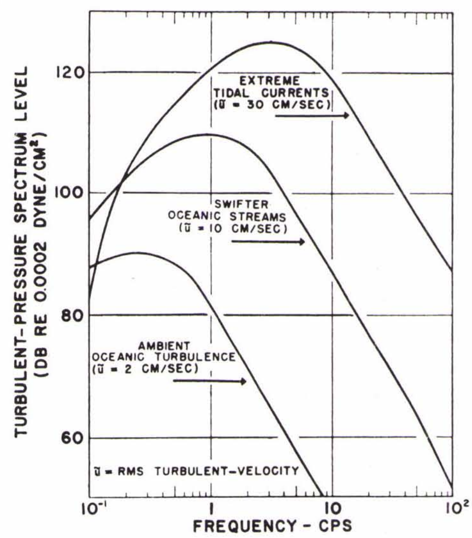


FIG. 10
COMPARISON OF AMBIENT NOISE SPECTRA MEASURED BY 500 m-CABLE HYDROPHONE, SHIP CONNECTED ▲ BEFORE ● DURING ■ AFTER SLACK CONDITION OF CONNECTING CABLE (Ref. 14)

FIG. 11
TURBULENT-PRESSURE-LEVEL SPECTRA, DERIVED FROM THEORETICAL AND EXPERIMENTAL RELATIONS (Ref. 13)



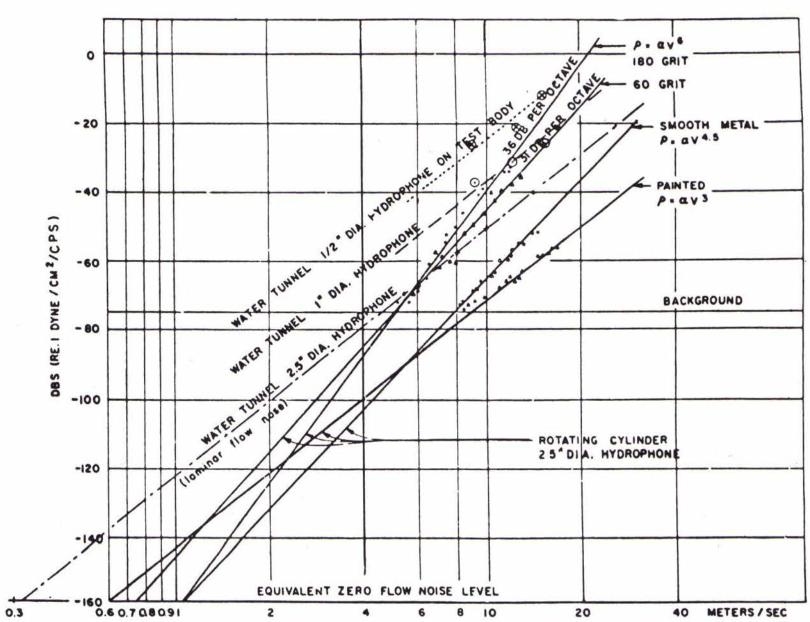


FIG. 12
FLOW NOISE VERSUS SPEED FOR DIFFERENT SURFACE TREATMENTS (Ref. 36)

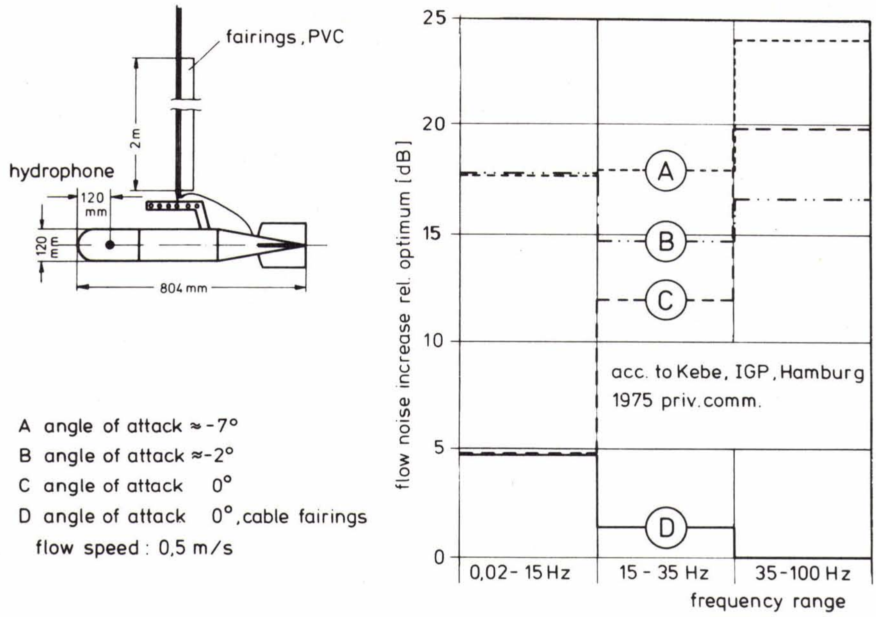


FIG. 13
INFLUENCE OF DOME CONFIGURATION ON FLOW NOISE

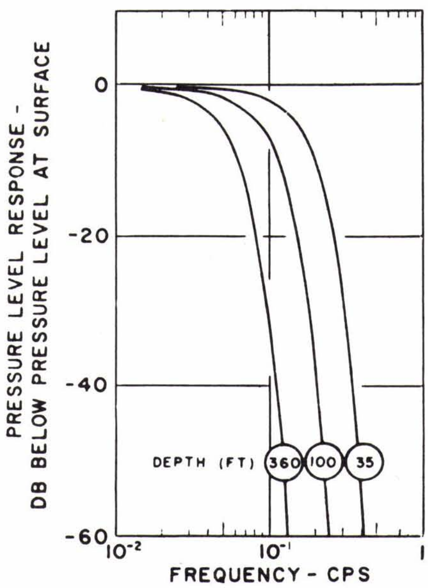


FIG. 14
DEPTH–FILTER CHARACTERISTICS, SHOWING THE ATTENUATION OF FIRST–ORDER PRESSURE FLUCTUATIONS AS A FUNCTION OF FREQUENCY AT THREE SELECTED DEPTHS (Ref. 13)

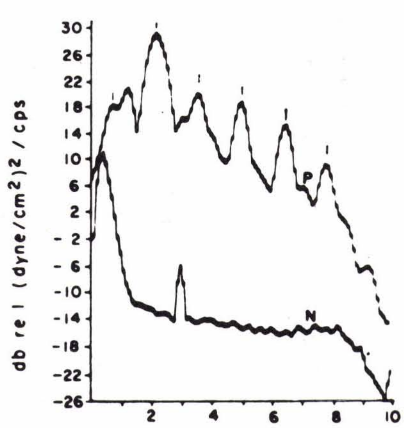


FIG. 15
SPECTRUM OF SEISMIC EVENT (Off Cape Mendocino, Calif. 29. June, 63)
lower curve : background noise (Ref. 37)

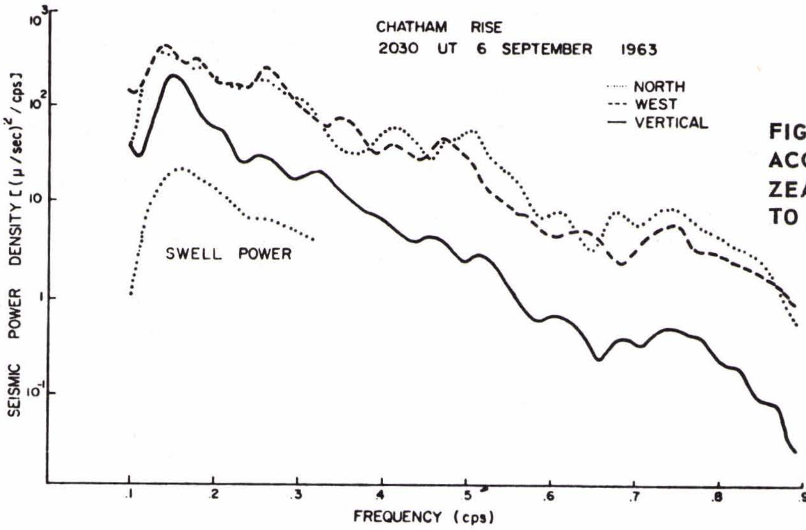
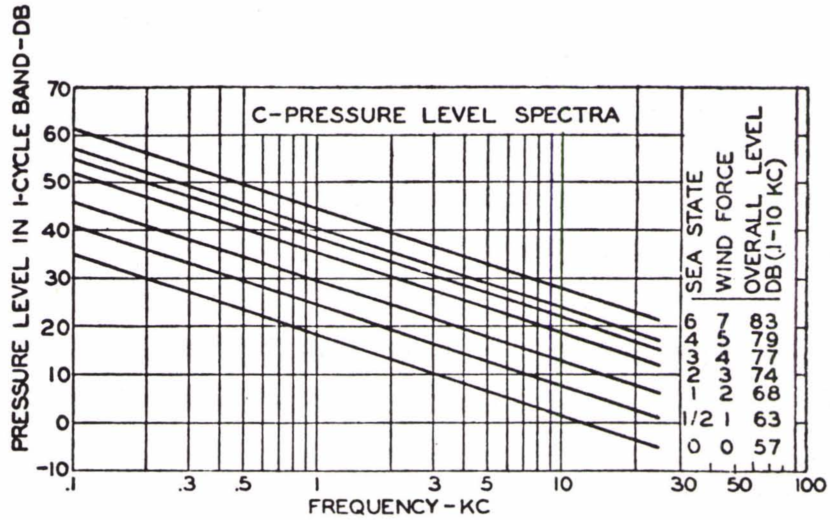


FIG. 16
ACCELERATION SPECTRA OF MICROSEISM NEAR ZEALAND. 0.01 Hz RESOLUTION. COMPARISON TO SWELL (Arbitrary scale) (Ref. 6)

FIG. 17
AMBIENT NOISE FROM WATER MOTION. OVER-ALL PRESSURE LEVELS AND SPECTRA AS A FUNCTION OF SEA AND WIND CONDITIONS (Ref. 38)



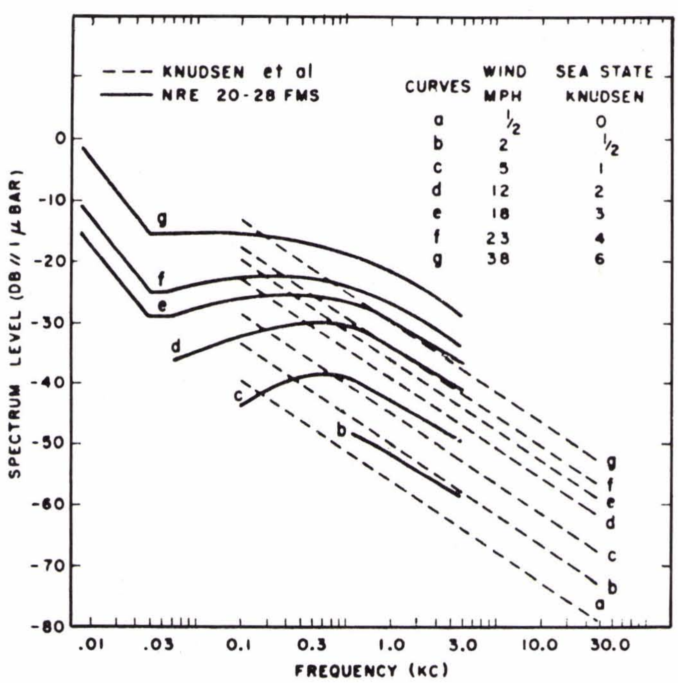


FIG. 18
AVERAGE SPECTRAL-ENERGY FOR VARIOUS WIND SPEEDS. COMPARISON OF KNUDSEN-DATA AND SHALLOW WATER DATA FROM PIGGOTT (Ref. 4)

FIG. 19
POSSIBLE MECHANISMS OF SEA NOISE IN THE KNUDSEN REGION

Mechanism	Comment
1. Hydrostatic pressure (1. order)	depth and frequency dependence too strong
2. Hydrostatic pressure (2. order)	suitable magnitude and frequency slope possible but no capillaries below 5 kn. Saturation of capillary waves at high wind speeds.
3. White capping air bubbles	suitable magnitude and frequency slope but white capping cutoff below 8 - 10 kn. Laminar rise of bubbles of other origin at low wind speeds.
4. Dashing waves	contribution at high wind speeds.
5. Turbulent boundary pressure	mainly pseudosound, sharp frequency cutoff;
6. Airborn boundary layer noise	too steep speed dependence

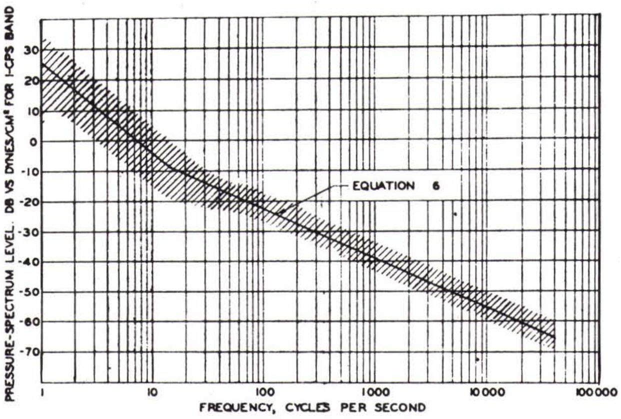


FIG. 20
SURFACE INDUCED SEA NOISE DUE TO THEORY OF SECOND ORDER PRESSURE FLUCTUATION
(Ref. 10)

gravity wave region: $P_f^2 = 94\ H^{6/5}\ f^{-3} \quad (f \leq 13\ \text{Hz})$

capillary wave region: $P_f^2 = 2.9\ H^{6/5}\ f^{-5/3} \quad (f \geq 13\ \text{Hz})$

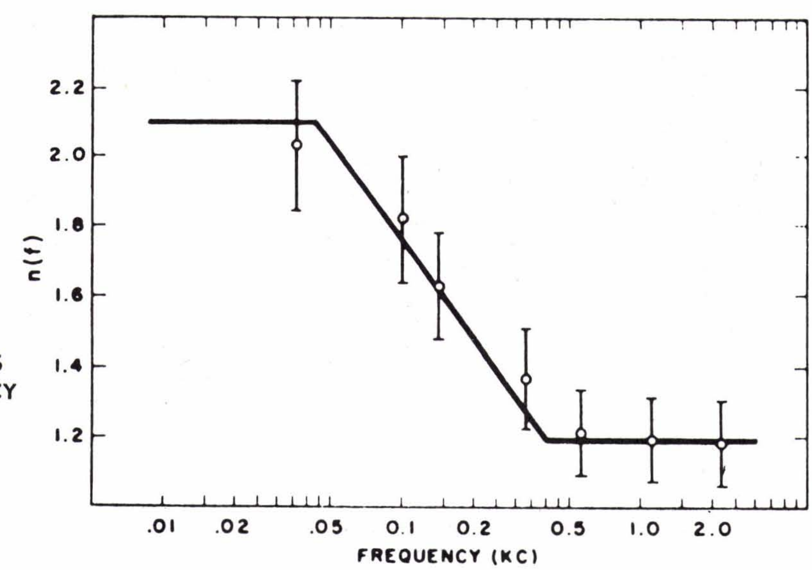


FIG. 21
SLOPE h(f) OF SPECTRUM LEVEL VERSUS WIND SPEED AS A FUNCTION OF FREQUENCY FOR SHALLOW WATER (Ref. 4)

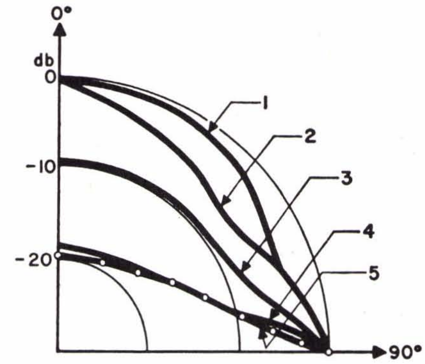


FIG. 22
VERTICAL DIRECTIONALITY OF AMBIENT NOISE AT 200 Hz (Deep water, low sea state) FOR SEVERAL SOURCE DIRECTIONALITY FUNCTIONS. COMPARISON TO MEASURED FUNCTION OF FOX (Ref. 25)

1. $g(\theta') = \cos^2(\theta')$
2. $g(\theta') = \begin{cases} [\cos(\theta')]^{(90-\theta')/10}, & 0 \le \theta' \le 70° \\ \cos^2(\theta'), & 70° < \theta' \le 90° \end{cases}$
3. $g(\theta') = \cos(\theta')$
4. $g(\theta') = 1$
5. MEASURED

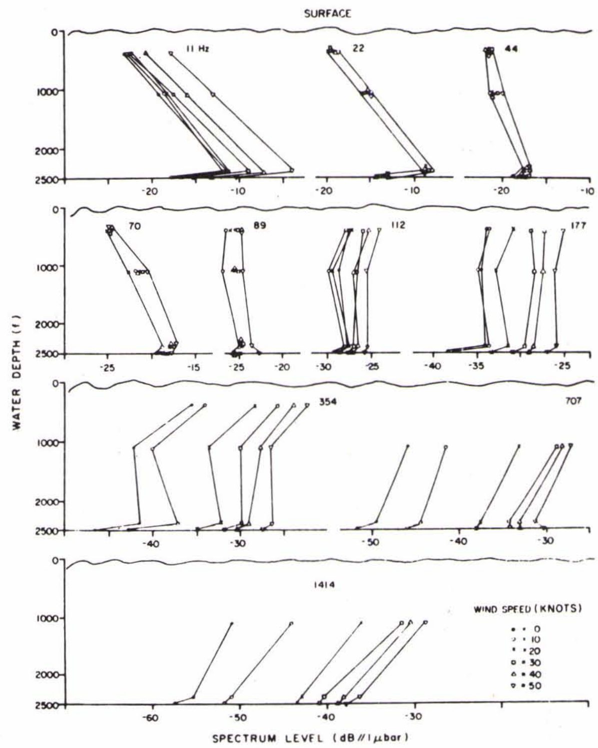


FIG. 23
DEPTH DEPENDENCE OF DEEP-SEA AMBIENT NOISE FOR 10 FREQUENCIES AT 6 WIND SPEEDS. PARAMETER: FREQUENCY (Ref. 29)

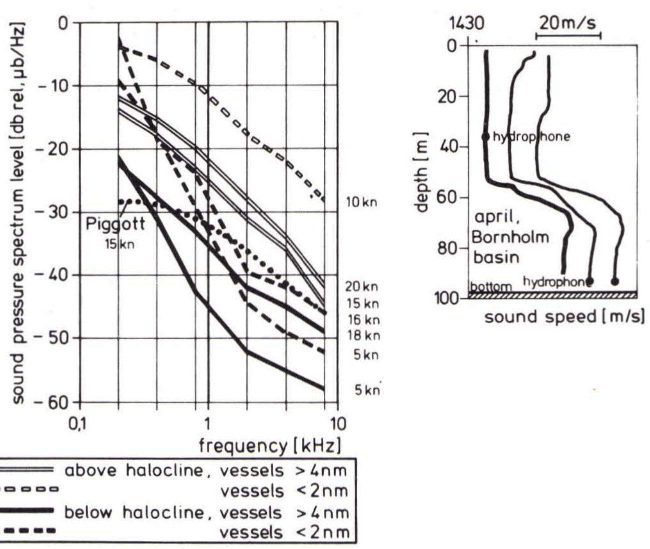


FIG. 24
AMBIENT NOISE, CENTRAL BALTIC ABOVE AND BELOW HALOCLINE

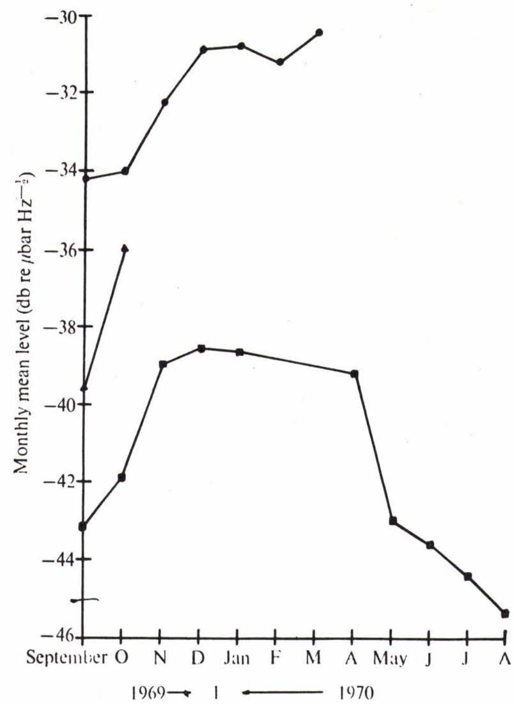


FIG. 25
MONTHLY MEAN AMBIENT NOISE LEVELS (150–300 Hz) AT THREE SEA MOUNTS IN THE PACIFIC (Ref. 34)

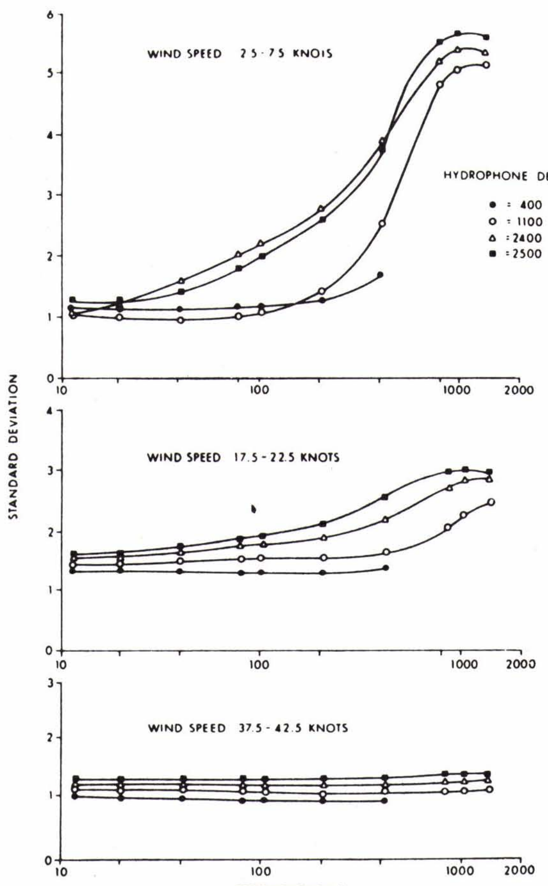


FIG. 26
STANDARD DEVIATION OF DEEP-SEA AMBIENT NOISE VERSUS FREQUENCY FOR FOUR HYDROPHONE DEPTHS AT THREE WIND SPEEDS (Ref. 29)