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EXPERIMENTAL INVESTIGATION OF NATURALLY PRODUCED BUBBLE LAYERS NEAR THE SEA SURFACE

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I. INTRODUCTION

A variety of experiments have been carried out by many workers in which sound signals have been transmitted in the sea near the surface at near grazing angles. Experience in this establishment and elsewhere has shown propagation in the near surface layers to be extremely variable, particularly within 15m of the surface. The assumption of a stratified layer model, together with well established ray path and propagation loss calculations, using either sound velocity profiles or bathythermometric and salinity data, have frequently yielded results several orders of magnitude different from observed conditions. A subjective correlation of this disagreement with the weather, particularly surface roughness has been noticed and a possible link between naturally produced air bubbles and the occurrence of poor propagation has been postulated.

The problems of sound propagation in a bubbly medium has been discussed extensively by Medwin[1]. The presence of bubbles affects the propagation of sound in three ways, scattering, absorption and dispersion. Thus there are three ways of obtaining experimental data on the bubble population. A program of work has been established in AUWE to measure the magnitude of each of these effects over a wide range of frequencies, 10-100 kHz. Subsequently attempts will be made to incorporate the results in an improved propagation model for the near surface layers. The program of work is being carried out in two phases. In the first, already completed, existing equipment comprising a tuned transducer array mounted on the sea bed, transmitting and receiving vertically was used to sample the back-scattering of sound from bubbly layers. This experiment was carried out in Summer 1975 and the results are presented in this paper. The results available are not of sufficiently wide application to enable a propagation model to be proposed at the present time. However, they have been of value in providing order of magnitude estimates of bubble populations for comparison with other workers. The second phase of work consists of direct measurements of absorption and velocity over a path length of a few metres. This program is in its formative stages and no results are yet available.

II. THEORY

Scattering

It has long been accepted that both scattering and absorption of sound by gas bubbles in liquids is dominated by resonance effects. Minnaert[2], using an adiabatic equation of state for the gas in the bubble shows that radius a, of resonant bubble is given by

$$a = \frac{1}{2\pi \nu_r} \left[\frac{3\gamma P}{\rho} \right]^{1/2} \qquad (1)$$

where P is total hydrostatic pressure

ν_r is the resonant frequency

ρ is the density of the water

γ is the ratio of the specific heats of the gas in the bubble (= 1.4 for air).

The scattering cross section σ_s of the bubble at its resonant frequency is shown in reference 3 equation 47 to be

$$\sigma_s = \frac{4\pi a^2}{\delta^2} \qquad (2)$$

where δ is the total damping constant of the bubble.

Combining equations (1) and (2) and expressing the hydrostatic pressure in terms of the depth of the bubble below the surface of the sea yields

$$\sigma_s = \frac{1}{\delta^2} \cdot \frac{1}{\pi} \cdot \frac{1}{\nu_r^2} \left[\frac{3\gamma}{\rho} \left(\rho g h + P_o \right) \right] \qquad (3)$$

where g is the acceleration due to gravity

h is the depth in metres

P_o is the atmospheric pressure at the surface.

The appropriate value of the damping constant δ has been the subject of much discussion. A summary paper by Devin[4], has recommended preferred values for the damping constant at frequencies in the range 1–1000 kHz. These values include contributions from thermal, radiation and viscous effects. They are significantly lower than those used in reference 3 however a wider field of evidence was available in Devin's more recent work and these values have been adopted throughout the present work. Since δ appears to the second power in equation (3), the calculated scattering cross section σ_s is very sensitive to the particular value of δ chosen. Using values taken from reference 4, equation (3) has been plotted as figure 1 for several frequencies, giving results over a range of depths where bubbles produced by wave motion are likely to occur. Values of δ are of the order of 0.05 to 0.11 and equation (2) shows that the effective scattering area of a bubble is magnified by a factor $1/\delta^2$. This accounts for the large scattering effect of even a few bubbles contained in a volume of water.

The target strength T of a unit volume of bubbly water containing n bubbles, resonant at frequency ν_r is

$$T = 10 \log \frac{n\,\sigma_s}{4\pi} \qquad (4)$$

Thus for a fixed value of ν_r, a measurement of T as a function of depth, can be used in conjunction with expressions (3) and (4) to yield a value of n as a function of depth provided the insonified volume of scattering bubbly water is known. This can be estimated using a conical beam approximation for the transducer beam pattern when, as shown in figure 2, the reverberant volume Ω for a pulsed system is shown by Urick[5] to be

$$\Omega = \frac{c\tau}{2} \psi R^2 \qquad (5)$$

where c is the velocity of sound in water

τ is the transmitted pulse length

ψ is the solid angle subtended by the equivalent conical beam and is equal to $2\pi(1 - \cos\theta)$ where θ is the half angle of the cone

R is the range from the transmitting transducer.

Transmission

Transmitted sound flux through a bubbly medium is reduced by scattering and absorption. An extinction cross section σ_e can be defined to include both effects. This is given in reference 5 and allowing for the depth dependence of pressure can be written as

$$\sigma_e = \frac{c_o}{\delta} \cdot \frac{1}{\pi} \cdot \frac{1}{\nu_r^2} \left[\frac{3\gamma}{\rho} (\rho g h + P_o) \right]^{1/2} \qquad (6)$$

The attenuation coefficient α of unit volume of bubbly water containing n bubbles resonant at frequency ν_r, each having extinction cross section σ_e is

$$\alpha = 4.34 \, n \, \sigma_e \quad \text{dB m}^{-1} \qquad (7)$$

Hence a procedure can be envisaged in which a distribution for n as a function of depth can be deduced by vertical backscattering measurements, using equations (3) and (4), followed by calculation of the attenuation per unit metre for propagation in horizontal layers using equations (6) and (7).

III. EXPERIMENT

The equipment was set up in 20m of water as shown in figure 2. The same transducer was used for transmission and reception and was designed so that θ, the half-angle of the equivalent conical beam was 10°. The unit was placed in the sea at a depth of 19m some 700m east of Fort Head in the centre of Weymouth Bay, and operated by cable from the shore. This arrangement was believed to be capable of yielding measurements at a single frequency in water relatively undisturbed by shore effects for conditions driven by easterly winds. The pulse length was selected to be as short as practicable to ensure a fine grain sampling of the back scatter profile. This was 0.25 mS with care being taken to ensure that both transmitter and receiver had adequate bandwidth to process the information. All results of the experiment are consequently related to a 4 kHz bandwidth.

Two experimental runs were performed during the periods 16–19 June 1975 (Run 1) and 21–24 July 1975 (Run 2). During the eight weeks the unit was available for use, the area was subjected to unusually stable and calm conditions, and for most of the period seas above state 1 did not exist. Thus the dependence of bubble population on sea state could not be assessed and the results presented herein should not be thought to be typical of UK coastal waters. However some measurements at low sea state conditions were made and an estimate of the magnitude of the additional attenuation in bubbly layers near the surface was then calculated.

IV. RESULTS

Scattering

The echoes from 20 consecutive transmissions at 4 second intervals, forming a group were recorded on magnetic tape hourly throughout runs 1 and 2. In addition an oscilloscope display of the first echo of each group was photographed. An example of the latter is reproduced as figure 3. The data from 67 such photographs, taken over the period of run 1 and 112 photographs taken over the period of run 2 have been analysed in detail, attempts being made to identify tidal and diurnal variations.

Each echo was analysed by dividing the range into increments of 2m of depth and the maximum amplitude of the echo in each increment was noted. Initially seven increments, 14m below the surface were analysed, however the results indicated that only 5 increments or 10m of depth need be considered under the circumstances of these runs.

The maximum amplitude value was converted to the number of resonant bubbles per unit volume averaged over each range interval using equations (3) and (4). The results are plotted in figure 4. No definite trends were observed between high water and low water or between the night-time average and the day-time average, and all values appeared to be within 5% of the overall mean. The stability of the weather was such that no significant variations in sea state occurred throughout and the results all correspond to a sea state 1 condition.

Attenuation

An attenuation profile can be deduced using the bubble population distribution shown in figure 4 by substituting the results into equations (6) and (7). This procedure yields the attenuation profile for a horizontally stratified model of the sea shown in figure 5. From this it can be seen that a near grazing angle sound wave at the frequency of the measurement, approximating to the middle of the frequency range of interest will be required to propagate through a region where the attenuation progressively increases to 10 dB Km^{-1} in addition to the usual attenuation of approximately 7–10 dB Km^{-1} encountered at these frequencies in the absence of bubble effects.

V. CONCLUSIONS

An indication of the bubble population distribution of bubbles resonant in a narrow band of frequencies has been obtained from back-scatter measurements. This density is significantly lower than the results of Medwin[1]. No explanation is offered except to point out the unusually calm conditions over an extended period of time, and the difficulty of comparing environmental conditions at different sites.

The limited range of conditions studied is recognised, however the primary purpose of the work was to gain information which could be used in the design of a more versatile equipment which could sample the bubble population on a wider range of frequencies. When such an equipment is available, the program of work will be expanded to include an attempt will be made to estimate dispersion due to bubble layers.

VI. ACKNOWLEDGEMENTS

Acknowledgement is made to the Director, Admiralty Underwater Weapons Establishment for providing the facilities for the work so far described and for permitting publication of this report. Appreciation is also expressed to the members of staff, too numerous to mention individually, who helped in setting up and operating the equipment.

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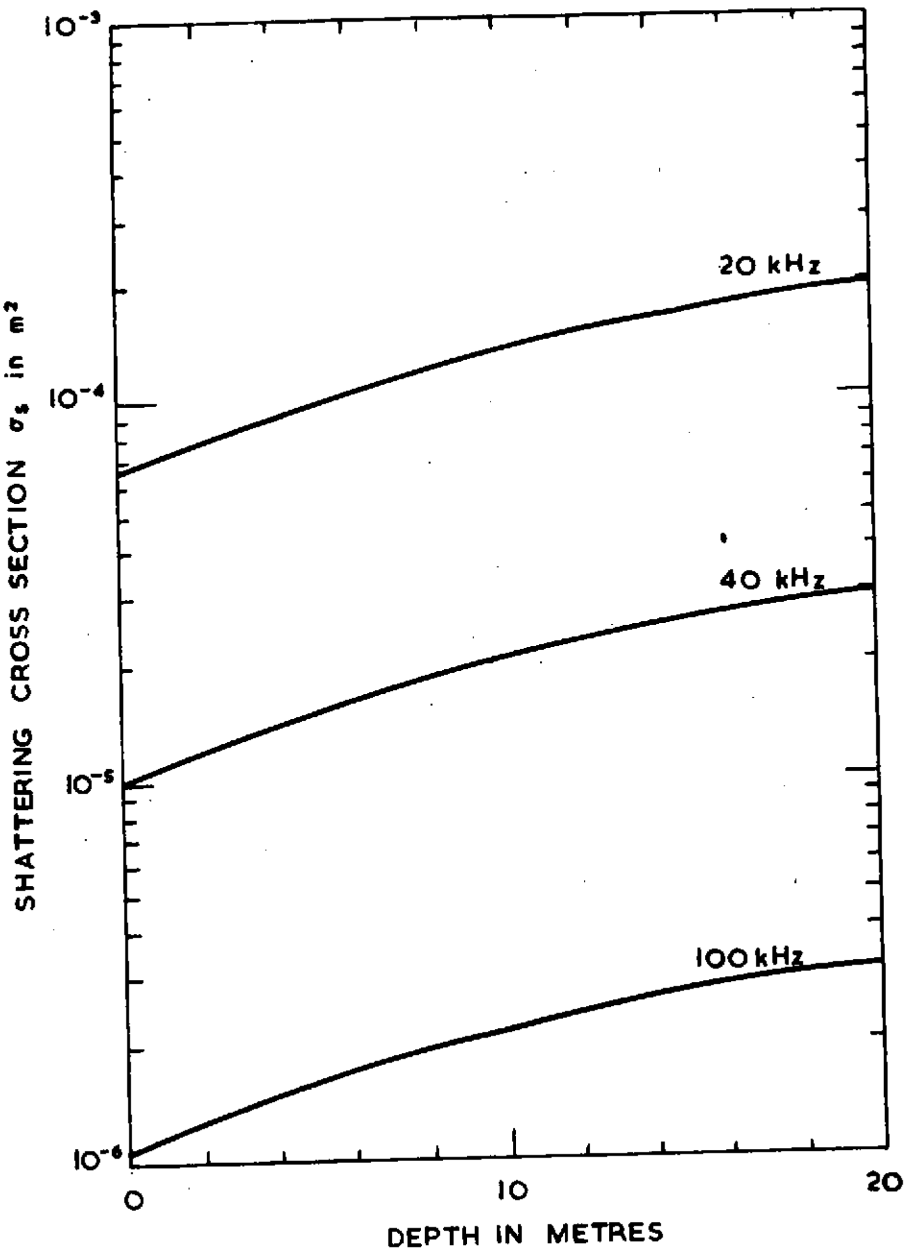

FIG. I. VARIATION OF SCATTERING CROSS-SECTION WITH DEPTH

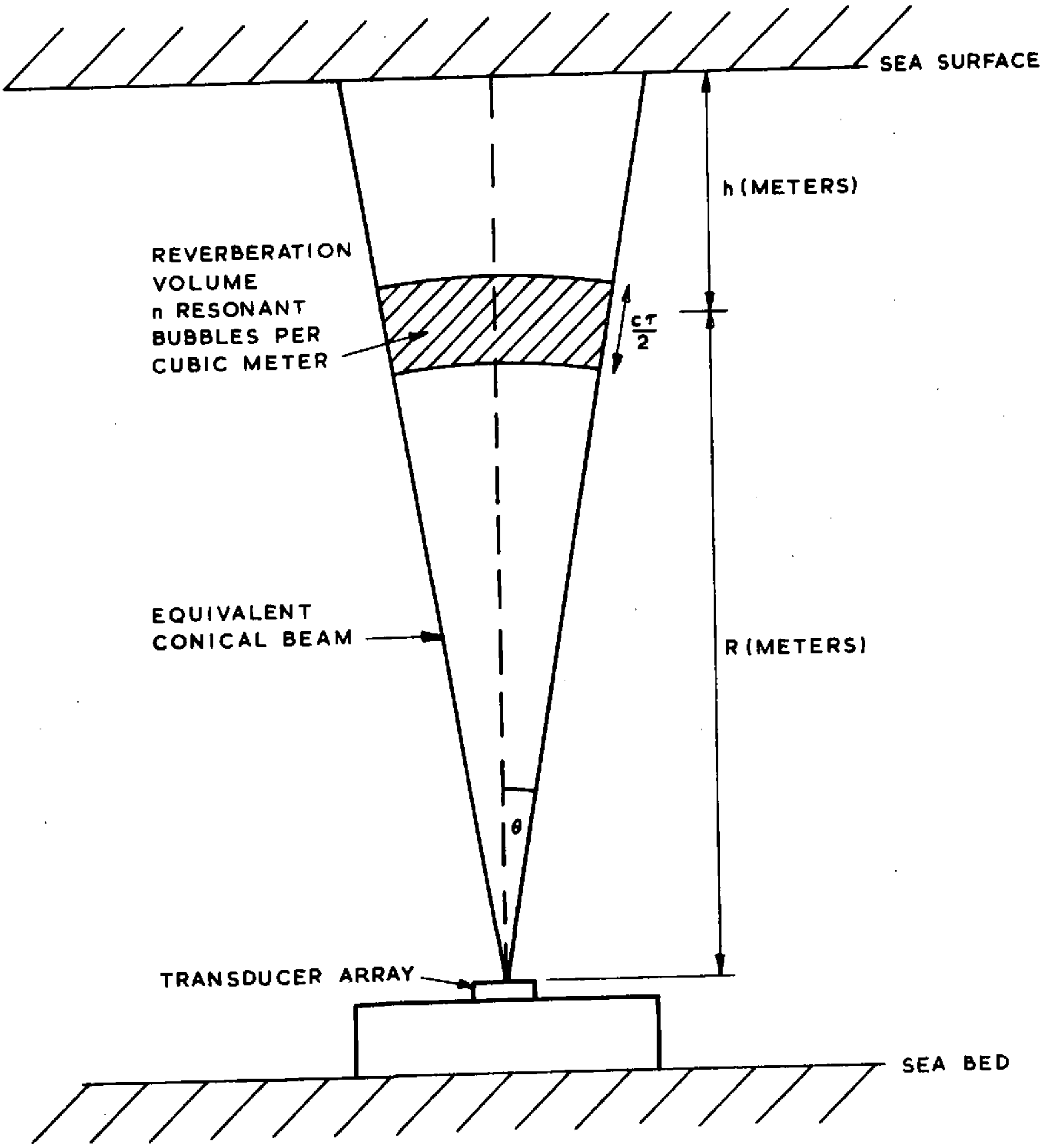

FIG. 2 EXPERIMENTAL ARRANGEMENT

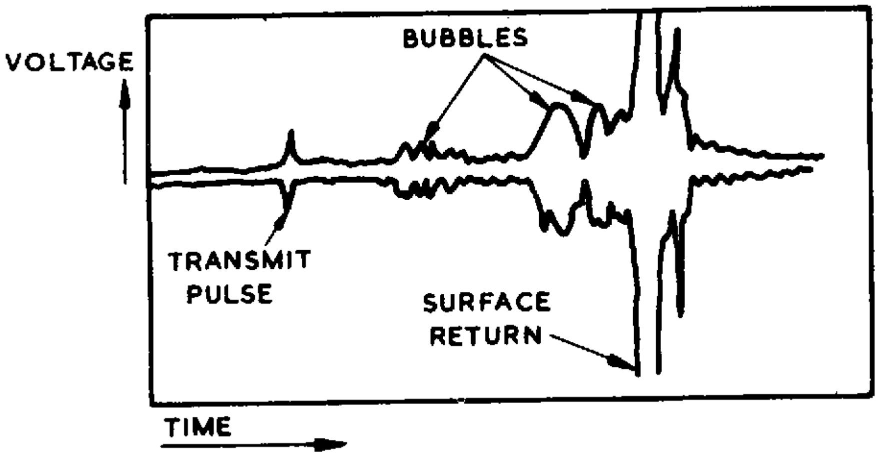

FIG. 3. TYPICAL ECHO ENVELOPE

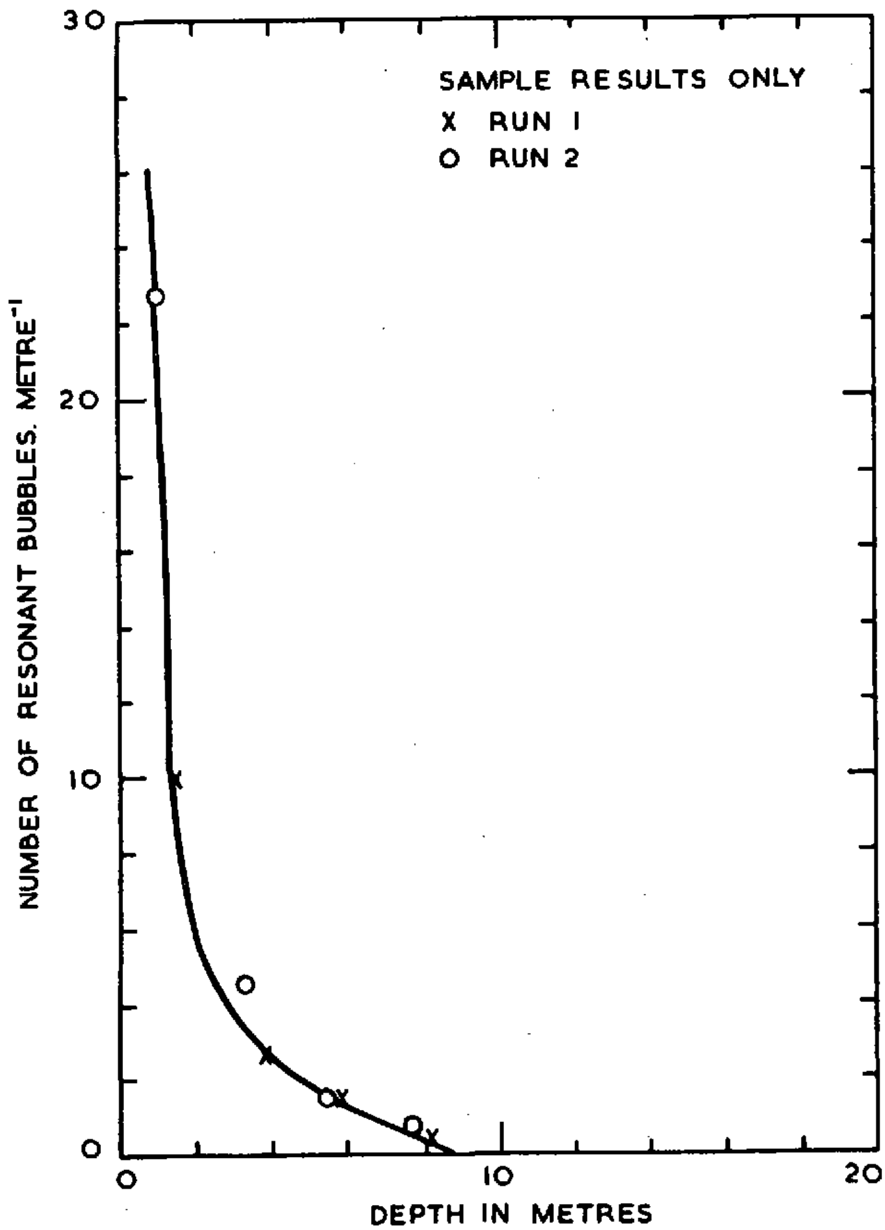

FIG. 4. AVERAGED RESULTS

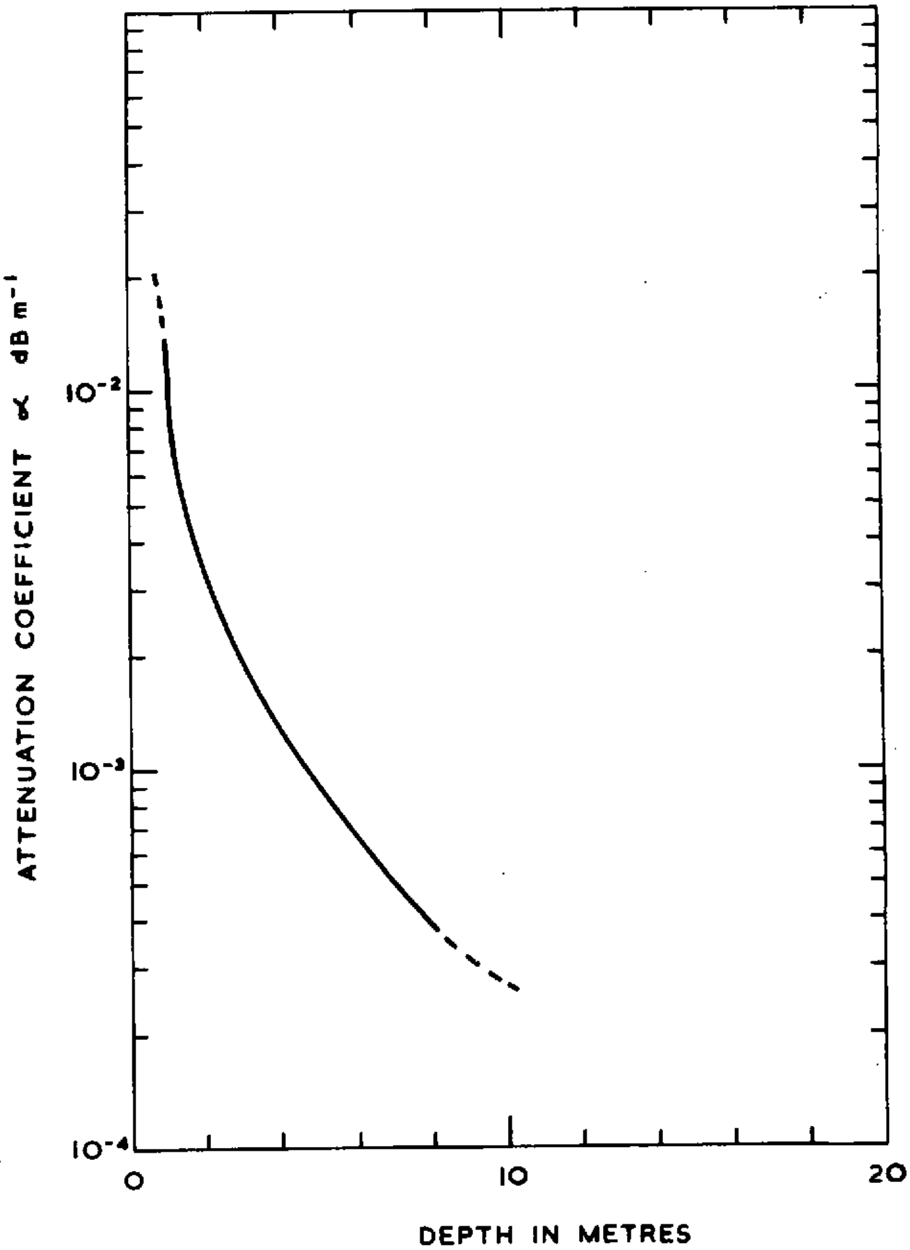

FIG. 5. ATTENUATION PROFILE FOR RESULTS OF FIG. 4. (SEA STATE 1)