Spectral characteristics of irregularities of density of marine sediments as indicated by deep-sea drilling data

Anatoliy N. Ivakin
University of Washington Seattle

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SPECTRAL CHARACTERISTICS OF IRREGULARITIES OF DENSITY OF MARINE SEDIMENTS AS INDICATED BY DEEP-SEA DRILLING DATA[1]

A.V. Yefimov, A.N. Ivankin and Yu. P. Lysanov

Andreyev Institute of Acoustics, Moscow
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Constructing a geoacoustic model of marine sediments is a major task of ocean acoustics. Not only does it provide the only means of predicting acoustic fields returned by the sea floor, but in addition it constitutes the only means of information on the physical characteristics of the bottom and its external structure from acoustic sounding. One of the main sources of input data for the construction of a geoacoustic model of the sea floor is deep-sea drilling data, much of which was obtained during the numerous expeditions of the U.S. ship Glomar Challenger. Analysis of these data indicates that the dependence of the main acoustic characteristics of the sediments (density and sound velocity) on depth has the form of irregular fluctuations superposed on an overall (regular) trend. Hitherto, the main focus in the construction of geoacoustic models of the sea floor has been on the regular component of these plots, obtained by averaging (smoothing of the irregular fluctuations) [1-4]. The resulting sea floor models, which describe the characteristic features of the regular (stratified) structure of sediments, are useful in forecasting the sound field reflected from the sea floor in various regions of the ocean. But they contain no information on random variations in the thickness of sediments which are needed to calculate the scattering properties of the sea floor. In the present paper we use deep-sea drilling data to analyze this irregular structure of the sediments and to construct a statistical model of random variations in their thickness.

From the deep-sea drilling data we selected seven drillholes [5]: Nos. 33 and 36 in the northeastern Pacific, and Nos. 42, 69A, 70, 71 and 72A in the central Pacific. All of these drillholes are in areas with ooze-type sediments. The greatest distance between wells was about 4000 km. Plots of the variation in porosity P (the volume fraction of water in the sediments) and the relative density ρ (the ratio of densities of bottom material and sea water) are available [5] for drillholes 33, 36 and 42, while only plots of P are available for the others. A computer was used to filter the data with a minimum resolution of 5 cm. The fast Fourier transform technique was used to calculate one-dimensional spectra of fluctuations in porosity $G_\rho(k)$. An analysis of the results indicated that in the interval of wave numbers k from 0.2 to 100 m^{-1}, the spectra were well approximated by the power-law equation

$$G_P(k)=Ck_0^{-1}(k/k_0)^{-\nu}, \tag{1}$$

where $k_0 = 1$ m^{-1}. The least-squares method gave values of $\nu = 1.5 \pm 0.3$ and $\log C = -1.8 \mp 0.5$ for the coefficients. Curve *1* in Fig. 1 gives the spectrum $G_P(k)$, averaged for all wells, while dashed curves *2* show the standard deviation rnage of the spectra for the individual wells. Line *3* represents the spectrum calculated from Eq. (1) with $\nu = 1.5$, $\log C = -1.8$; as will be seen, it gives a good representation of the spectrum of the measured fluctuations in the porosity of the sediments.

The spectrum of the fluctuations in relative density $G_\rho(k)$ is also well approximated by Eq. (1) with the same value of ν, but the ratio $G_\rho(k)/G_P(k)$ varies from 1.6 to 3.2, in good agreement with the known empirical regression relationship between ρ and P [6]:

$$\rho=1+\gamma(1-P), \tag{2}$$

where γ ranges from 1.15 to 2.35 within the confidence interval and its most probable value is $\gamma_0 \approx 1{,}6$. This result is in good agreement with our range of values $[G_\rho(k)/G_P(k)]^{1/2} \simeq \gamma = 1{,}3-1{,}8$. Thus, empirical equation (2) is useful in modeling both the regular and random characteristics of sediments. For example, if the deep-sea drilling data can be used only to define the spectrum of the porosity fluctuations (as was the case in several of the drillholes that we investigated), the spectrum of the fluctuations in relative density can be obtained from the equation

$$G_\rho(k)=\gamma^2 G_P(k). \tag{3}$$

[1]Translated from: Spektral'nyye kharakteristiki neodnorodnostey morskikh osadkov po dannym glubovodnogo bureniya. Doklady Akademii Nauk SSSR, 1988, Vol. 301, No. 3, pp. 710-712.

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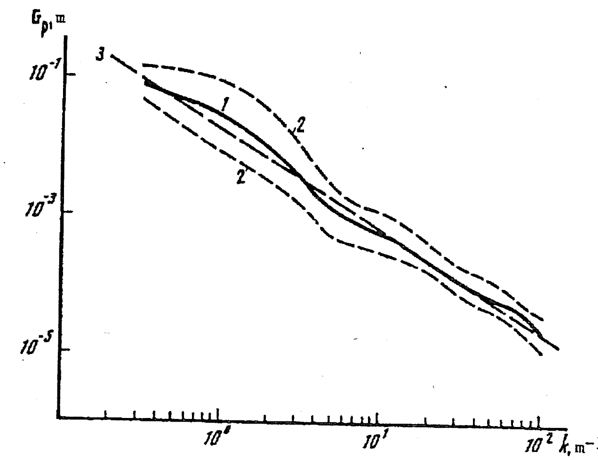

Fig. 1. Spectrum of fluctuations in porosity of sediments of depth.

To calculate the time-angle characteristics of the acoustic field scattered by three-dimensional irregularities in marine sediments, we need to know the three-dimensional spectra of fluctuations in relative density and refractive index. But it has been found that in ooze sediments, fluctuations in density are of the most important; the mean-square value of these fluctuations is considerably larger than that for fluctuations in the refractive index [7]. The relationship between the three-dimensional spectrum $\Phi_\rho(\mathbf{q})$ and the one-dimensional spectrum $G_\rho(k)$ for isotropic irregularities is well known [8]:

$$\Phi_\rho(\mathbf{q}) = -\frac{1}{2\pi q}\frac{d}{dq}G_\rho(q), \qquad \mathbf{q} = \{q_\perp, q_z\}. \tag{4}$$

This correlation can be generalized to the case of anisotropic irregularities when their spatial correlation function is

$$B_\rho(\mathbf{r}, z) = B(\sqrt{\alpha^2 r^2 + z^2}), \tag{5}$$

representing refraction from ellipsoidal irregularities [9]: α is the degree of anisotropy of the irregularities (the ratio of their vertical and horizontal scales). Isotropic irregularities then represent the special case $\alpha = 1$. The three-dimensional spectrum of the irregularities, with a correlation function of type (5), will satisfy the equation

$$\Phi_\rho(\mathbf{q}) = -\frac{1}{2\pi q_0 \alpha^2}\frac{d}{dq_0}G_\rho(q_0), \tag{6}$$

where $q_0 = [(q_\perp/\alpha)^2 + q_z^2]^{1/2}$. Consequently, substituting empirical equation (1) into Eq. (6) and then substituting Eq. (3), we obtain the three-dimensional spectrum of the fluctuations in the relative density of the sediments.

$$\Phi_\rho(\mathbf{q}) = \frac{C\nu\gamma^2}{2\pi\alpha^2 k_0^3}(q_0/k_0)^{-\nu-2}. \tag{7}$$

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