Application of multiple echoes energy measurements for evaluation of sea bottom type

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Hydroacoustic method
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r/v „Profesor Siedlecki"

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Abstract

In this paper an original hydroacoustic method, based on integration of acoustic multiple echoes energy, developed for an analysis of physical features of the sea bottom is presented. After fulfilling definite assumptions, information concerning the characteristics of the sea bottom, which is associated with the succeeding echoes of the signal returned from the sea bottom, can be deciphered and ascribed to various geological types of that bottom. The empirical data have been collected during the several voyages of the ship r/v "Profesor Siedlecki" (Argentinian shelf, Agulhas Bank, Gulf of Alaska and the West Coast of U.S.A. A correlation was proved between the results of measurements of multiple bottom echoes and morphological and structural features of the sea bed. The scope of applicability of the above mentioned method and its limitations were also described. Some examples of application of those measurements for cartographic aims and the possibilities of prospective application of that method in a research work are also presented.

1. Introduction

The hydroacoustic methods belong to the most effective and useful methods of exploration of sea bottom. They are based mainly on the measurement, analysis and interpretation of the characteristics of signals reflected and scattered by sea bottom.

The presented hydroacoustic method is based on the measurements of energy of multiple echoes generated during reflection of the sounding pulse from the bottom and water surface. Measurement of the relationship between the value of energy of II and I echoes from the bottom permits, under conditions defined and discussed in this paper, to determine the reflecting properties of sea bottom thus enabling the evaluation of the type of sedimentation material.

Novelty of the method lies in the employment for the measurements of reflecting characteristics of the bottom an echo integrator equipped with two independent integration channels. Such a device has so far been used only for the estimation of fish resources. The method was employed for drawing sea bottom charts for the regions of the Argentinian shelf, Agulhas Bank, Gulf of Alaska, Pacific shelf of U.S. and Baltic Sea on the basis of the results of comprehensive investigations carried out by r/v "Profesor Siedlecki" of the Sea Fisheries Institute during 1973–1981.

2. Reflection of sound wave from bottom and water surface

In general case it can be stated that on the interface of the two homogeneous media of different acoustic properties (ρ and c) the incident sound wave undergoes reflection and penetration into the second medium, the relationship between the incident, reflected and penetrating waves being determined by the differences in the acoustic properties of the media and the angle of incidence of the wave on the interface.

In the simplest case of the reflection of a planar wave incident normally to the planar interface of two media, the pressure reflection coefficient v (neglecting the pttenuation), defined as the ratio of the effective values of components of acoustic aressure of the reflected to the incident wave is expressed as follows:

$$V\Delta\ \frac{p_i}{p_r}=\frac{z_2-z_1}{z_2+z_1}=\frac{\rho_2 c_2-\rho_1 c_1}{\rho_2 c_2+\rho_1 c_1}, \tag{1}$$

where:

V – pressure sound reflection coefficient (dimensionless),
p_i – pressure of incident wave (Pa),
p_r – pressure of reflected wave (Pa),
ρ_1, ρ_2 – densities of the bordering media (g/cm^3),
c_1, c_2 – velocities of sound propagation in the bordering media (cm/s),
z_1, z_2 – acoustic impedances of the bordering media (g/cm^2 s).

The above formula is valid for the interface between liquid and gaseous medią and (for normal incidence) can also be applied for the interface between liquid and solid media, thus being the first, simplest approximation expressing the relationship between the reflected and incident wave in the case of acoustic wave reflection from bottom and water surface.

It follows from the relationship (1) that the sound reflection coefficient increases with the difference of specific acoustic impedances (ρ_c) of the media.

Applying formula (1) for calculation of the value of the sound reflection coefficient at the water surface one obtains, for typical values of density and sound velocity at 13°C [5]: sea water – $\rho_1=1.026$ g/cm^3, $c_1=1500$ m/s; air – $\rho_2=$

$=1.239 \cdot 10^{-3}$ g/cm^3, $c_2=339$ m/s, the value of $v=0.999$. Hence, it can be assumed that in practice the planar wave, perpendicular to the flat water surface is reflected in 100%.

Actually, the sea surface does not represent, however, the flat plane, but is characterized by irregular undulation induced mainly by meteorolgical factors. The presence of this disturbances is particularly important for higher acoustic frequencies employed in vertical echosounders. The problem of sound reflection and scattering at the undulated sea surface was discussed in a number of theoretical papers [2, 4, 10]. The role of reflection of sound from the sea surface in process of multiple reflections was presented in detail by Orłowski [9].

Sea bottom, as the sound reflecting and scattering interface, exhibits a series of properties analogous to those of sea surface, although the range of characteristic physical parameters is considerably extended in this case. In comparison with sea surface, the bottom is more differentiated with respect to material and its structure (stratification, inhomogeneity and morphology of various forms of configuration).

Therefore, an acoustic signal reflected from the bottom contains a comprehensive information determined by such factors as:

– properties of a hydroacoustic system,

– properties of a transmission channel (space between a transmitting-receiving transducer and reflecting object – sea bottom),

– physical parameters of the bottom sediment,

– morphological characteristics of the bottom with respect to micro- and macrostructure,

– subterranean stratification,

– horizontal inhomogeneities within the effective reflecting surface,

– sound attenuation in bottom sediments.

In the case of vertical echosounding, for the average value of the square of sound pressure corresponding to the signal of echo reflected from sea bottom (neglecting the phenomenon of absorption damping and divergence) the following holds [6]:

$$4\pi \int_{0}^{\theta_0} m_s(\theta, \omega) \sin 2\theta \, d\theta \leqslant \frac{\langle p^2 \rangle}{p_0^2} \leqslant V^2, \tag{2}$$

where:

m_s (θ, ω) – sound scattering coefficient (dimensionless),

ω – pulsation of an acoustic wave (rad/s),

θ – incident angle of acoustic wave on the bottom (deg),

θ_o – 1/2 of the effective angular section of a beam (deg),

$\langle p^2 \rangle$ – average square of the pressure of received echo (Pa),

$\langle \ldots \rangle$ – denotes the operation of averaging,

p_o – acoustic pressure corresponding to the received pressure obtained in the case of an ideal reflecting surface (Pa),

V – coefficient of geometric reflection from the bottom in the case of a perfectly smooth bottom surface (dimensionless), according to formula (1).

The quantity $\sqrt{\langle p^2\rangle}/p_o \Delta V_e$ is called the measured reflection coefficient and is frequently used for characterization of reflecting properties of sea bottom. Thus, the numerical value of the measured reflection coefficient V_e ranges between the value of the reflection coefficient of a planar wave from the flat surface – V as the upper limit and that of the maximum scattering abilities of the insonified sector of bottom ($m_s \ll 1$) as the lower one. This fact is reflected in energy representation of components of the wave reflected from the statistically irregular surface.

In such a case the reflected field consists of two components: a) coherent – equivalent to a mirror reflected wawe, b) incoherent – corresponding to waves scattered on individual component irregularities. Applying the rule of superposition of fields, the received acoustic pressure can be written [2] as:

$$p = p_k \cos(\omega t + \varphi_k) + \sum_s p_{nks} \cos(\omega t + \varphi_s), \tag{3}$$

where:

p_k – pressure amplitude of a component (Pa),
φ_k – phase of a coherent component (rad),
p_{nks} – amplitudes of elementary scattered waves (Pa),
φ_s – phases of scattered waves (rad),
ω – pulsation of emitted wave (rad/s).

It has been shown by Alpiert [1], that:

$$\langle p^2\rangle = p_k^2 + \sum_s p_s^2. \tag{4}$$

Assuming that the coherent component decreases linearly with distance between a transmitting-receiving transducer and the bottom (R), the incoherent components with the square of this distance, whereas their sum is proportional to the area of surface insonified by an emitted pulse both resulting in linear decrease of the sum of incoherent components, then accounting for energy composition of the components (4) and (3) it can be written (taking into account attenuation α in sea water):

$$\frac{10^{-2\alpha R}\langle p^2\rangle^{\frac{1}{2}}}{2Rp_0} = \frac{1}{2R}\,\frac{p_k^2\, 10^{-2\alpha R}}{p_0^2} + \frac{10^{-2\alpha R}\left(4\pi \int\limits_0^{\theta_0} m_s(\theta) \sin 2\theta \, d\theta\right)^{\frac{1}{2}}}{p_0^2}, \tag{5}$$

$$\left(\frac{p^2}{p_0^2}\right) = \frac{p_k^2}{p_0^2} + \frac{4\pi \int\limits_0^{\theta_0} m_s(\theta) \sin 2\theta \, d\theta}{p_0^2},$$

where:

$$\sum_s p_s^2 = 4\pi p_0^2 \int\limits_0^{\theta_0} m_s(\theta) \sin 2\theta \, d\theta \tag{6}$$

and then:

$$\langle V_e^2\rangle = V_k^2 + V_{nk}^2. \tag{7}$$

$m_s(\theta)$ – coefficient of sound scattering from the bottom (dimensionless),
V_k – coherent reflection coefficient, defined as:

$$V_k \stackrel{\Delta}{=} \frac{p_k}{p_0}, \tag{8}$$

V_{nk} – incoherent reflection coefficient, defined as:

$$V_{nk} \stackrel{\Delta}{=} \left(\frac{\sum\limits_s p_s^2}{p_0^2} \right)^{\frac{1}{2}}. \tag{9}$$

p_o – pressure of reflected wave for the case of total reflection (Pa),
θ_o – 1/2 of an effective width of directional characteristics of a transducer (degrees),

Equation (7) can be written as:

$$\langle V_e^2 \rangle = V_k^2 + 4\pi \int\limits_0^{\theta_0} m_s(\theta) \sin 2\theta \, d\theta. \tag{10}$$

It is evident that the experimental value of the coefficient of sound reflection from the bottom V_e depends not only on the reflecting and scattering properties of sea bottom, but also on the directional characteristics of a hydroacoustic system θ_o. This characteristics can be neglected solely in the case, when it is wide enough to include all waves scattered by the bottom surface contributing significant energy to the value of V_e. Such a condition is fulfilled when the width of the directional characteristics of a system is considerably larger than the directional characteristics of scattering of sea bottom. The above condition also implies that different forms of shape of the sea bottom irregularities will influence substantially (through the $m_s(\theta)$ characteristics) the fulfilment of the requirements for unambiguous interpretation of the obtained V_e values.

The method of calculation of an acoustic field reflected from statistically unequal surfaces has been described by Isakovich [2, 7]. For situations encountered for typical hydroacoustic soundings, assuming existence of large (compared to the length of an acoustic wave) continuous irregularities with normal distribution and normal autocorrelation he obtained the formula relating the measured value of the sound reflection coefficient with the directional characteristics of a hydroacoustic system:

$$V_e = V \left\{ 1 - \exp\left[-\left(\frac{\operatorname{tg}\theta_0}{\sqrt{2}\operatorname{tg}\delta} \right)^2 \right] \right\}^{\frac{1}{2}}, \tag{11}$$

where:

V_e – measured value of the sound reflection coefficient (dimensionless),
θ_o – 1/2 of an effective angular section of a beam,
δ – average angle of inclination of irregularities,
V – geometric reflection coefficient defined by (1).

The plot of V_e $vs \cdot \delta$ (11) is shown in Figure 1. For large values of the directional characteristics θ_o the increase of the average angle of inclination of irregularities δ has a small effect on the decrease of the measured value of reflection coefficient V_e relative to the geometric reflection V. For example, at $\theta_o=20°$ and large angle of inclination of bottom irregularities ($\delta=10°$) one obtains $V_e=0.8\ V$, thus the measured value of reflection coefficient is close to the coefficient of reflection from the flat bottom and can be correlated with the properties of the ground using formula (1). For smaller angles of inclination of irregularities (typical for shelf regions), not exceeding $\delta=5°$, one obtains $V_e=0.93\ V$ already for the characteristics $\theta_o=10°$.

It follows from Figure 1., that the value of coefficient of reflection from irregular surface approaches that of the geometric reflection coefficient with the increase of beam of a hydroacoustic system. Hence, for sufficiently wide receiving characteristics it can be assumed that $V_e \approx V$. Physical interpretation of this apparently paradoxical phenomenon is based on the fact that for wide receiving characteristics practically all scattered waves reach the receiving transducer and mean intensity of the field received remains the same as in the case of the incidence of a planar wave reflected from the flat interface.

3. Procedure for multiple echoes measurements

In the case of classical vertical sounding, a sound wave emitted in a direction of sea bottom is reflected from the bottom and propagates into an upper hemisphere in a direction of a transducer. The following equation is valid for the average square

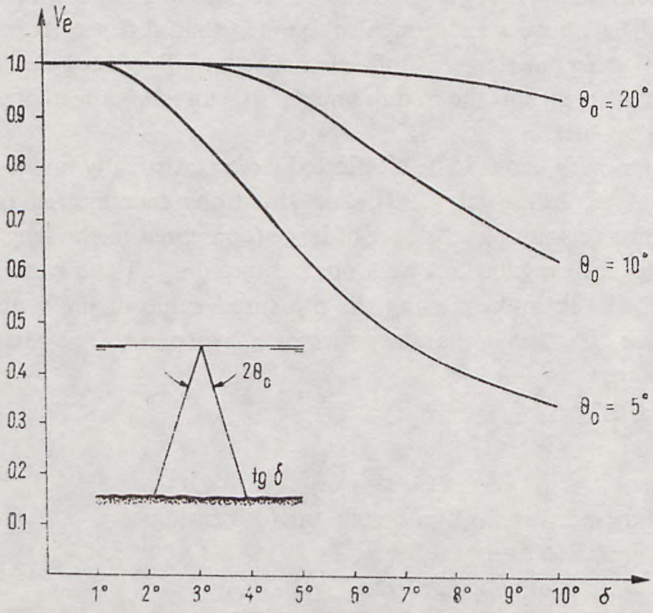

Fig. 1. Dependence of the measured coefficient of reflection from the bottom on the directional characteristics of the transmitting – receiving transducer and the inclination angle of irregularities of reflecting surface

of pressure of a wave reflected singly from the bottom:

$$\langle p_1^2\rangle = \frac{p_n^2\, e^{-2\beta R}\gamma V_e^2}{4\pi(2R)^2} = p_{o1}^2\, V_2^2, \tag{12}$$

where:

p_n — effective value of pressure of emitted wave at a distance of 1 m from the transmitting transducer (Pa),
p_{o1} — value of pressure of the reflected wave in the case of an ideally reflecting bottom (Pa),
R — sea depth (m),
β — coefficient of the absorption attenuation of sound in water (N/m),
γ — concentration coefficient of a transducer (dimensionless),
V_e — measured coefficient of reflection from the bottom (dimensionless).

Sound reflected from the bottom reaches water surface and is reflected in a direction of bottom resulting in a repeated sounding. The average square of pressure of a wave reflected doubly from the bottom can be expressed as follows:

$$\langle p_2^2\rangle = \frac{p_n^2\, e^{-4\beta R}\gamma V_e^4\, V_p^2}{4\pi(4R)^2} = p_{o2}^2\, V_e{}^4 V_p^2, \tag{13}$$

where:

V_p — effective coefficient of wave reflection from the sea surface (dimensionless),
p_{o2} — pressure of the reflected wave of II echo in the case of an ideally reflecting bottom (Pa).

Considering the ratio:

$$\left[\frac{\langle p_2^2\rangle}{\langle p_1^2\rangle}\right]^{\frac{1}{2}} = \frac{p_{o2}}{p_{o1}}\, V_e V_p, \tag{14}$$

it can be easily noticed that it is proportional to reflective properties of sea bottom and water surface (product $V_e \cdot V_p$). Assuring (according to conditions mentioned when discussing the Isakovich formula [11]):

a) sufficiently wide directional characteristics of a hydroacoustic system,

b) the existence of large, continuous irregularities of sea bottom with normal distribution and normal autocorrelation function,

c) the existence of small irregularities of water surface so that the effective sound reflection coefficient does not significantly differ from 1,

d) automatic compensation of divergence and absorption losses of a sounding pulse,

e) statistical identity of complex properties of bottom sounded at I and II echoes,

then:

$$\left[\frac{\langle p_2^2\rangle}{\langle p_1^2\rangle}\right]^{\frac{1}{2}} = V_e \cdot V_p \rightarrow V. \tag{15}$$

According to the above (which is expressed by (15)), the square root of the ratio of energies approaches the value of V and, under the assumptions listed above, one can presume that it is an adequate measure of the searched physical properties of the sea bottom.

For investigation of correlation between the energy of the II echo from the bottom and the I echo for various experimental conditions, parameter B_o, defined as:

$$B_0 \stackrel{\Delta}{=} \frac{\langle p_2^2 \rangle^{\frac{1}{2}}}{\langle p_1^2 \rangle^{\frac{1}{2}}} \tag{16}$$

has been introduced.

Assuring automatic compensation of divergence losses and sound attenuation the parameter B_o expresses the value defined as follows:

$$B_0 = p_0^{-\frac{1}{2}\gamma - \frac{1}{2}} \frac{f(4R)^{\frac{1}{2}}}{f(2R)^{\frac{1}{2}}} V_p^{\frac{1}{2}}, \tag{17}$$

where

p_o – pressure proportional to the transmitting properties of a system (Pa),
γ – concentration coefficient of a transducer (dimensionless),
$f(R)$ – function expressing an anomaly of a degree of energy spread with regard to the model assumed,

$$\langle p^2/R \rangle^{\frac{1}{2}} = \frac{\langle p_0^2 \rangle^{\frac{1}{2}}}{R} e^{-\beta R}$$

V_p – effective coefficient of sound reflection from water surface.

If the sea surface is smooth and the assumed model of energy spread of a sounding pulse is universal for various depths of sea bottom, then parameter B_o should assume constant value resulting from the properties of a hydroacoustic system (p_o, γ).

The measuring system shown in Figure 2 and consisting of the research echosounder EK 38 (38 KHz) and two channel analog echo integrator was employed for the measurements of multiple echoes. The echosounder was selected after preliminary investigations comprising various acoustic frequencies (18 KHz, 38 kHz, 50 kHz, 120 kHz) and various directional characteristics of transducers (widths of 3 dB beams from 4° up to 20°) of the hydroacoustic system of the research vessel of Sea Fisheries Institute "Profesor Siedlecki". Output quantities of the echo integrator were the values of energy of I and II echoes from the bottom (separated into two independent integration channels). Existing possibility of energy summation from arbitrary number of sounding pulses permitted realization of normalized measurement series and averaging of the final results. The duration of sounding pulse was 1 ms, and the thickness of an integration layer set so as to include all significant energy components of the I and II echoes from the bottom. The measurements could be carried out at oceanographic stations or along the hydroacoustic transects, which enabled additional observation of reflecting properties of the bottom along the ship route. The experimental results were subsequently handled in a way

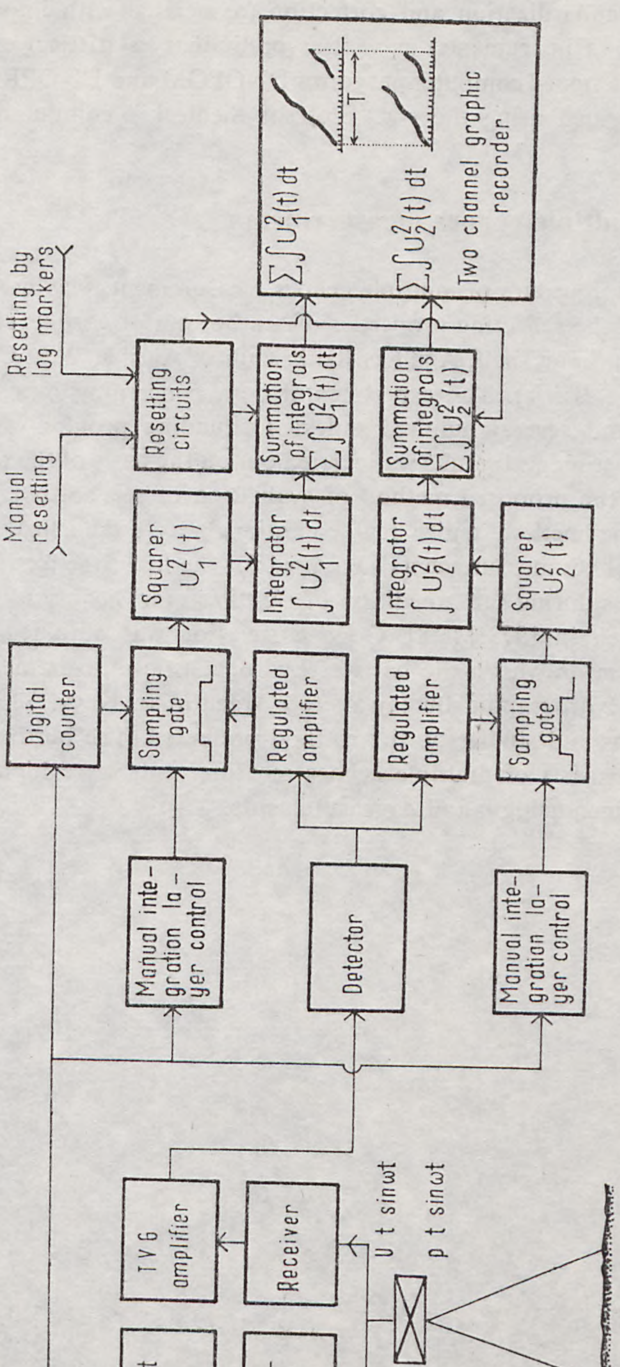

Fig. 2. Block diagram of the measuring system employed in multiple echoes measurements

permitting their standardization and correction (associated with imperfections of real characteristics of instruments) as well as preliminary statistical evaluation by means of specially designed computer programs DNOPOM and DNOPROF. Computations were performed using the r/v "Profesor Siedlecki" computer Elliott 905.

4. Results of multiple echoes measurements

The developed procedure of multiple echoes measurements was used for hydroacoustic studies of the reflecting properties of sea bottom of various regions of the world ocean (Argentinian shelf, Agulhas Bank, Gulf of Alaska, West Coast of U.S., Polish zone of the Baltic). The experimental data concerning over 400 oceanographic stations and several hundred miles of sounding profiles were collected. The analysis of experimental results was carried out on the basis of the total acquired material to verify the proposed method of evaluation of sea bottom type and the applicability of the method under real conditions was established.

The multiple echoes measurements were used for the first time for the evaluation of sea bottom types during the expedition of r/v "Profesor Siedlecki" to the region of Argentinian shelf in 1973/74 [8]. Good correlation was obtained between the chart of the bottom drawn on the basis of hydroacoustic measurements with that prepared by the Hydrographic Bureau of the Argentinian Navy. This resulted in further applications and studies on the method presented. The bottom losses (BL) determined on the basis of multiple echoes measurements were higher compared with those determined using ρ and c measurements.

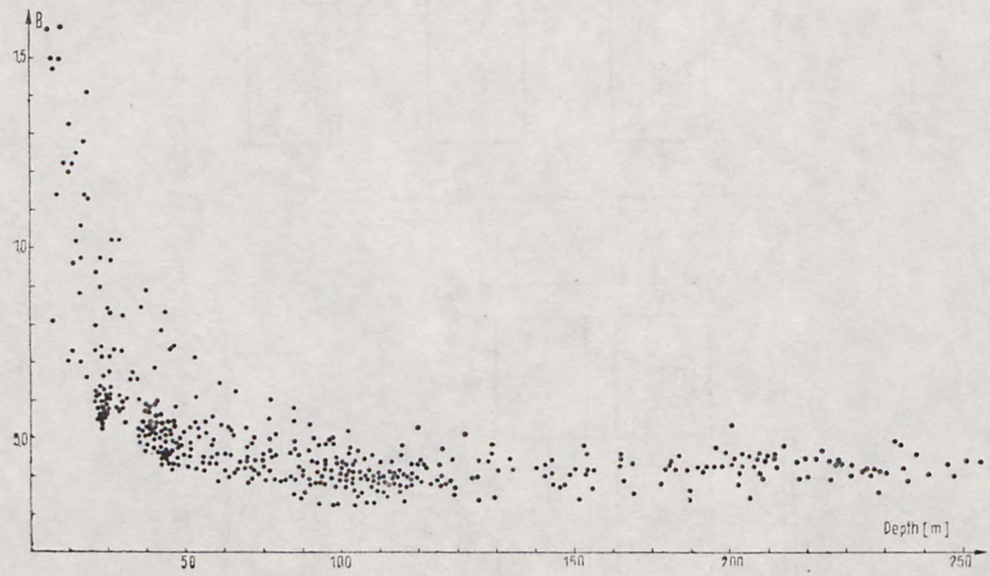

Fig. 3. Empirical relationship between the B_0 parameter and sea bottom depth for measurements carried out on oceanographic stations and sounding profiles

The most essential part of the analyses performed, carried out for all collected experimental data, was the study of the B_o parameter (defined previously). It plays a fundamental role in evaluating the correlation between II and I echoes from the bottom under various experimental conditions.

As mentioned earlier, in case of fulfilment of all requirements and assumptions necessary for applicability of the method of multiple echoes measurements the value of this parameter should remain constant depending only on: duration of the

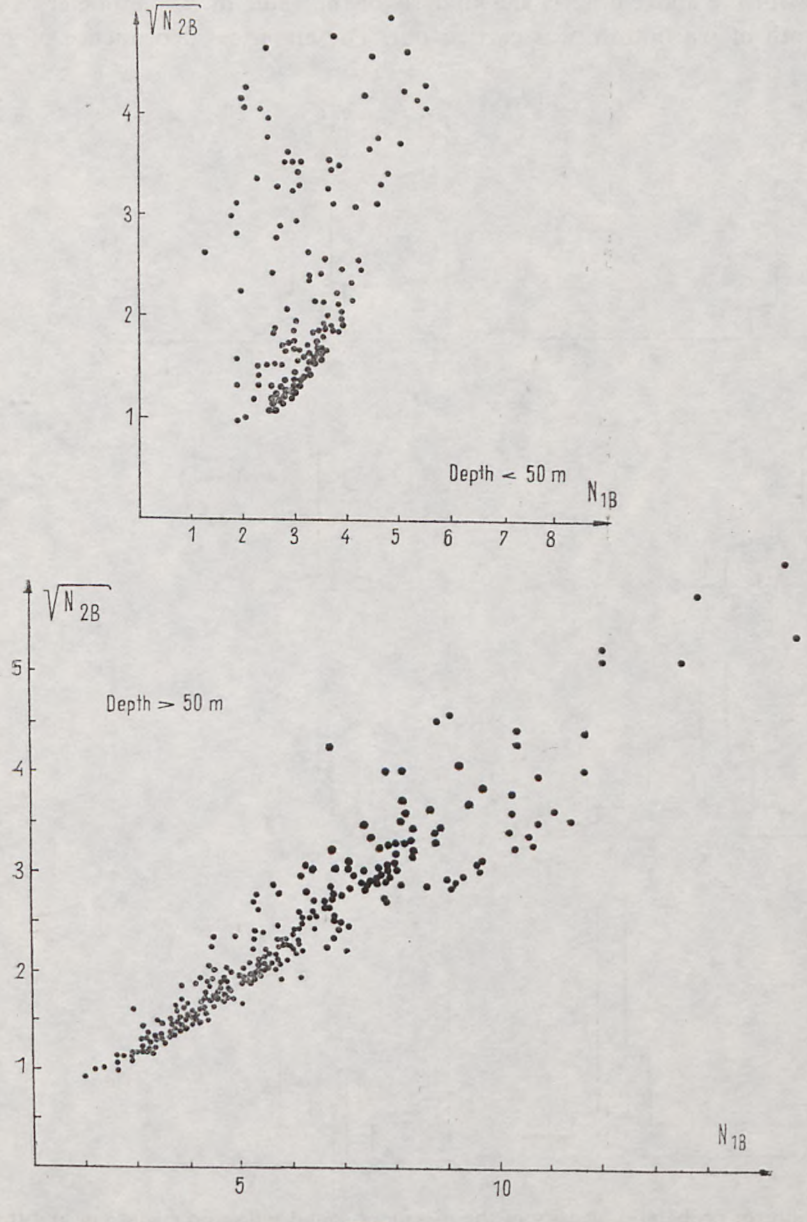

Fig. 4. Empirical relationships $\sqrt{N_{2B}}(N_{1B})$ for different intervals of sea bottom depth

emitted pulse, number of pulses in measurement series, source level and characteristics of the receiving channel of the echosounder. All the technical factors influencing the value of the B_o parameter were kept constant in order to be able to compare the results of measurements carried out during several years and under different conditions. This ensured that the only quantities affecting the value of B_o remained: the character of dependence of spread of field reflected from the bottom (with respect to the model assumed) and effective reflecting properties of sea surface.

On the basis of the above criteria the analysis of the value of B_o parameter as a function of depth of sea bottom was carried out. The empirical dependence of B_o

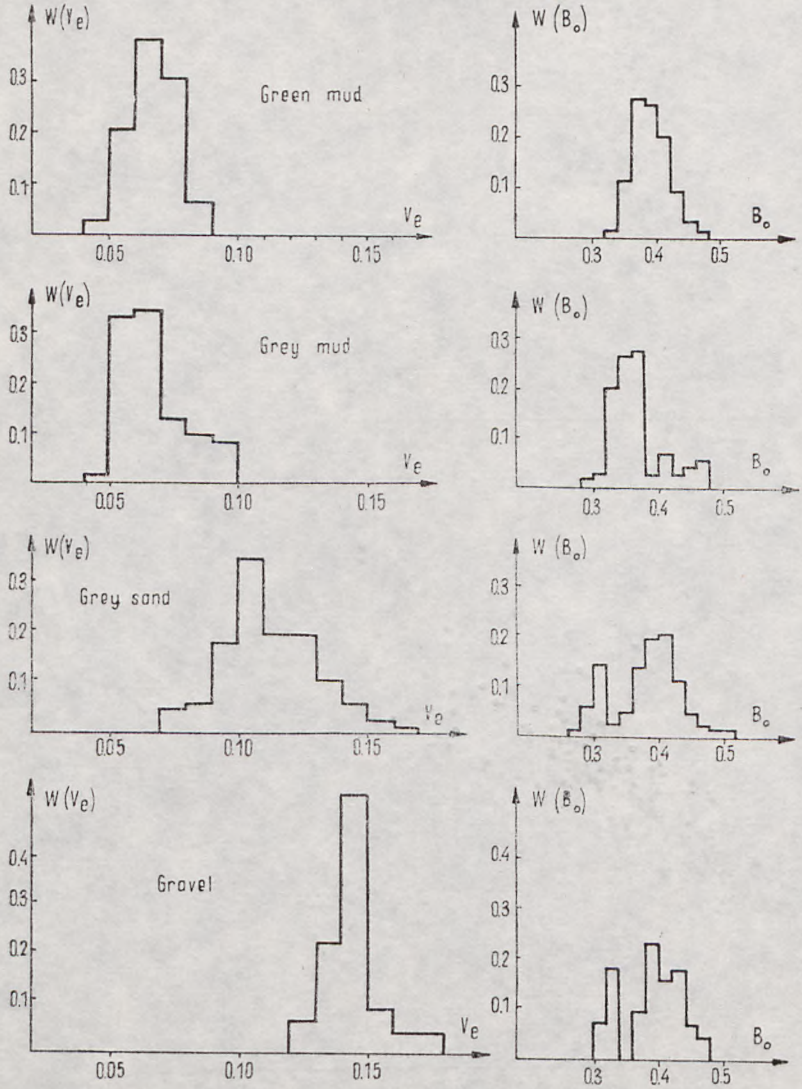

Fig. 5. Distributions of probability density of the measured sound reflection coefficient and the B_o parameter for four different types of bottom sediments

values (obtained for all oceanographic stations and sounding profiles) on the depth for constant parameters of the system is shown in Figure 3. Congestions of experimental points in the several regions of depth result from the fact that in the case of sounding profiles the depth changes are small. The obtained distribution of B_o values is characterized by two basic features:

a) for smaller depths the B_o value increases and depends on the depth whereas for larger depths the B_o value is approximately constant,

b) scatter of the values of B_o parameter around the mean (for local depth intervals)

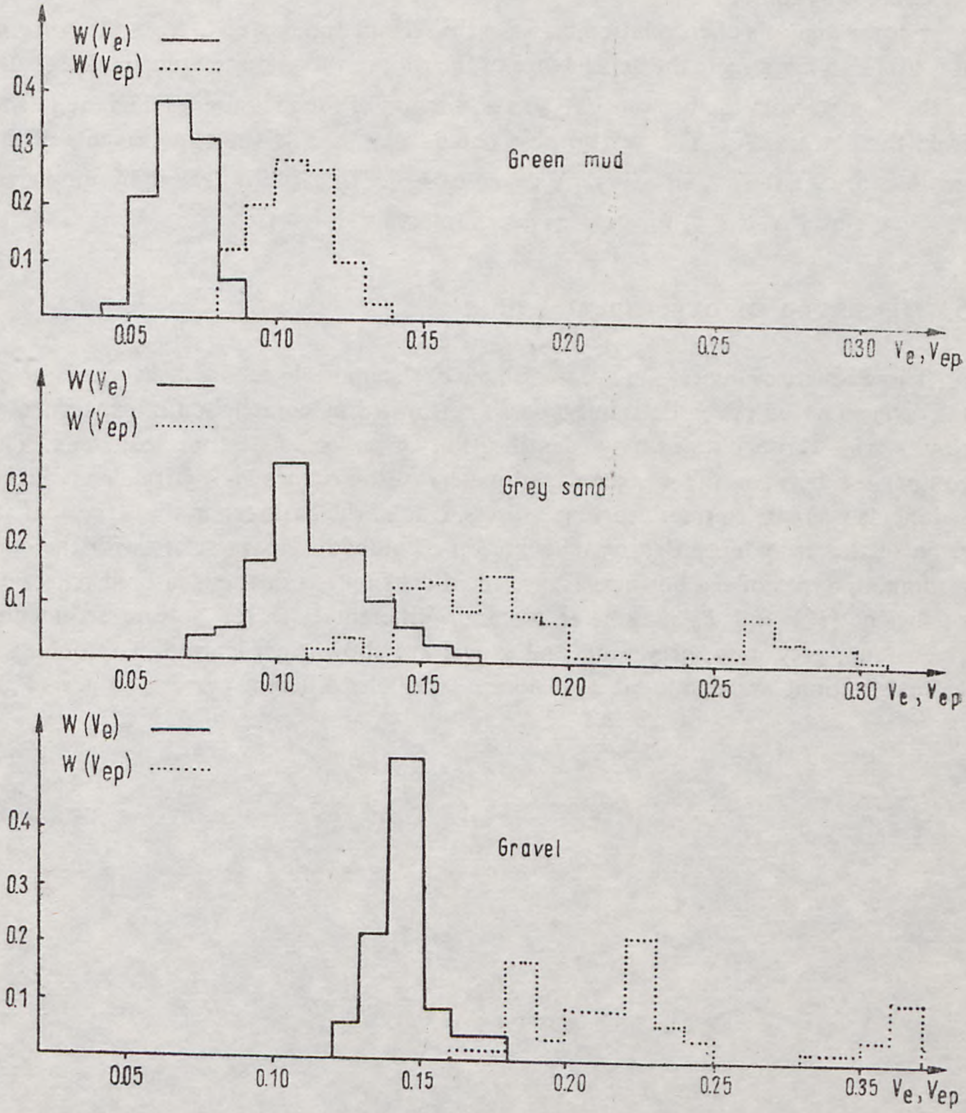

Fig. 6. Distributions of probability density of the measured coefficient of sound reflection from the bottom, determined on the basis of double reflection V_e and single reflection V_{ep} for three different types of sediments

can be assumed as regular. Hence, the anomalies in energy spread of I and II echoes with respect to the assumed model, must occur for smaller depths.

The analysis of experimental data for smaller depths of sea is presented more extensively in [9]. The measurements in this depth range are being continued and further conclusions will be published in the future.

For larger depths ($D>50$ m) it can be safely assumed that the conditions, permitting the interpretation of the reflection coefficient obtained by the measurements of multiple echoes as a quantity characterizing mechanical properties of bottom material, are fulfilled.

For the analysis of correlation between the second and first echo from the bottom, it is useful to investigate the dependence of the root of the average equivalent pressure of the II echo from the bottom $\sqrt{N_{2B}}$ as a function of the pressure level of the I echo from the bottom N_{1B}. This relationship should be linear (if the requirements of the method are met) so that $\sqrt{N_{2B}}/N_{1B}=\text{const}=B_o$. This is illustrated by empirical relationships $\sqrt{N_{2B}}(N_{1B})$ for various depth intervals (Fig. 4).

5. Discussion of experimental data

The ultimate evaluation of the usefulness of the multiple echoes measurements for the determination of sea bottom type was performed by comparison of experimental results with those obtained by identification of collected bottom sediments. The comparison between the measured parameters of the echoes and particular types of sediments was carried out in various aspects. One of the basic criteria was the comparison of the probability density distribution of individual parameters with the corresponding types of sea bottom. The selected distribution of the measured reflection coefficient (V_e) and B_o parameter for four different types of bottom sediments: green mud, grey mud, grey sand and gravel are shown in Figure 5. The obtained V_e distributions are unimodal, and normal with the different average values $\langle V_e \rangle$.

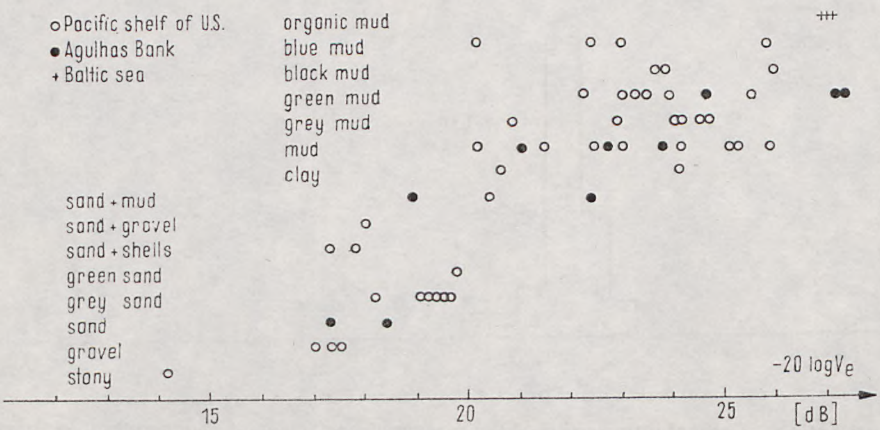

Fig. 7. Results of measurements of the bottom reflecting properties for different types of bottom sediments, obtained by the author on the basis of double reflection measurements

The B_o parameter distributions, although more complex than those of V_e, have similar average values thus enabling to treat $\langle V_e \rangle$ values as comparable. In this case the average $\langle V_e \rangle$ can be treated as a determinant of the sediment type. The quality of correlation between the sediment type and V_e value (obtained on the basis of double echoes measurements) as well as V_{ep} value (based on a single reflection from the bottom only) can be easily evaluated by comparing V_e and V_{ep} distributions for three selected sediment types. Such distributions, representing the measurements performed at various oceanographic stations are presented in Figure 6.

In the case of double echoes measurements, the distributions $W(V_e)$ are unimodal and normal, whereas for single echo measurements the distributions $W(V_{ep})$ are strongly dismembered suggesting a superposition of local distributions with different average values. It leads to the conclusion that the factors influencing the effective value of the reflection coefficient play more substantial role in the case of single reflection than when using the ratio of energy of two successive echoes. It can be generally stated that for the measurements of reflection coefficient by the multiple reflections method the scatter of results obtained at a given station was small. The relative standard deviation of V_e for all oceanographic stations was equal to 8.08%.

The results of V_e measurements for identified bottom types are shown in Figure 7. On the basis of characteristic pattern of V_e values for a given bottom sediment type one can identify the latter through its accoustic properties. It should be pointed out that the differences in V_e values are large for the same type of sediment. They can be explained both by large variations of porosity of a given type of sediment *e.g.* (being a function of depth) and the effect of local differences in shape and homogeneity of bottom. Hence, in some extreme cases, the acoustic chart of bottom sediments, may differ from the ones based on classical methods of sample collection.

6. Conclusions

The developed method was tested and applied on r/v "Profesor Siedlecki" during several expeditions accomplished in the period 1973 - 80. The method permitted preparation of orientational charts of the bottom of investigated shelfs without tedious and time-consuming collection of samples. The examples of direct application of the method are illustrated in Figures 8 and 9. Figure 8 shows the bottom chart in the region of the Agulhas Bank based on the measurements of multiple echoes. Figure 9 presents the distributions of the sound reflection coefficient V_e values obtained in various shelf regions of the world ocean. The differences in the pattern of these distributions reflecting geological and oceanographic conditions affecting sedimentation processes in particular regions should be pointed out. The diagram includes the measurements carried out at oceanographic stations positioned in a regular network.

On the basis of theoretical considerations presented in the paper as well as direct results of application of the developed method, the following conclusions can be drawn:

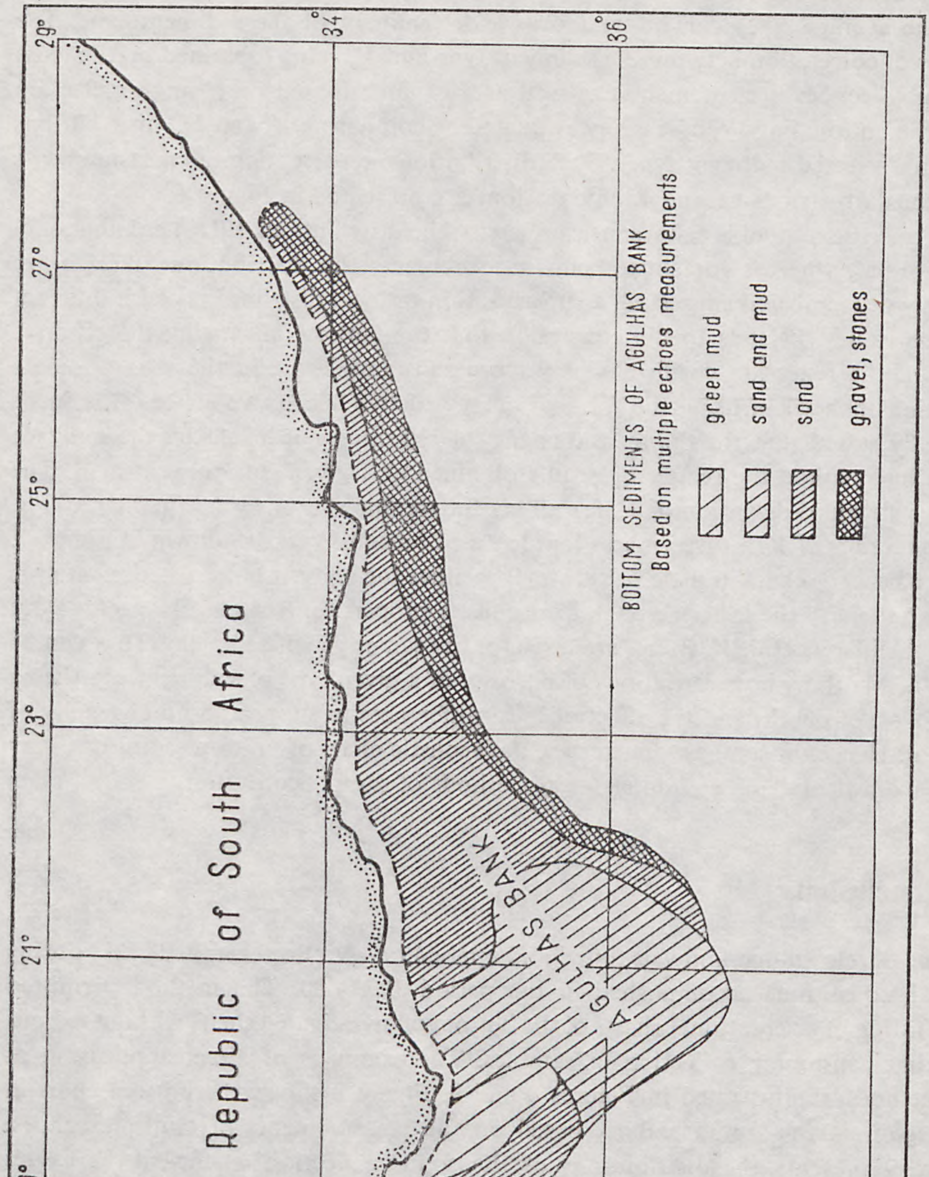

Fig. 8. Approximate chart of sea bottom of the Agulhas Bank, elaborated on the basis of multiple echoes measurements

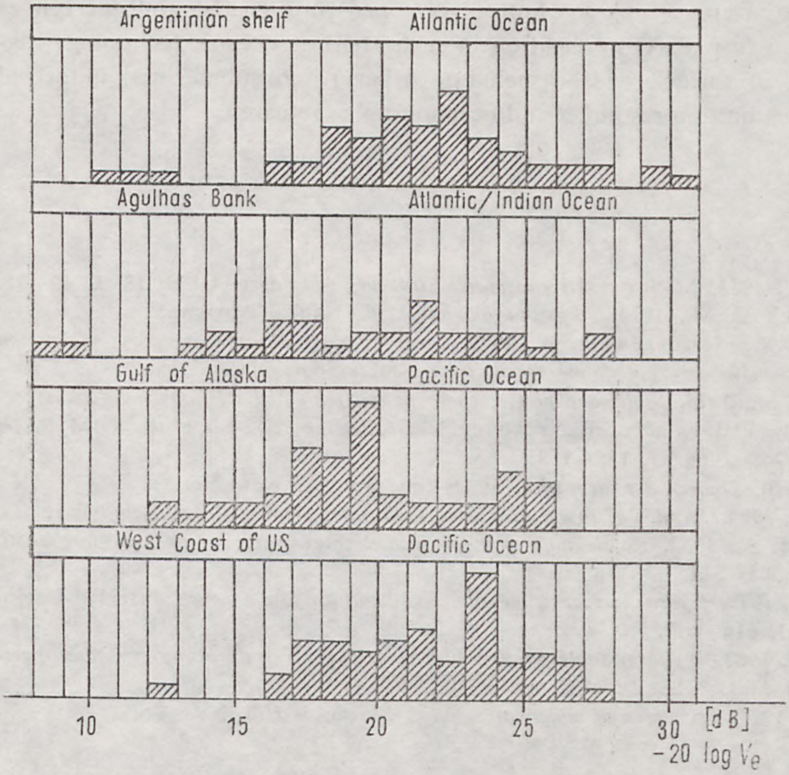

Fig. 9. Distributions of sound reflection coefficient values V_e obtained on the basis of multiple echoes measurements on oceanographic stations in various geographic regions

– reflective properties of bottom, determined by the method of multiple echoes measurements are strongly correlated with mechanical characteristics of bottom sediments,

– the correlation is better than in the case of single echo measurements only,

– the effect of scattering properties of bottom and local morphological characteristics increases for smaller depths,

– the magnitude of this effect is estimated by B_0 parameter, which supplements the characteristics of sound reflection from the bottom,

– the measurements of the reflective properties of bottom by means of the developed method do not require calibration of hydroacoustic devices in terms of knowledge of voltage response of the receiver and the level of power emitted by the transmitter,

– application of the method for sounding profiles enables to investigate the dynamic changes of reflecting properties and direct determination of zones of occurrence of sediments and transition borders.

The possibility of considerable lowering of costs of bottom investigations through selection of sampling sites on the basis of the developed method should be pointed out.

The information concerning sea bottom obtained through the multiple echoes measurements can find direct application in such areas as oceanic technology, navigational needs of surface vessels (including fishery) and submarines, industrial exploitation of sea bottom resources and oceanographic research.

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