# APPLICATION OF THE SEAFLOOR FLAKY STRUCTURE FOR NAVIGATION OF UNDERSEA VEHICLES

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***Abstract-*** **This paper suggests a new method of navigation of an underwater vehicle using acoustic data. The known methods of making seafloor acoustic maps are not effective for navigation in areas of smooth relief. The suggested method allows make maps using acoustic sectional view of the seafloor layers. The different areas of seafloor have acoustic layers of various size and geometric form - using this property allows make maps for navigation of an underwater vehicle in areas of smooth relief.**

**When comparing structure of bottom layers in given point with its geographical coordinates, the location of undersea vehicle could be identified by way of processing of reflected from seabed layers the acoustic signal. Approximate structural scheme for implementation of the presented method of navigation is provided in the paper.**

**The results of experimental observations obtained by applying device that was assembled according to proposed structural scheme for several plots of bottom in Zolotoy Rog Bay (Golden Horn Bay) as well, considered in the report.**

***Keywords-*** **acoustic features, coefficient of reflection, frontier, ocean crust, penetration, pseudo-map, reflectivity, structure of bottom layers, time spans, undersea vehicles.**

## I. INTRODUCTION

The employment of undersea vehicles to fulfil underwater operations, to research ocean crust demands processing of their placement identification methods and to use marine bottom properties. The methods applied for acoustic seafloor mapping are of low efficiency in the bottom areas with smooth relief. In such cases, evidently, some other physical properties data are necessary to verify connection between the features of a certain bottom spot with geographic coordinates. There is maybe a chance to compile not the map of bottom, but a sort of pseudo-map that of the set of data comparable with the same area of ocean bottom.

In the researched phenomenon of the acoustic waves penetration in some depth of ground (depending on frequency), and then on returning back they carry information on structure and parameters of layers that have distinctive features as well as the structure of bottom layers. This exploitable property can be used to compare parameters of bottom layers with geographic coordinates of this bottom area having been under investigation and parameters measurement.

The thickness of layers and coefficient of reflection from the water-ground frontier and from boundaries of bottom layers in underlying crust are offered to be used as such type of information.

## II. THEORY

After generating of square modulated acoustic pulse signal, the first reflected pulse will bring information on distance to bottom and the coefficient of reflection of water-bottom interface, the subsequent pulses carrying information on thickness of layers and the coefficients of layer-layer reflection – Fig.1.

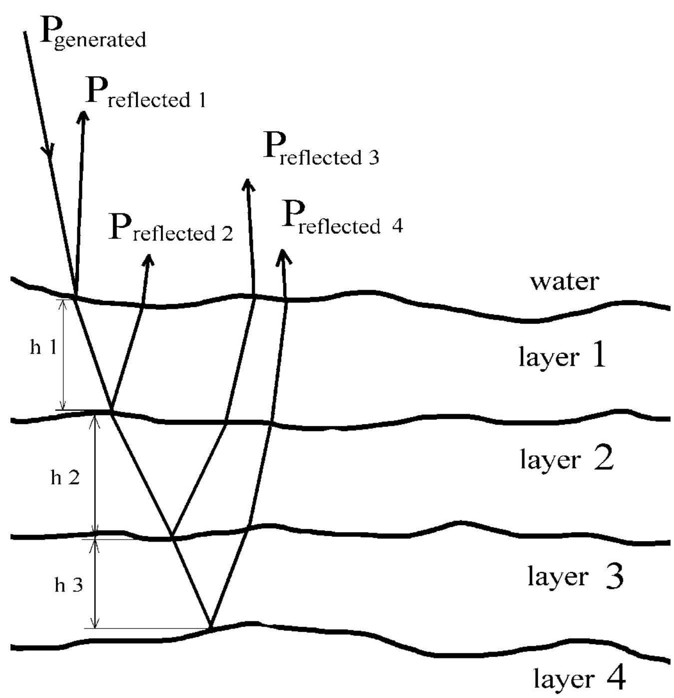


Fig. 1. Reflecting from bottom layers.

There are important the time spans between successively arrived pulses reflected from layers boundaries. Due to the constancy of thickness and sound velocity in the layers the magnitude of these spans will be that informational data, connecting bottom property and geographical coordinates – Fig. 2.

Spans between two neighboring layers reflections equal $t_n = 2 \cdot ( h_n / c_n )$, where $h_n$ – thickness of n layer, $c_n$ – velocity of sound in n layer. Also, the coefficients of layers reflection bring information about features of bottom spot under investigation. In presented case of waves drop perpendicularly to reflecting boundary the coefficient of reflection doesn't depend on that angle of drop but being dependent only on acoustic features of bottom layers.

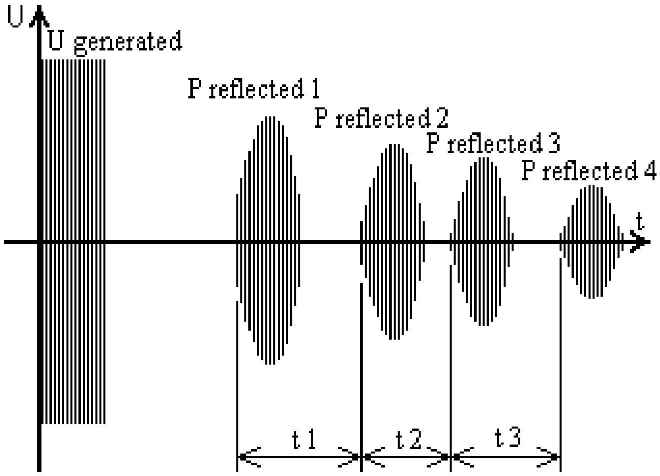


Fig. 2. Distribution of reflected signals in time.

Reflectivity of layers is being calculated by means of amplitude measurement of generated and received signals separately for every layer under question.

Map of reflectivity as well assumes to reduce or totally drive at zero this dependence of external map appearance on spherical divergence of waves in the medium if the reflectivity is calculated basing on the next model [1].

Helmholtz equation

$$\Delta\varphi + K_m^2(\mathbf{r})\varphi = \delta(\mathbf{r}_m - \mathbf{r}_0). \qquad (2.1)$$

with boundary conditions

$$\rho_m \varphi_m \big|_{S_m} = \rho_{m+1} \varphi_{m+1} \big|_{S_{m+1}},$$

$$\frac{\partial \varphi_m}{\partial n}\bigg|_{S_m} = \frac{\partial \varphi_{m+1}}{\partial n}\bigg|_{S_{m+1}}, \qquad (2.1a)$$

where $\varphi$ - potential of acoustic waves in the upper layer;
$f_m$ - angular frequency;
$m$ - number of the layers;
$\rho$ - density;
$C_m(r)$ - phase velocity (it depends upon the point coordinates);
$K_m = \dfrac{\omega_m}{C_m(r)}$;
$\delta(r_m - r_0)$ - Dirac delta function;
$m$ and $m+1$ - numbers of upper and lower layers respectively;
$r_{m.}(\theta,\varphi)$ – depicts frontier of arbitrary configuration.

Stringent solution of equation (2.1) is found in geodesic coordinate system with variables $d\xi = K(xyr)\, dx$, $d\varepsilon = K(xyr)\, dy$, $d\eta = K(xyr)\, dz$. In accordance with [1], there is introduced the spherical system of coordinates $Rm.$, $\varphi\eta$, $\theta\xi$.

The solution of (2.1) under boundary conditions (2.1a) may be written in the form of

$$P(R_m) = P_0 \left[ \frac{e^{iK_m R_m}}{R_m} + K_{refl.} \frac{e^{-iK_m R_m}}{R_m} \right] \mathrm{F}(\gamma_{m\xi}), \qquad (2.2)$$

where $P(R_m)$, $P_0$ - pressures of reflected and incident waves on transmitter and receiver correspondingly;
$F(\gamma_{m\xi})$ – antenna directivity diagram;

$$R_m = \sqrt{r_{0\xi}^2 + r_{mS\xi}^2 - 2 r_0 r_{mS\xi} \cos\gamma_{m\xi}}, \qquad (2.3)$$

where
$\cos\gamma_m = \cos\theta_{0\xi} \cos\theta_{m\xi} + \sin\theta_{0\xi} \sin\theta_{m\xi} \cos(\varphi_{m\xi} - \varphi_{0\xi});$

$r_{0\xi}, \theta_{0\xi}, \varphi_{0\xi}$ are geodesic coordinates of transmitting and receiving antennas onboard the underwater vehicle to be evaluated by the algorithm;
$r_{mS\xi}, \theta_{m\xi}, \varphi_{m\xi}$ are the coordinates of the reflection point.

From the solution (2.2) it is possible to obtain stringent equation of reflection coefficient using measured $P(R_m), P_0$ and distance $r_{mS\xi}$ which is the result of received data processing:

$$K_{m\,refl.} = \left[ \frac{P(R_m)}{P_0 F(\gamma_{m\xi})} - \frac{e^{iK_m R_m}}{R_m} \right] \cdot$$
$$\cdot \frac{R_m}{e^{-iK_m R_m}} = \qquad (2.4)$$
$$= \frac{R_m}{e^{-iK_m R_m}} \cdot \frac{P(R_m)}{P_0 F(\gamma_{m\xi})} - e^{2iK_m R_m},$$

where $P(R_m)$ and $P_0$ - magnitudes of the pressure on receiver and transmitter, correspondingly.

At $R_m = const$ $K_{mrefl}$ depends on angular coordinates only.

Magnitudes of reflectivity of seafloor layers are reckoned up accordingly (2.4) for each area. Application of such algorithm of calculation admits to eliminate the dependence of reflectivity map on the receiving antenna height above ground.

Summarily, it can be noted, that at the registration of reflections from N layers in some area of bottom, these data of area could be comparable with N+(N-1) values (N reflectivity $K_{mrefl}$ and N-1 temporal spans $t_m$) inherent only in it. Measurement of these parameters for each bottom spot in the region will result in navigation pseudo-map.

To emplace underwater vehicle on the map require to install the same type of devices that were applied when compiling the map, although measured data should be compared to information in memory obtained earlier to determine which geographic coordinates they respond to.

Resolution capacity of suggested method depends on the used wavelength. Working frequency is chosen accordingly condition of optimal penetration of acoustic waves into the marine bottom layers till 250-300 m depth [2]. Optimal frequency adopted for work is equal to 1-15 kHz [3]. So it should be chosen on the one hand in such way that a signal could penetrate into the number of ground layers, which information assumes rigorously to compare these bottom strata with geographic coordinates, on the other hand the increase of frequency will reduce penetration of a signal into the ground, but it decreases plotted crust area and magnifies capability to resolution of smaller structures, thus every region requires to estimate its own optimal frequency.

Method of device-using navigation can be that of based on echosounder application, working on definite frequency and supplying needed duration of transmitted pulses. Only processing of receiving unit data additionally is required to assume the amplitude and temporal spans fixation of reflected pulses from layers number for accurate determination of coordinates.

The following scheme-structure (Fig. 3) is offered for fulfillment of such arrangement.

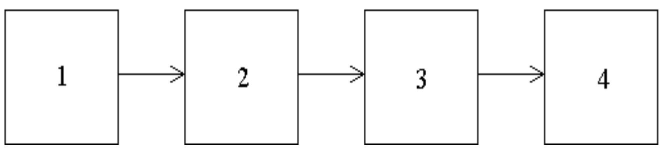


Fig. 3. Proposed scheme of device structure.
1 – echosounder; 2 - amplifier; 3 - analog-to-digital converter; 5 - computer.

Echosounder operates as usual, but the transmitted and received by echosounder signals run into the appliance being used for coupling of signal parameters to the forms that are required for normal functioning of analog-to-digital converter, which will cipher the transmitted and received signals from echosounder. Then the ciphered signals as samples are preserved in the computer memory, where their amplitude and temporal spans between them are identified. Basing on these data the reflectivity of bottom crust under investigation is counted accordingly algorithm.

While initial mapping, the region for which this map is being compiled needs to be explored measuring reflectivity, temporal spans and connecting it to geographical coordinates of bottom crust.

## III. EXPERIMENTS

In compliance with the offered structural scheme there was compiled the experimental device-setting up and software service program developed. The device-setting up consisted of: 1. Echosounder «Humminbird» of which operating frequency, beam width, pulse duration and repeating frequency were 200 kHz, 24°, 0.1 ms, and 4 times per second respectively; 2. Amplifier to strengthen signal from the receiver output till the level needed for normal function of analog-to-digital converter; 3. 8-Bit analog-to-digital converter; 4. Computer of “Pentium” type. Output of receiver in the echosounder is put in analog-to-digital converter through amplifier.

After beaming and reception of acoustic pulse by echosounder the program is processing sequence of 638 samples of signal reflected from seabed on analog-to-digital converter with assigned temporal span (within 0.04 ms – 2.2 ms). Then the program is recording it into file and making image on the screen as a horizontal line from left to right. Color of a point in line matches up voltage values in the output of echosounder receiver. Lines of reflected signals go up and down at the screen. Due to acoustic signal reflection taking place on the media frontiers with different acoustic parameters, the consequent change of colors on the screen would be commensurate to the boundaries of layers separation. When at the screen the appreciable number of lines will be drawn vertically, these vertical lines might be contemplated as the ones adequate to the frontier of water and ground layer separation or boundaries of ground layer-to-layer separation.

This device setting up provided measurements onboard the ship having been operated in the Zolotoy Rog Bay (Golden Horn Bay). Beamer of echosounder was placed at the depth of 0.5 m.

The experimentally obtained pictures of bottom layers structure for 4 points in the examined region (A, B, C, D) are provided in the presented paper. Due to representation of resulted dimensions as digital parameters being visually unclear the data are given as images. It is fixed time in the certain point along vertical axis and along horizontal axis the time since moment of arrival of pulse reflected from the water-ground frontier of separation. Such image assumes the observation of pulse to be reflected from boundaries of ground layers separation. Color of the points corresponds to voltage on output of receiver appliance. All measurements were fulfilled under the time interval of 0.055 ms when sampling.

In Fig. 4 the picture resulted from the point A at coordinates of N 43° 06,521'; E 131° 53,174' is displayed (reading of GPS-receiver). Fig. 5 demonstrates picture that obtained in B point being located in 10 meters far from A point. Fig. 6 demonstrates picture that obtained in C point being distant in 10 meters far from B point. Fig. 7 demonstrates picture that obtained in D point being located in 10 meters far from C point.

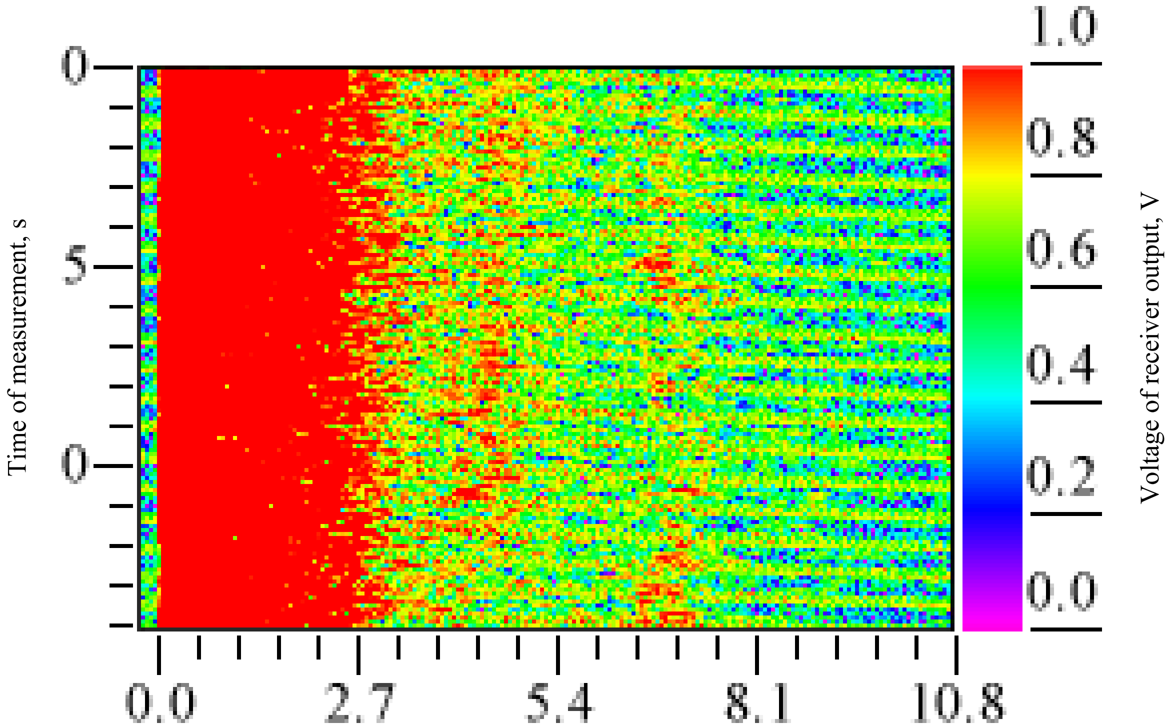


Fig. 4. Layers structure in A bottom point.

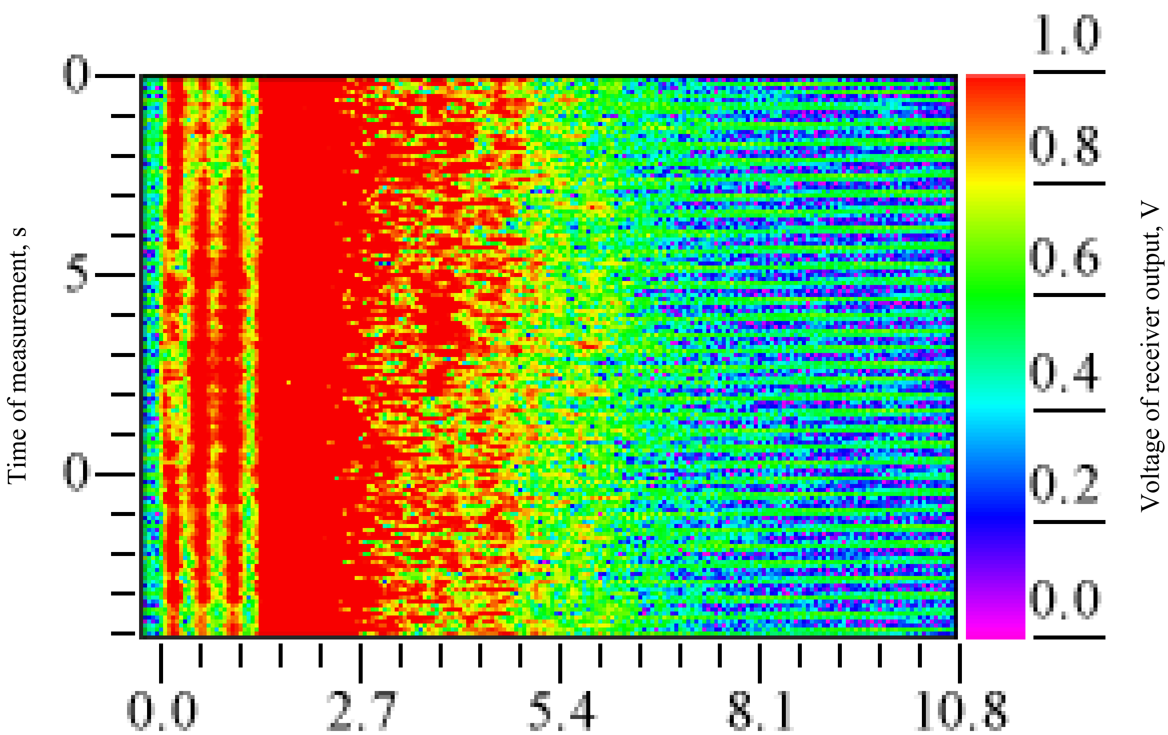


Fig. 5. Layers structure in B bottom point.

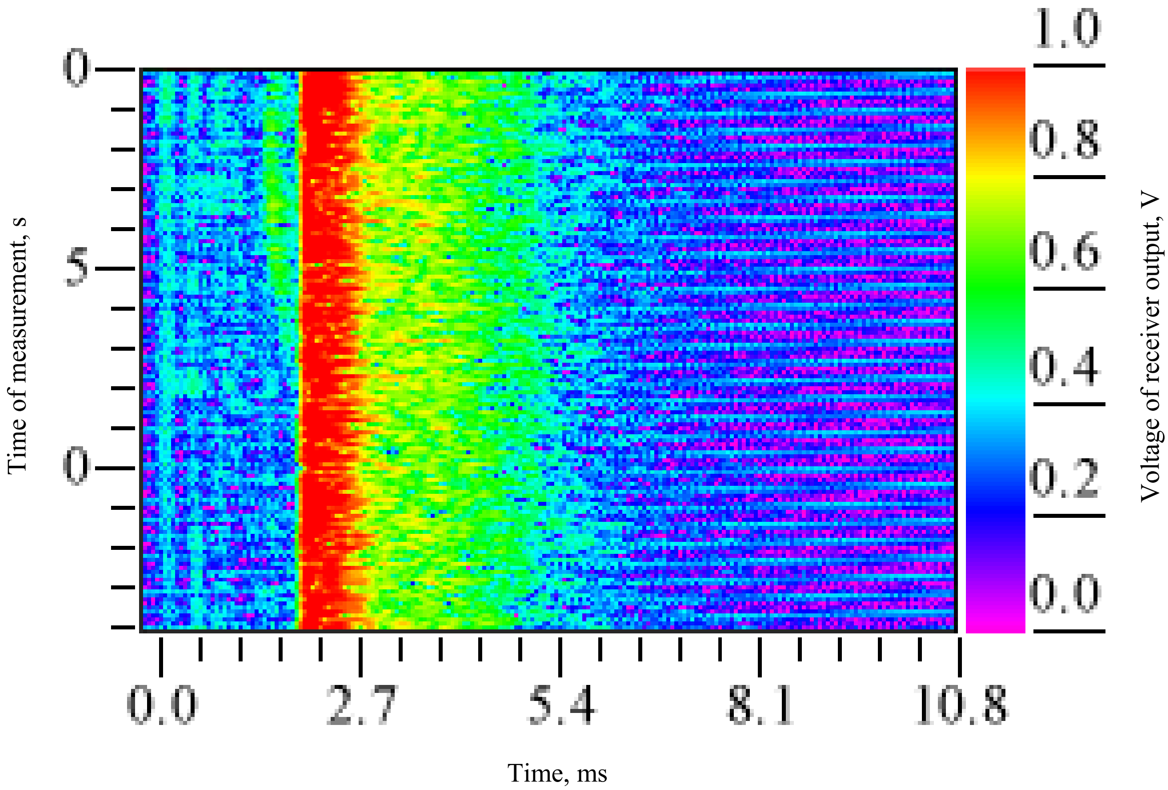


Fig. 6. Layers structure in C bottom point.

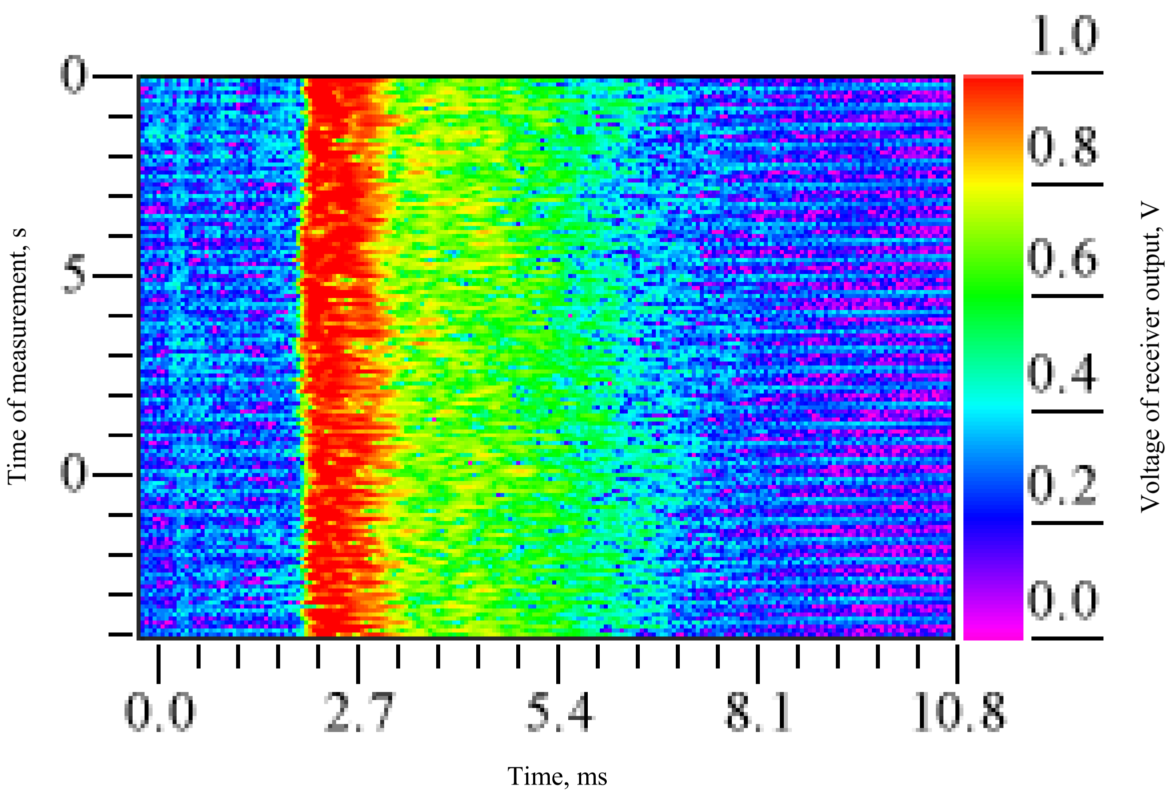


Fig. 7. Layers structure in D bottom point.

## IV. CONCLUSION

It is evident that every point of marine bottom responds to inherent picture of layers and every picture being referred to coordinates assume to compile navigational digital map of the bottom. Such map could be applied for navigation of operating submarines.

Use of underwater vehicles with inertial navigation systems for navigation usually cannot provide with acquired precision. The offered method of navigation could be used for correction of coordinates of undersea vehicles that operate on inertial navigation systems.

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