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The algorithm for predicting reservoir properties of rocks based on the mutual phase spectrum of reflected seismic waves

Nowadays, a number of methods for predicting the geological section have been created. There are soft-ware systems for processing and interpretation of seismic data, which widely use dynamic parameters of waves bound with the amplitude and the energy of reflections. The phase characteristics of reflections are used to a lesser extent [2].

Thus, there is an increased relevance for searching new ways to analyze seismic records in order to ex-tend the number of informative parameters. Among such parameters there is the mutual phase spectrum (MPS) of reflected waves.

The law of signal phase spectrum change contains information allowing the most reliable detection of signals against intense noise and assessment of their kinematic parameters. The MPS of reflections carries information about acoustic properties, heterogeneity of absorption and dispersion of geological environments [1].

The purpose of this work is the description of algorithm for predicting properties of geological section basing on the MPS of reflected waves. To achieve this goal the following objectives should be accomplished:

1. In order to isolate the information properties of MPS of reflected seismic waves a model of layered absorbing media should be considered.

The algorithm for predicting geological section properties basing on the MPS of reflected waves should be described.

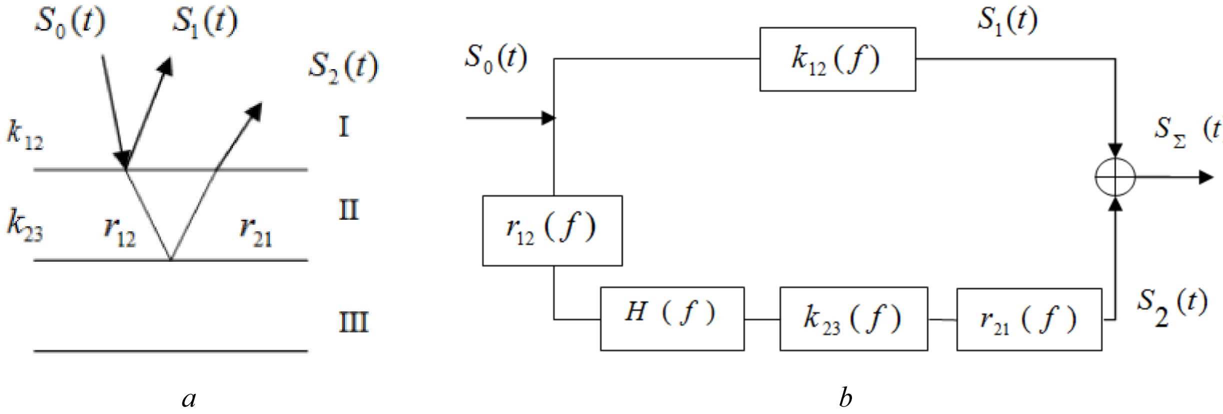

Fig. 1. The model of plane-parallel layered absorbing formation

Where $S_0(t)$ – the initial seismic signal; $S_1(t)$, $S_2(t)$ – signals reflected from top and bottom of the observed formation II; $k_{12}(f)$ and $k_{23}(f)$ – the reflection coefficients from top and bottom of layer II; $r_{12}(f)$ and $r_{21}(f)$ – the refraction coefficients on the top of layer II; H(f) – frequency characteristic of the absorbing layer.

Let's consider the model of layered absorbing formations. The construction of such a model with horizontal interfacial boundaries represents the whole thing in the form of a linear system, which introduces some changes in the oscillation [3]. The example of a simple model of a plane-parallel layered absorbing formation (fig. 1, *a*) shows the essence of the approach (fig. 1, *b*).

The spectra of the waves reflected from the top and bottom of the layer II:

$$S_1(f) = k_{12}(f) \cdot S_0(f) = |S_1(f)| \cdot e^{j \cdot \varphi_1(f)} \tag{1}$$

where $\varphi_1(f) = \varphi_{k_{12}}(f) + \varphi_0(f)$ defines the phase spectrum of the reflected wave $S_1(f)$, which depends on the argument of the reflection coefficient $\varphi_k(f)$, and the initial phase of the incident wave $\varphi_0(f)$.

$$S_2(f) = r_{12}(f) \cdot H(f) \cdot k_{23}(f) \cdot r_{21}(f) \cdot S_0(f) = \left|S_2(f)\right| \cdot e^{j \cdot \varphi_2(f)} \tag{2}$$

where $\varphi_2(f) = \varphi_{r_{12}}(f) + \varphi_{H_s}(f) + \varphi_{k_{23}}(f) + \varphi_{r_{21}}(f) + \varphi_0(f)$ defines the phase spectrum of the reflected wave $S_1(f)$, which depends on the arguments of the coefficients refraction $\varphi_r(f)$ and reflection $\varphi_k(f)$, as well as the phase-frequency characteristics of the system $\varphi_H(f)$, and the initial phase of the incident wave $\varphi_0(f)$.

An important factor used for the prediction of reservoir rock properties is the absorption. In absorbent environments there is velocity dispersion. Absorbing and dispersive properties of layered media can be measured by the MPS of a wave. Assuming that the processes $S_1(f)$ and $S_2(f)$ are deterministic, then the mutual spectral density is:

$$Q_{12}(f) = S_1^*(f) \cdot S_2(f) = \left|Q_{12}(f)\right| \cdot e^{j \cdot \varphi_{12}(f)} \tag{3}$$

where $S_1(f)$ and $S_2(f)$ complex spectra of the reflected waves $S_1(t)$ and $S_2(t)$, $|Q_{12}(f)|$ – mutual energy spectrum, $\varphi_{12}(f) = \varphi_2(f) - \varphi_1(f)$ – is the mutual phase spectrum.

Substituting the values of (1) and (2), it is possible to obtain:

$$Q_{12}(f) = \left|S_0(f)\right|^2 \cdot k_{12}^*(f) \cdot k_{23}(f) \cdot H(f) \cdot r_{12}(f) \cdot r_{21}(f) \tag{4}$$

$$\varphi_{12}(f) = \varphi_{k_{23}}(f) - \varphi_{k_{12}}(f) + \varphi_{r_{12}}(f) + \varphi_{H_s}(f) + \varphi_{r_{21}}(f) \tag{5}$$

From the expressions (4) and (5) it is possible to deduce that the absorbing and dispersive properties of the environment II appear in the MPS of a wave. It should also be noted that distortion doesn't affect the evaluation of absorption and dispersion of the observed formation, calculated

through the MPS of waves. Therefore, the spectral characteristics of the mutual reflection of the observed formation provide more reliable and stable estimates.

To assess the information content of MPS the following parameters can be introduced [2]:

1. Mean value of MPS:

$$\overline{\varphi_{12}(f)} = \frac{1}{n} \sum_{i=1}^{n} \varphi_{12}(f_i)$$

2. The central point of the 2nd order for the MPS:

$$\sigma_\varphi^2 = \frac{1}{n-1} \sum_{i=1}^{n} \left(\varphi_{12}(f_i) - \overline{\varphi_{12}(f)}\right)^2$$

3. The average value of the phase delay:

$$\overline{\tau_\varphi} = \frac{1}{n} \sum_{i=1}^{n} \tau_\varphi(f_i)$$

where $\tau_\varphi(f_i) = \dfrac{\varphi_{12}(f_i)}{2\pi f_i}$ – mutual phase delay at the i-th frequency.

4. The central point of the 2nd order for mutual phase delay:

$$\sigma_\tau^2 = \frac{1}{n-1} \sum_{i=1}^{n} \left(\tau_\varphi(f_i) - \overline{\tau_\varphi}(f)\right)^2$$

Thus, the parameters (1–4) may be used as informative while studying reservoir rock properties using the MPS of reflected waves.

Currently, the proposed algorithm is implemented on a computer and the research of its effectiveness is carried out on the model of layered absorbing environments.

References

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