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Experience in Low-Frequency Spectral Analysis of Passive Seismic Data in Volga-Ural Oil-Bearing Province

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Abstract

In this paper, we consider our experience with passive low-frequency seismic exploration for oil and gas. We present the data on the phenomenology of the effect, sets out possible geophysical mechanisms of effect, present results of numerical simulations in comparison with the observed results; we describe the main approaches to the interpretation of seismic data studies and give a brief overview of geological results of our microseisms research in the Volga-Ural oil province.

Introduction

Geological exploration in areas of old oilfields such as field Romashkino in the territory of the Republic of Tatarstan has a number of features (Mouslimov et al., 2007). Targets of geological exploration are predominantly the exploration of small fields and exploration of producing fields in the boundary zones. These objects are characterized by complex geological structure, structural traps have a small amplitude, small size, have numerous complications such as lithological replacement and tectonic faults.

Under these conditions, the effectiveness of structural seismic studies was decreases. Combination of structural seismic method and methods of local prognosis of oil-bearing is necessary to improve the efficiency of drilling. However, traditional non-seismic methods - high-precision gravimetric, electrical, geochemical studies have sufficiently large radius of the study and also not effective for small search objects.

The method of passive seismic ANCHAR (Aroutyunov et al., 2001) was tested in 2002 in the Republic of Tatarstan as a method of local prognosis of oil-bearing for solve this problem. According to this method in the spectrum of microseisms over natural gas and oil deposits should be observed pronounced spectral maxima in the range of 1-10 Hz. Work was carried out in two areas and have produced mixed results. On the one hand, the predictions of oil-bearing by this method have the conflict with the existing ideas about the geological structure and the drilling has not been undertaken for this predictions. On the other hand - microseismic noise over oil deposits and outside them had obvious differences. Mixed results and the need for an effective method of local prediction led to a large complex of experimental and theoretical studies of the structure microseismic field as a possible indicator of oil saturation. In this report we present the results of science research and practical application of passive microseismic research to address the various geological problems of Petroleum Geology.

1. Phenomenology

1.1. Characteristics of the effect and the conditions of his observation

As is well known, the Earth's microseismic background at the observation point is a superposition of vibrations caused by as natural causes - the waves earthquakes, local microearthquakes, surface noise, the influence of solid tides, ionospheric phenomena, weather phenomena - rain, hail, strong winds, so and anthropogenic sources - moving vehicles, work machines, the movement of livestock. To solve the practical problems of geological exploration we should be confident in the stability characteristics of the microseismic field and analyze potential interference. It is also necessary to assess the duration and conditions of observations required to obtain statistically stable estimates of parameters of microseismic signal. We used highly sensitive broadband seismic sensors with a bandwidth of 0.1 - 0.5 Hz to 40 – 60 Hz to record microseismic noise. Fig. 1 shows a typical form of microseismic signal duration of 1500 seconds, with detailed plots of duration 100 and 5 seconds, vertical axis show the vertical velocity fluctuations of the Earth's surface in location of registration.

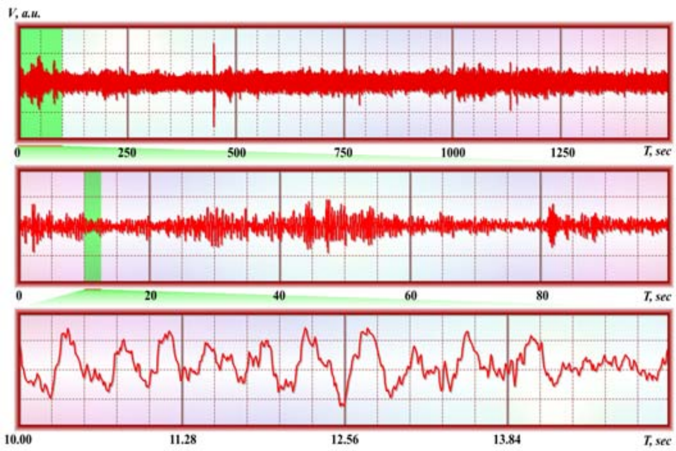

Fig. 1. Microseismic signal in time domain

From Fig. 1 implies that the microseismic signal consists of individual wave packets of varying amplitude and phase. In the Fig. 1 also shows that the amplitude of the signal changes with time quite significantly. Given the nonstationarity of the recorded signal for the construction of spectra appropriate to apply the method of splitting the signal into frames of equal duration and averaging of the spectral curves for these frames.

The minimum frame size should be chosen from the condition of sufficient spectral resolution, allowing observing the anomaly. Maximum frequency signal, which can be observed, is equal to half the sampling frequency. When sampling frequency is a 100 Hz, which is characteristic of the used equipment, there is a spectral range of 0-50 Hz. To observe the anomaly, it is necessary that its width had to at least 4 of point in the scale of frequency. Since the width of the anomalies of the order of 0.5-1 Hz, the frame size should be about 500 samples. Given the desirability of using the fast Fourier transform to improve the performance of spectral constructions, frame size is chosen from the set of numbers 2^n. In the future we will operate on frame size 512 samples, which correspond to 5.12 seconds.

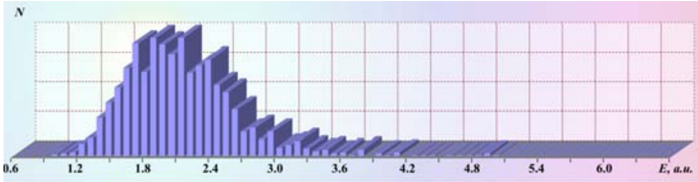

Fig. 2. Energy distribution by frame duration of 5.12 seconds

For the adequacy of averaging procedures is necessary to estimate the distribution of the total energy of frames. From Fig. 2 shows that the energy distribution of frames quiet microseismic signal single-mode, but has a pronounced tail in hight energy part of diagramm. This, in particular, demonstrates the non-Gaussian nature of the microseismic process and requires a careful approach to the homogenization of the spectral curves. In particular, it found that the the signal's level significantly affects to spectrum of microseismic signal. Fig. 3 shows typical averaged spectra of training microseismic signal duration of 5 seconds, depending on the range of the signal power in the frame. It is noticeable that with increasing energy frames maximum spectral density shifted toward higher frequencies.

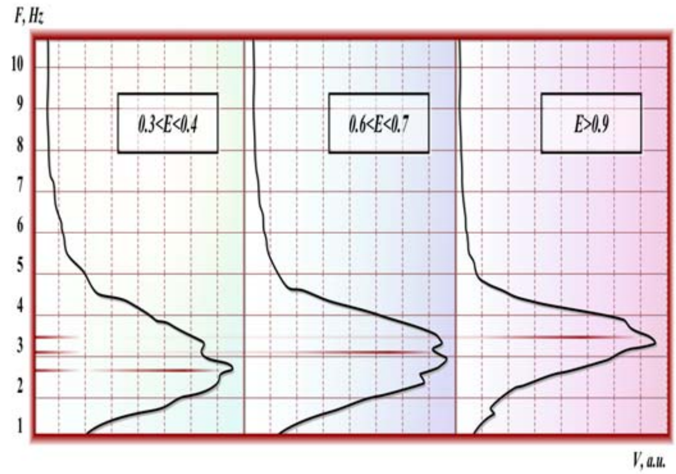

Fig. 3. Typical dependence of the averaged microseism spectra of their energy

However, the signal spectrum within the energy range of personnel differs by no more than twice and is in the field of fashion energy distribution shows a good statistical stability. Fig. 4 shows the average spectrum of microseism frames from energy range 0.3-0.4 with superimposed confidence intervals 3σ. In spectrum averaging are participated about 500 frames. Confidence interval on the spectral curves is important to assess the statistical justification for the existence of the maxima of spectral density as compared with background values. Showned in Fig. 4 confidence intervals allows making explicit judgments about the presence of the maximum.

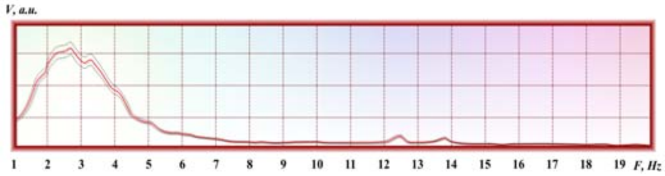

Fig. 4. Power spectrum of the microseism signal with marked confidence intervals

Experimental research shows that for the spectrum with a pronounced maximum is need no more 30-50 frames for detect of maximum. Thus, for the signal in a stable environment and a pronounced maximum is sufficient for 3-5 minutes observation to unambiguously determine the presence and position of the spectral peak in the spectrum of microseism at the observation point.

However, in some cases may require considerably more time observing. In particular this applies to observation points with less pronounce of the maximum over the background value. The anthropogenic noise also leads to increasing observation time.

1.2. Differentiation of natural and anthropogenic microseisms.

During observations of natural microseisms in populated areas is a problem of visibility on the background of anthropogenic sources of various types. The main power of the spectral composition of the signal of anthropogenic noise in the frequency range over 5 Hz, which overlaps with the target range 1-10 Hz. Revealed two major types of interference from closely spaced anthropogenic sources: impulsed broadband noise and narrowband interference from mechanisms.

Impulse noise characterized by a broad spectral composition of the order of 30 Hz and their duration from fractions of seconds or more. Movement of vehicles is a series of impulse noise observed an average during minute, depending on the type of car its speed, distance to it. In Fig. 5 in the spectrogram shown some impulse noise caused by the movement of road transport. According to our data at a distance of more than 2 km from the highway impact of vehicles on the spectrum of natural microseisms practically does not occur, whereas at a distance less than 200m pulse noise from a moving vehicle completely dominate over natural microseisms. In Fig. 5 broadband noise is marked by dashed ellipses. Narrowband noise has a narrow bandwidth 0.01-0.2 Hz. Mechanisms which generated this noise is the electrical machines, drilling machines, pumps and other. The radius of their influence depends on their power of and can reach 3-5 km. In Fig. 5 narrowband noise marked by dashed rectangles.

Comparative analysis of time-frequency characteristics of both types of noises with the characteristics of natural microseism allows differentiating them visually on the spectrogram and using specialized filtering methods for computer processing. The simple process of elimination of impulse noise from the signal is a rejection of the power frames from total signal. This is justified, since the power pulse noise is always higher than natural levels of background microseism. Excluding from the spectral processing of frames with energy exceeding the threshold of the natural background, we therefore exclude the impulse noise from nearest shock sources with spectrum like white-noise.

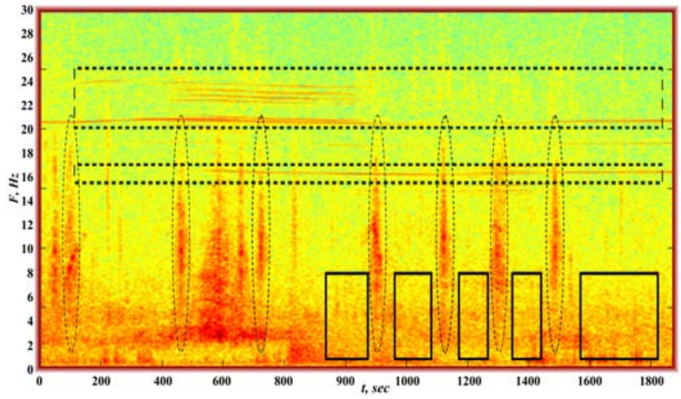

Fig. 5. Spectrogram of microseism signal from anthropogenic noise.

On the Fig. 7 presented spectrums obtained in the zone of intense impulsed noise. Fig. 6 shows the energy distribution of the signals frames. The distribution is statistically multimode. The first mode corresponds to the natural background, the second and third mode - two different impulse sources. Restriction of frame energy not-over the energy of first mode eliminates the distortion of the spectrum of impulse noise. From Fig. 7 follows that all the peaks above 3 Hz make of impulse noise sources. After removal of impulse noise in the range of 7 - 11 Hz appeared anthropogenic narrow-band interference, which can also be removed by the following methods of narrow-band filtering.

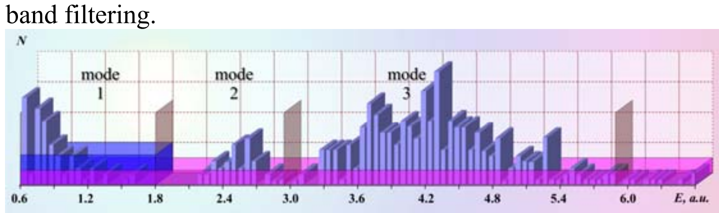

Fig. 6. The energy distribution of frames signal complicated impulse noise

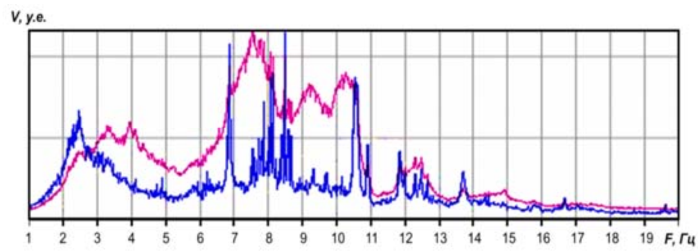

Fig. 7. The resulting spectrum of the microseism signal is complicated by impulse noise (red), after discarding frames with energies above the first mode energy distribution (blue).

For filtering the narrowband noise in signals a good result given the methods of median filtering of the spectrum and other methods of nonlinear filtering (Fig. 9). In the spectrum of anthropogenic narrowband noise observe series of narrowband peaks with width less than

0.1 Hz. Such fine structure is due, probably, by the processes of the beats in oscillatory systems (Fig. 8). Spectrum of natural microseism does not have this feature. Median filter can effectively remove this anthropogenic narrow-band noise, almost without distorting of the spectrum of natural microseism.

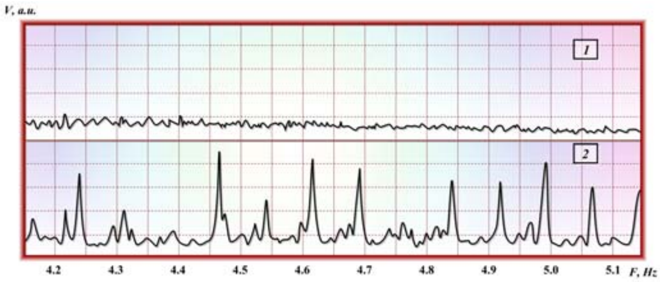

Fig. 8. A Series of anthropogenic narrowband noise (2) in comparison with the spectrum of natural microseism (1).

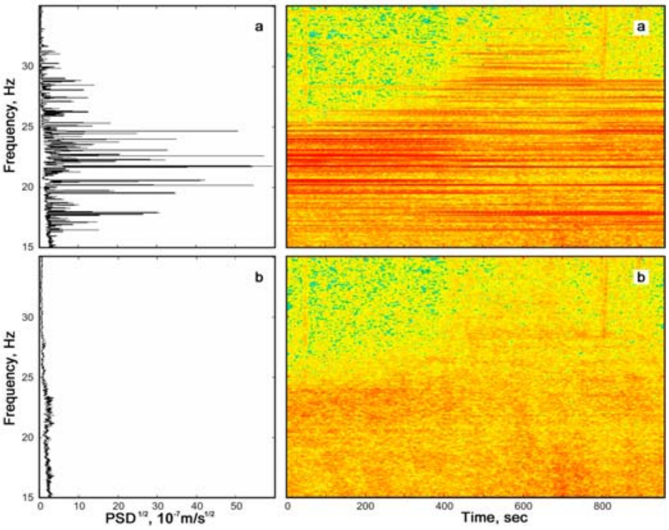

Fig. 9. Comparison of the spectrograms and the signal before and after filtration.

Thus, the impulse and narrowband noise are well differentiated from the natural signal of microseism and can be effectively removed from total signal.

1.3. Stability of the spectral characteristics over time.

The above results apply to short continuous observations period (one hour). For practical application of microseism research in the geological survey should be also identify the behavior of the phenomena observed for longer periods of time. It is obvious that the time variation of the microseismic field can lead to non-comparability of the results obtained at different times even on the same area within one field season.

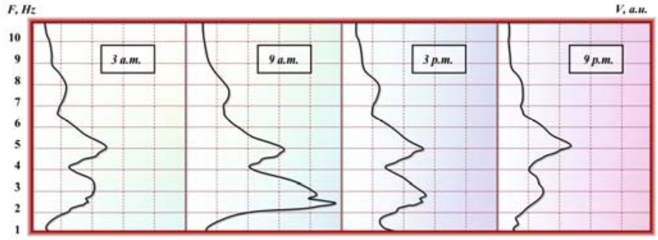

Fig. 10. Microseism spectrum at different times during the day.

From results of continuous daily monitoring follow that anomaly are unstable by amplitude. In Fig. 10 shows the typical variation of the spectrum during the day. Continuous observations show that although the frequencies of the peaks are approximately equal but their amplitude varies strongly within the day.

For the estimation of anomalies over the background in microseism prospecting for hydrocarbons was taken the ratio of "Signal + Noise" / "Noise", where the "Noise" is the amplitude of the natural background noise in the spectrum, and the "Signal + Noise" is amplitude of the spectral anomaly. In Fig. 11 shows the variation of this parameter within the day for the anomaly in the 3 and 5 Hz.

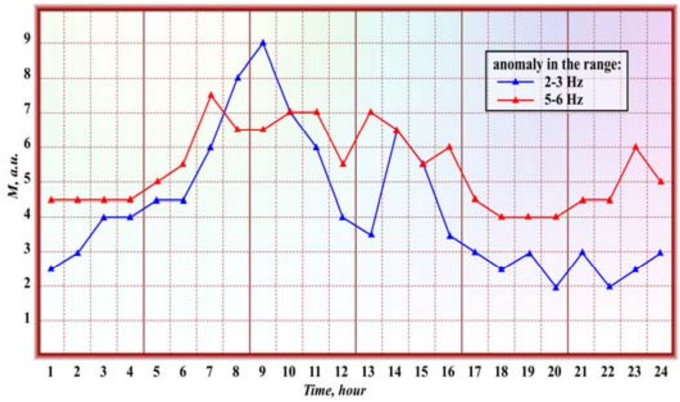

Fig. 11. Typical variation of the "Signal + Noise" / "Noise" parameter during the day.

The available experimental material does not allow for reliable statistical analysis of the dependence of the parameters of microseism spectra from season to season. Unfortunately, available from various observations relate mainly to the different areas. Considering the observations in general, be noted that a significant changes characteristics of the spectral peaks depending on the season is not marked. Thus, we must conclude that the effect is manifested at all temperatures and states of the earth's surface (snow, wet, dry).

However, comparison of individual observations, conducted in one point in different seasons, show the possibility of changing the characteristics of the observed spectrum of microseism. In Fig. 12 shows the microseism spectra in one and the same point of the study before and after the snowmelt (March - May). It is noticeable that after the snowmelt in the spectrum of microseism have additional frequency components in the range of 10 Hz and above, as well as reduces the contrast of the observed anomalies in the range of 2-4 Hz.

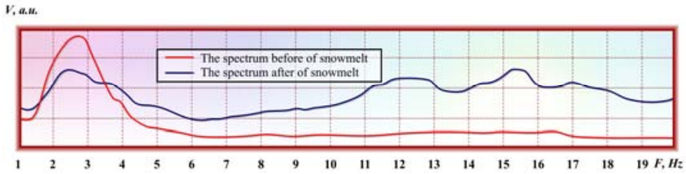

Fig. 12. The microseism spectrum at the observation point before and after the snowmelt

Experimental studies show that with adequate reflection of the power spectrum of variations in time and spectral characteristics of microseisms are sufficiently stable parameter.

2. Physical base of interpretation of microseisms

2.1. Physical model of the phenomenon

Currently, the physical nature of changes in the spectrum of microseisms over the oil and gas deposits has no universally accepted explanation. There are two main hypotheses to explain the nature of the phenomenon.

According to the first group of hypotheses (Aroutyunov et al., 2001), (Holzner et al., 2007) the anomalous component is due to the spectrum of the microseisms source. According to the authors, oil and gas reservoir is in the state of the deterministic or turbulent chaos, which generates microseisms with the observed spectral anomalies. Microseisms siganals in the Earth's surface over the oil and gas deposits takes the form of a random signal with a spectral maximum in the range of fundamental frequencies of the deposit.

The second group of hypotheses (Birialtsev et al., 2005), (Birialtsev et al., 2006) explains the spectral anomalies as filtration microseismic field by geoenvironment. Sedimentary cover has mainly horizontally-layered structure in which propagating microseisms experiencing many of reflection and refraction. It is known that the comparability of the lengths of propagating seismic waves and the thickness of layers (thin layer) give selective changes in different parts of the spectrum of this waves. For the frequency range 2.5 Hz, in which is a significant part of the observed spectral anomalies, the wavelength is about 1 kilometer, which is comparable with the depth of the productive horizons. Thus, the whole body of sedimentary rocks from light surface to deposit is thin layer from the standpoint of classical continuum mechanics, and inevitably has an impact on the spectrum of microseisms.

Comparing the hypothesis should be noted that they both have a right to exist. In real geological environment they may well be present as the effects caused by one or another reason. Spectrum of full microseismic wave field is determined by several components. In addition to the above, these include the scattering of Rayleigh waves by subsurface heterogeneities (Gorbatikov et al., 2004), as well as the effect of the microseisms increased activity in the area of oil and gas deposits (Shapiro et al,. 1997). Despite the fact that the first effect is most pronounced at low frequencies (below 1 Hz) and the second - on the contrary in the high frequency range under consideration (seismic frequency 30-60 Hz and more), their influence may extend to the analyzed interval.

It should also be noted that out of all these possible causes of changes in the spectra of microseisms, microseisms filtering by geoenvironment more than any other has quantifiable calculation. This effect is based on well-known laws of mechanics of viscoelastic continuum and allows not only qualitative but also quantitative research. The most difficult issue in the calculation of filtration of microseisms spectra by geoenvironment is to define the mechanics characteristics of the oil and gas deposits in the low frequency range. Calculations conducted on the basis of the rheological law of oil and gas deposits for seismic frequencies (over 10 Hz), show an insufficiency of contrast of deposits as a reflecting boundary for the full justification effects.

A number of experimental (Goloshubin et al., 2006) and theoretical (Silin et al., 2004), (Quintal et al., 2009) studies show that in the low-frequency rheology of oil and gas deposits is different from it rheology in the frequency range of standard seismic. Reducing acoustic hardness of oil and gas deposits in the low frequencies (3-5 Hz) up to 30-50% compared with the acoustic hardness of the same layers in the seismic range.

Thus, the hypothesis of filtering microseisms by geoenvironment has some physical justification and has developed mathematical apparatus of wave propagation in layered viscoelastic media. However, given that the spectrum of microseisms in the areas of oil and gas deposits is influenced by several reasons, the question remains about the visibility of this effect on the general background. Below we present some arguments in support of the visibility of this effect and its possible use for the solution of geological problems.

2.2. Phenomenology of hypothesis of filtering microseisms by geological environment

Numerous studies of the spectra of microseisms in the Republic of Tatarstan have identified some typical structure of the spectrum. In Fig. 13 shows the microseisms spectra, characteristic of the geological section without oil saturation (left), oil saturation in the Devonian (middle) and oil saturation in the Carboniferous (right). It may be noted that a pronounced peak maximum at 2.5 Hz is characteristic for all types of spectrum, including the absence of oil saturation. From the standpoint of hypothesis generation microseisms by oil reservoir this effect is inexplicable. From the standpoint of the hypothesis filtering microseisms geoenvironment this maximum may be caused by a relatively shallow contrasting geological boundary. This boundary exist, since the boundary of the crystalline basement - sedimentary cover located on the territory of the Republic of Tatarstan at a depth of about 1700-2000 m .

If this maximum is actually caused by this boundary, it must show the displacement along the spectrum depending on the depth of the crystalline basement and with increasing depth of the frequency must fall on a hyperbolic law.

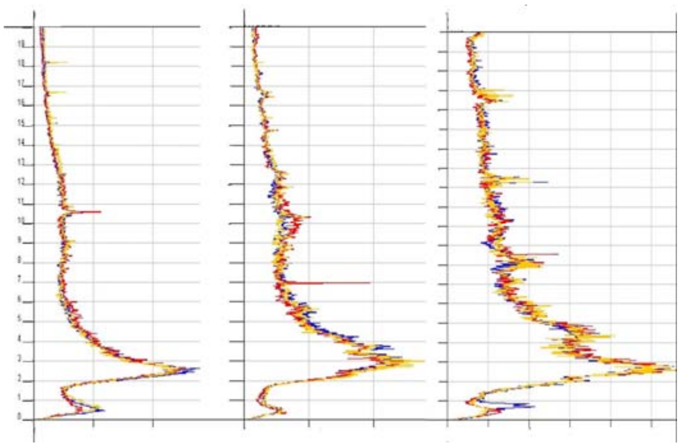

Fig. 13 A typical microseisms spectra of the Republic of Tatarstan (frecuency in Hz by vertical axis)

In the first study we used data of microseisms spectra in 259 points to 16 areas of research in the Republic of Tatarstan. Regression analysis of temporal power (the feedback frequency) the first maximum of the spectra of the microseisms and the power of the sedimentary cover has shown that at a given interval of values of the power of the sedimentary cover with its variations in the 291 m dependence can be considered linear with a statistically significant correlation coefficient of 0.79. This is confirms the assumption about the relationship capacity of sedimentary cover at the observation point and the frequency of the first maximum in the spectra of the microseisms (Fig. 14).

In the second group of studies we check the dependence of frequency of the first peak above 2.5 Hz and the altitudes of point of research separately for areas of research. In this case, the depth of the crystalline basement can be considered approximately equal in all locations and thickness of sedimentary cover is determined only by the altitude point of observation.

On the investigated area, located within the Melekess depression was found statistically significant association between the altitudes of observation point and the value of the first maximum on the scale of frequencies with a correlation coefficient of about 0.66 - 0.8. In Fig. 15 we show the character of this dependence.

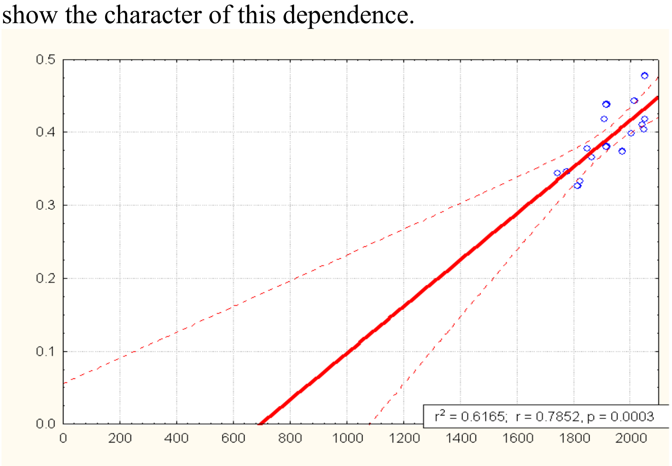

Fig. 14. The dependence of the feedback frequency (sec) of the first maximum of the capacity of sedimentary cover (m).

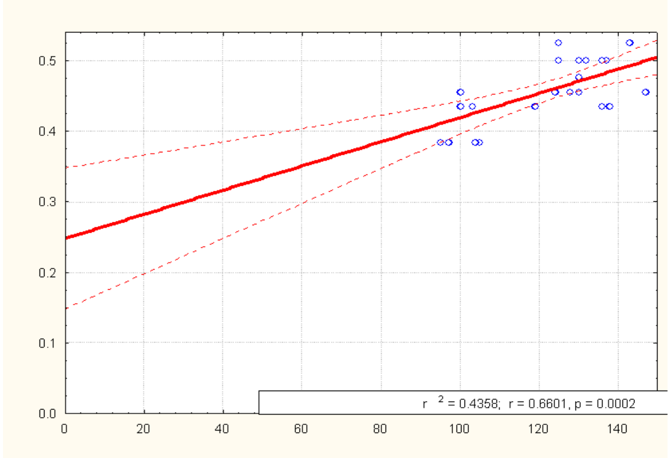

Fig. 15. The dependence between the feedback frequency (sec) of the first peak and the altitude of point of observation (m).

Thus, the first spectral maximum shows a clear dependence on the thickness of sedimentary cover at the observation point, with additional peaks in the presence of hydrocarbons in the section in the Devonian (~ 1600 m), m and Carboniferous (~ 1000 m) located above this maximum.

These studies have shown that the structure of the geological environment has a strong influence on the spectrum of microseisms at the observation point, even in absence of oil saturation.

Another differentiating factor of this two hypothesis is the arrival direction of MS. Thus, if the microseisms generated by deposit, then the wave vector of the microseisms will be directed mainly from deposits. If the deposit is a passive filter element, then the wave vector will be directed from the dominant noise source. In Fig. 15 shows a spectrogram of the signal and the typical distribution of angles of arrival of microseisms in one point of observation near the oil and gas deposit. We may notice that in some cases, the angles of arrival of microseisms are grouped in elongated trajectory. Comparison of these moments with the observations around events, shows that these cases correspond to active displacement of vehicles. In other cases microseisms show no noticeable grouping, although this observation was made near the known oil deposits.

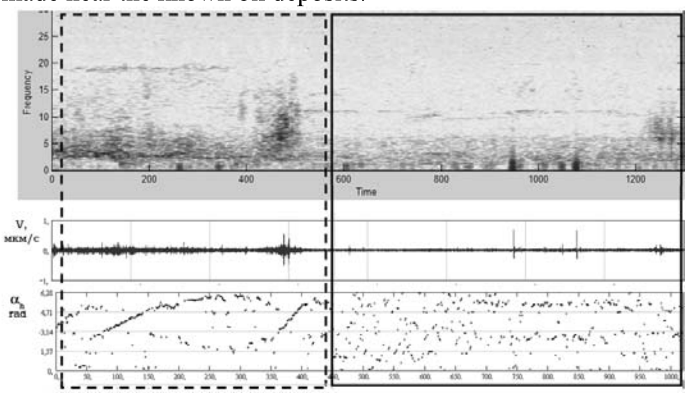

Fig. 16. Noise from close sources and useful background signal. Where V - velocity of the vertical component of MS, α - Azimuth angle of arrival of microseisms waves.

2.3. Numerical simulation.

Mathematical calculations of wave propagation in layered media can definitely confirm or refute the hypothesis of filtering microseisms by geological environment. However, analytical calculations can be made only for very simple cases, such as the spread of seismic waves in an infinite homogeneous medium with the lack of damping. In practice and geological cross-section and the deposit itself are much more complex geometry, for which analytical calculations are impossible. In the absence of adequate analytical models of the only possible method of theoretical study of the behavior of microseisms is the numerical simulation. The authors provide a series of computational experiments for real geological environment. In particular, a numerical simulation of the spread of microseisms in the geological environment, for which there was a large number of experimental data (Fig. 17).

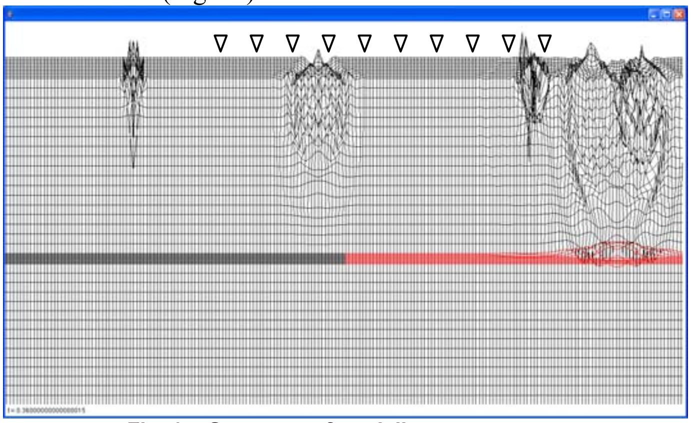

Fig. 17. Geometry of modeling

Simulated field reflects the typical conditions of occurrence of deposits in the Middle Carboniferous to the conditions of the Republic of Tatarstan, and contained a zone of low velocities, sediment cover a capacity of 2 km, the basement rock and reservoir with a depth of 800 meters. Field simulation model had a size of 10 km along the strike and 20 km in depth. Sedimentary cover and its layers of simulated finite element size of about 20x20 meters, the crystalline basement - elements of order 50x20 m. Geological environment simulated by Voigt model with characteristics typical for the Republic of Tatarstan. Model of the sedimentary cover had a density of 2.2 g/cm^3 and speed V_p and V_s of 4500 m/sec and 2200 m/sec, respectively. Attenuation in cover corresponded to the order of the order 500-1000 for frequencies 1-3 Hz (50-100 for the frequencies 20-60 Hz). The model had a basement density of 2.5 g/cm^3 and velocity V_p and V_s 6500 m/sec and 3200 m/sec, respectively, with the same attenuation. Reservoir located in the right half of the model area and had a density of 1.8 g/cm^3 and the velocity V_p and V_s 2400 m/sec and 1200 m/sec, respectively. Attenuation in deposits corresponded to the order of 30-90 Q parameter for the frequencies 1-3 Hz. The solution was the finite element method for the implicit scheme with time step 0.01 sec. Microseism simulated pulses from 0.01 to 0.1 seconds with a force about 10^4 N. At the modeling Earth's surface at several points (in Fig. 17 designated symbols ▽ was recorded values of vertical velocity.

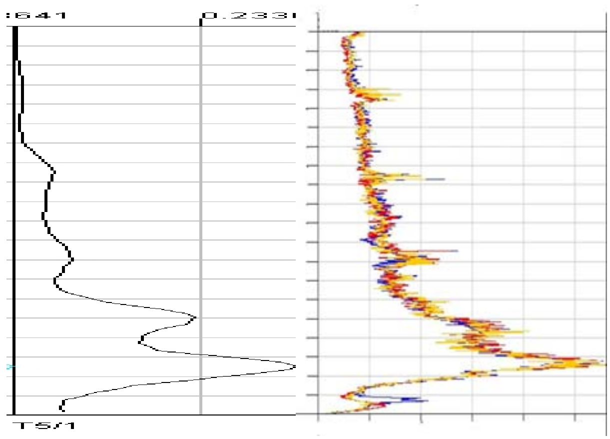

Fig. 18. Comparison of experimental (right) and model spectra.

To assess the adequacy of computer simulation experiments were conducted with variations of the temporal and spatial steps of modeling, as well as geometric and mechanical characteristics of model elements. A comparison of model spectra and experimental data (Birialtsev et al., 2006) in the appropriate geological conditions shows good agreement between experiment and model calculations under the condition of the surface excitation (Fig. 18).

3. Technology of microseisms analisys

3.1. Interpretation of microseisms spectra

Usually, we conducted research in the areas already studied. For these areas it was known seismic velocity model, and several wells were drilled. In the presence of wells with known oil bearing, we used the comparison of microseisms spectra near these wells and the spectra at the points of research. In the presence of the seismic velocity model, we performed modeling of microseisms and obtained synthetic spectra for different horizons of the possible deposits. In most cases, the spectra for the geological section with no deposit and deposits for various provisions differed quite well, but sometimes the behavior of the spectra was unexpected.

In Figure 20 shows one of the most complex cases, which demanded a detailed interpretation of numerical simulation. Initial clustering of the spectra in the study area allowed identifying three types of spectra (Figure 19, right). Pronounced maximum in the spectrum of the type A1 and its concentration on the square in 2 compact clusters predisposes to the identification of this type of spectra with an indicator of oil-bearing in the observed area. However, mathematical modeling showed that, in these geological conditions, this type of spectrum characterizes the salt tectonics, and oil-bearing type of the spectrum corresponds to A2. The type of spectrum B corresponds to the absence of both the oil saturation in the section, and the lack of influence of salt diapirs. As a result of over-interpretation of data taking into account the results of simulation was built predictive map (Fig. 21), corresponding to the drilling data.

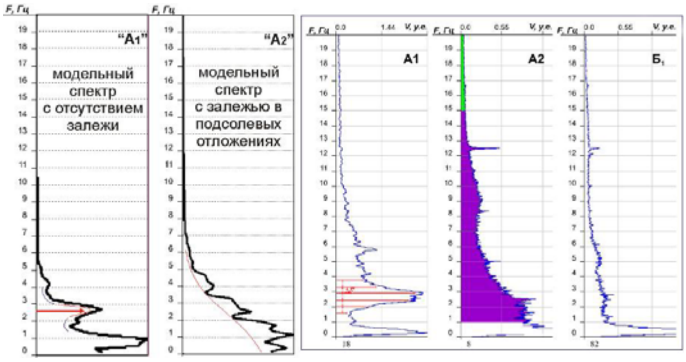

Fig. 19 Observed (right) and model spectra (left) on the area of research (Orenburg region).

Thus, mathematical modeling provides theoretical types of microseisms spectra with their distribution in a specific geological setting. In some cases, mathematical modeling shows that the change of the spectra in the oil and gas deposits are not always accompanied by the presence of additional peaks in the spectrum, but rather sometimes contributes to smoothing the spectrum. It should be noted that in most cases, additional peaks still appear, or at least amplified the severity of existing ones. In addition to identifying the theoretical shape of the spectral curve in the contour and outside the contour of oil-bearing, mathematical modeling shows the nature and extent of edge effects caused by diffraction and interference on the edge of the contour of oil-bearing area. This contributes to a significant improvement in prognosis, especially for small deposits.

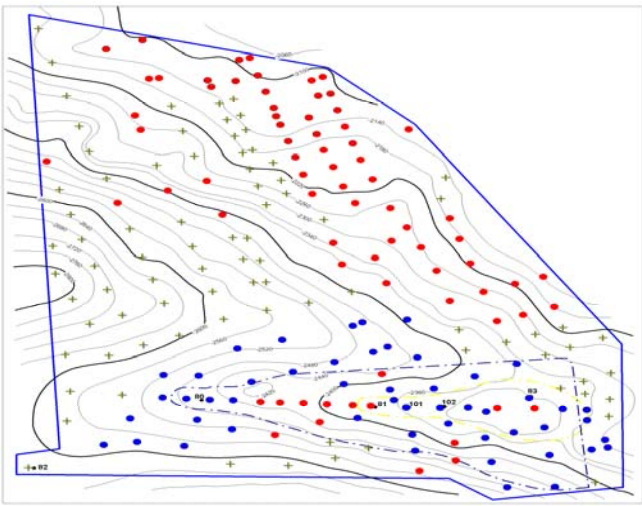

Fig. 20. Distribution of types of spectra in area studies

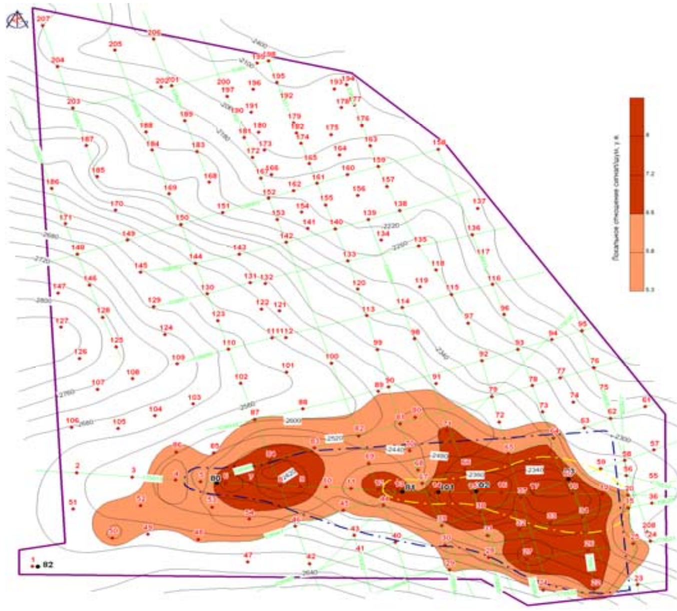

Fig. 21. Interpretation types of spectra in the light of mathematical modeling.

3.2. Analysis of microseisms signals in time domain.

It should be noted that the spectra in the presence of deposits at different levels differ not always. The fact is that in obtaining the power spectrum loses phase signal, and averaging a large number of frames with alignment of their level of power leads to loss of information about the true amplitude of spectral components. Thus, to distinguish between the spectra of deposits at different levels is possible only if the new deposit leads to the appearance of new spectral lines or sharp redistribution of energy between them.

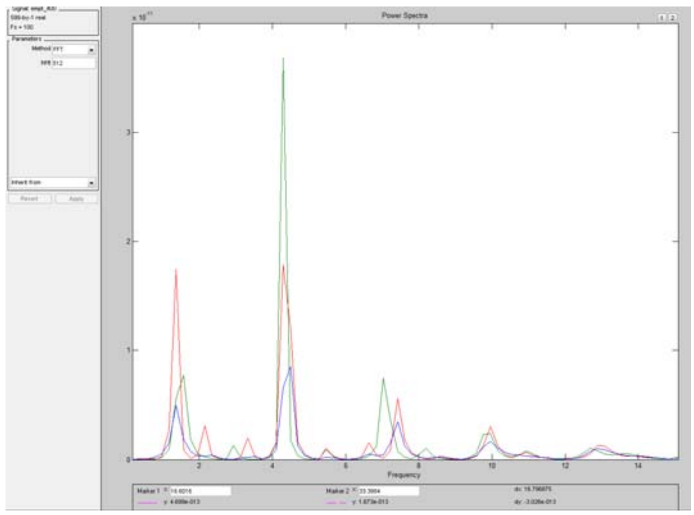

Fig. 22. Model spectra to study site

In Fig. 22 shows the model spectra of real oilfield for the cases of lack of deposits (blue), the deposits in the Lower Carboniferous (red), and deposits in terrigenous Devonian (green). We can be seen that the most greats spectral peaks occur at frequencies of 4-4.5 Hz and 1.3-1.5

Hz, with their relative amplitudes are close enough to each other. In Fig. 23 shows a typical spectrum and spectrogram of microseisms in this area. It may be noted that the highest level of antropogenic noise is observed above 4 Hz, so that for research is most suitable less noisy range 1.4 Hz, where the level of antropogenic noise is relatively low. Given that the study area has a very high level of antropogenic noise from producing fields and from the settlement, to allocate such weak differences spectral peaks against the background noise is very difficult.

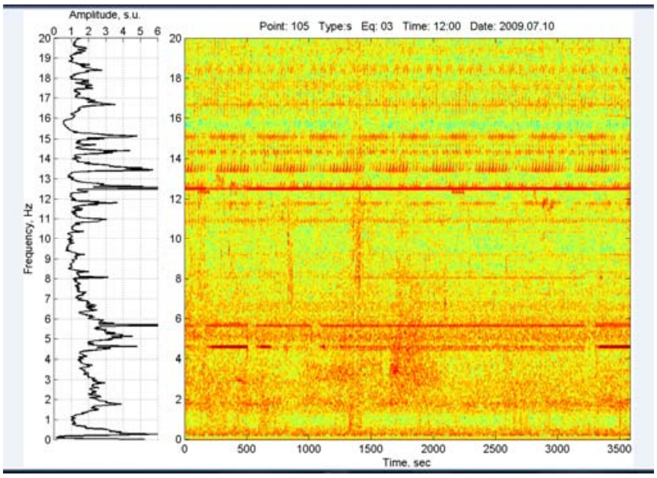

Fig.23. A typical spectrum and spectrogram of microseisms in the study area

Given the availability of detailed information about seismic velocity model in this case to separate the signals we apply the correlation method of allocating the signal to background noise. Correlation analysis is a well known method of detection and recognition of signals on the background noise and, unlike spectral analysis uses all the information about the frequency, phase and amplitude of the signal. Given that the signal is above 4 Hz much noisier for the analysis appropriate to use the frequency band 0-4 Hz. After filtration, the filtered data signals are sufficient differences to conduct the correlation analysis (Fig. 24).

For the correlation analysis was applied the following method. At the first stage the accumulation of useful signal. In the filtered low filter frequency 4 Hz field recordings detected the moment of maximum correlation signal the beginning of the current model of signals in a time warp from 0 to 2 seconds, and filtered according to filter. This area was chosen for the early detection of the signal because it is approximately the same for all types of useful signals. From the beginning of the detected signal were chosen 10% with the highest correlation and frames, length of 6 seconds, starting with the detected time averaged. The level of correlation for the selection of frames for the accumulation was chosen based on their statistical criteria, the number of accumulated frames ranged from 300 to 1300 copies of the signal.

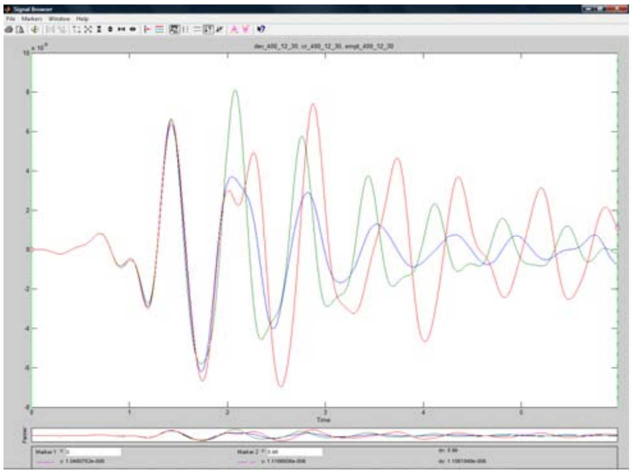

Fig. 24. Model signals after lowpass filtering

At the second stage, the accumulated signal is compared with model signals for various geological. For received frames averaged correlation coefficient was calculated with various model signals. Given the differences in the noise environment for different points of research for comparison were taken normalized to the sum of the correlation coefficients of correlation values for each case. As a result, values obtained were normalized correlation coefficients of the model signal for each of the geological hypotheses with real accumulation signals at each point of research. For each of the correlation coefficients were constructed maps on which a forecast of oil-bearing. In Fig. 25 shows a map of the distribution of the correlation coefficient of accumulated signal from the signal model for deposits in the Carboniferous. It is clear that appear on the map several areas with good correlation. These areas coincide with the known data from drilling information on the contour of oil-bearing in the Carboniferous.

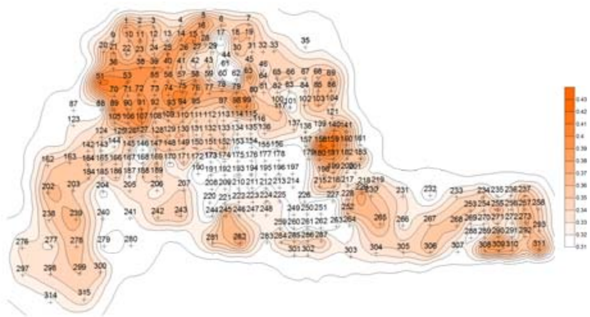

Figure 25. Map of correlation coefficients of the observed and model signals.

4. Short summary of geological results

Methods of interpretation of the spectrum of MS, based on the hypothesis that filtration of microseisms by geological environment, widely used in 2005-2008 on the territory of the Republic of Tatarstan, as well as in the republics of Udmurtia, Komi, Kalmykia, Samara and Orenburg regions of Russia. Studies have been conducted on more than 100 areas with different geological and geophysical conditions. According to the prospects drilled over 80 explorations and productions wells (Table 1).

Table. 1. The effectiveness by years of research.

Year of research	Number of drilled wells	Evidence of forecast	The success of forecast, %
2005	38	37	97,1
2006	14	11	78,5
2007	29	21	72,4
2008	3	3	100,0
Total	**84**	**72**	**85,7**

According to the results of research in these areas can be noted that the characteristics of the amplitude of spectral peaks show statistics depending on the characteristics of the deposit. Since this investigation conducted mainly on small deposits of comparable statistical material is not very much, but the available material on some fields can identify some trends in the parameters of microseisms depending on the parameters of the deposit.

One of the comparisons of the spectral parameters of microseisms and reservoir properties kynovskih sediments of the Upper Devonian conducted on data Uratminskogo deposits (Fig. 26). In terms of structural-tectonic area is located within the northern part of the western slope of the South-Tatar arch. The main production facility is represented by terrigenous deposits of the Upper Devonian productive Kynovsky horizon. The seams - collectors composed of well sorted coarse-grained sandstones and siltstones occur between clay siltstones and argillites. The deposits of oil are strata-arched.

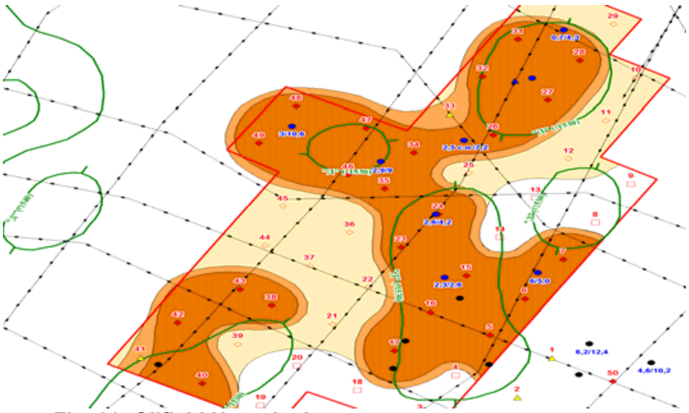

Fig. 26. Oilfield Uratminskoe

The main parameter of the spectrum of MS, according to which we make the forecast of oil-bearing in this area, was the relative amplitude of the second peak in the spectra of microseisms (the ratio of the amplitude of the second peak observed in the spectrum in the range of 1-10 Hz to the average level of the background in the range of 1-10 Hz). They are studied the dependence of this parameter of observation points and filtration-capacitive properties of an opened reservoir in the 10 wells. In Fig. 27 show dependence the parameter signal to noise ratio on oil-saturated thickness and oil saturation.

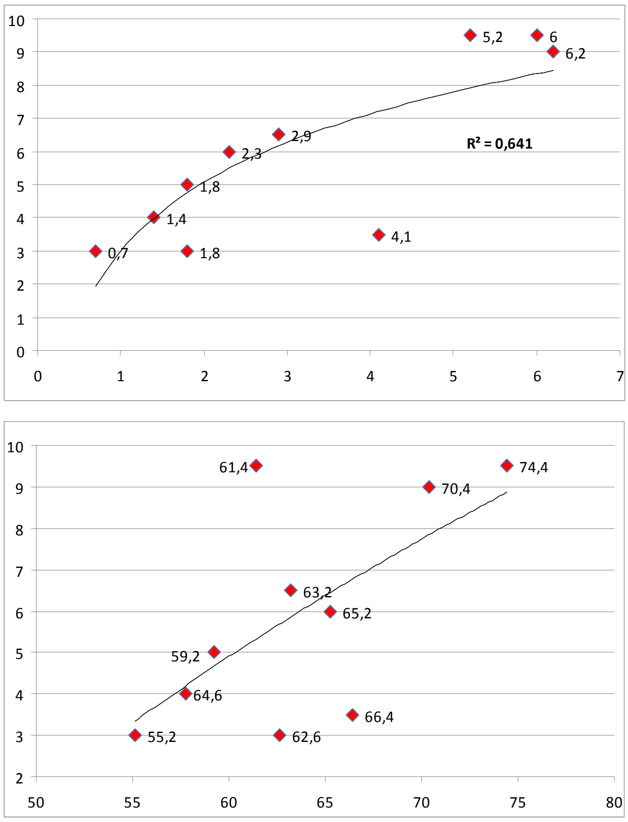

Fig. 27. Dependence of the relative amplitude of the maximum (axis Y) of oil-saturated thickness, m, (up) and oil saturation,% (down).

Graph of the parameter signal to noise ratio and oil-saturated thickness shows that with increasing oil saturation the thickness is increased anomalies. The second graph shows a linear dependence of the amplitude of the signal from the oil saturation. As a result, it is possible to evaluate some parameters of the collector by parameter of signal to noise ratio in specific geological conditions.

Conclusion

Our microseismic field studies of more than 100 areas (more than 7 thousand points of observation) in various geological and surface conditions at different times of year and day can make some conclusions about the prospects and risks of passive low-frequency seismic surveys in the exploration for hydrocarbons.

Deposits of natural hydrocarbons in a significant number of cases are the reason for change the structure of microseismic field. These changes do not depend on the structure of the trap and are caused only by the presence of hydrocarbons in it. Usually, these changes are in emergence of new spectral peaks in the range of 1-10 Hz, or a substantial strengthening of the maxima exists in spectra of microseisms outside of the deposit's contour. In some cases, these changes are less obvious nature and are in the changes of phase of the observed spectral components. However, it should be noted that similar changes may occur in the absence of deposits and produced due to change in the thickness of the upper part of the section, the presence of tectonic faults, karst and other geological boundaries. The field of microseisms has a significant variation of the daily and seasonal cycle, and also depends on the level of antropogenic noise. These factors can significantly distort the results of research and require compulsory registration.

Geophysical mechanisms causing of discussed effect insufficiently studied. We adhere to the hypothesis filtering microseisms by geological environment, but we do not disprove the other hypotheses about the causes of the rising microseismic field. Also, the hypothesis filtering microseisms geological environment has a theoretical disadvantage, because it requires a more acoustic contrast hardness deposits in relation to the overburden, than it follows from the measurements of contrast ratio of deposits in the seismic range. However, as a working hypothesis for the interpretation of seismic research in the exploration for oil and gas, it justifies itself, that follows both from the numerical calculations of microseisms and their comparison with the actual microseisms and from the general success of the oil-bearing projections made on the basis of this hypothesis.

Synthetic microseisms show a high sensitivity to mechanical characteristics of the geological section. For adequate interpretation of the spectra of MS, we must have a detailed characteristics of seismic waves propagation or several wells in the area of research. Without knowledge of these data microseisms analysis can provide objective information only on changing geological conditions in the area of research. These data can be useful when integrated interpretation, but by themselves do not carry information about the oil-bearing of points in the area of research.

Our experience shown, that the most efficient use of microseisms analysis in problem solving appraisal of the prospects identified by seismic uplift and refinement of the boundaries of the production fields, including in areas where the use of structural seismic difficult on surface conditions. In the presence of a sufficient number of wells in the study area can be built of local correlation dependencies for this type of geological section between the parameters of microseisms and the parameters of the reservoir and further evaluation of the parameters of the reservoir by parameters of microseisms.

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