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Nonlinear Seismic Technology - Complex of Various Nonlinear Seismic Properties of Medium for Reservoirs Investigation

A. P. Zukov, K. I. Loginov, M. B. Shneerson
Geophysical Data Systems Ltd.

Summary

A new system of methods to identify and delineate hydrocarbon structures by analyzing different non-linear seismic effects has been developed. In contrast to traditional seismic methods this methods uses non-linear model of the media which takes into account seismic non-linearity of the natural gas and oil reservoirs distinguishing them from surrounding rocks. This system of methods bases on four main non-linear effects which observed in hydrocarbon reservoirs:

- Non-linear behavior of registered signal amplitudes comparative to emitted signal amplitudes.
- Oscillations with multiple, combinative - summarized and differential - frequencies appear in the reservoir.
- The phenomenon of seismic noise, characteristic for reservoirs.
- An exchange of energy of waves and environments.

There is an opportunity to speak about Nonlinear Seismic prospecting Technology (NST) already at a modern stage of experimental works.

Introduction

It's well known now - complex geological media such as hydrocarbon reservoir shows elastic non-linear effects and radiates micro seismic oscillations. Thus, in practice there is a complex relationship between seismic response and fluid saturation in a reservoir. It depends on many factors, such as cracks, poor consolidations, porosity and permeability of the reservoir rocks, viscosity and compressibility of the fluid, reservoir thickness, and physical properties of the surrounding medium.

Using of vibroseis source allows efficient choosing, analyzing and controlling source signal, that's why all the field data had been registered with help of traditional vibroseis method and hardware for an ordinary seismic exploration.

All the results presented in this paper had been obtained in the field experiments carried out at different Russian oilfields. Terrigeneous and carbonate sediments with various contents of geological material were investigated. The target oil-bearing layers have 800-1500 m depths. Well-logging and well test data was available from previous geophysical works on these oilfields.

Technology

Sedimentary rock display non-linear elastic behavior. According to previous works and the results of field experiments, it was concluded that nonlinearity appears in properties which has been marked above. A new technology for reservoir characterization has been created on basis of these four phenomena and results of field works.

So NST consists of four main methods:

1. Analysis of the combinative - summarized and differential - frequencies oscillations after emission of two different mono-frequency signals and analysis of results of mono-frequency and linear-modulated sweep interaction.
2. Analysis of non-linear behaviour of registered signal amplitudes comparative to emitted signal amplitudes.

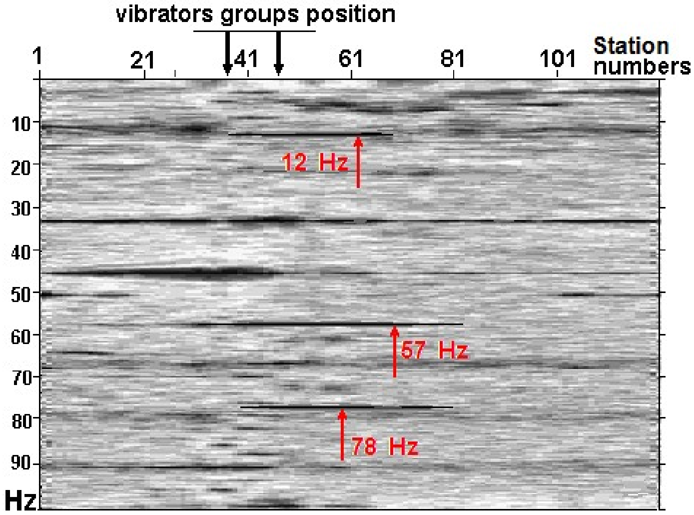
3. Analysis of seismic emission from reservoirs.
4. Analysis of changes of waves with change of movement of a liquid in the reservoirs.

Resulting interpretation uses the correspondence principle of these methods results: presence of hydrocarbon reservoir and fluid-saturation properties.

Method 1 - Hydrocarbon reservoir location prediction

This metod consists in analysis of the combinative – summarized and differential – frequencies oscillations after emission of two different signals.

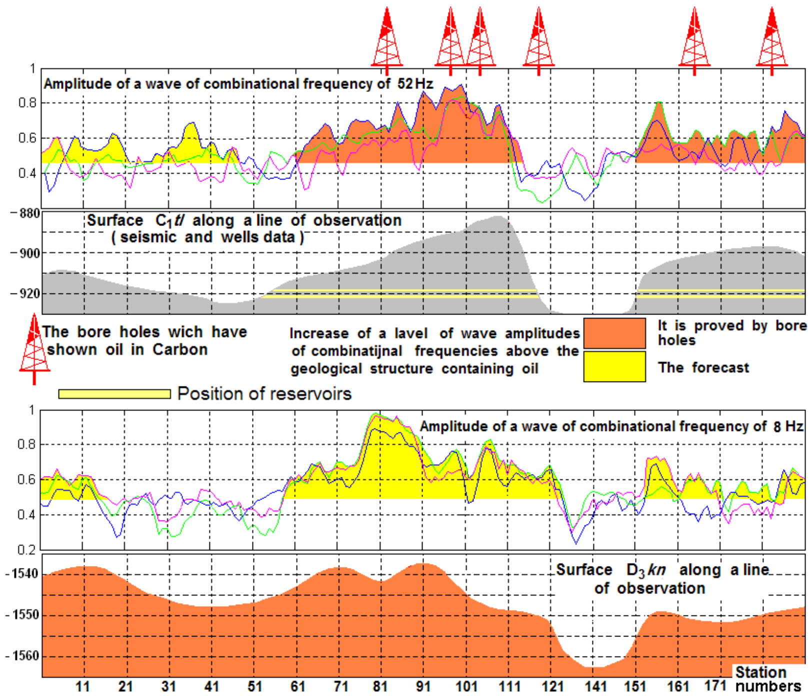
The first idea used in field experiment included simultaneous generation of two different mono-frequency signals by two group of vibrators located on different distances between them along line. Amplitude spectra of vibroseis records were analyzed. The typical amplitude spectragramm of the vibroseis record with f_1 = 33 Hz and f_2 = 45 Hz was shown on the fig.1.



There's a presence of the combinative - summarized (f_1 + f_2 = 78 Hz) , differential (f_2 - f_1 = 12 Hz) - waves, and more complex nonlinear components, 12 + 45 = 57 Hz, for example. Waves of the basic frequencies of 33 and 45 Hz have maxima of amplitudes in the field of vibrators. Maxima of nonlinear waves are displaced to the right and have place above reservoir.

Fig. 1. Typical spectragram of the vibroseis record with basic frequencies 33 and 45 Hz.

Fig.2 demonstrates nonlinear changes of combinative - summarized and differential wave amplitudes. There are several zones of increased amplitude. It is zones in under a seismic line which can contain reservoirs. Zones values marked by orange color - the ones, confirmed by well-logging data and yellow - a prediction.



Second idea consists in analysis of the combinative - summarized and differential - frequencies oscillations after emission of mono-frequency signal and linear-modulated sweep signal.

Fig. 2. Changes of combinative – summarized and differential - wave amplitudes.

The vibrators were divided into two groups during field works. The first group generated an ordinary linear-modulated sweep (f_1-f_2) and the second - a mono frequency signal with the same time duration and frequency was lower then the lowest sweep frequency (f_3<f_1). Only non-correlated vibroseis records were registered during the fieldwork.

The “basic” and “differential” time section are shown on fig.3. The basic section is shown by black color. It is imposed on differential section which is shown by color coding of amplitudes.

Three different time sections were generated during the processing stage: the first – “basic” - with main sweep [f_1-f_2] used for cross-correlation, the second – “differential” – with synthetic sweep [(f_1-f_3)-(f_2-f_3)] and the third – “summarized” with synthetic sweep [(f_1+f_3)-(f_2+f_3)].

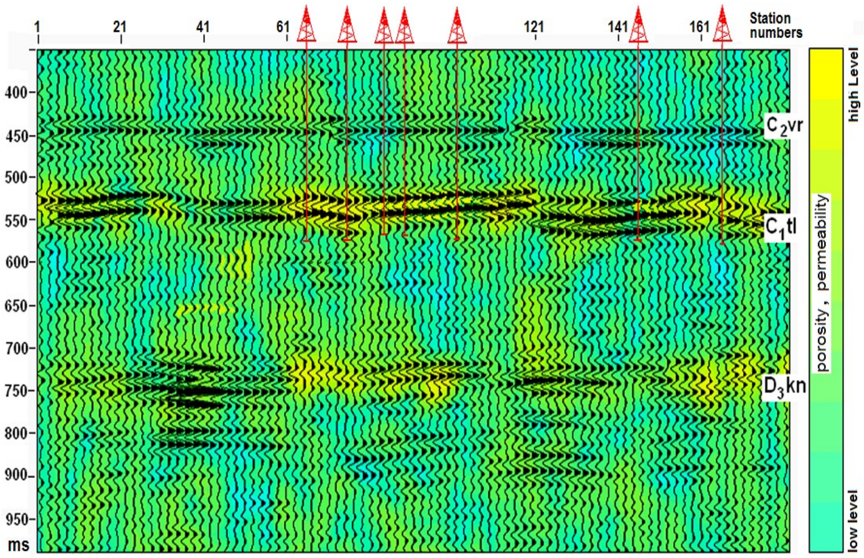


Fig.3. “Basic” and “differential” time sections generated with main f_1-f_2 and differential [(f_1-f_3)-(f_2-f_3)] synthetic sweep for cross-correlation

Analysis bases on the fact that porous, permeable, oil-saturated rocks can generate combinative frequency oscillations. It is obvious, that potentially oil-bearing horizons in C_1tl and D_3kn distinctly stand out by their dynamic attribute on “differential” time section.

Method 2 - Fluid-saturation prediction

This method consists in analysis of non-linear behaviour of registered signal amplitudes comparative to emitted signal amplitudes.

Linear frequency modulated sweep signals were generated at separate locations on the test line. Only signal amplitudes were different.. According to linear-elastic approach, amplitude ratio of waves reflected from different reflectors must be the same for all shots generated under such conditions. If this ratio changes we can consider that one or both geological objects have non-linear properties. Amplitudes level was changed in 4 times during the experiment.

Results of experiments have shown, that waves reflected from the reservoirs sated by oil do not submit to laws of linearity concerning amplitude in a source. Other reflections - submit. This method can be applied to definition of type of a saturation of rocks.

Method 3. Use of seismic emission.

This method consists in the volumetric analysis of natural seismic noise. Noise are observed in breaks of usual seismic works with use of usual systems of registration. The method of the analysis of noise of usual seismic records is possible too. Major principle of processing is use of elements of a seismic tomography. The success depends on volume of the saved up supervisions.

Use of the usual seismic equipment and field performance simultaneously with standard seismic researches - the main advantage of the given method in comparison with other uses of emission.

Method 4. Analysis of changes of waves with change of movement of a liquid in the reservoirs.

The phenomenon of an exchange of energy between waves and streams in the environment is well studied in classical nonlinear acoustics. The sound generates a stream " an acoustic stream " and, on the contrary, a stream changes parameters of fluctuations.

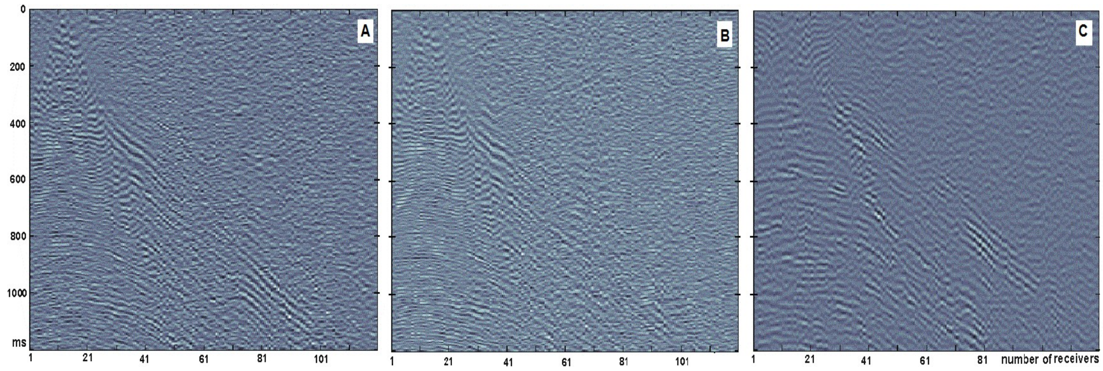


Figure 4. Usual seismic record (4-A), the record was registered on a backgroundnot synchronous additional influence of 100 Hz (4-B), a difference of first two records (4-C).

Similar effects are possible and in the porous, permeable environment. These effects have been studied by authors in wells, in laboratory and, at last in field experiments.

The idea of field experiment consist in the following. Sweep by frequency 14 - 100 Hz was registered in itself and, separately, on a background of non synchronous excitation of 100 Hz, duration of a signal of 100 Hz in some times exceeded length of sweep.

The seismic record received without additional 100 Hz, is shown in figure 4-A. In the figure 4-B - image of record with additional influence, after a filtration which has cleared record from 100 Hz. These records are visually identical. It becomes clear, that it not so if to subtract one of another. Their difference in the picture 4-C show, that instead of simple noise, usual for the linear environment, in record there are separate regular waves. These waves - reflections from porous horizons. Movement of a liquid in the rocks in result of 100 Hz influence lead to characteristic change of the reflected waves.

Conclusions

The result of final interpretation of four methods represents as time sections or maps with marked predicted zones of hydrocarbon reservoir location.

The use of mentioned non-linear properties and some processing techniques described above allows us to create a new technology - **Nonlinear Seismic Technology** - directed to locate and delineate hydrocarbon reservoirs.

References

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