International Conference and exposition SEG 2006, New Orlean, USA

Technology of hydrocarbon indication and delineation using non-linear seismic effect

Zhukov A.P., Shneerson M.B., Loginov K.I., Shulakova V.E.

Geophysical Data Systems Ltd.

Summary

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

- non-linear behavior of registered signal amplitudes comparative to emitted signal amplitudes.
- oscillations with multiple, subharmonic, combinative – summarized and differential frequencies appear in the reservoir.

Vibroseis method is chosen to investigate a non-linearity of geological environment because it allows efficient choosing, analyzing and controlling source signal.

Introduction

All conventional 2D and 3D seismic methods use linear-elastic model of geological environment. But it's well known that 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.

As a result of many field experiments carried out at different Russian oilfields it was proven that hydrocarbon reservoir causes the following non-linear effects:

- initiation of oscillations with multiple, subharmonic, combinative – summarized and differential – frequencies relative to source signal frequencies,
- non-linear behavior of registered signal amplitudes comparative to emitted signal amplitudes.

Kinematics and dynamic parameters of linear components of wave field for collectors and country rocks little differ in value whereas these parameters of non-linear components essentially differ.

These basic non-linear effects underlie a new technology of identification and delineation hydrocarbon structures. 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. The technology consists of several methods which allow to get some additional information about reservoir and expects less volume of field works then conventional seismics.

Method 1 - Hydrocarbon reservoir location prediction

This stage consists in analysis of the combinative – summarized and differential – frequencies oscillations after emission of two different mono-frequency signals. A method 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. Every group of vibrators generated its own mono frequency signal: 22 and 30 Hz, for example. Amplitude spectra of vibroseis records were analyzed.

The typical amplitude spectra of the vibroseis record with $\omega 1$= 22 Hz and $\omega 2$= 30 Hz was shown on the fig.1.

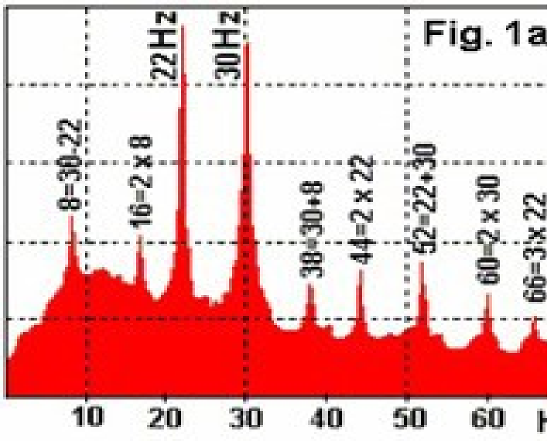


Fig. 1. Typical amplitude spectra of the vibroseis record with basic frequencies 22 and 30 Hz

There's a presence of the combinative – ($\omega1+\omega2$ = 30+22 = 52 Hz), differential ($\omega1-\omega2$ = 30-22 Hz = 8 Hz) and different multiple frequencies ($2\omega1$ = 44 Hz, $2\omega2$ = 60 Hz, $3\omega1$ = 66 Hz, $2(\omega1-\omega2)$ = 16 Hz) besides the basic mono frequencies $\omega1$ and $\omega2$.

Fig.2 demonstrates nonlinear changes of combinative – summarized and differential wave amplitudes. There are several zones of increased amplitude values marked by orange color – the ones, confirmed by well-logging data and yellow – a prediction.

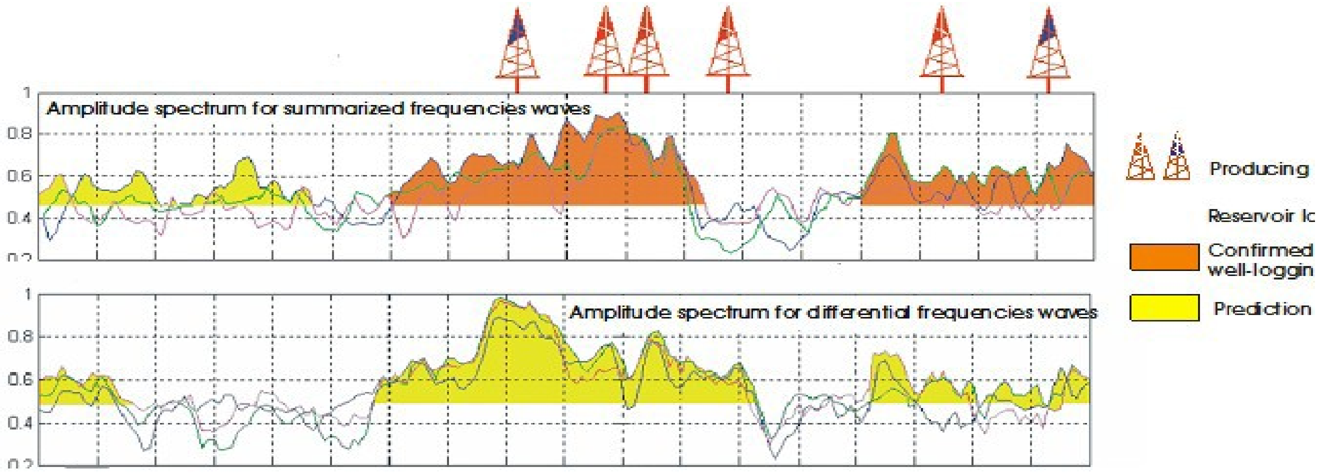


Fig. 2. Nonlinear changes of combinative – summarized and differential wave amplitudes after emission of two different mono-frequency signals.

Method 2 - Fluid-saturation prediction

This stage 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 nonlinear properties. Amplitudes level was changed 5 times during the experiment.

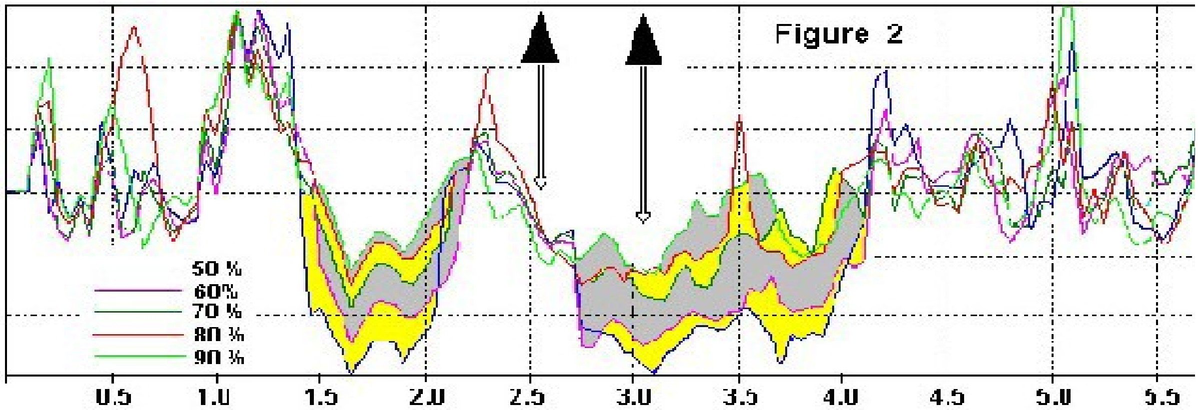
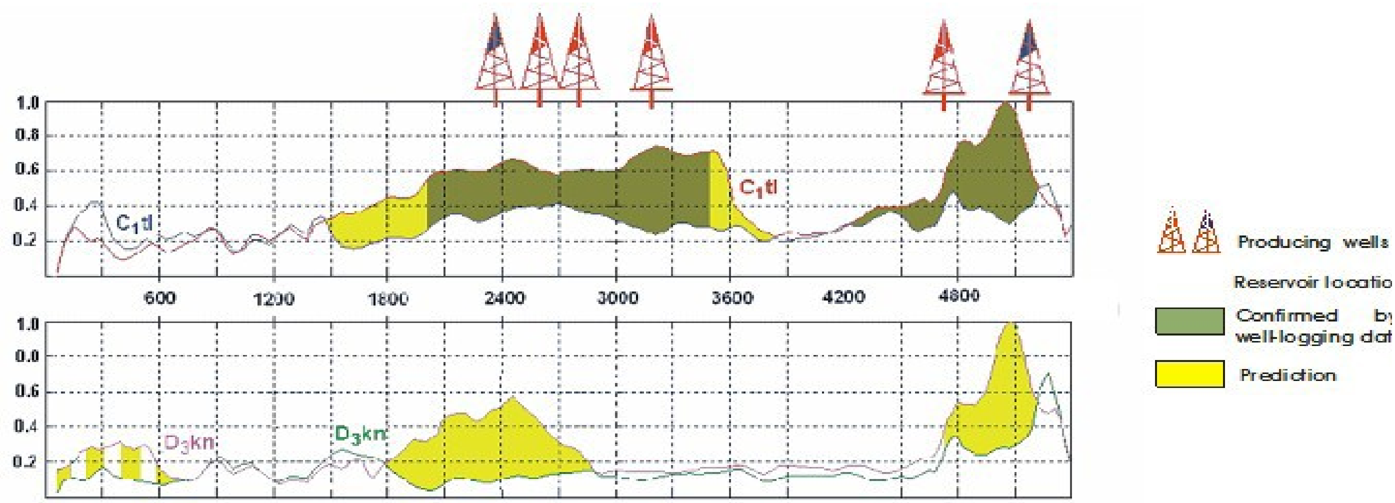


Fig. 3. Nonlinear changes of reflected wave amplitudes depending on signals amplitude.

Fig.3 demonstrates amplitude ratios for all 5 amplitude levels. Ratios of amplitude along two reflector hyperbolas associated with two geological units - terrigeneous deposits (C1tl) and Permian sulphate-carbonates were calculated. These ratios satisfy the linear-elastic assumption within experiment accuracy except two zones, which is located from 1.45 to 2,2 km and from 2.7 to 4.15 km. Well data showed that the first horizon saturated by oil within this zone.

Therefore, according the effect of non-linear behavior of registered signal amplitudes comparative to emitted signal amplitudes, oil-bearing deposits can show non-linear seismic properties.

Another example of amplitudes changes depending on signal amplitude for two different horizons C1tl and D3kn presented on fig.4. Green zones mark hydrocarbon reservoir location confirmed by well-logging data and yellow zones mark prediction reservoir location.



Method 3 – Reservoir localization

This stage consists in analysis of the combinative – summarized and differential -frequencies oscillations after emission of mono-frequency signal and linear-modulated sweep signal and also in analysis subharmonics and multiple frequencies.

The vibrators were divided into two groups during fieldworks. The first group generated an ordinary linear-modulated sweep (f1-f2) and the second - a mono frequency signal with the same time duration and frequency was lower then the lowest sweep frequency (f3<f1).

Only non-correlated vibroseis records were registered during the fieldwork.

Three different time sections were generated during the processing stage: the first – "basic" - with main sweep [f1-f2] used for cross-correlation, the second – "differential" – with synthetic sweep [(f1-f3)-(f2-f3)] and the third – "summarized" with synthetic sweep [(f1+f3)-(f2+f3)].

The "basic" and "differential" time section are shown on fig.5.

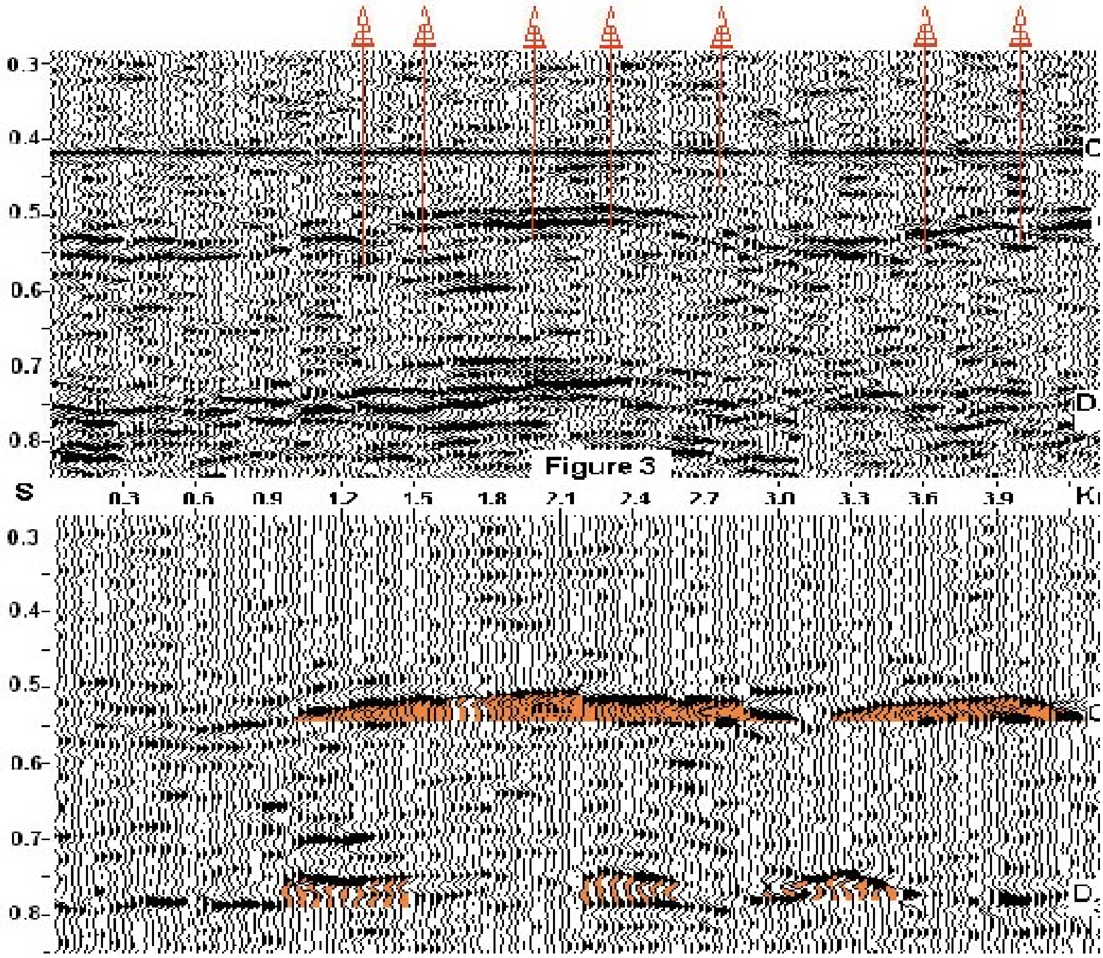


Fig.5. "Basic" (a) and "differential" (b) time sections generated with main f1-f2 and differential [(f1-f3)-(f2-f3)] synthetic sweep for cross-correlation.

Analysis bases on the fact that porous, permeable, oil-saturated rocks can generate combinative frequency oscillations. One can notes that potentially oil-bearing horizons in C1tl and D3kn distinctly stand out by their dynamic attribute (fig.5b).

A simple visual analysis shows that in interval 0.9-3 km and 3.3-4 km amplitude's value for horizon C1tl is a lot more then on the other parts of the section. As stated above an industrial oil deposit is situated right in this area.

More accurate technique then just visual analysis had been designed. It allows comparing "basic", "summarized" and "differential" time sections and delineate potential oil-bearing zones.

Some additional results can be obtained using multiple frequencies and subharmonics. Fig. 6 show "basic" and "subharmonic" time section generated with main (14-100 Hz) (A) and synthetic half sweep (7-50 Hz) (B). The collectors appear as zones with high amplitude values.

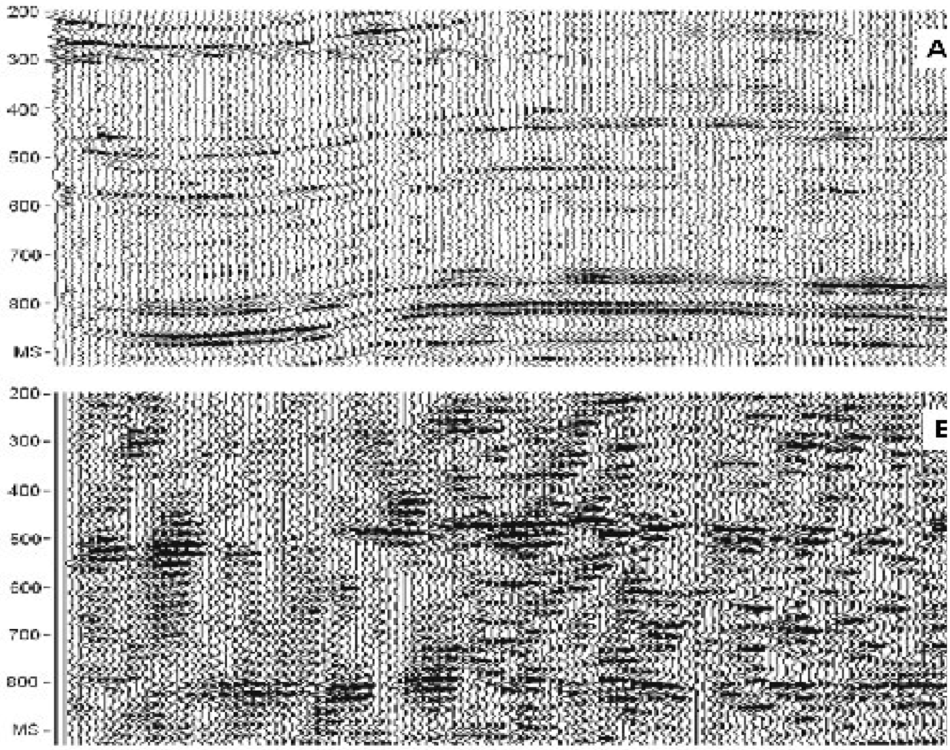


Fig.6. "Basic" (a) and "subharmonic" (b) time sections generated with main f1-f2 and half [f1/2-f2/2] synthetic sweep for cross-correlation.

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

Conclusions

Non-linearity of rock seismic parameters becomes apparent in such fundamental properties as:

- an appearance of the combinative – summarized and differential – frequencies oscillations and multiple harmonics,
- non-linear dependence between registered and generated signal amplitudes.

The use of mentioned non-linear properties as well as a special technology of vibroseis exploration and some processing techniques described above allows us to create a new technology directed to identify and delineate hydrocarbon reservoir.

Acknowledgments

We would like to thank "Tatneftegeophizika" for their support and collaboration.

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