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Microtremor Analysis in Seismic Reflection Data for Identification of Oil and Gas Reservoirs

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SUMMARY

A new method of spectral analysis of ‘hydrocarbon tremors’ (microseisms) is developed for seismic exploration of oil and gas. As an input data this method uses standard 3D seismic reflection data. In comparison with other methods of passive seismology, this method does not require any specific field acquisition and devices, since the input data can be extracted from conventional seismic reflection data. The know-how of the method is in using the time intervals in the wave records before the first arrivals, as input data for the method. Then, we have developed the method furthermore by using the intervals of seismic traces corresponded to the latest times, that is after all the reflection-waves’ events. As an example, an algorithm is presented by its application to Oriental Siberia data. There is a strong correlation of the tremor spectrum intensity with the oil/gas pay-zone location. In the well perforated following our prognosis, substantial gas flow has been obtained with an excellent production rate.
Introduction

Thirty years ago, geophysicists found out a special kind of natural microseismic activity related to the presence of hydrocarbon reservoirs in the Earth; they call this phenomenon the oil and gas microtremor or the microseisms’ (MS) emission of hydrocarbons (Sadovskiy and Nikolaev 1982; Nersesov et al. 1990). These microtremors of hydrocarbons have energy in the low frequency spectrum, in the certain interval from 2 Hz to 5 Hz. The discovery of this kind of hydrocarbon (HC) microtremors has led to the development of passive microseismic technologies for seismic exploration (e.g. Arutyunov et al. 1998; Birialtsev et al., 2006; Holzner et al. 2005; Hanssen and Bussat 2008; Lambert et al. 2009; Saenger et al. 2009; Katebi et al. 2011; Gerivani et al. 2012). The MS response of oil and gas reservoirs from different oil/gas fields in the world has the same characteristics of frequency range and spectrum shape. For example, Dangel et al. (2003) demonstrate similar MS amplitude spectra from the places as distant as United Arab Emirates and Switzerland. Saenger et al. (2009) show amplitude spectra from the Burgos Basin in Mexico, which are very similar to those mentioned, with the same frequency range. There were performed numerous efforts to understand the causes of this phenomenon of microseisms related to oil and gas (e.g. Korchagin 2000; Birialtsev et al. 2006; Saenger et al. 2009; Frehner et al. 2009; Holzner et al. 2009; Broadhead 2010; Suntsov and Smirnov 2010; Svalov 2010; Rapoport 2013; Shabalin et al. 2013).

Nowadays there is no unique theory which perfectly explains all the aspects of this phenomenon. However in spite of absence of a unified theory, various methods of MS spectral analysis are rapidly developed for seismic exploration of oil and gas.

In order to detect MS emission, there are commonly used complex multi-channel seismic stations including broadband seismographs measuring the natural seismic activity during long periods of time (from several days to weeks) (e.g. Lambert et al. 2009). Instead of these expensive data acquisitions, we have developed a method which enables using standard seismic reflection data to analyze the microseismic emission. As we know, the detection of microseismic events comes from passive seismology, while seismic reflection-wave surveys are related to active methods of seismic exploration, because of the use of artificial sources (such as seismic vibrators, shot guns, explosions, etc.). The question of how to merge these techniques from these two different approaches— that is the active and passive methods – was solved by Vedernikov (2001), who developed a quite ingenious method to detect microseismic events from seismic reflection data.

Method

The method uses the early-time portions of common-shot-point gathers, before the first arrivals of seismic wave fronts, as shown in Figure 1 (the area marked by number 1). Such portions of seismic records contain all needed information on natural microseisms and are considered as an input data in the method. Figure 1 shows the zone with square (rectangle) geometry that is formed by the offsets’ interval (1500 m; 4000 m) and the time interval from 0 to 500 ms, for this case study performed in oil/gas field of Oriental Siberia. In other words, Vedernikov method uses long offsets and early times (e.g. Vedernikov 2006; 2012; 2013; Vedernikov and Hogoev 2006; 2013). An example of the method application is illustrated in Figure 4. Figure 4-c shows 2D seismic section from a zone where a productive well was drilled. Total amplitude spectrum along the section is shown in Figure 4-b, where the zone with the productive well exhibits evident spectrum anomaly. The MS spectrum exhibits predominant frequency range at the interval from 10 Hz to 20 Hz (shown in Figure 4-a). Note that this frequency range of microseisms is higher than in the case of conventional passive MS monitoring that is usually from 1 Hz to 5 Hz as mentioned in the introduction. The background theory of Vedernikov method is based on the latest studies, which have shown that the amplitude spectrum of hydrocarbon tremors can be made broadband (e.g. from 1 to 40 Hz) and/or more intensive by stimulation of vibroseismic-source excitation (Vedernikov et al. 2001, Alekseev et al. 2004, Suntsov et al. 2006, Serdyukov and Kurlenya, 2007, Kuznetsov et al. 2007). Thus, during conventional field jobs on seismic data acquisition for the method of reflected waves, concomitant stimulation of HC microseisms by artificial seismic sources (vibrators, shot guns, explosions, etc.) evidently takes place.

Workflow of the method (Hogoev 2008). The first step in the workflow is selection of the appropriate seismic traces based in a threshold value given by the following equation: \[ |M - \mu| > 3\sigma \], where \( M \) is
the mean, and \( \sigma \) is the variance of the RMS amplitude distribution in seismic traces \( (u_i) \) along seismic profile. The rejected traces are those whose difference between the RMS amplitude with respect to the mean is larger than three times the standard deviation (square root of the variance) of the amplitude distribution. With the application of the rejection criteria, the traces with extreme RMS values are eliminated. Figure 2 shows histogram of RMS amplitude of traces along a profile, before (Figure 2a) and after (Figure 2b) the application of the rejection criteria. The traces below the threshold value were used for stacking along the profile; the most of the MS data has good quality with stacking fold close to 30 (Figure 2c).

In the next step, Fast Fourier Transform was applied trace by trace to calculate the MS-amplitude spectrum along the seismic profile line. The following ranges of frequencies are selected to calculate the mean value of spectra: (1) from 0 to 10 Hz, (2) from 10 to 20 Hz, and so on, up to the interval from 50 to 60 Hz. The resultant graphs of MS-amplitude spectrum as a function of horizontal distance along the profile line are shown in Figure 3, before (a) and after (b) application of smoothing and filtering procedures. Note the highest MS energy at the low frequency intervals from 0 to 20 Hz.

Method Development and Results

Our development of the method is based on use of traces at the latest times as an input data, instead of using the early times as in the original method of Vedernikov. We assume that after 3.5 s of active seismic records, the attenuation of active seismic waves took place and so that the main portion of energy came exclusively from microseisms. So, from each common shot point gather, we use those parts of seismic traces, which enter into the zone marked by number 2 shown in Figure 1. To evaluate the developed method, we compare its results with the old method that is the original method of Vedernikov. The amplitude spectra calculated with using late times show higher contrasts in frequency anomalies in comparison with the original method. And also it allows us to find anomalies not identified before by the original methodology.

The low-frequency anomalies in the MS amplitude spectrum are mainly located at an anticline shown in Figure 4c.
From the traditional methods of seismic-reflection-data interpretation, this anticline has been identified, but there was uncertainty if it could be related to a hydrocarbon reservoir.

Figure 4.
Spectral analysis of MS in oil/gas field from Oriental Siberia, where the successful well Bh-1 drilled in a zone with a low-frequency anomaly.

The results of the MS analysis have reduced the uncertainty. Then, when the well Bh-1 (shown in Figure 4a) was drilled, it has proved the method by high rate of gas production (974,000 m$^3$/day) as well as gas condensate flow at the depth 1500 m. Figure 5 shows a map of MS spectra, where there is a pair of mutually intersected profiles oriented approximately N-S and W-E. (The profile N-S is shown in Figure 4.) The map shows the total (for the interval from 0 to 40 Hz) MS-amplitude spectrum (normalized to its maximum value). In the map, all the dry wells are located outside of the zone of MS-spectrum anomaly. The only producing well Bh-1 is situated inside of the zone of the evident MS anomaly. As we can see, there are other perspective places with higher probability of hydrocarbons for well drilling which can be highly recommended. It should be done to the north - north-east from the well Bh-1, where the strongest anomaly of microseisms has been found. In Figure 6, one can compare two independently determined MS-amplitude spectra, estimated in the cross point of the two profiles (W-E and S-N). Each spectrum is calculated separately in its own seismic section along its corresponding profile (W-E or S-N). Both spectra graphs having high correlation coefficient of 0.925 are very similar to each other. This test can support and prove the method.

Conclusions
The method of MS spectral analysis is useful to reduce uncertainties during exploration stages. The proposed workflow uses standard seismic reflection data as an input data, and therefore it can be applied in most oil/gas fields, with a very low economic inversion because it does not require any additional efforts for field data acquisition. The method provides seismic profiles with distribution of the amplitude spectra of microseisms (MS) along these profiles, as well as the MS spectral attribute maps. This independent and valuable information complements the results of standard interpretation.
such as structural and stratigraphic maps and sections. The method provides direct hydrocarbon indicators, and therefore it would be promising and could open new perspectives in exploration of unconventional reservoirs such as shale gas/oil plays, in which there are no any evident oil and gas traps as in conventional reservoirs.

References


