ROME 2008
LEVERAGING TECHNOLOGY

P234

Survey of Heterogeneity of Oil-gas Saturation of Reservoir Using Seismic Emission Waves SLEC Technology

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SUMMARY

Considered is application of passive seismic monitoring technology SLEC (Seismic Location of Emission Centers) to survey the heterogeneity of oil saturation of reservoir in one of the fields of Orenburg region (Volga-Ural area, Russia). Presented is a brief description of SLEC technology designed for surface-based passive monitoring of seismic emission of geological formations and estimation of characteristics of reservoirs, particularly, reservoir fluid saturation type. Among benefits of SLEC technology are its surface based observation system and the use of Slionkin Focusing Transformation algorithms allowing to focus SLEC locator to any points of a geological formation (within the range of a few kilometers), thus allowing distinguish between useful and interference sources of emission signals. Presented are results of long-term SLEC monitoring. A comparison of SLEC processing results map of oil saturation index versus production data acquired in operating wells and well test data supports the reliability of SLEC-based maps of reservoir oil saturation heterogeneity. These heterogeneity maps can be used to improve the efficiency of oil production and for post-exploration of the field.

Introduction

Geological formations are emitting elastic waves permanently and spontaneously. This phenomenon known as seismic emission (SE) is most pronounced during earthquakes when the giant portions of energy are released within relatively long periods of energy accumulation. Microseismic emissions are produced by geological formations practically continuously, they are known in seismic exploration and sonic well logging as microseism and acoustic noise. The study of microseismic noise has become an urgent problem in seismic exploration since it was recognized that SE-waves bring us valuable information about the dynamics of stress-deformed state, fracturing, mechanical properties, and fluid saturation of formations. Possibility of acquiring information about the type and spatial heterogeneity of fluid saturation of formations is of much value for improving the efficiency of seismic exploration and production of HC reserves. SLEC passive seismic technology is designed to solve these specific problems at the production stage, yet, SLEC can be successfully applied at prospecting and exploration stages [1, 2].

Brief description of SLEC Technology

Seismic Location of Emission Centers (SLEC) is a modification of passive seismic exploration methods which allows to study seismic emission of geological formations in prospected areas and oil fields in course of production [3]. Because of the extra-low energy of SE-waves and spontaneous character of seismic emissions both in space and time, we applied a principle of "passive location of the lower hemisphere." Passive seismic locator consists of the receiver aperture with relatively regularly positioned 100-200 groups of seismic sensors, seismic workstation providing recording seismic signals, and a computer unit which allows on-line processing of seismic data in a real-time mode (Fig.1). To distinguish seismic emission waves in the recorded wavefield and to provide scanning of the lower hemisphere we use Slionkin Focusing Transformation [3] applied to time series of continuous seismic records (duration of the series is approximately 10 s) acquired within a long-term period of one month. Such duration of monitoring is caused by the necessity of estimated non-biased steady-state characteristics of multiplicative quasi-random process of seismic emission in each point of the scanned geological formation. Other specific features of SLEC system are surface-based observation system, specialized interface of the seismic workstation allowing long-term continuous recording of all seismic signals and simultaneous on-line processing of the real-time distribution of SE for target horizons.

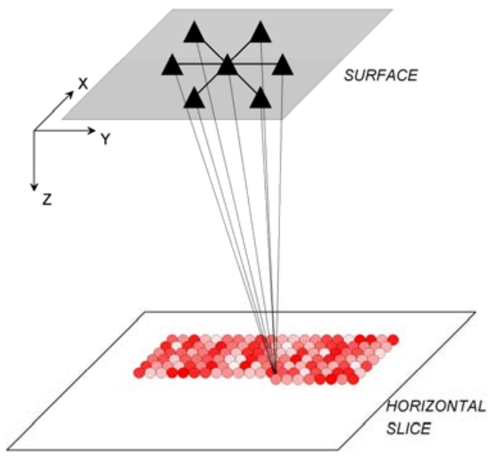

Fig.1. Schematics of passive seismic scanning of emission centers (SLEC)

Fig.2. presents time variation (specific for the Orenburg area) of the energy of seismic emission in one of the points of scanned volume of the studied geological formation in comparison with a diagram of time derivative of gravity. Time variation of gravity, caused by changes in the mutual position of the Earth, moon and sun, is responsible for lunisolar solid tides which in turn control the major harmonic component of the quasi-random process of emission of elastic waves by geological formations. Major steady-state characteristics of this quasi-random process are as follows: mean value of seismic emission, variance of seismic emission, and autocorrelation function of SE. The latter characteristic – numerical values of the correlation radius or autocorrelation at a specific displacement delay ($\tau = const$) predominantly depends on a fluid saturation type for rocks of similar lithology. This

correlation was experimentally established in laboratory experiments and in situ for oil fields under production [2, 3, 4].

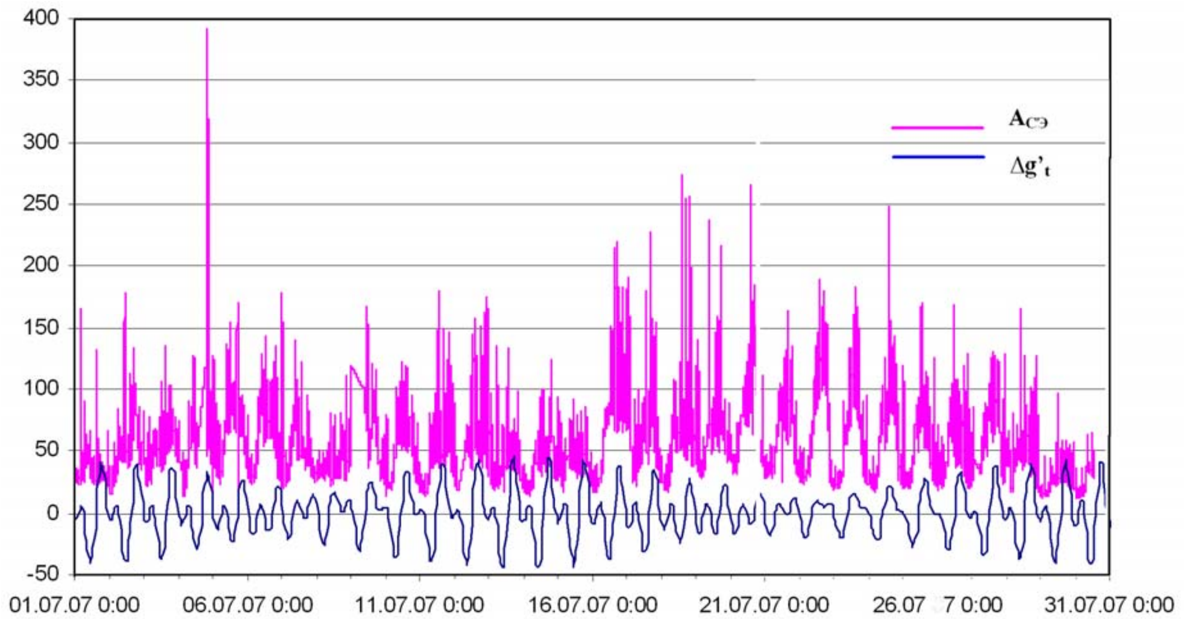

Fig.2. Time derivative of gravity caused by lunisolar solid tides and correlated variation of seismic emission energy in one of scanned points within one month.

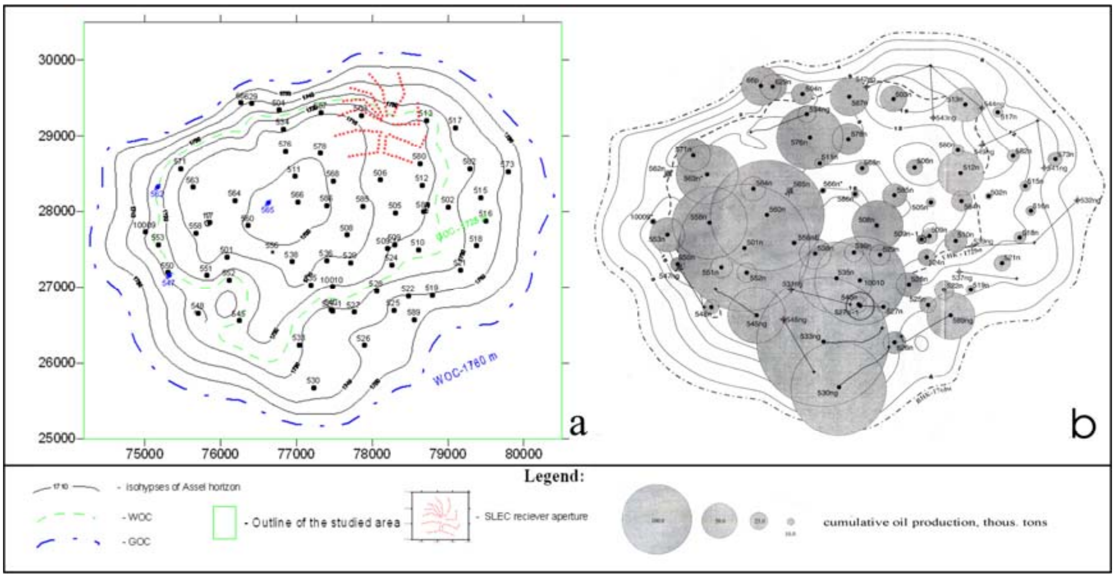

Fig.3. Structural map (a) and diagram of cumulative oil production for the first pay horizon (b).

Example of the survey of heterogeneity of oil-gas saturation of reservoir.

Solution of this problem is given by the example of one of oil fields in Orenburg region. Fig.3 presents a structural map on top of carbonate pay horizon (where red dots show a position of SLEC receiver aperture (a) and a diagram of cumulative oil production in each well, presented as circles with a size proportional to quantity of oil produced. This diagram schematically shows heterogeneity of oil saturation of pay horizon under production. The studied area was scanned by SLEC locator with spacing of 100 m along X and Y axes at the depths of two basic pay horizons. The duration of monitoring was 1 month. Statistical characteristics of emission quasi-random processes (Fig.2) were calculated for each of scanned points of two deep horizons at the depths H= 1720 m and H= 2200 m. Next, a relationship between the autocorrelation function and oil saturation data was analyzed and maps of oil saturation index for these horizons were prepared (Fig.4 and Fig.5). By "oil saturation index" is meant the oil saturation characteristic estimated by a geophysical method (for example by SLEC technology).

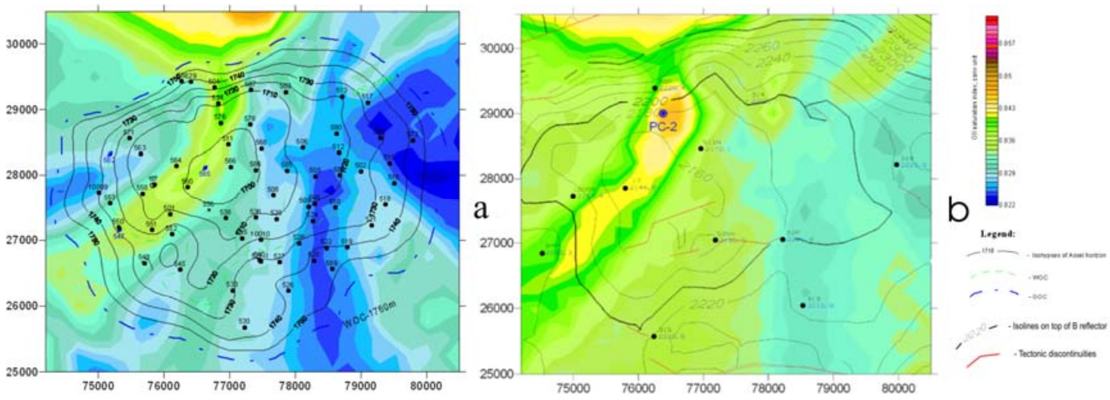

Fig.4. Distribution of oil saturation index found from autocorrelation function at τ = 200s for the first (a) and second (b) pay horizons of the field.

A comparison of the map of oil saturation index for the first pay horizon (Fig.4a) and areal production diagram (Fig.3b) points to a good agreement of these maps. Firstly, the eastern part of the reservoir is characterized by low and minimal values of oil saturation index and low values of cumulative oil production. Secondly, in the southeast and south sectors characterized by relatively high oil saturation index (from SLEC data) there are wells characterized by high and maximum cumulative oil production. Thirdly, wells characterized by a maximum cumulative oil production (wells #501 and #560) are located at the axis of a linear zone of abnormally high oil saturation.

In addition to this qualitative analysis correlations between production rate of wells operating during SLEC monitoring and oil saturation indices found from the autocorrelation function were computed (Fig.5a). During SLEC monitoring period 9 wells were under operation – 2 wells are characterized by high skin effect, they drop out of this correlation. High correlation coefficient suggests a direct relationship between the parameters analyzed.

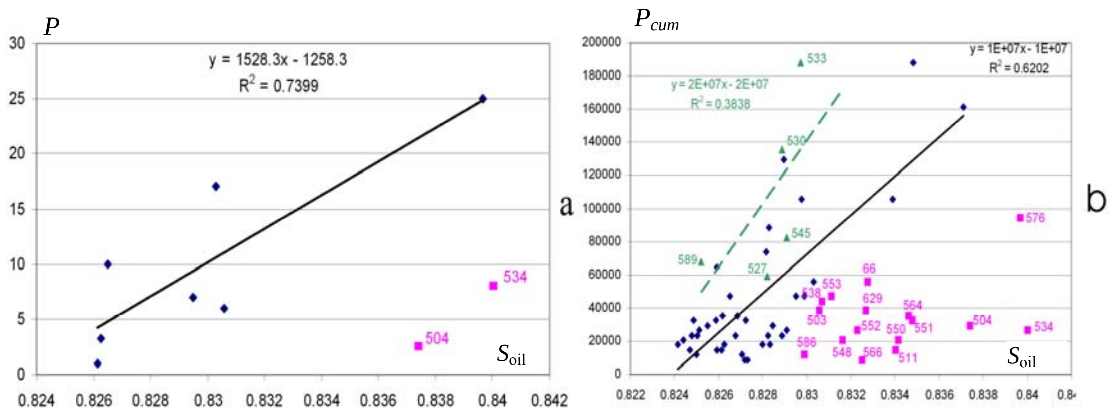

Fig.5. Correlation between oil saturation index S_{oil} and production rate P (a) and cumulative production P_{cum} (b).

Next a correlation between the values of oil saturation index and values of cumulative oil production was considered for all operating wells of the field (Fig.5b). A direct correlation was found between parameters analyzed (upon exclusion of wells characterized by a positive skin-effect). Moreover, such correlation for horizontal wells is much steeper as compared to that or vertical wells. This fact is owed to better oil inflow to horizontal wells as compared to vertical ones. The comparative analysis of the map of oil saturation index for the second pay horizon (Fig.4b) was performed using results of tests made in exploratory wells among which only one well #17, located in a zone of abnormal values of oil saturation index, has produced a commercial HC inflow whereas other wells turned out to be nonproductive.

Thus, the results of comparative analysis support the reliability of SLEC-derived maps of oil saturation index found based on the computation of autocorrelation function of seismic emission process. It means that results of SLEC monitoring can be applied to improve the efficiency of oil recovery from the first pay horizon of the reservoir and for post-exploration of the second pay horizon in this oil field.

Conclusions

1. SLEC technology designed to study the seismic emission allows acquire reliable information about heterogeneity of oil saturation of geological formations, particularly of pay horizons.
2. As applied to oil fields under production SLEC-derived maps of oil saturation index allow optimize positions of production wells to provide a more complete recovery of HC reserves. Moreover such maps allow identify wells (characterized by a positive skin effect) which should the first targets for IOR operations.
3. Passive seismic technology SLEC allows materially enhance the efficiency of geological exploration of oil and gas due to additional information about heterogeneous oil saturation of studied areas.

Acknowledgements

Authors are thankful to managers of JSC Orenburggazprom for valuable consultations and support to implementation of SLEC survey.

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