The optimal tight oil and shale gas development based on pre-existing fracture and principal stress models: case study.

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Summary

The optimal development of tight oil and shale gas based on the new knowledge of geological models for zones of pre-existing fractures and for principal stress axes is discussed. Pre-existing fracture model is built by special processing of scattered seismic waves by the CSP (Common Scattering Point) method. Stress model is based on surface microseismic monitoring of the hydraulic fracturing and special processing of these data by the SMTIP (Seismic Moment Tensor Inverse Problem) method. Both models are used further for well trajectory design to increase drainage area. The roadmap for optimal tight oil and shale gas development is offered.

Introduction

In technologies of production of shale gas and tight oil the important place is taken by planning (design) of a trajectory of a horizontal part of a well for carrying out multistage hydraulic fracturing. For optimal development of tight oil and shale gas, it is important to take into account the geo-mechanical and geological characteristics of shale body. Information on the principal stress characterizes a geomechanical properties of shale rock. This information is essential for planning the optimal trajectories of the horizontal section of the well. Multistage hydraulic fracturing would be most effective if the fractures will be directed orthogonally trajectory. The latter is achieved when the well trajectory direction coincides with the minimum of stress axis in the environment.

From the point of view of the effectiveness of hydraulic fracturing, it is important to use the information about decompaction zone, including the natural fractures in the shale rock, which was formed as a result of tectonic processes in the region. The zone of pre-existing fractures means as large faults in shale rock or fine fractures in them. Both types of environment irregularities are detected by the specialized CSP-processing of 2D or 3D CDP seismic data. The solution of seismic moment tensor inverse problem for hydraulic fracturing provides obtaining the geomechanical characteristics of shale body, including the principal stress axes in the rock.

Methods

Integrated approach based on the two methods:

a) Method of the CSP seismic inverse problem (Common Scattering Point), which provides extract from a full seismic field the scattered component which is responsible for decompaction, fractures and faults zones in the shale rock. Method is based on processing of standard seismic 2D or 3D CDP data and is described by Kremlev *et al*.(2011).

b) Method of the Seismic Moment Tensor Inverse Problem (SMTIP), which is described by Erokhin *et al.* (1987). It is focused on the data processing for the surface microseismic monitoring and can to supply the definition of the directions of the maximum and minimum stress in a shale rock with tight oil or gas.

The knowledge about zones of pre-existing fractures or decompaction zones, containing a fluid is very important for the development of tight oil and shale gas. Unfortunately these zones don't reflect, but only scatter weak seismic energy. The seismic migration method, which focuses the scattered waves in places of their emergence allows to allocate and to map these zones (Erokhin *et al.*, 2012). For this purpose it is necessary to subtract from full wave field the very strong (in comparison with scattered) reflected waves. Effective method for research of scattered objects is the CSP method. The CSP method relates to the new direction of seismic survey – «seismic survey using scattered waves». The CSP method makes it possible to obtain time diffractors cubes which contain the image only of the scattering elements of the environment (the CSP-diffractors) and time reflector cubes without the scattering elements (the CSP-reflectors). The CSP-diffractors cubes include the unique information about fracture cavernous which are completely lost when seismic data processing is based on conventional methods. Moreover, the quality of the CSP-reflectors is much higher than the quality of the ones obtained using traditional processing. The CSP method is based on the theory of inverse and ill-posed problems of mathematic geophysics and on the using of supercomputer.

The mathematical algorithms for SMTIP-inversion is based on determining the right-hand side of special kind for the Lame differential equation system (Erokhin *et al.* 1987, 2002; Anikonov *et al.* 1997). The purpose of the microseismic inverse problem, formally, is detection the kinematic parameters (beginning of the event and coordinates t_0, y) and the dynamic parameters: seismic moment tensor of rank 2 – $M_{ij}(t)$ by data of surface

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microseismic monitoring. The detection of the kinematic parameters is the solution of the so-called “kinematic inverse problem”. The method of the parameters detection is described in the patent (Erokhin *et al*., 2008). Determination of the tensor elements is the solution of the so-called “dynamic inverse problem”. The algorithms of the solutions the both kinematic inverse problem and dynamic inverse problem are designed for supercomputer processing. The method of the solution of both problems we called SMTIP-method (Seismic Moment Tensor Inverse Problem). The distinctive technological feature of the SMTIP method is universality, high mobility and compactness of the surface acquisition system. The method uses original algorithms of signals processing that make it possible to define both kinematic parameters of microseismic sources and their dynamic properties (energy, principal stress axes, shear and hydrostatic stress etc.) with high accuracy. Processes occurring in oil deposits are visualized both statically in space and dynamically in time.

The integrated approach to the optimization of the development of tight oil and shale gas based on the seismic exploration on scattered waves and surface microseismic monitoring of multistage hydraulic fracturing is offered. Specialized processing of scattered waves is applied to identification of fault and zones of pre-existing fractures. The microseismic monitoring of the multistage hydraulic fracturing allows receiving the model of principal stress axes for shale. Results are used for planning of trajectories of horizontally directed wells.

Examples

As a rule, the cube of reflectors is the basis for creation of the faults and the block model. However, for tight oil often the faults on the reflected waves aren't traced. In this case it is necessary to use simultaneously both the cube of reflectors and the cube of diffractors. In Figure 1 time slice of the CSP-reflectors cube (Figure 1a) and time slice of the CSP-diffractors cube (Figure 1b) for one of the oilfield of Western Siberia are presented. The horizons marked with Б and Б1 mean a roof and the base of the tight oil, carrying the name "bazhenovsky suite". In Figure 1a (CSP-reflectors) the some faults are traced (from below up). But they disappear at the level of the T horizon. In Figure 1b (CSP-diffractors) the same faults are traced above on a section, including horizon of bazhenovsky suite. In Figure 2 the diffractors map in the range of tight oil of bazhenovsky suite is represented. It is obvious, that the expressed elongation on the northwest of disseminating structures in a body of tight oil can be considered when planning the direction of horizontal part of a trajectory of a well when carrying out multistage hydraulic fracturing.

There is even more impressive example of use of information on structure of the deconsolidation received on the basis of the CSP method. Let's apply to a CSP-diffractors cube the traditional attributive processing. In Figure 3a the map of amplitudes of scattered waves on the horizon of tight oil is submitted. Here pre-existing fractures are observed. In Figure 3b the map of the acoustic impedance calculated on the CSP-diffractors cube is presented. Here we already observe not simply the pre-existing fractures, but a detailed network of the lowered filtrational resistance.

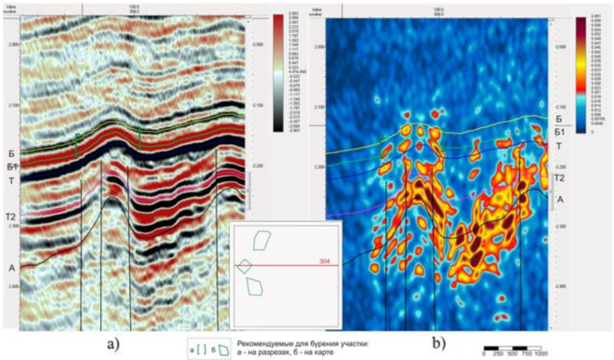

Figure 1: 3D CSP-reflectors cube time section (a) 3D CSP-diffractors cube time section (b)

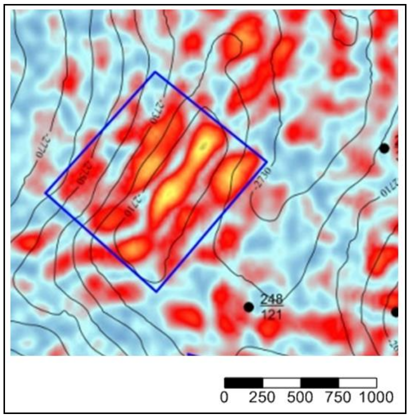

Figure 2: The map of amplitudes of scattered waves in the range of tight oil of bazhenovsky suite

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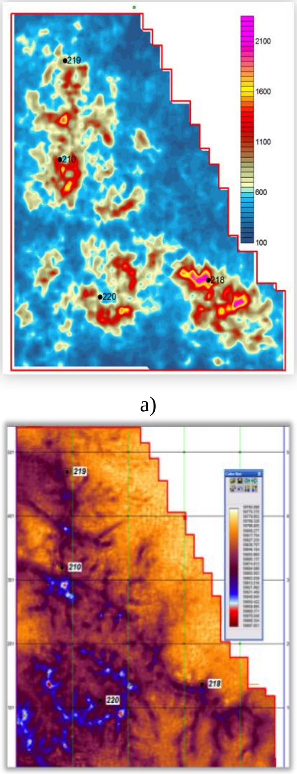

a)

b)

Figure 3: The map of amplitudes of scattered waves for tight oil of the bazhenovsky suite (a). The map of the acoustic impedance calculated on the 3D CSP-diffractors cube (b).

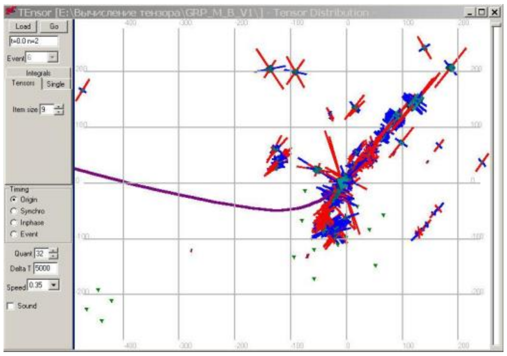
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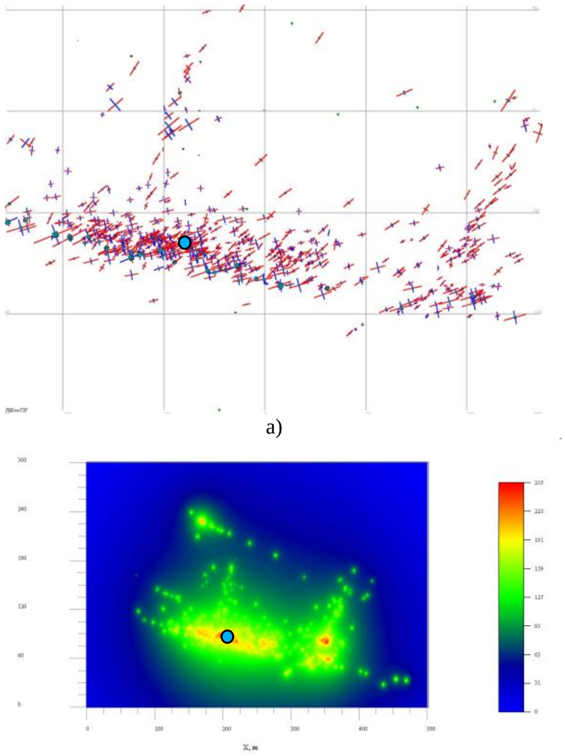
Figure 4. The horizontal plane image of seismic emission during one-stage hydraulic fracturing. The depth is 2766m. The grid is 100x100 meters. The red and blue arrows are the principal stress axes of the sources. The curve line - projection of the well bore onto a horizontal surface. The green triangles - depiction of seismic sensors.

Figure 4 represents time-averaged distribution of micro straining in the regions of microseismic emission (with directions of main strain axes) in a plane of one of the hydraulic fracturing events. Figure 5 shows the results of hydraulic fracturing microseismic monitoring in two forms: in Figure 3(a) the sources with the principal stress axes are presented, in Figure 3(b) the energy distribution in the emission plane.



a)

b)

Figure 5: The horizontal plane image of seismic emission during hydraulic fracturing the sources (a) principal stress axis (b) energy distribution. The depth is 2540 meters. The grid is 50x50 meters. The red and blue arrows – the principal stress axes of the sources. The blue circle shows the projection of the borehole bottom onto the monitoring plane during hydraulic fracturing.

The directions of the maximum stresses in Figures 4 and 5a (red axis) coincide, as a rule, with the direction of the main cracks. The trajectory of the well for multistage hydraulic fracturing has to go perpendicular to this direction.

Figures 6-7 represent some schemes of decision-making on planning the trajectory of a well for multistage hydraulic fracturing. Let's suppose that we know the pre-existing fracture zones obtained by CSP method (yellow areas at the pictures). Let's suppose that we know also the principal stress axis, obtained by SMTIP method during some test

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pre-hydraulic fracturing (shooters in the left bottom corner with an angle α). In such situation there exist two alternatives of designing well trajectory: the first - to direct the horizontal part of well trajectory lengthways (parallel) to pre-existing fracture zones (Figure 6) and second - to direct the horizontal part of well trajectory orthogonal to the direction of maximal stress (Figure 7). In the first case there exists probability the penetration of cracks along well trajectory. On the other hand, in the second case cracks will be orthogonal to well trajectory (good situation), but the drainage area of the pre-existing fracture zones in that case will be smaller.

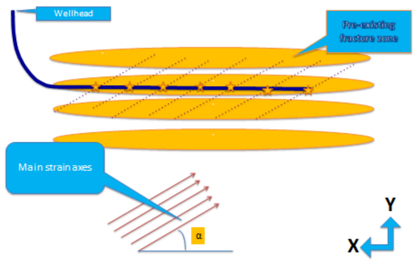

Figure 6: The scheme of planning the horizontal part of a well trajectory for multistage hydraulic fracturing. The case of the maximal using the information about the pre-existing fracture zone.

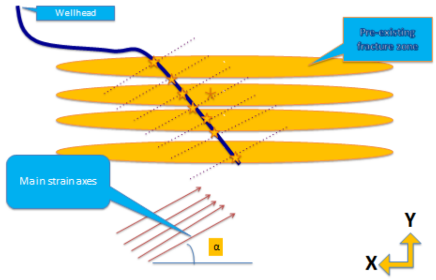

Figure 7: The scheme of planning the horizontal part of a well trajectory for multistage hydraulic fracturing. The case of the maximal using the information about main directions of stresses.

Roadmap for optimization oilfield development

Thus, it is possible to formulate some roadmap of steps for optimal development of tight oil and shale gas. The following steps are represented reasonable:

- Special-purpose processing of 3D CDP data using the CPS method. Obtaining the 3D CSP-reflectors and 3D CSP-diffractors cubes. Attributive processing of 3D CSP-diffractors cube.
- Joint interpretation of both cubes. Detection of heightened scattering zones in shale.
- Detection of faults and pre-existing fracture zones in shale.
- Acoustic impedance attributive processing of the 3D CSP-diffractors cube. Detection of lowered filtration resistance zones.
- Performance of the test pre-hydraulic fracturing. The microseismic data registration based on the surface acquisition system and processing the data.
- Identification of the principal stress axes in shale. Calibration of the SMTIP method for microseismic inversion.
- Trajectory design of the multistage hydraulic fracturing with due consideration of the information on topology of pre-existing fracture zones, GIS data and of the results of microseismic inversion (principal stress axes) of the pre-hydraulic fracturing.
- Performance of multistage hydraulic fracturing. Operational control of all stages based on the results of processing of microseismic data by SMTIP method.

Conclusions

The new complex approach for the optimal development of tight oil and shale gas is proposed. This approach is based on the information about pre-existing fracture zones and principal stress axes. The model of pre-existing fracture zones is built by the CSP method, which deal with the scattered seismic waves. The model of principal stress axes is computed by the SMTIP method during the hydraulic fracturing on the base of registration data of microseismic events and using the surface acquisition system. These models are used for design of well trajectory with the purpose to increase drainage area. Application of suggested approach can significantly reduce the costs of development of tight oil and shale gas.

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EDITED REFERENCES

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REFERENCES

Anikonov, U. E., B. A. Bubnov, and G. N. Erokhin, 1997, Inverse and ill-posed sources problems: VSP.

Erokhin, G. N., and P. B. Bortnikov, 1987, Inverse problem of determination of the earthquake source seismic moment tensor: Geology and Geophysics, **4**, 115–123.

Erokhin, G. N., V. P. Kutov, N. L. Podkolodny, S. A. Fedorov, A. F. Kushnir, and L. M. Haikin, 2002, Computational aspects of seismic monitoring technology of weak earthquakes and explosions on the basis of the solution of a seismic moment tensor inverse problem: Inverse Problems and Information Technologies, **1**, no. 2, 41–67.

Erokhin, G. N., A. N. Kremlev, L. E. Starikov, V. V. Maltcev, and S. E. Zdolnik, 2012, CSP-method prospecting of fracture-cavernous reservoirs in the Bazhen Formation of the Salym Oilfield: 74th Annual International Conference and Exhibition, EAGE, Extended Abstracts, Y028.

Erokhin, G. N., S. M. Mynagashev, P. B. Bortnikov, A. P. Kuzmenko, and S. V. Rodin, 2008, The technique of hydrocarbons deposit hydraulic fracturing monitoring: RU No. 2319177, Bulletin 7.

Kremlev, A. N., G. N. Erokhin, L. E. Starikov, and S. V. Rodin, 2011, Fracture and cavernous reservoirs prospecting by the CSP prestack migration method: 73rd Annual International Conference and Exhibition, EAGE, Extended Abstracts, B024.

DOI http://dx.doi.org/10.1190/segam2014-1037.1