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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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GEOMECHANICAL MODELING OF STRUCTURES OIL AND GAS FIELDS

Abstract. The presence of areas of accumulation of hydrocarbons in the sedimentary strata is genetically related both to the conditions of sedimentation and to secondary changes in the properties of the geological environment, caused along with other and geodynamic processes. At the same time, it is the stress-strain state that is the key characteristic of the environment, the analysis of which makes it possible to predict the influence of geodynamic factors that cause deformation processes in the sedimentary stratum, on the formation of zones of decompaction and increased fracturing, areas of increased filtration-capacity properties of reservoir rocks, the direction of natural migration of hydrocarbons.

Using the example of 3D seismic data obtained at the Akshabulak area, the possibility of integrating geomechanical modeling and additional express analysis of seismic data in solving problems related to determining the probable places of accumulations and directions of natural migration of hydrocarbons is shown.

Key words: math modeling, decompaction zones, seals.

Introduction. The geological environment is exposed to mechanical force fields of various nature and, as a result, is in a certain stress-strain state (SSS). In the general case, at any point in the geological environment, a number of independent force fields act, primarily lithostatic and tectonic fields. There is a wide range of reasons for the occurrence of tectonic stresses. In the conditions of the sedimentary strata, one of the main reasons is the deformation of sedimentary rock layers in the course of their geodynamic evolution.

Today, seismic exploration is the only geophysical method that allows, on the one hand, to perform detailed structural constructions of the studied stratum, which reflects the total deformation that the geological environment experienced during its evolution from the accumulation of sediment strata to the manifestation of modern neotectonics, and on the other based on the analysis of the velocities of propagation of elastic waves and density to give very accurate information about the elastic properties of the medium. Such information, in turn, allows building a geomechanical model, which is a structural model with specified elastic properties. In recent years, researchers have repeatedly noted in their works the possibility of studying the stress-strain state on the basis of structural-velocity models of the medium according to seismic data when solving problems of oil and gas geology [1-7].

Research methodology. The following stages can be distinguished in the development of models:

Stage 1. Creation of spatial models of the distribution of decompaction zones.

The construction of such models can be used at the prospecting stage, since they make it possible to identify, in the section of the studied structure, areas of decompaction, which can be associated with the real spatial position and morphology of possible reservoirs, as well as those elements of the deep structure that can serve as supply channels, migration channels or areas of possible accumulation of hydrocarbons.

To solve this problem, we used data on the distribution of values of travel time of longitudinal seismic waves to the corresponding reflecting boundaries. Spatial representation of the distribution of travel time values, as a carrier of information about the inhomogeneities of the geological environment, makes it possible to identify and establish the position of decompaction zones, which manifest themselves as areas of relatively increased travel time values distributed in the investigated volume of the earth's crust [8].

Stage 2. Construction of a spatial model of a geological section in the parameters of the stress-strain state.

Mechanical and mathematical modeling of the geological environment involves the calculation of a set of parameters of the stress-strain state with a spatial reference of the calculated values. The distribution of the latter in the geological space can be used to solve a wide range of applied problems. Including when performing geodynamic zoning of territories and determining areas of potential energy concentration, identifying zones of increased permeability and assessing the directions of possible movement of fluids, etc.

To calculate the parameters of the stress-strain state, the well-known relations of the theory of elasticity and plasticity are used under the condition of the continuity of the medium, which is expressed in the continuity of stresses and displacements, as functions of the coordinates of the point.

Let us give in general form the basic equations of the theory of elasticity in invariant form, which are used to determine the stress-strain state of rocks.

Equation of motion in invariant form:

$$\rho \frac{\partial^2 \vec{u}}{\partial t^2} = \mathrm{div}(\sigma) + \rho \vec{F}; \qquad (1)$$

Cauchy equations:

$$\varepsilon = \mathrm{sym}(\nabla \vec{u}) \equiv \frac{1}{2}\left(\nabla \vec{u} + (\nabla \vec{u})^{\mathrm{T}}\right);$$

The equation of state for elastic media (Hooke's law), expressed through the Lamé coefficients:

$$\sigma = \lambda \mathrm{trace}(\varepsilon)\mathrm{I} + 2\mu\varepsilon; \qquad (3)$$

where

$$\lambda = \frac{E\nu}{(1+\nu)(1-2\nu)}, \quad \mu = \frac{E}{2(1+\nu)}, \quad K = \frac{E}{3(1-2\nu)}; \qquad (4)$$

E – is the modulus of elasticity; ν – is Poisson's ratio; K – volumetric expansion module.

To get an idea of the possible directions of fluid migration, calculations of the spatial distribution of lithostatic pressure (5) were performed with the subtraction of vertical pressure or pressure under the action of gravity:

$$P_{hydro} = (\sigma_{xx} + \sigma_{yy} + \sigma_{zz})/3 \qquad (5)$$

$$P_{ostat} = P_{hydro} - \rho g h \qquad (6)$$

Stage 3. Development of complex parametric models.

The construction of complex models is aimed at analyzing the correspondence of the distribution of decompaction with the distributions of the parameters of the stress-strain state in the investigated block of the earth's crust. In particular, the identification of areas of low pressure is one of the main conditions for the movement of fluids in the geological environment. Therefore, it seems important to establish their spatial position and link them with the distribution of decompaction zones, which, by definition, can be reservoirs, as well as serve as channels for their migration. The applied methodology was previously tested on the data of regional seismic observations and showed good convergence of the established decompaction zones with the known hydrocarbon deposits of the Caspian region. The main provisions of the proposed method of statistical analysis are given in the works.

Results and discussion. The object of this study was the Akshabulak structure, confined to the Aryskum depression, the thickness of the sedimentary cover is ~ 3 km, including the known hydrocarbon-producing horizons, localized in the depth interval 1.5-2 km from the earth's surface.

To develop density models, isochron and iso-depth maps were used for the next horizons, which made it possible to form the basis of future models (Figure 1):

- roofs of the Aryskum horizon of the Lower Neocomian deposits (II).
- roofs of Upper Jurassic deposits (III);
- intermediate horizon in the Middle Jurassic (IV);
- the surface of the Paleozoic basement (Pz).

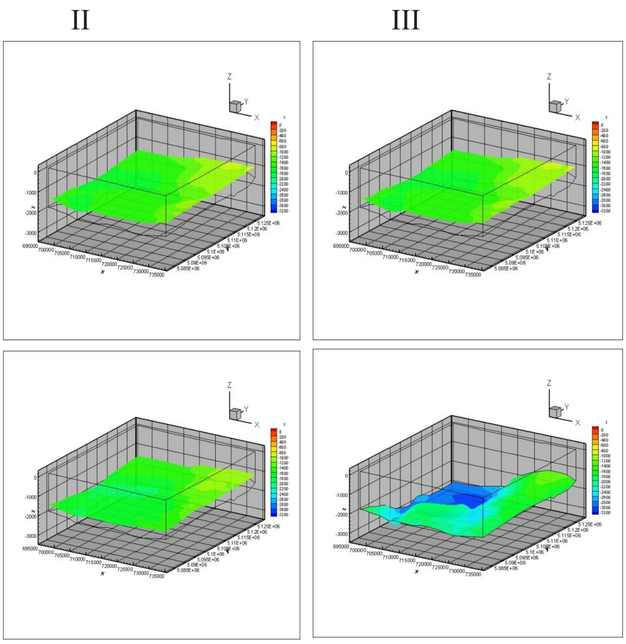


Figure 1. 3D images of iso-depth maps of the Akshabulak structure (Y axis points North)

Features of the spatial distribution of density inhomogeneities.

The analysis of the results of the obtained distribution of travel times was carried out taking into account the known materials [19] about the position in the section of productive strata and tectonic faults.

The model shown in Figure 2 (A) indicates that the Akshabulak structure is a geological object that includes two clearly visible uplifts, to which the Akshabulak and Ashisay deposits are confined. Its section contains relatively decompacted layers, localized at the same depths as the productive horizons.

From the results illustrated in Figures 2 (B) and 4, it follows that the relatively decompressed sections of the section, shown by shades of yellow, stand out in the form of columnar segregations and can function as migration channels that ensure the movement of fluids from the lower horizons to the earth's surface.

A feature of the created models is a very low threshold of the time interval, which is on the order of (- 0.02 +0.03) s at a smoothing depth of 50, which, apparently, can be correlated with the composition of the rocks of the geological section. It is possible that the entire lower half-space is a fluid-saturated stratum separated by natural barriers - fluid seals.

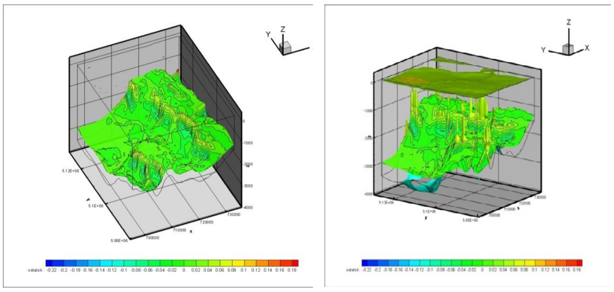


Figure 2. Spatial model of the site – A.
The model of the distribution of zones of decompression in the geological cross-section of the Akshabulak – B.

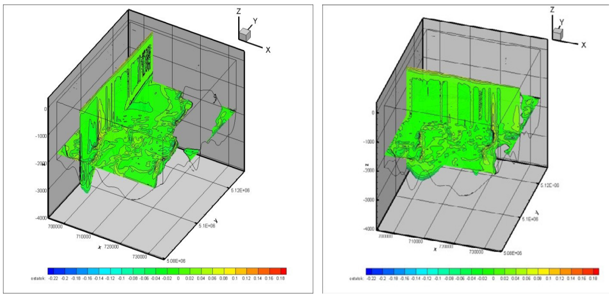


Figure 3. Spatial projection of vertical sections of the distribution of areas with reduced density in the geological section of the Akshabulak structure

Features of the possible direction of fluid flows in the geological half-space.

In order to differentiate the section from the point of view of the geometry of weakened zones and the associated possible directions of migration paths of fluids, including hydrocarbons, it is necessary to get an idea of the spatial distribution of the values of the horizontal component of the lithostatic pressure.

Figure 4 illustrates the distribution of the values of the horizontal component of the lithostatic pressure in the section of the Akshabulak structure, and they indicate that the lower half-space of the geological section is heterogeneous in its permeability. In accordance with the legend on the drawing, the distribution of colors should be interpreted as a decrease in pressure when changing from light blue to blue.

A B

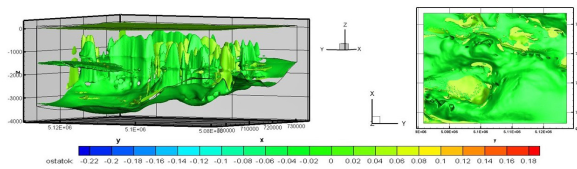


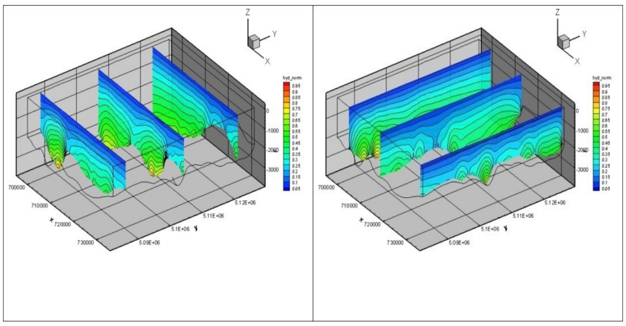
Рисунок 4. An example of the distribution of density inhomogeneities in the context of the Akshabulak structure. A -3D; B – bottom view.

The frontal distribution of reduced pressure (Figure 5) indicates that there are at least two low pressure channels in the investigated half-space, separated by a large area of relatively high pressure. The identified channels spatially coincide with the location of the Akshabulak fields.

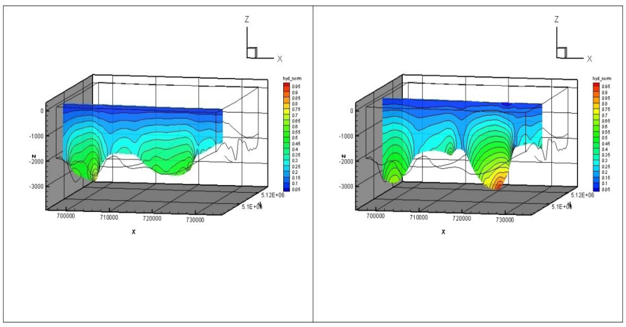
In the presence of conditions for the accumulation of hydrocarbons, due solely to the geostructural features of the site, conclusions can be drawn about the possible ways of fluids entering natural traps.

Attention is drawn to the morphology of the identified areas of reduced pressure. If at the base the section is differentiated laterally with clearly pronounced elements of vertical zoning according to the values of the pressure distribution, then as it rises to the day surface this pattern degenerates with the formation of extensive lateral areas - potential zones of increased permeability. The latter can be interpreted as areas of possible lateral migration of fluids. Provided there is a seal, there is a potential for the formation of a structural trap.

A B



C D



E (h= -1100 m) F (h= -1400 m) G (h= -1800 m)

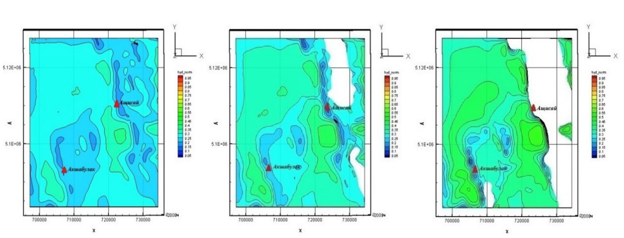


Figure 5. Spatial projections of vertical (A, B, C, D) and horizontal (E, F, G) sections of the distribution of mean pressure values in the section of the structure of the Akshabulak field.

The validity of this assumption is confirmed by the distribution of density inhomogeneities in the above figure 3, 4.

A B

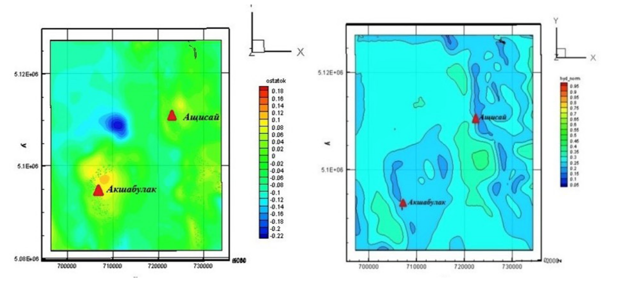


Figure 6. Distributions of mean pressure values (A) and distributions of areas with low density in the section of the structure of the Akshabulak field.

As shown in Figure 6, the distribution of decompaction zones and SSS parameters are correlated with each other, being complementary and mutually confirming data, which make it possible to increase the efficiency of geophysical studies, both at the stage of prospecting and at the stage of exploitation of hydrocarbon deposits.

The main conclusions are as follows.

1. The proposed method for analyzing seismic data allows you to get a visual spatial representation of the properties of the geological environment. In particular, the position of the reservoirs, the supply channels for the migration of hydrocarbons, the identification of new zones of increased permeability. The data on the distribution of the parameters of the stress-strain state also reflect the physical state of the considered volume of the geological environment and can be used to identify and localize possible tectonic faults or weakened zones.
2. A visual representation of the morphology of productive horizons provides a basis for the design of well placement and allows conclusions to be drawn regarding the possible location of new deposits.
3. The proposed methodology can be used as one of the stages of the search and exploration of hydrocarbon deposits in the predicted areas in order to identify productive horizons in the section.

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МҰНАЙГАЗ КЕН ОРНЫ ҚҰРЫЛЫМДАРЫНЫҢ ГЕОМЕХАНИКАЛЫҚ МОДЕЛЬДЕУ

Аннотация. Шөгінді қабаттарда көмірсутектердің жинақталу аймақтарының болуы генетикалық тұрғыдан тұнба жағдайымен де, геологиялық ортаның басқа да геодинамикалық процестермен қатар туындаған қасиеттерінің екінші реттік өзгеруімен байланысты. Сонымен қатар, қоршаған ортаның негізгі сипаттамасы болып табылатын стресс-деформация күйі болып табылады, оны талдау шөгінді қабатта деформация процестерін тудыратын геодинамикалық факторлардың әсерін, ыдырау мен сынудың жоғарылау аймақтарының пайда болуына, су қоймасының жыныстарының сүзілу-сыйымдылық қасиеттерінің жоғарылауына, көмірсутектердің табиғи миграциясының бағытына әсерін болжауға мүмкіндік береді.

Ақшабұлақ учаскесінде алынған 3 өлшемді сейсмикалық мәліметтер мысалын қолдана отырып, көмірсутектердің жинақталған орындары мен табиғи көші-қон бағыттарын анықтауға байланысты мәселелерді шешу кезінде геомеханикалық модельдеуді және сейсмикалық деректерге қосымша экспресс-талдауды енгізу мүмкіндігі көрсетілген.

Түйін сөздер: математикалық модельдеу, декомпрессия аймақтары, сұйық тығыздағыштар.

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ГЕОМЕХАНИЧЕСКОЕ МОДЕЛИРОВАНИЕ СТРОЕНИЙ НЕФТЕГАЗОВЫХ МЕСТОРОЖДЕНИЙ

Аннотация. Наличие областей аккумуляции углеводородов в осадочной толще генетически связано как с условиями седиментации, так и с вторичными изменениями свойств геологической среды,

обусловленными наряду с иными и геодинамическими процессами. При этом именно напряженно-деформированное состояние является той ключевой характеристикой среды, анализ которой позволяет прогнозировать влияние геодинамических факторов, обуславливающих деформационные процессы в осадочной толще, на формирование зон разуплотнения и повышенной трещиноватости, областей увеличения фильтрационно-емкостных свойств пород-коллекторов, направление естественной миграции углеводородов.

На примере 3D сейсмических данных, полученных на участке Акшабулак, показана возможность комплексирования геомеханического моделирования и дополнительного экспресс-анализа сейсмических данных при решении задач, связанных с определением вероятных мест скоплений и направлений естественной миграции углеводородов.

Ключевые слова: математическое моделирование, зоны разуплотнения, флюидоупоры.

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