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NON-UNIFORMITIES OF TERRIGENOUS COLLECTORS DISPLAY AT CONSTRUCTION OF OIL DEPOSIT GEOLOGICAL MODELS

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Questions of display formalization of reservoir lithologic-facies features at geological models construction of oil and oil-and-gas deposits are considered. Process formalization allows building more adequate digital model of geological object. This, in turn, allows to formalize geological model adaptation process as far as data accumulation in process of deposit operation and to optimize extraction of hydrocarbons with application of new technologies.

Actuality

The modern condition of oil and oil-and-gas deposit development is characterized by a number of features [1] which contribute to the development of research, analytical and engineering works at composition of the design-technological documentation. Let us mark only some stimulating introduction of new technologies: a significant degree of preserves depletion of many deposits, high flooding of extracted oil, growth of difficultly extracted preserves share, a big fund of inactive wells, etc. For Western Siberia deposits and, in particular, for deposits of Tomsk area, it is necessary to point out the features of terrigenous collectors characterized by high non-uniformity and weak coordination of filtration-capacitor properties (FCP). The specified features demand improvement of methods and means of operation designing by technology application, such as layer hydrobreak, drilling of horizontal wells, kickoff of lateral stems. Use of computer simulation methods with construction of 3D seismic, geological and hydrodynamical models of reservoirs is perspective. Evolution of computer modeling methods of hydrocarbon deposit development shows increased requirements to construction of productive reservoirs geological models. In particular, all variety of collector filtration-capacitor non-uniformity should be considered in the model, the latter actualizes improvement of approaches to the research in reservoir non-uniformity properties caused by lithologic features of the layer.

Non-uniformities of the reservoir caused by lithologic features of the layer show themselves in their external and internal properties [2]. External properties reflect the facies non-uniformity of collector construction, formation of which is connected, as a rule, with a number of concrete conditions of sedimentation. Each condition has the spatial development where filtration-capacitor properties of the collector can be characterized by individual dependence of porosity and permeability. Formation of impenetrable barriers presented by clay and carbonaceous sandstone interlayers, playing a role of frontal screen for deposits of oil and gas, is peculiar to borders of facies condition section. It is possible to classify its macrofiltration non-uniformity to a section and on the area to collector external properties. In sections it is reflected in consesectionive increase or reduction of granulometric differences influencing values of permeability from the sole to the roof of the layer, or homogeneous, gradational distribution of granularity. The sequence of granulometric distributions on the section, influencing the position and size of an interval of hydrocarbon inflow in volume of the collector, is peculiar to each of the facies condition.

Internal properties of the layer appear in its textural features forming microfiltrational non-uniformity of the collector and describing non-uniformity (anisotropy) of hydrocarbon inflow into the well by the area. The observed variety of the obliquely laminated structures, connected with display of ripples (moon-like, wavy, lenticular), is possible to unite in two big groups – ordered-layered and chaotic. The good consistency of interlayers in one direction and their frequent alternation in perpendicular is peculiar for the ordered group. In chaotic obliquely laminated collectors the consistency of interlayers in any direction is absent. Thereof in the first (ordered) group the spatial anisotropy of filtration takes place, and in the second it is absent.

Formation of terrigenous collectors correct classification technique

In practice of foreign investigations integration of porosity and permeability parameters at description of granular collector FSP is considered in a view of the ***hydraulic stream units (collector)*** concept [3–5], allowing for differentiation of types (classes) of rocks with close characteristic of the pore space. According to the formulation *collector hydraulic unit (stream)* – HU is defined as «***representative elementary volume of rock inside of which geological and petrophysical properties, influencing liquid current, are mutually coordinated and predictedly distinct from other rocks***». Besides petrophysical parameters hydraulic units have spatial development, emphasizing lithologic and facies non-uniformity heterogeneity of the collector. But, at the same time, one type of the collector can be formed in various facies conditions and, on the contrary, there are some hydraulic units of stream within the limits of one facies as a rule. Opportunity of HU to characterize filtration-capacitor non-uniformity of reservoir in space allows choosing it as the base element for design of collector mathematical model.

Determination of stream hydraulic unit is based on calculation of parameter of the hydraulic unit indicator (*FZI*) by porosity and permeability values obtained for specific core samples:

$$FZI = \frac{0,0314\sqrt{\frac{k}{\phi}}}{\frac{\phi}{1-\phi}},$$

where *FZI* is the flow zone indicator of hydraulic unit; ϕ is the porosity; k is the permeability.

The concept of hydraulic units implies that there is a limited number of collector types described by unique average value *FZI* and the disorder of values *FZI* around an average is caused by casual experimental errors. First of all, it is necessary to define the number of such collector types and borders *FZI* for each of them. Procedures developed in terms of the technique of the given direction are focused on the use of available experimental data on core and set of qualitative, graphic and analytical methods. The performed systematization of distribution *FZI* depending on values of reservoir porosity and permeability in view of its pore space non-uniformity (size and similarity of grain form, tortuosity of pore channels and so on) has allowed [6] for development of classification scheme of terrigenous collectors for deposits of Western Siberia on the basis of stream hydraulic units determination. For all the system of terrigenous reservoirs of the investigated deposits the classes of stream hydraulic units having certain ranges, characterized by average values *FZI*, were allocated. The resultant characteristics *FZI* calculated for the layer U_1^3 of the Krapivinskiy deposit are shown in the table.

Practical procedures of collector classification and design of filtration model based on this approach are based on calculation (Fig. 1Б) and the subsequent systematization (Fig. 1Д) of the complex parameter *FZI*. The basic systematization is the determination of the complex parameter *FZI* cumulated frequency (Fig. 1Д) in the graph of the rectilinear sites corresponding to stream hydraulic units (collector classes).

Table. *Characteristics of collector hydraulic units*

HU	*FZI*			ϕ, д.е.	k, мД	Lithologic characteristics
	Min.	Max.	Average			
7	6,00	10,69	7,7	0,190	711	Medium-grained, homogenous, well sorted sandstones
6	3,00	5,99	4,2	0,175	174	Medium-fine-grained, homogenous sandstones
5	1,50	2,99	2,1	0,167	36	Fine-medium-grained sandstones with gradational lamination
4	0,75	1,49	1,10	0,145	5,75	Fine-grained sandstones and aleurolites with interlayers of argillo-carbonaceous detritus
3	0,37	0,74	0,54	0,139	0,92	Sandy-aleurite-argillo differences
2	0,20	0,36	0,3	0,118	0,18	Sandy-aleurolite-argillo differences. Various laminations
1	0,19	0,186	0,164	0,112	0,07	Aleurite-argillo differences. Various laminations

If *FZI* has steady correlation dependences with lithologic, petrophysic, granulometric, geophysical rock properties (Fig. 1А) then classes of collector are connected with hydrodynamic (Fig. 1Б, 1Е) parameters of the layer (capillary curve and relative phase permeability). In a view of stream hydraulic units the correlation of porosity and permeability parameters is considered as a totality of dependences for each of the defined collector classes (Fig. 1Г). It allows defining its permeability more precisely by porosity values and the determined collector class of a collector.

Forecast of reservoir collector properties according to 3D seismic simulation

Nowadays the technology of seismic prospecting data interpretation finds wider application for the purpose of forecasting reservoir collector properties with use of acoustic rigidity calculations (the inversion procedure). Research in physical properties of rocks on core including the Krapivinskiy deposit shows that there is a close connection between acoustic rigidity and porosity of rocks. The given approach allows for study of not only borders of reflecting horizons, but also stratigraphic properties of layers according to seismic simulation and in terms of them for prediction of FCP characteristics. Simulation with application of three-dimensional inversion procedure allows creating a multilayered cube of impedances [6]. (The impedance is a product of speed on density). Application of the specified procedures and techniques of interpretation allows for tracking all layers in a seismic cube and visualizing impedance value for each layer. In the international practice, the application of the given technique for the decision of various problems as a stage of investigation and at the decision of optimization problems of development cycle is common. The use of special interpretational software packages at interpretation of 3D seismic prospecting data (in particular the three-dimensional stratigraphic inversion or analogues) allows for:

- determination of reservoir non-uniformity and distribution of fluids between twowells;
- tracing improvement of vertical resolvability, in particular the allocation of microlayers for development objects;
- correlation between wells parameter values of the layer-collector calculated by acoustic parameters.

These and other functional possibilities of special interpretational packages create new opportunities for application of 3D seismic simulation for horizontal wells design and, in general, for development optimization.

The technology is tested [8] for calculation of inversion on the Krapivinskiy deposit (Fig. 2). For the forecast of filtration-capacitor properties distribution in collector volume the inversion transformations of seismic data, with cube of acoustic rigidity obtaining, were performed. Inversion transformations were performed on the package STRATA of Hampson-Russell Company on 20 prospecting wells, logging curves in which were preliminary edited. During processing the algorithm

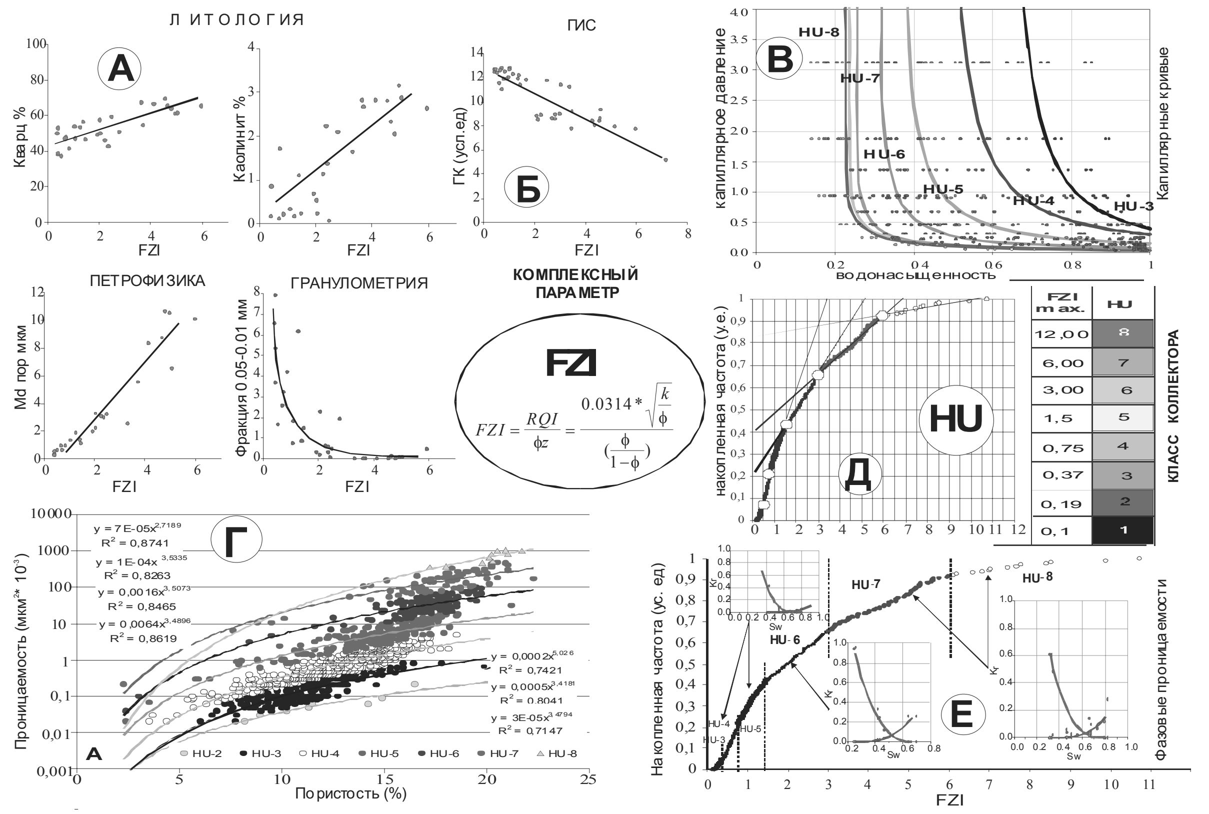

Fig. 1. *Allocation of collector classes on the example of the layer U_1^3 of the Krapivinskiy deposit*

Explanation to Fig. 1:

Литология – Lithology
Каолинит – Kaolinite
ГИС – GIS
Капиллярное давление – Capillary pressure
Кварц – Quartz
Капиллярные кривые – Capillary curves
Водонасыщенность – Water saturation
Петрофизика – Pegtrophysics
Гранулометрия – Granulometry
Комплексный параметр – Complex parameter
Md пор мкм – Pore Md mcm
Фракция – Fraction
Накопленная частота – Accumulated frequency
Класс коллектора – Collector class
Проницаемость – Permeability
Пористость – Porosity
Накопленная частота (усл.ед.) – Accumulated frequency (stand. Unit)
Фазовые проницаемости – Phase permeability

Explanation to Fig. 2:

График пластовой скорости – The layer speeds graph
Баженовская свита – The Bazhenovskaya series
Надугольная толща – Percoal strata
Межугольная толща – Intercoal strata
Подугольная толща – Subcoal strata
Нижневасюганская свита – The Nizhnevasuganskaya series
Карта изопахит высокопроницаемой пачки – The map of iso-pachous high-permeability pack
Высокопроницаемая пачка (Ю$_1^3$) – High-permeability pack U_1^3
Нефть – 316 м³/сут на 8 мм штуцере – Oil – 316 m³/day on 8 mm choke
Низкопроницаемая пачка (Ю$_1^3$) – Low-permeability pack (U_1^3)

Explanation to Fig. 3:

Пористость – Porosity
Акустичечкая жесткость – Acoustic rigidity

of the basic model inversion was used, and impulse selection was carried out in all available wells.

The obtained sections of acoustic rigidity, where high-permeability thickness of beach sandstones was distinctly showed (Fig. 2), testify to possibility of highly productive zones allocation in volume of the layer U_1^3.

The analysis of acoustic rigidity sections showed their suitability for the quantitative forecast of sandy layer collector properties (porosity) in the deposit as a whole. Recalculation of the average acoustic rigidity map (Fig. 3A) into the map of average porosity was carried out on the basis of core-core dependences, constructed according to laboratory researches (Fig. 3Б).

Based on the obtained map of average porosity and character of its change in the section on well data the three-dimensional model of porosity distribution of porosity in the deposit as a whole (Fig. 4A) is constructed. For recalculation of three-dimensional model of porosity into three-dimensional model of permeability (Fig. 4B) the calculated for the Krapivinskiy deposits by attribute of an instant phase the complex parameter *FZI* reflecting dependence of porosity from permeability

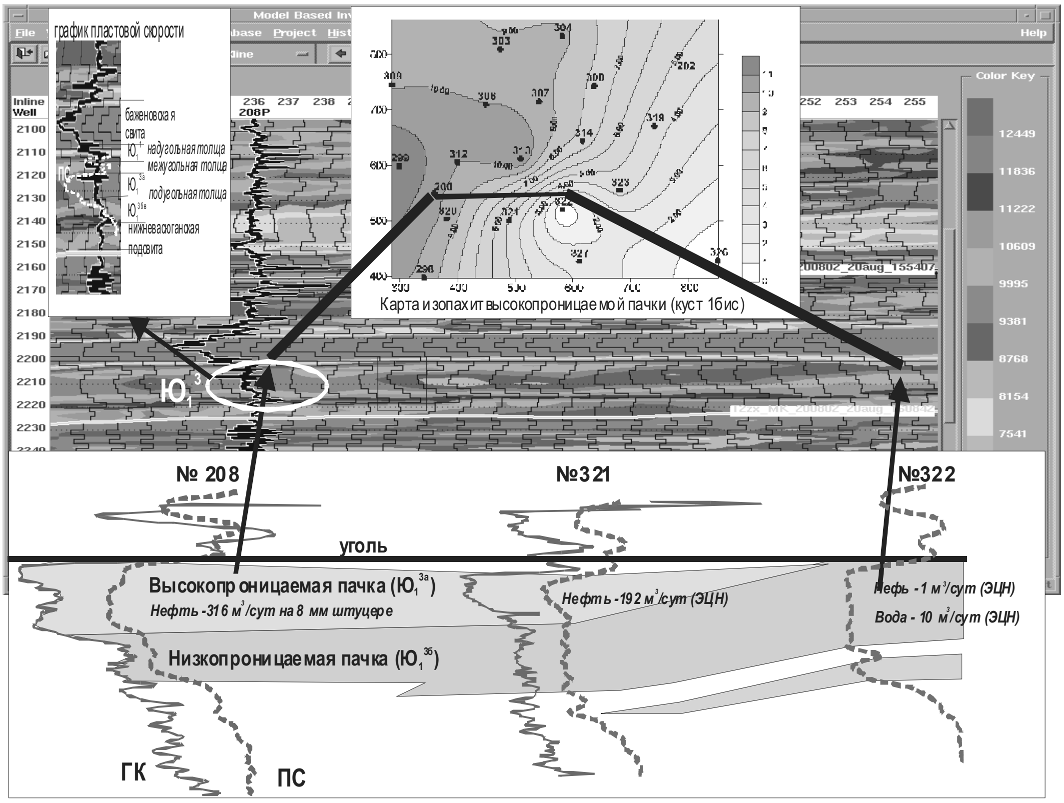

Fig. 2. *Allocation of high-permeability packs in volume of the layer U_1^3 from temporal sections with use of the «inversion» procedure*

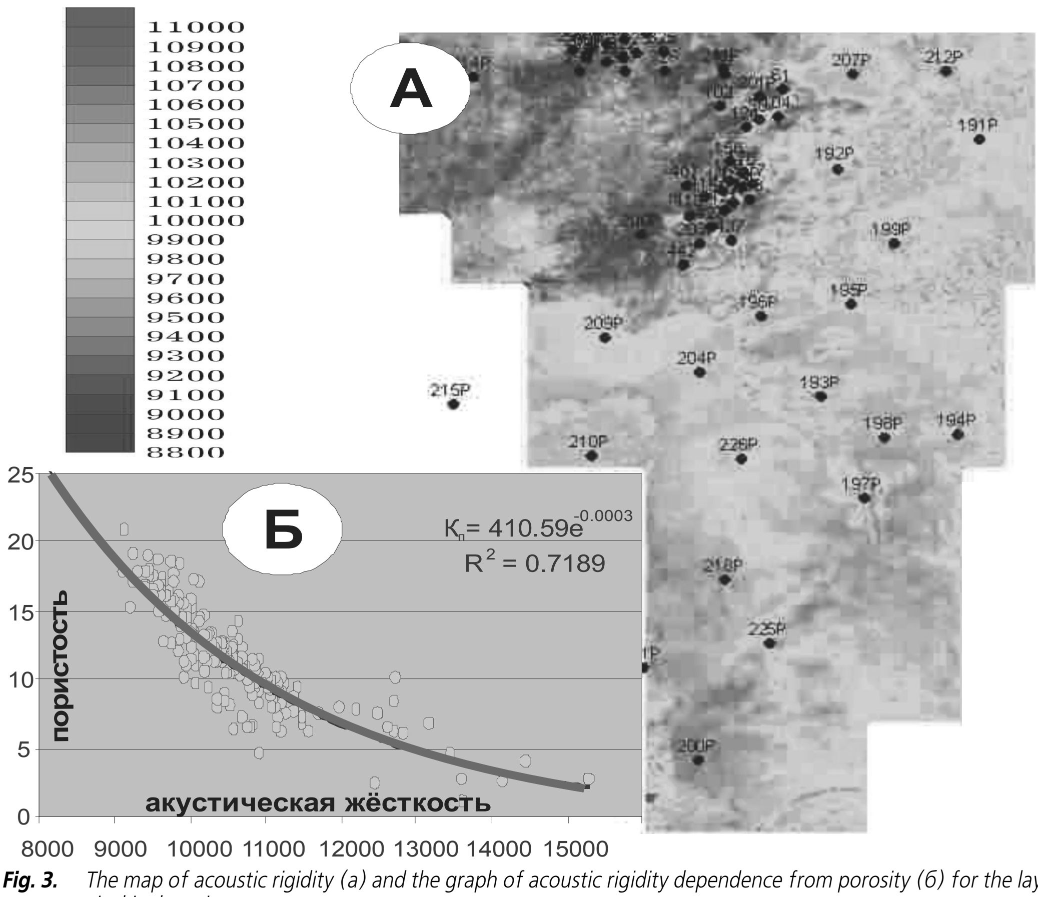

Fig. 3. *The map of acoustic rigidity (a) and the graph of acoustic rigidity dependence from porosity (б) for the layer U_1^3 of the Krapivinskiy deposit*

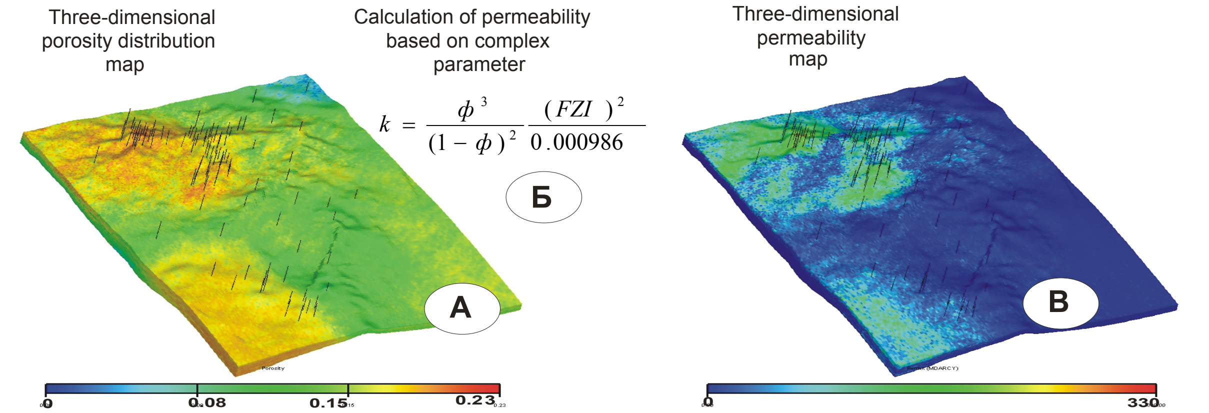

Fig. 4. *Distribution of filtration-capacitor properties in the layer* U_1^3

(Fig. 4Б) was used. Further, the obtained FSP spatial distributions on the layer $Ю_1^3$ were taken as the basis for construction of hydrodynamic model.

Technique of deposit geological model construction

Reflection of reservoir formation geological features in computer geological model assumes development of adequate methods and procedures allowing for the fullest volume of information on reservoir structure. The process of reservoir static geological model simulation taking into account its lithologic-facies structure is supposed to be performed in following stages:

- construction of the lithologic-sedimentation model – revealing of lithofacies and lithotypes, according to GIS data, core research, seismic prospecting data;
- determination of collector types (stream hydraulic units) participating in the structure of the deposit productive layer, simulation of *FZI* indicator for each collector type according to core research;
- design of the petrophysical model taking into account the stochastic distribution of stream hydraulic units within the limits of each facies condition.

Methodical approaches to lithofacies and lithotypes revealing are considered in details with participation of authors in work [9]. Being based on the above described approach of collector type determination and simulation of the *FZI* indicator for each collector type, we shall generate finishing procedure of geological model design. Considering realization of reservoir stochastic model in interwell space for each layer within the limits of each facies condition, the histograms of stream hydraulic unit distribution are formed. The performed *FZI* systematization allows constructing dependence of porosity and permeability on the collector class, there is the opportunity of the collector permeability forecast, if the porosity and number of stream hydraulic unit are determined for the analyzed section point according to GIS data.

Procedures of petrophysical model formation taking into account determination of collector classes provide following step-by-step actions:

Step 1. Formation of model volumetric grid according to existing regulations, Fig. 5A.

Step 2. Determination of collector classes system (stream hydraulic units) in volume of the analyzed layer and boundary values definition of petrophysical and hydrodynamical parameters according to laboratory research data (porosity and permeability, residual water-saturation, relative phase permeability, capillary curves), Fig. 1.

Step 3. Calculation of porosity and permeability individual dependences for the defined lithotypes (lithofacies) according to laboratory research data, Fig. 5E.

Step 4. Calculation of porosity and water-saturation according to GIS data in wells (Fig. 5Б).

Step 5. Forecast of three-dimensional model of collector porosity taking into account the data of seismic simulation (Fig. 5Г), possible variants of realization: 1) correction of porosity three-dimensional stochastic model designed according to the drilling data for separate facies conditions, the card of layer average porosity according to 2D or 3D seismic prospecting (Fig. 5B); 2) design of porosity cube by the technique of 3D seismic simulation data transformation with application of the inversion procedure (described above).

Step 6. Simulation of permeability three-dimensional model (Fig. 5Ж) by three-dimensional porosity cube (Fig. 5Г) with the use of individual filtration-capacitor dependences (Fig. 5B) and specified facies model (Fig. 5Д).

Step 7. Simulation of three-dimensional model of collector classes distribution (Fig. 5K) on the basis of complex parameter calculation (Figs. 53, 5И) by three-dimensional porosity and permeability maps.

Step 8. Taking into account facies characteristics of section defined lithotypes each geological cell, depending on predicted type of lamination (ordered or chaotic) the anisotropy vectors of absolute and phase permeability can be specified.

Thus, the foundation of the petrophysical model is the model of collector class distribution (Fig. 5K). For each cell it allows, on one hand, for determination of hydrodynamical parameters (capillary curves, phase permeability) peculiar to the given class (Fig. 1B, 1E), and the other hand, for correction of permeability, being based on porosity values in the cell (Fig. 5Г) and exi-

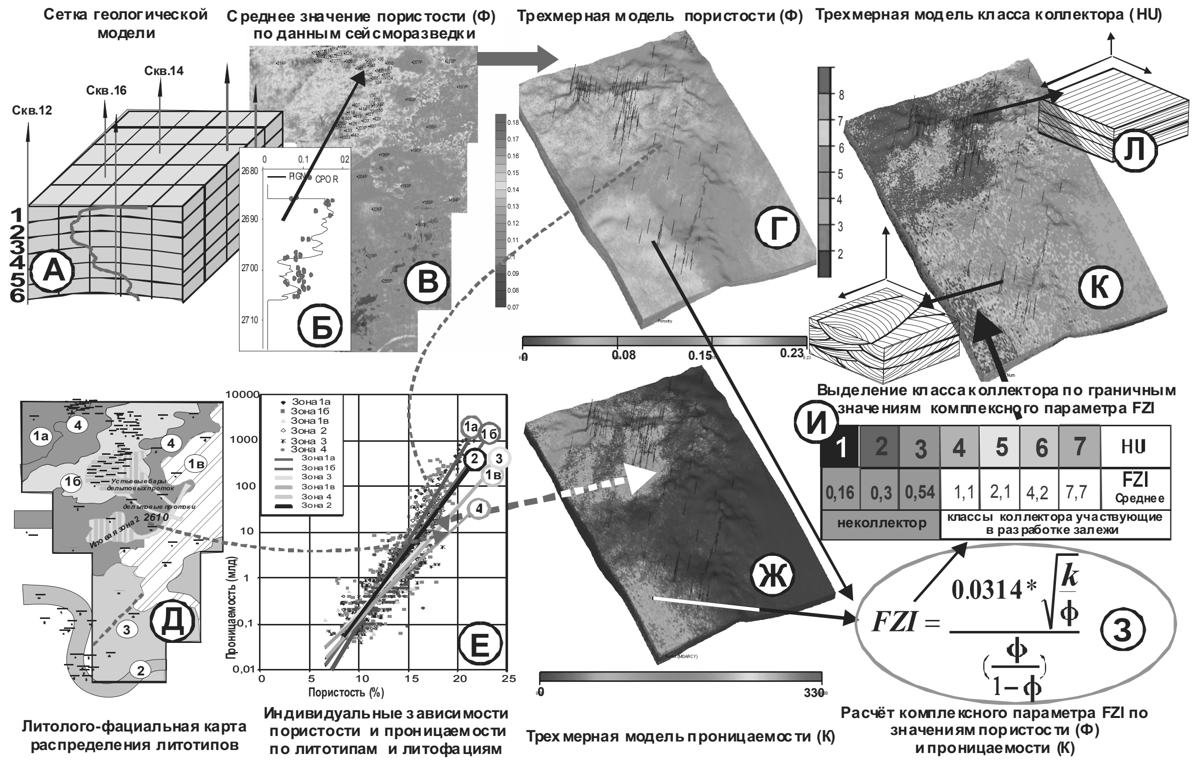

Fig. 5. *Sequence petrophysical model construction*

Explanation to Fig. 5:

Сетка геологической модели – Geologic model grid
Среднее значение пористости по данным сейсморазведки – Average value of porosity according to seismic prospecting
Трехмерная модель пористости – Three-dimensional model of porosity
Трехмерная модель класса коллектора – Three-dimensional model of collector class
Скв. 12, Скв. 16, Скв. 14 – Well 12, Well 16, Well 14
Выделение класса коллектора по граничным значениям комплексного параметра –
Allocation of collector class based n boundary values of complex parameter
Неколектор – Non-collector
Классы коллектора участвующие в разработке залежи – Collector classes participating in deposit development
Литолого-фациальная карта распределения литотипов – Lithologic-facies map of lithotype distribution
Индивидуальные зависимости пористости и проницаемости по литотипам и литофациям –
Individual dependences of porosity and permeability based on lithotypes and lithofacies
Трехмерная модель проницаемости – Three-dimensional model of permeability
Расчет комплексного параметра FZI по значением пористости и проницаемости –
Calculation of FZI complex parameter based on values of porosity and permeability

sting dependences of porosity and permeability from collector class (Fig. 1Г).

Conclusion and summary

Collector structure predetermines dynamics of liquid phase motion of in it; in that case, simulation of geological models of oil fields in view of reservoir structure can essentially raise efficiency and adequacy of computer modeling. Development of the filtration processes simulation techniques in non-uniform collectors make collector non-uniformity formalized description procedures demanded. The designed geological model on the basis of division of collectors on classes of stream hydraulic units allows for the correction of hydrodynamical model in view of permeability change as collector cell class value at constant value of porosity changes. Hences, without changing the size of balance stocks of hydrocarbon deposit it is possible to simulate more effective variant of deposit development in terms of new values of permeability and hydrodynamic parameters.

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INVESTIGATION OF INITIATION CONDITIONS OF RELATIVE DISPLACEMENTS OF THE FAULT-BLOCK MEDIA UNITS UNDER VIBRATION LOADING

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On the basis of computer modeling by the method of movable cellular automata the theoretical investigation of initiation conditions of relative displacements along the interfaces of complex stressed geological media blocks in the complex intense condition under local vibrating loading has been performed. It is shown, that defining factors at formation of unstable shift on the interblock border of fracture-block geological environments are the relative value of shift stresses and also the frequency of vibrating loading, i. e. time of impulse energy allocation. Low in power, but long-continued loadings on influences on high-voltage borders of section are the most effective in respect to power inputs.

Introduction

It is known that geological environments possess the hierarchical multilevel organization of their block structure [1]. Any part of the earth's crust represents a set of structural elements divided by continuity infringements of different scale. Block interfaces have lower strength and deformation characteristics than material of blocks itself. Therefore continuity infringements of various scales are one of the ways of mountain massif existence at greater irreversible deformations [2]. Realization mechanisms of complex stressed geoenvironment elastic energy can be various [3]. The main one among them is localization of irreversible deformations along interfaces of the earth's crust blocks. The mode and speeds of block relative displacements on active fractures are defined by features of structure and the local stressed condition, and also by the external natural and technogenic factors [4, 5]. Values of displacement speeds can fluctuate from several mm/years (crypic mode) up to the first m/s at strong earthquakes. One of the earthquake mechanisms is relative shift movement of blocks. Its realization is connected with achievement of limiting value of shift stresses along the interface. Therefore the relevant problem of geophysics is the definition of initiation conditions of unstable displacement by active interfaces of the earth's crust.

In the present work, on the basis of computer modeling by the method of movable cellular automata (MCA) [6], the investigation of initiation conditions of block dynamic sliding along the interface located in a complex stressed condition under vibrating loading has been carried out. We shall note that during number of years the MCA method is successfully used for studying of response features of complex heterogeneous materials and environments [7, 8].

Problem statement of numerical modeling

For solution of stated tasks on the basis of MCA method the qualitative bidimentional model of section interface of structural elements of block environment, Fig. 1, *a*. has been developed. The model sample consisted of two high-strength blocks divided by the interface area for which the mechanical properties of broken down substances were set. Response functions of block automata and the interface are shown on Fig. 1, *b*. It is visible, that for block automata the response linear function was set, and for the interface the response function had a long irreversible area. Continuity infringements in the interface area, size of which is much smaller than the size of cellular automata, were modeled implicitly through the response function (curve 2 on Fig. 1, *b*). Infringements of greater scale were modeled by setting of unbound pairs of cellular automata in the interface material.

In performed calculations the lower surface of the model sample was fixed, and loadings were applied to the upper surface, Fig. 1, *a*. It is important to note that geological environments are located in the constrained conditions limiting volumetric deformations of blocks, and freedom of their relative moving along interfaces. The pair of environment elements, environment influence of which was brought to increase inertia movements and also to intensive absorption of mechanical loading energy was considered in the work. For imitation of these environment properties on automata of la-