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Research of the Sandy Rocks Stability

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Исследование устойчивости песчаных горных пород

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modeling, sand formations, sanding, bottomhole zone, sanding causes, rock stability, physical model, sanding prediction, geological properties, mechanical properties, filtration properties, strength, input parameters, artificial core, natural core.

Factors influencing the stability of rocks were identified, taking into account changes in saturation and physical and mechanical properties of the reservoir. Existing methods for modeling sandy rocks were considered: empirical, numerical and analytical methods, as well as laboratory modeling. It was concluded that in order to obtain the most accurate prediction of the destruction of the bottomhole formation zone with the subsequent removal of mechanical particles, it was necessary to use a combination of methods, since none of them separately allowed obtaining comprehensive data for the prediction.
The input parameters for modeling sandy rocks were considered. The model should take into account a combination of geological, physical-mechanical and filtration methods, which would make it possible to create the most accurate model of sand reservoirs. The physical model of sandstone can be represented as a set of four components: sand grains, cementing clay substance, water and cracks.
Within the framework of this work, geological properties were analyzed: structure, texture, mineralogical composition and type of void space. The analysis of these properties made it possible to find and determine the relationship between the properties of rocks and their strength characteristics.
The mechanical properties of rocks were considered. These included strength, deformation and rheological properties. To determine the deformation properties of the rock, deformation diagrams were constructed that took into account pre-limit, limit, and beyond limits. The ability of the massif to resist destruction under long-term loading depended on the rheological properties of the rock. These included: long-term strength, creep, stress relaxation.
Within the framework of this work, the prerequisites and causes of sand manifestations in wells were presented. The main ones included: non-consolidation of rocks, excess of compression forces and migration of small particles. An important role in the sanding process was played by the well completion method.
Criteria for the formation of studies on natural and artificial cores were identified.
The results obtained can be used to improve the efficiency of wells in sandy rocks and predict their trouble-free operation.

Ключевые слова:
моделирование, песчаные породы, пескопроявления, призабойная зона, причины пескопроявлений, устойчивость горных пород, физическая модель, прогнозирование пескопроявлений, геологические свойства, механические свойства, фильтрационные свойства, прочность, входные параметры, искусственный керн, естественный керн.

Выявлены факторы, влияющие на устойчивость горных пород с учетом изменения насыщенности и физико-механических свойств коллектора. Рассматриваются существующие методы моделирования песчаных горных пород: эмпирический, численный и аналитический методы, а также лабораторное моделирование. Сделан вывод о том, что для получения наиболее точного прогноза разрушения призабойной зоны пласта с последующим выносом механических частиц необходимо использовать совокупность методов, так как ни один из них в отдельности не позволяет получить исчерпывающие данные для прогноза.
Рассматриваются входные параметры для моделирования песчаных горных пород. Модель должна учитывать совокупность геологических, физико-механических и фильтрационных методов, что позволит составить наиболее точную модель песчаных пластов-коллекторов. Физическую модель песчаника можно представить в виде совокупности четырех компонентов: зерен песка, цементирующего глинистого вещества, воды и трещин.
В рамках данной работы анализируются геологические свойства: структура, текстура, минералогический состав и тип пустотного пространства. Анализ данных свойств позволяет найти и определить зависимости между свойствами пород и их прочностными характеристиками.
Рассматриваются механические свойства горных пород. К ним относятся прочностные, деформационные и реологические свойства. Для определения деформационных свойств горной породы строятся диаграммы деформирования, учитывающие допредельные, предельные и запредельные состояния. Способность массива сопротивляться разрушению при длительной нагрузке зависит от реологических свойств породы. К таковым относятся: длительная прочность, ползучесть, релаксация напряжений.
В рамках данной работы представлены предпосылки и причины пескопроявлений в скважинах. К основным можно отнести: неконсолидированность пород, превышение компрессионных сил и миграцию мелких частиц. Важную роль в процессе пескопроявления играет способ заканчивания скважин. Были выявлены критерии формирования исследований на естественных и искусственных кернах.
Полученные результаты могут быть применены для повышения эффективности эксплуатации скважин в песчаных породах и прогнозирования их безаварийной работы.

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Introduction

To understand the processes of failure of the bottomhole reservoir zones (BHZ) accompanied by the bearing-out of sand particles into the wellbore it is necessary to take into account the failure source, strength and other geomechanical properties of rocks. Today, there is a need to predict the occurrence of this negative process since the selection of the optimal technology for casing the BHZ will minimize sand entry in wells, reduce operating costs and increase hydrocarbon production at the field.

Sand prediction models are created at the design stage or at the beginning of field development and are the basis for selecting the optimal well completion, well design, operating mode, and surface equipment layout.

To create an optimal model of sand formations it is necessary to take into account a number of factors which disrupt the stability of rocks.

The purpose of the work is to identify factors affecting the stability of rocks considering the changes in the saturation and physical and mechanical properties of the reservoir.

Analysis of Existing Methods for Modeling Sand Rocks

Today, the main methods for modeling sand rocks are:

1. Empirical method based on field data. The principle of the empirical method is to predict the dependence of borehole data obtained during sand mining on reservoir field data. Various factors influencing the stability of the rock are taken into account: filtration and capacitive properties of rocks; parameters related to the fluid filtration rate; elastic and strength properties of rocks, etc. [1].

2. Laboratory modeling. This method is based on recreating reservoir conditions in the laboratory and determining the prerequisites for the removal of sand particles. Reservoir cores or bulk models are used as an object of research. It should be noted that this approach depends on experimental equipment, quality and quantity of core material, and is time-consuming [2].

3. Numerical method. The principle of the method is to determine the dependence of the behavior of rocks under the influence of elastic and plastic deformations. The method covers a large number of input parameters, as a result of which it is characterized by high accuracy and reliability, on the one hand, and a large amount of time, on the other [3].

4. Analytical method. The method is based on mathematical calculations and consideration of structural inhomogeneity and stresses and their impact on the stability and strength characteristics of sand rocks [4, 5].

In order to obtain the most accurate prediction of the bottomhole formation zone failure with the subsequent removal of mechanical particles a combination of these methods is used since none of them separately allows obtaining exhaustive data for the forecasting. Besides, this process as a whole is difficult to predict and requires some kind of creative approach [6, 7].

Input Parameters for Simulation Sandy Rocks

All reservoir rocks can be represented as a set of geological, physical, mechanical, and filtration characteristics [1, 8]. They are also influenced by various geological conditions, conditions of development and operation of wells (Fig. 1) [9, 10].

The main physical and mechanical properties of rocks are: plasticity, density, elasticity, strength, hardness, abrasiveness, brittleness, water permeability, etc. [11, 12]. They are determined by the methods of deformable solid mechanics based on the theories of elasticity, plasticity and creep [13, 14].

Such geological properties as structure, texture, mineralogical composition and pore type are decisive. For example G.G. Litvinsky in his work [13] concludes that the process of considering the strength characteristics of rocks is impossible without taking into account structural inhomogeneity. The main defect influencing the strength of the rock, in his opinion, is cracks. Ranging in size from a fraction of a millimeter to several meters, they have a significant impact on the mechanical properties of the rock and the filtration of fluids.

In the work of L.L. Bachurin [15], on the basis of experiments aimed at determining the crack resistance of sandstones, it was concluded that cracks exist in almost all rocks. In his study [16], A.K. Nosach determined that cracks in sandy rocks are formed due to the interpenetration of cement and quartz particles, differences in the plastic properties of rock components, and also arise inside the particles themselves due to the compression of the rock.

To model sand entry it is also necessary to take into account the filtration characteristics of rocks [17]. In fluid mechanics the filtration of single- and multiphase systems in the environment of different homogeneity is considered [18].

The processes of water and sand production are interrelated. The final stage of field development is very often characterized by high water cut due to water breakthrough to the bottom of the well. This process is one of the main causes of sand carry-over. In his work A.G. Latypov explains the destruction of the rock skeleton during water breakthrough by the washing out of the cementing substance and a drop in the coefficient of internal static friction of the rock [19].

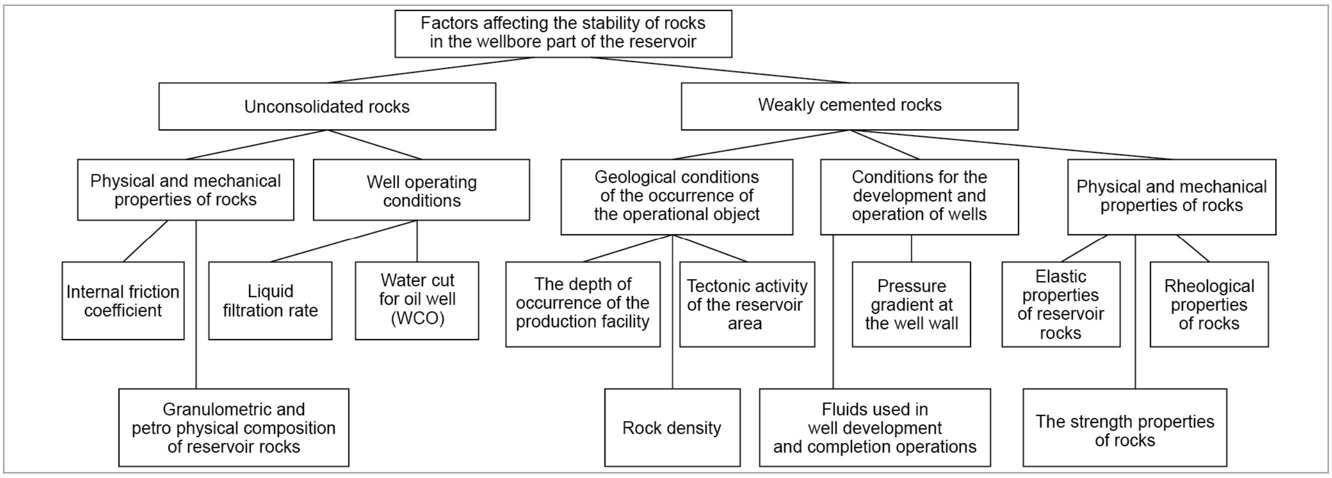

Fig. 1. Factors Influencing Rock Stability [9]

In addition, water, interacting with solid rock, causes a pressure difference, which contributes to the filtration of fluid through reservoir channels. Thus, water is a catalyst for the appearance of new defects in the reservoir, which can lead to its destruction.

In his work [20] A.T. Karmansky analyzes the moisture strength of various rocks (Fig. 2). It has been established that the compressive strength of the rock and the strength under other stress states are inversely related to the amount of moisture in the reservoir. In other words, with an increase of the water content in the rock, its strength decreases and the probability of destruction of the reservoir layer grows up [21].

In the process of modeling sand rock it is necessary to consider the strength of the reservoir as a combination of various defects and imperfections that have different origins and have different influence on the rock.

The model should take into account a combination of geological, physical, mechanical, and filtration methods. All this will make it possible to compile the most accurate reservoir model for predicting withdrawal of sand from sand reservoirs.

Thus, the physical model of sandstone can be represented as a set of four components: grains of sand, cementing clay substance, water and cracks. Sand rock is characterized by stronger sand grains and connecting them much less durable cementing agent. Cracks in combination with water washing out the cementitious substance lead to the strength retrogression of the rock up to critical values [22, 23].

Geological Properties of Sand Rocks

The geological properties of the rocks are determined on the basis of core analysis. The main purpose of studying the core extracted from wells is to obtain information about the geological structure of the reservoir, the location of oil and gas water saturation zones, the position of cap rocks and reservoirs.

The specificity of the core study method consists in the fact that data on the structure of the reservoir can be reliably obtained only in the vertical direction within the core itself (thickness of the formation, its structure). Horizontal data are calculated theoretically, taking into account well cores from an area with a similar geological structure. The selective nature of coring also makes it difficult to study [25].

The main characteristics of sedimentary rocks are: structure, texture, composition, presence and type of void space.

The structure of rocks characterizes the ratio of rock grains, their size and morphology. It is determined macroscopically or using stencils (Fig. 3).

The particle size distribution is the basic parameter for the classification of sedimentary rocks. A popular classification divides clastic particles into groups of sizes 0.01–0.1; 0,1–1; 1-10 mm and so on.

In the core analysis process, another important characteristic of the rock must be taken into account, namely texture. It determines the location of the rock layers relative to each other and the rock as a whole, and like the structure allows you to assess the filtration properties of the reservoir rock.

The process of describing the core texture is divided into two stages:

1. First, the primary texture of the rock (sedimentation) is determined, showing the distribution of layers in the process of sedimentation.

2. Secondary processes that influenced the young rock in the process of its formation and immersion deep into the Earth are taken into account. Based on this, the secondary (superimposed) texture of the rock is determined.

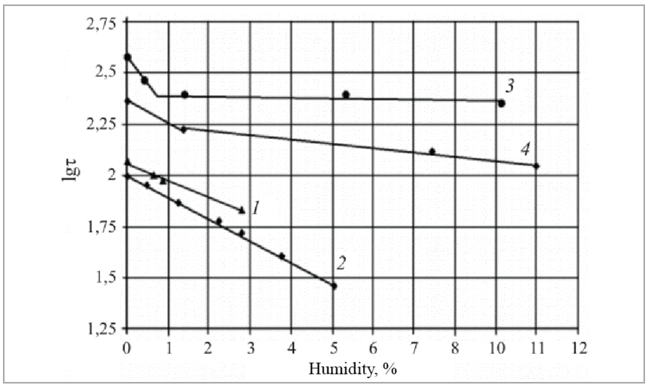

Fig. 2. Graph of the dependence of the logarithm of the shear stress on the moisture content of the rock [21]: lgτ – logarithm of the shear stress; *1* – medium-grained sandstone; *2* – kainite rock; *3* – quartz sandstone; *4* – oil shale.

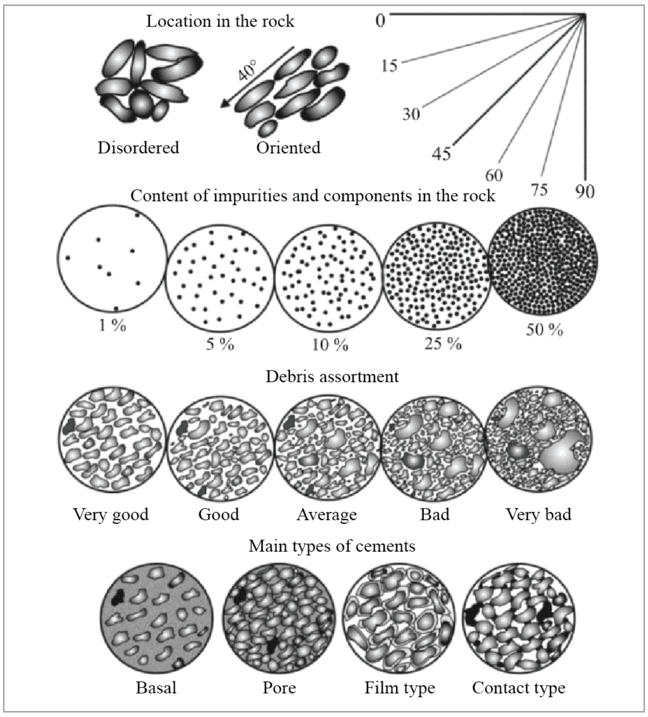

Fig. 3. Stencil for description of terrigenous rocks [26]

The primary textures are: non-layered (homogeneous or inclusions), layered (horizontal, oblique, and wavy-layered) and layered (layers are implicitly expressed).

After macroscopic analysis of the rocks, the composition of the terrigenous rock is specified at the microscopic level.

The cementitious substance is most often represented by clay (kaolinite, chlorite), siliceous (quartz), carbonate (siderite, calcite, dolomite) and ferrous (hematite, iron hydroxides) compositions, less often glauconite and pyrite. The nature and degree of rock destruction under the influence of external forces depends on the composition of the cement.

From the work [27] it can be concluded that the presence of clay material as a binding component is a negative factor for the filtration properties of the formation [28]. The composition of the shales determines the reservoir properties, as well as the nature and degree of rock destruction under the influence of external forces [29, 30].

The void space of rocks is represented by three main types.

1. Pores. It is a very common species in terrigenous rocks. The voids are located in the free space between the grains.

2. Caverns. They are found mainly in carbonate or terrigenous rocks with high carbonate content. They are relatively large voids formed as a result of rock leaching.

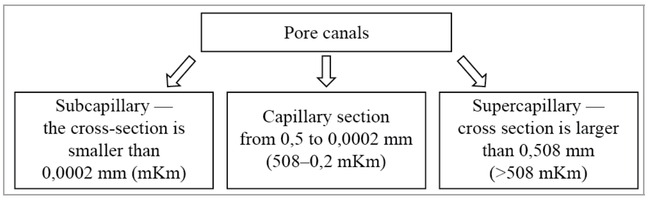

Fig. 4. Classification of pore canals by their size [26]

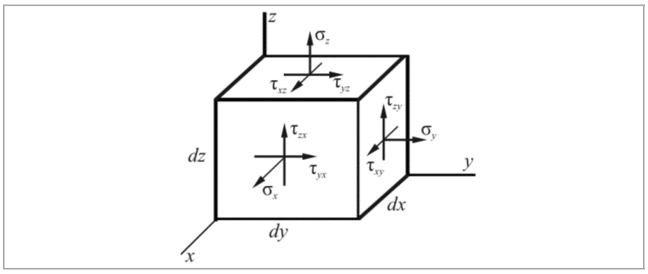

Fig. 5. Components of Stresses Acting on Rock [31]

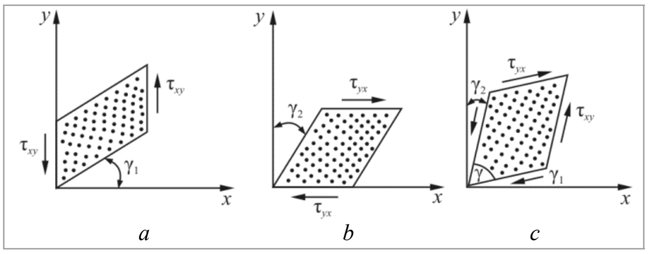

Fig. 6. Shear strain (*a–c*) under the action of Shear Stress Components [31]

3. Cracks. This type of void space is present in all rocks and is the result of tectonic activity. It has a major influence on fluid movement.

As a rule, a rock is a collection of represented types of voids.

Voids are classified into primary (formed during sedimentation and digenesis) and secondary (the result of subsequent processes of destruction, recrystallization, dissolution, etc.).

The main characteristics of the void space that affect the reservoir properties of rocks are the size of pore channels (Fig. 4), the degree of their connectivity and spatial distribution. Based on the analysis of these indicators the type of reservoir in the void-pore space is determined.

Thus, the following geological properties can be identified as input parameters for modeling sand rocks: structure, texture, mineralogical composition, and type of void space. Competent analysis will allow you to find and determine the dependencies between the properties of rocks and their strength characteristics.

Mechanical Properties of Rocks

The rock, experiencing the pressure of the overlying deposits is in a constant state of stress. Various tectonic forces and physicochemical reactions also affect the reservoir rock.

To determine the physical and chemical properties of a rock it can be represented as an elementary volume (Fig. 5). Each face of the volume is affected by normal (σ) and shear (τ) stress components. Normal voltage components act according to the axis perpendicular to the faces, and the tangents lie on the plane of these faces.

The set of these stresses is called the stress tensor and is represented in the form:

$$T = \begin{Bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{Bmatrix}.$$

Due to the action of normal stress components σ rock experiences tension and compression. The tangent components of the stress tensor are responsible for the shear deformation (Fig. 6).

The main mechanical properties of rocks include strength, deformation and rheological.

The strength characteristics of rocks are considered according to the scale of destruction. There are several levels [32]:

1. Megascopic. It appears during open mining of rock masses, during landslides, etc. At this level the main criteria for strength are cracks and large deformations.

2. Macroscopic. This level of fracture is characteristic of the destruction of rocks by various mechanical tools. In this case the strength depends on the porosity, fracturing of the rock, and the contact of different layers.

3. Microscopic. It occurs in case of rocks pulverizing. At this level, the strength is characterized by the presence of microscopic defects and deformations in the rock, since the interconnection of the individual grains that make up the mass is broken.

Since a single rock sample is not able to fully reflect geological deformations in the entire massif, it is introduced the criterion of structural weakening which takes into account the difference in strength characteristics at different levels.

$$R_{сж} = K_с \cdot \sigma_{сж},$$

where $R_{сж}$ – Compressive strength of the entire massif; $K_с$ – coefficient of structural weakening; $\sigma_{сж}$ – compressive strength of an individual sample.

To determine the deformation properties of a rock it is constructed deformation diagrams which take into account pre-limit, limiting, and out-of-limit states [33, 34].

The pre-limiting state of the rock is the state of the rock massif in which destruction does not yet occur under the influence of loads. It is characterized by a modulus of deformation $E_д$, which is always less than the modulus of elasticity E.

A characteristic of out-of-limit state is the modulus of decay M. With an increase in this parameter, the deformation-spatial stability of the rock is violated, its strength characteristics change, and the probability of brittle fracture increases.

The ability of the massif to resist failure under long-term loading depends on the rheological properties of the rock. These include: long-term strength, creep, stress relaxation [35, 36].

The origin of sand occurrence in wells

The spatial stability of sand reservoir rocks depends on a number of factors. The main factors influencing sand occurrence in wells are [37, 38]:

1. Degree of cementation of the sand reservoir.
2. Reservoir fluid viscosity.
3. Depression on the reservoir.
4. Fluid velocity in the reservoir.
5. Stresses in the bottomhole zone of the formation.
6. Bottomhole contamination.

It is possible to systematize the causes of the formation of free sand particles in the reservoir and divide them into three main groups: unconsolidated rocks, excess of compression forces, and migration of small particles (Fig. 7) [39].

An important role in the process of sand production is played by the method of completion of wells [40]. In the case of an open face well, the rock stability of the bottomhole zone is mainly dependent on stresses, including rock pressure and filtration stresses.

In addition, in the cased well the stresses of the "pipe-cement-rock" system come into force [27, 41].

Criteria for the Formation of Studies on Natural and Artificial Cores

Prediction of mechanical characteristics using modern methods of modeling is mainly associated with determining the relationship between various physical parameters [42].

It is possible to predict the behavior of the rock and the removal of mechanical particles from it on the basis of physical modeling. There are two types of physical models of reservoir fluid filtration: laboratory models with artificial porous media (sand, glass beads, etc.) or natural rock samples (cores) [43, 44].

An artificial core is an approximate model of a weakly cemented reservoir. It is created from a mixture of sand, cement and water using ramming or a press [45]. A natural core is a sample of a real geological environment. It is a complete imitation of a collector.

Determination of dependencies for natural or artificial cores will allow you to create a relevant model of reservoir behavior for quick prediction of the probability of sand production taking into account changes in the mode and conditions of operation.

Conclusion

The main input parameters that should be considered in the process of experimental studies aimed at creating mathematical or physical model of sandy rocks have been determined.

For comprehensive and accurate modeling of sand rocks, the following parameters should be taken into account:

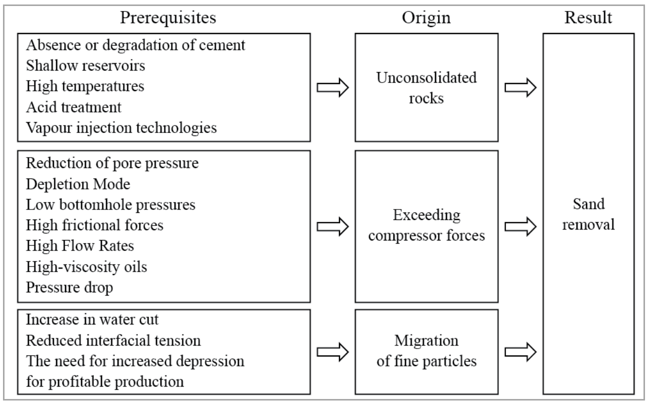

Fig. 7. Prerequisites and Causes of Sand Occurrence in Wells [36]

1. Component composition of the rock (it is necessary to specify the components that will make up the model).
2. Parameters of rock components (ratio of the proportions of sand particles, cementing substances and water to the mass of the entire rock).
3. Sandstone parameters (permeability, porosity, density of sand particles, cementitious substances and water).
4. Geological properties of sandstone (structure, texture, composition, presence and type of void space, etc.).
5. Mechanical properties of sandstone (strength, deformation and rheological properties).
6. Brittleness, plasticity of the rock, nature and parameters of destruction.

Sand modeling studies provide an opportunity to predict the behavior of reservoirs during their operation, as well as predict sand production processes in wells. This will significantly increase the productivity of both one well in particular and the entire field on the whole.

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