Manuscript

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BACKGROUND AND SUPERIMPOSED TYPES OF LITHOGENESIS IN SANDY AND SILTY DEPOSITS OF THE LATE AND EARLY CRETACEOUS (CASE STUDY OF JuS_1^1 BS_{11}^1 CLAY MINERAL STRATA OF KUSTOVOYE OIL DEPOSIT IN WESTERN SIBERIA)

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ABSTRACT of THESIS
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GENERAL DESCRIPTION OF THE THESIS

Relevance of the research. Nowadays the development of resources in West-Siberian region, which are difficult to extract, as well as the so-called residual oil, is an issue of utmost importance. To solve this complex and practically important problem in modern oil-and-gas lithology it is necessary to study thoroughly terrigeneous rocks of the main productive strata that have been objects of oil production for a long time.

It is known that the productivity of species are affected by many factors, among which sedimentological and lithogeneous factors should be considered as the major ones (Alekseyev, 2002; Burlin, Konyukhov et al., 1991; Kuznetsov 2012; Sakhibgareyev 1989; Yapaskurt, 2005 and others.). The first factor implies conditions in which sediments of certain composition and structure are formed. The second one involves the physical and chemical processes that turn the sediment into a rock, which can experience secondary changes as well. It is admitted that sedimentological factor determines mineral composition and structure of terrigeneous rocks to a greater extent than a lithogeneous one, largely being the cause of their emptiness. However, the role of the latter, namely the lithogeneous factor, is often underestimated.

It is well known that fluid penetration into the rock causes the balancing process of different chemical mediums - solid, liquid and gaseous, resulting in the formation of zones for secondary processes, some of which can significantly affect the properties of reservoir rocks. According to many researchers (Ushatinsky, 1981; Sakhibgareyev, 1989 and others), who studied productive strata of oil and gas deposits in the West-Siberian oil-and-gas basin, there is a generally accepted statement that filtration-reservoir properties of rocks are determined by the peculiarities of their structural and material composition. It is also known that fluid distribution in the pore space of sedimentary rocks is greatly influenced by quantitative content and mineral composition of the finely-dispersed component of terrigeneous sediments.

Therefore, the study is mainly focused on the argillaceous cement of reservoir rocks, the composition and spatial distribution of clayey minerals, as well as their impact on the reservoir properties of rocks. The study of the genesis of finely-dispersed component in sandstones and siltstones, namely the main clayey minerals such as kaolinite, chlorite and hydromicaceous minerals, will help to predict most productive and less "risky" zones or areas in the development of deposits.

Objects of the research and factual material. The object of the study were terrigeneous rocks (argillaceous sandstones and siltstones) in productive strata of the Late Jurassic JuS_1^1 and the Early Cretaceous BS_{11}^1 of Kustovoye oil deposit, which is located at the junction of Nizhnevartovskian and Surgutian Arches, i.e. the positive structures of the first order (Shpilman, 1998; Kontorovich, 2004).

The dissertation is based on the results of complex lithologial-and-petrophysical studies of core carried out in the laboratories of the "KogalymNIPIneft" Center for Core Studies and Strata Fluids, a branch of LTD LUKOIL-Engineering in Kogalym City. The material from 26 wells of more than 700 linear meters was studied in the course of the work. The results of more than 800 samples were systematized by the author, including more than 100 thin sections, more than 500 determinations of mineral and granulometric composition of rocks, and more than 700 determinations of their petrophysical properties. More than 100 samples were tested by scanning electron microscopy.

Research methods and techniques. The research methods applied for core material involved macroscopic study of core, its correlation with GIS data, sample selection for petrographic analysis, scanning electron microscopy, electron probe microanalysis, granulometric and X-ray analysis, including the determination of the degree of crystallinity and filtration-reservoir rock properties. The results of the research were compared with the geological and production data by using statistical methods for their processing.

It is assumed in the dissertation that the main factors, that determine the reservoir properties of rocks, are sedimentogenesis and lithogenesis, including secondary changes of superimposed character (Yapaskurt, 2008 and others). Their role was assessed in view of geological and historical approaches.

The objective of the research. The objective of the work is to reveal the influence of the background and superimposed types of lithogenesis as the key factors in the formation of reservoir properties of productive strata in clayey minerals of sandy and silty rocks.

The main goals of the study:

1. Determination of lithological and petrophysical characteristics of sandy and silty rocks.

2. Finding the cause-and-effect relationships between the identified lithological-and-mineralogical and reservoir parameters of sandstones and siltstones.

3. Identification of influence of the background and superimposed types of lithogenesis on reservoir properties of the rocks.

4. Assessment of impact of clay minerals in sandstones and siltstones on the efficiency of productive strata development.

Scientific novelty:

1. The research suggests the determination of morphological, chemical and structural peculiarities of clayey minerals, sandstones and siltstones.

2. The author proposed morphological-and-genetic typification of clayey minerals in sandstones and siltstones.

3. The impacts of background lithogenesis (catagenesis) and secondary changes of superimposed character in the formation of reservoir properties of argillaceous sandstones and siltstones were revealed in the dissertation.

The practical significance:

1. A lithologic-and-technological typification of productive strata rocks was suggested.

2. Lithologic-and-technological schemes of the deposit productive strata were constructed on the results of clay minerals under study.

3. The influence of the selected lithologic-and-technological rock types of productive strata on the commercial efficiency of their development was revealed.

Statements to be proved:

1. Morphological and genetic typification of clayey minerals of cement in sand and silty rocks was carried out on the basis of optical-microscopic, electron-microscopic and X-ray researches. Two morphological genetic types, which differ in morphology, spatial arrangement of grains, degree of crystallinity, chemical composition and their origin, were revealed for every clayey mineral (kaolinite, chlorite, and hydromica).

2. According to interpretation of the results of granulometric composition of clayey sandy and silty rocks, the quantitative composition of clayey minerals and reservoir properties of rocks, the impact of sedimentation and background lithogenesis on the one hand and secondary changes of superimposed character (superimposed

lithogenesis) on the other hand on the formation of reservoir rock properties was determined.

3. Comprehensive consideration of the laboratory findings of core and production data allowed us to establish the influence of the clayey component mineral composition in productive strata rocks on the economic indices of their exploitation. It was shown that zones of rock development with a high content of kaolinite as a mineral of the least swelling are the most favorable for the development.

Presentations and published works. The main propositions of the dissertation were presented at All-Russia and international meetings and conferences: "Mathematical Modeling and Computer Technologies in Field Development" (Ufa, 2012); All-Russia Lithological Meetings (Kazan, 2011, St. Petersburg, 2012, Novosibirsk, 2013), the Ural Lithological Meetings (Yekaterinburg, 2012, 2014), the 3rd International Conference "New Geotechnologies for Old Provinces" (Tyumen, 2013); at the Annual Conferences of Young Professionals and Young Scientists of the "KogalymNIPIneft" branch of LTD LUKOIL-Engineering in Tyumen (Tyumen, 2011-2014). Besides, the materials of the dissertation were presented at the annual scientific conferences "Ways of Implementation of Oil-and-Gas and Ore Potential in Khanty-Mansi Autonomous District - Yugra" (Khanty-Mansiysk, 2011, 2012, 2013, 2014) and «XIII Conference of Young Professionals Working for the Companies Involved in Using Mineral Resources in the Territory of Yugra "(Khanty-Mansiysk, 2013). The research resulted in 15 published works, including 3 peer-reviewed papers by recommended Higher Attestation Commission of the Russian Federation.

Original contribution of the author. The author personally systematized the results of laboratory researches of core, which became the basis for lithologial and petrophysical description of core section. In addition the author selected core samples and personally held their X-ray, optical microscopic and electronic microscopic studies. The analysis of geological and field information was carried out as well.

The reliability of the results. The reliability of the results is determined by significant amounts of the examined core material and analytical studies, reproducibility of the results obtained, contemporary knowledge of laws of terrigeneous sediment formation applied in data interpretation including sedimentogenesis, background lithogenesis and secondary changes of superimposed character.

Structure of the work. The dissertation consists of introduction, five chapters and conclusion. It numbers 136 pages, including 64 figures and 6 tables. The list of references which covers both Russian and foreign publications consists of 175 items.

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SUMMARY OF THE THESIS

INTRODUCTION

The introduction of the thesis deals with relevance of the work, the objectives and goals of the research. The scientific novelty of the dissertation, its practical importance, and the basic statements to be proved are formulated in the beginning. The objective of the research and factual data, methods and research techniques as well as the reliability of the work are substantiated in the part of the thesis. The author gives information about the research presentations and her original contribution to the study. The author also expresses her gratitude for given advice and recommendations in the introductory part of her dissertation.

1. GENERAL INFORMATION ON SPRAY DEPOSIT AND ITS GEOLOGICAL STRUCTURE

The development of Western Siberia began in the last century, in the late 1940s - early 1950s. A great contribution to the study of the tectonics of the region was made by V. S. Bochkaryov, O.G. Zhero, A.E. Kontorovich, N.N. Rostovtsev, M. Ya. Rudkevich, V.S. Surkov, N.P. Tuayev, D.F. Umantsev, V.I. Shpilman and others. The lithology and mineralogy of the Mesozoic deposits of Western Siberia because of their oil and gas has been studied by such researchers as L.G. Vakulenko, F.G. Gugari, T.I. Gurova, A.V. Yezhova, Ye.A. Zhukovskaya, O.G. Zaripov, Yu.P Kazansky, A.D. Korobov, N.M. Nedolivko, G.N. Perozio, Ye.A. Predtechenskaya, R.S. Sakhibgareyev, Z.Ya. Serdyuk, I.N. Ushatinsky, O.V. Yapaskurt, P.A. Yan, and others.

According to the regional stratigraphic scheme of Mesozoic and Cenozoic sediments of the West Siberian Plain dated the year of 2004, the rocks under study belong to the Upper Jurassic and Lower Cretaceous. Major oil-bearing intervals are confined to the upper structural-tectonic floor of the West Siberian Plain, which was formed in the Mesozoic-Cenozoic time in a long steady sagging of the area.

Kustovoye oil field was discovered in 1984. Tectonically it is located in the southwestern part of the North-Vartovskian megaterrace (I-order structure), in the zone of its junction with the Nizhnevartovskian arch, Surgutian arch and Yuganskian megabasin (Shpilman, 1998) (Fig. 1). The megaterrace in the area of exploration is complicated by Vatëganskian rampart and Mogutlorskian trough. The field is located in Surgut oil-and-gas region in the Middle-Ob oil-and-gas field, where five oil-and-gas complexes can be singled out: Lower-Middle Jurassic, Vasyuganian, Bazhenovian, Achimovian and Neocomian. The rocks of oil-bearing productive strata JuS_1^1 and BS_{11}^1, standing out in volume Vasyuganian and Neokomian and oil-and-gas complexes respectively are studied in the dissertation.

Figure 1. Tectonic Setting of Kustovoye Deposit

JuS_1^1 BS_{11}^1 strata are represented by sandstones and medium-and-fine-grained, fine-grained siltstones and fine-coarse-grained siltstones, the rocks being pore-type collectors. The mineralogical composition of the terrigeneous sandstones and siltstones is polymictic and corresponds to greywacke arkoses.

One should say that, despite the fact that abovementioned strata are well-studied as collectors, there are many important practical questions of the influence of clayey minerals on the petrophysical properties of rocks and effectiveness of their development, which are still open.

2. THE RESEARCH METHODS AND TECHNIQUE

At the preliminary stage of the research a macroscopic description and photographs of core correlated by depth were made in accordance with GIS data. This is followed by selection of representative samples for further laboratory studies.

Methods of interpretation of the obtained experimental data are based on the following assumptions. The term "lithogenesis" is currently understood in two ways. On the one hand, it includes all stages of the formation of sedimentary rocks - hypergenesis, material transportation, sedimentogenesis, diagenesis, catagenesis and metagenesis (Strakhov, 1960-1962). N. V. Logvinenko (1968), V.N. Kholodov (1983), V.N. Shvanov (1988) and others share the same point of view. On the other hand, it implies only the stages of sedimentary process, which are unified by common term "rock formation" - diagenesis, catagenesis, metagenesis and secondary changes of superimposed character (Makhnach 1989, 2000; Morozov, Kozina, 2007; Sedimentary Basins ... 2004; Kossovskaya, Shutov, 1971; Timofeyev, Kossovskaya et al., 1974; Yapaskurt 2005 et al.). The preference is given to the latter in this thesis.

There can be background and superimposed lithogenetic changes in sedimentary strata (Sedimentary Basins ..., 2004). The background lithogenetic changes (diagenesis, catagenesis, and metagenesis) cover large volumes of sedimentary strata and are found everywhere. The factors of such changes, first of all, are temperature and pressure, which increase with depth. Fluids of sedimentary nature or those formed by defluidization of sedimentary rock components play an important role in such changes. The changes are often isochemical, but under defluidization of rocks they can also be non-isochemical due to fluid migration.

As a rule the superimposed type of lithogenesis as opposed to the background type leads to non-isochemical transformation of rocks that mainly happen locally. The maximum changes herein are usually observed within the apical (arched) parts of elevations that are more permeable to the ascensive fluids (Faif, Prais et al., 1981), or fracturing zones.

Both in case of background and superimposed types of lithogenesis a rock undergoes changes, which are often called post-sedimentary. Post-sedimentary changes in terrigeneous rocks of the region were classified as background and superimposed by V.P. Morozov in accordance with the criteria proposed in his dissertation (2009).

The criteria by which post-sedimentary changes in terrigeneous rocks are considered to be background processes of lithogenesis includes their ubiquity, the absence of spatial connections of changes in tectonic structures, and the absence of spatial connections of changes in areas of oil- or water-saturated rocks and so on.

The criteria by which post-sedimentary changes in sedimentary strata are regarded as secondary processes of superimposed nature imply import of substance causing the metasomatic alteration of rocks, certain spatial localization of process caused by lithological and tectonofluid dynamic factors, and secondary minerals or their parageneses, which are atypical for a particular stage of background lithogenesis.

3. THE MORPHOGENETIC TYPIFICATION OF CLAY MINERALS, SANDSTONES AND SILTSTONES

The morphogenetic typification of clayey minerals in sandstones and siltstone is based on the data of electro-microscopic and radiographic studies, as well as the determination of the chemical composition of minerals. They were carried out in accordance with results of macro- and microscopic research of core samples and alongside the data identifying the reservoir properties of the rocks.

Among clayey minerals, which play the role of cement in sandstones and siltstones of productive strata, one can find kaolinite, chlorite and hydromica, the content of which does not exceed 10-15%. According to the radiographic researches the latter contains up to 10% smectite component.

Two morphological types of kaolinite appear in the analyzed sandstones and siltstones. The first type is represented as closely packed xenomorphic grains (Fig. 2, point 1). The second type of kaolinite, which differs from the first in greater crystallinity, has the form of vermiculite-like aggregates of pseudohexagonal morphology; the crystals are euhedral or less often subhedral, their grains being loosely packed (Fig. 2, point 2). This kind of kaolinite is more common in terrigeneous rocks with higher reservoir properties.

The second morphological type of kaolinite presents in the parts of rocks where corroded grains of feldspar and idiomorphic grains of quartz are found (Fig. 3).

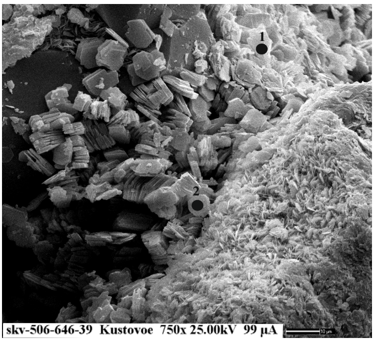


Figure 2. Morphological variations of kaolinite: 1st point - anhedral grains; 2nd point – pseudohexagonal grains

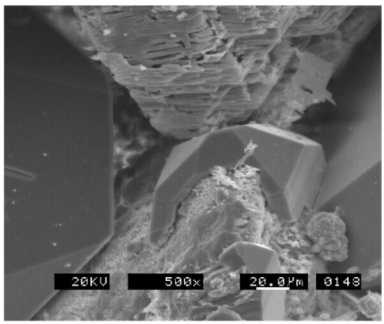


Figure 3.Dissolution of feldspar and quartz grains regeneration

Therefore, it can be admitted that the formation of the kaolinite is caused by dissolution of feldspar and can be accompanied by quartz regeneration. According to calculations, the process of complete transformation of potassium feldspars into kaolinite results in increased porosity by 46% if the silica is not spent for the regeneration of quartz, or by 12% if all silica is spent for regeneration of quartz. Due to this process the porosity increase in rocks is lower since according to the optical-microscopic research the feldspars’ content in clastic component is less than 50%. This fact explains high values of porosity and permeability of rocks with increasing content of the second variety of kaolinite in them.

Chlorite can also be of two morphological types (Fig. 4). The first type forms dense aggregates with subparallel arrangement of xenomorphic grains and according to the determined chemical composition differs from the second type in lower ferruginous content. The second-type chlorite forms well-crystallized particles presented as membranes and crustified margins on clastic grains. The grains are usually subhedral, aggregates being loosely packed.

Hydromicaceous minerals can also be of two morphological types (Fig. 5). Their dense aggregates (the top of the picture) are very widespread. They are composed of laminar particles with uneven side surfaces that provide dense arrangement of grains. The other ones (the center of the picture) are quite rare and have laminar loosely arranged filiform grains.

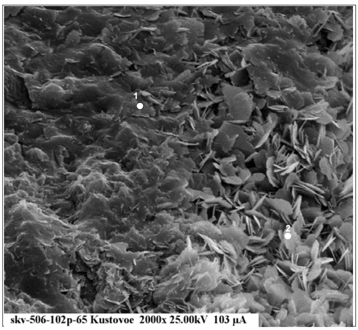


Figure 4. Morphological variations of chlorite: 1st point - anhedral grains; 2nd point - subhedral grains

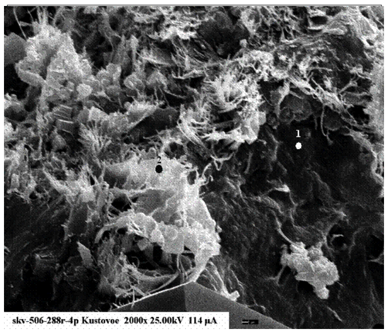


Figure 5. Morphological variations of hydromica minerals: 1st point - anhedral grains; 2nd point - plate-filamentary grains

It should also be noted that, according to X-ray analysis, there are smectite layers in the structure of minerals, which are identified by asymmetry of diffraction reflections of d = 10Å and the changed degree of asymmetry in samples with ethylene glycol and their ignition.

The morphological type of clayey minerals with loosely-packed grains and better-shaped particles is often found in the rocks of increased porosity, and another morphological densely arranged type with xenomorphic and laminar particles is common in rocks of low porosity. In other words, the degree of euhedral clayey particles increases from the rock spots of low porosity to the sites where porosity is much greater.

The study shows that the origin of the identified species of clayey minerals in our opinion can be defined quite strictly by morphological and chemical characteristics and the degree of crystallinity.

The euhedral grains of clayey minerals indicate their authigenic origin, i.e. the abovementioned minerals are newly-formed either during catagenesis, or as a result of secondary superimposed processes. They can be formed either by dissolution of other minerals or by recrystallization of sedimentary grains of the same mineral.

The established facts of co-presented second-type kaolinite, partially dissolved feldspar grains and regenerated quartz grains evidence that the kaolinite grains are newly formed. Their appearance, in our opinion, is caused by implementation of secondary superimposed changes.

The absence of both dissolution features of some grains and crystallization of the other grains near the second-type chlorite and hydromicaceous grains suggests that their formation was caused by recrystallization of sedimentary types.

Densely arranged xenomorphic grains of clayey minerals (the first morphological types of kaolinite, chlorite and hydromica) have signs of their sedimentary origin.

Thus, according to the results of the research, morphological-and-genetic typification of clayey minerals can be suggested (Table. 1).

Material of the chapter justifies the first proposition of the dissertation.

4. LITHOLOGICAL FACTORS OF RESERVOIR PROPERTIES' FORMATION IN TERRIGENEOUS ROCKS

The conclusions made in this chapter are based on the results of statistical data processing of granulometric analysis of rocks, their porosity and permeability, as well as the content of clayey minerals.

Table 1

Morphological and genetic typification of clay minerals

Minerals	Name of type	Morphological features	Grain arrangement	Place localization in clastic rocks	Genesis
Kaolinite	Xenomorphic type	Anhedral grains	Dense	In dense rocks	Sedimentogene
	Idiomorphic type	Vermiculitelike aggregates of pseudohexagonal grains	Loose	In porous rocks	Secondary mineral formed by superimposed processes (feldspar kaolinitization)
Cholite	Xenomorphic type	Xenomorphic grains	Dense	In dense rocks	Sedimentogene
	Subhedral type	multiple laminar grains	Loose	In porous rocks	Catagenetic mineral formed by recrystallization
Hydromica mineral	Xenomorphic laminar type	Xenomorphic grains	Dense	In dense rocks	Sedimentogene
	Laminar-filiform type	Laminar filiform grains	Loose	In porous rock sections	Catagenetic mineral formed by recrystallization

Note: identified morphological variations also differ in the degree of crystallinity and chemism (see. in the text)

The data obtained in Chapter 4 was also taken into account.

The relationship between permeability and porosity of JuS_1^1 and BS_{11}^1 strata sediments is not strictly exponential (Fig. 6). The highest discrepancy of these relationships is marked by high values of porosity and permeability, which can be clearly seen on the right side of the graphs. It indicates multifactorial relationships that can be defined as sedimentary-catagenetic processes (background lithogenesis) and secondary superimposed changes (superimposed lithogenesis). We draw up other diagrams, which let us assess the impact of each factor on the reservoir properties of rocks to determine the influence of them.

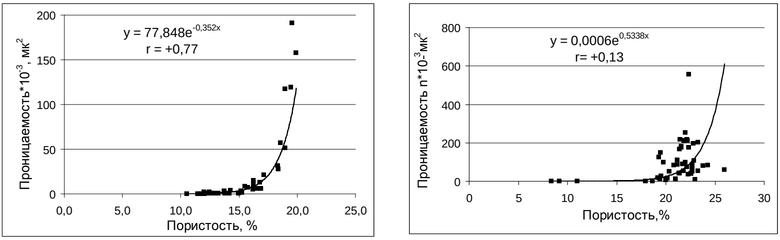


Figure 6.The graphs of permeability versus porosity: stratum JuS_1^1(left) and stratum BS_{11}^1 (right)

However, it is not possible to include a large number of diagrams in the abstract of thesis, so the summarized data is given in Table 2.

The analysis of the Table shows that there are both positive and negative connections between the collector properties of clastic rocks, their granulometric composition and content of clayey minerals. Interpretation of Table 2 may be based on factors, which determine the reservoir quality of sandstones and siltstones (Table. 3). They include, on the one hand, sedimentogenesis, diagenesis and catagenesis, and on the other - secondary changes of superimposed character.

So for example, sedimentogenesis and the following stages – diagenesis and catagenesis determine positive relationship between porosity and permeability on the one hand, and the median grain size on the other. The relationship is positive, i.e. porosity and permeability increase when the median grain size increases. This answers mechanogene sedimentation. Such appropriateness cannot change in the process of diagenesis and catagenesis in general. Reversed relationships, i.e. negative connections between the porosity and permeability on the one hand and sorted grain ratio on the other, also corresponds the.

Table 2

Values of correlation coefficients between the reservoir properties of rocks, their granulometric composition and the content of clayey minerals

	Porosity, %	Permeability $n \cdot 10^{-3}$ мкм^2	Md, mkm	So	Pelitic fraction, %	Kaolinite content in PF, %	Chlorite content in PF, %	Hydromica mineral content in PF, %
Porocity, %		+ 0,77 + 0,13	+ 0,68 + 0,20	– 0,28 – 0,05	– 0,54 – 0,23	+ 0,69 + 0,10	– 0,62 – 0,09	– 0,69 – 0,13
Permeability, $n \cdot 10^{-3}$ mkm^2	+ 0,77 + 0,13		+ 0,48 + 0,64	– 0,28 – 0,27	– 0,52 – 0,06	+ 0,55 + 0,42	– 0,57 – 0,43	– 0,49 – 0,53
M*d*, мкм	+ 0,68 + 0,20	+ 0,48 + 0,64		– 0,41 – 0,43	– 0,66 – 0,37	+ 0,81 + 0,59	– 0,73 – 0,60	– 0,80 – 0,60
So	– 0,28 – 0,05	– 0,28 – 0,27	– 0,41 – 0,43		+ 0,76 + 0,57	– 0,07 – 0,09	+ 0,03 + 0,08	+ 0,12 + 0,12
PF content, %	– 0,54 – 0,23	– 0,52 – 0,06	– 0,66 – 0,37	+ 0,76 + 0,57		– 0,44 – 0,09	+ 0,45 + 0,11	+ 0,41 + 0,06
Kaolinite content in PF, %	+ 0,69 + 0,10	+ 0,55 + 0,42	+ 0,81 + 0,59	– 0,07 – 0,09	– 0,44 – 0,09		– 0,91 – 0,99	– 0,97 – 0,99
Chlorite content in PF, %	– 0,62 – 0,09	– 0,57 – 0,43	– 0,73 – 0,60	+ 0,03 + 0,08	+ 0,45 + 0,11	– 0,91 – 0,99		+ 0,80 + 0,93
HM content in PF, %	– 0,69 – 0,13	– 0,49 – 0,53	– 0,80 – 0,60	+ 0,12 + 0,12	+ 0,41 + 0,06	– 0,97 – 0,95	+ 0,80 + 0,93	

Note: 1) correlation coefficients are given in the table lines; the data for JuS_1^1 stratum at the top, for BS_{11}^1 stratum at the bottom of each cell; the amount of data is 42 for JuS_1^1 stratum and 53 for BS_{11}^1 stratum; 2) Md - median grain size, So - sorted ratio, PF - pelitic fraction, HM - hydromicaceous mineral

Table 3

Genetic interpretation of the relationships shown in Table 2

Factors that determine the reservoir properties of sandstones and siltstones in JuS_1^1 and BS_{11}^1 strata	
Sedimentogenesis-catagenesis	Secondary changes
The porosity / permeability - the median grain size (+)	
The porosity / permeability - sorted grain ratio (-)	The porosity / permeability - the content of kaolinite (+)
The porosity / permeability - the content of pelitic fraction / chlorite / HM (-)	
The median grain size - sorted grain ratio (-)	The median grain size - the content of kaolinite (+)
The median grain size –content of pelitic fraction / chlorite content/ HM (-)	
Sorted grain ration - the PF content / content chlorite / HM (+)	Sorted grain ration - kaolinite content (-)
The content of pelitic fraction - the content of chlorite / HM (+)	The content of pelitic fraction / chlorite / HM - the content of kaolinite
The content of chlorite - the content of HM (+)	

Note: 1) sign of relashioship - the positive (+) or negative (-) is given in parentheses; HM - hydromicaceous mineral.

statements of mechanogene sedimentation. Similar arguments can be given to other relationships, given in the left column of Table 3. It is important for all of them to be interpreted from the viewtpoint of mechanogene sedimentation and subsequent diagenesis and catagenesis.

Another kind of relationships, which do not reveal connections with sedimentogenesis-catagenesis (i.e. the processes of sedimentation and background lithogenesis) is obtained while assessing the connection between the kaolinite content and reservoir properties of rocks, granulometric coefficients, pelitic fraction content, as well as chlorite and hydromicaceous minerals (the right column of Table 3). The results obtained suggest that kaolinite opposite to chlorite and hydromicaceous minerals is slightly sedimentogeneous-catagenetic; the greater part of it should be considered as authigenic minerals formed as a result of changes in feldspars.

The highest content of kaolinite as opposed to other clayey minerals is observed in clastic rocks with a large median particle size and a higher degree of their sorted ratio that can be explained by initial high porosity and permeability of such deposits. That is why the kaolinitization processes are more intensive in them because of fluids migrating through the rocks.

Thus, the given material let us evaluate the role of two major factors, which control reservoir properties of clastic rocks. This is a sedimentary-catageneous factor caused by the processes of sedimentary submerge of rocks and secondary changes of superimposed character, caused by the processes of fluid dynamics. The most important of the latter is kaolinitization. The material of the chapter justifies the second statement to be proved in the dissertation.

5. EFFECT OF CLAYEY MINERALS OF PRODUCTIVE STRATA ROCKS ON THE EFFICIENCY OF THEIR DEVELOPMENT

It is known that clayey minerals have one of the most important properties that must be taken into account in the development of deposits, namely swelling. Rocks which consist of clayey minerals of labile structure (smectites, mixed-layered formations like illite-smectite) have the greatest value of swelling. Swelling of kaolinite and chlorite is noticeably smaller. According to N.V. Sokolov (2000) and Sh. A. Gafarov (2003) kaolinite is the least swellable, chlorite is more swellable, and smectites and mixed-layered formations with labile interlayer spacing are of the highest swellability.

According to the experience of L.N. Bruzhes (2011), V.G. Izotov, and L.M. Sitdikova (1998) the analyzed clastic rocks may be tyified by relative content of clayey minerals in cement. They pointed out 9 paragenetic associations.

The author, taking into consideration mineralogical peculiarities of the clayey component of the analyzed rocks, as well as their different swellability, which influences the choice of composition of the injected water into injection wells for oil displacement, makes lithologic and technological classification of productive strata (Table 4), which resulted in three types of rocks. According to gathered and analyzed material, the development of rocks with increased content of hydromicaceous minerals and a few labile interlayer gaps is the most "risky", so the necessity for mapping the locations of their distribution is out of the question.

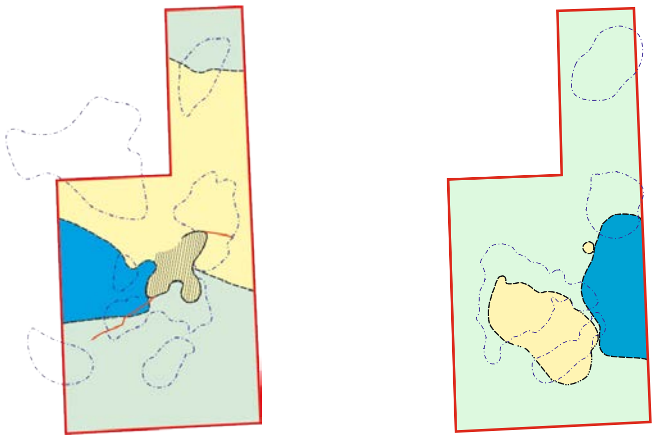
Table 4

Lithological and technological typification of rocks in productive strata

Type of rocks with content of clayey minerals considered		Composition of cement%	
		Stratum BS_{11}^{1}	Stratum Ju_{1}^{1}
I	Increased content of hydromicaceous minerals (HM)	Kaolinite-1-2 Chlorite-3-5 HM-3-4	Kaolinite-5-6 Chlorite-1-1,5 HM-2,7-3
II	Intermediate kaolinite content	Kaolinite-2-3 Chlorite-0,2-1 HM-0,2-1	Kaolinite-3-6 Chlorite-0,5-2 HM-1-2
III	Increased kaolinite content	Kaolinite-3-6 Chlorite-1-3 HM-1-2	Kaolinite-6-8 Chlorite-o,5-2 HM-1,5-2

Note: HM –hydromicaceous mineral

Taking it into account we drew up lithologic-and-technological schemes of JuS_{1}^{1} and BS_{11}^{1} strata (Fig. 7). They are divided into zones (areas), which differ from each other in the impact of the clayey cement mineral composition on the process of oil displacement from the stratum. Three main zones are marked out for two strata of rocks. Zone I is represented by sandstones and siltstones that consist of the greatest number of hydromicaceous minerals. Zone II is represented by rocks with intermediate content of kaolinite. Rocks with increased content of kaolinite are found in zone III. The swelling of clayey minerals and accordingly the risk of possible complications in oil production decreases in the same row I-II-II. The risk of collectors' colmatage due to injection of poorly mineralized water also reduces in this row.



Conventions

	The border of the licensed area		Zone I (rock type I), where highly mineralized (stratal) water is necessary for oil expulsion
	The outer contour of the oil-bearing		Zone II (rock type II), where the water from overlying aquifers of lower mineralization can be used in oil expulsion
	Clay line		
	The boundary of lithologic-and-technological areas		Zone III (rock type III), where brackish water can be used for oil expulsion

Figure 7. Lithologic and technological schemes of Kustovoye deposit for JuS_1^1 (left) and BS_{11}^1 (right) strata

However, the influence of mineralogical characteristics of the clayey component of rocks on the efficiency of field development can be traced while analyzing not only laboratory results, but also the field data. In the course of this work we revealed a link between mineralogic-and-lithological features of rocks in productive layers, on the one hand,

and the type, amount and expenses for geological and technological activities in a certain area on other hand (Table 5).

Table 5

Economic efficiency of wells' exploitation with various types of collectors (for the last 10 years)

Stratum	Collector type	UWR, CWR, HFF, RIW (number of activities)	Expenses for UWR, CWR, HFF,RIW (in thousand rubles)
BS_{11}^{1}	I	59	15 135,7
	II	50	12 690,4
	III	11	2 893
JuS_{1}^{1}	I	72	70 894
	II	29	7 481
	III	24	6 239

The aanalysis of Table 5 shows that there is a direct connection between the mineral composition of rocks in productive strata and the cost of their exploitation which should be taken into account for more efficient process of their development.

Thus, the least expensive and the least "risky" from the viewpoint of rock swellability is lithologic-and-technological zone III, where kaolinite dominates the composition of clayey minerals of cement, and the most expensive and the most "risky" is lithological and technological zone I with predominating hydromicaceous minerals in the composition of the rock cement.

Note: URW - Underground repair of wells, CRW – capital repair of wells, WFT – well-face treatment, RIW - repairing isolation work, HFF – hydraulic formation fracturing.

The researches have shown that consideration of mineralogical features of rocks, genesis, structural and physico-chemical properties of clayey minerals of pelitic fraction affects the efficiency of field development. The results of the work performed should be used in predicting the geological and technical activities while preparing projects of deposit development.

The material of the chapter proves the third statement of the thesis.

CONCLUSION

The undertaken lithological researches of rocks in productive strata of Late (JuS_1^1) and Early Cretaceous (BS_{11}^1) of Kustovoye oil deposit allowed us to specify some of the important features of their structure and material composition. The results are as follows.

Morphological and genetic typification of clayey minerals of the cement of arenaceous and silty rocks has been carried out. It takes into account such characteristics as the degree of grain shape perfection (the degree of idipmorphism), the degree of crystallinity, chemism, spatial (dense or loose) arrangement of grains, the morphology of aggregates, and the place of localization (in dense or porous rock areas).

According to the abovementioned features the determined clayey minerals are divided into two main types:

– the first type includes xenomorphic clayey minerals with densely packed grains localized in dense areas of rocks with relatively low degree of crystallinity (kaolinite) and ferrum content (chlorite); the genesis of clayey minerals is sedimentary;

– the second type implies clay minerals of high idiomorphism with loosely packed grains, fan-shaped or vermikulite-like (kaolinite), “brush-like” or crustified (chlorite), and filamentous (hydromica) structures of aggregates. They are characterized by higher crystallinity (kaolinite), ferrum content (chlorite), localized in porous areas of rocks; the genesis of such clay minerals is catagenetic (chlorite, hydromica) and secondary (kaolinite).

The revealed morphological-and-genetic types of clayey minerals have different effects on the reservoir properties of rocks in producing strata. Minerals of the first morphological-and-genetic type reduce collective properties of rocks, whereas minerals, attributable to the second morphological-genetic type, intensify them. For example, secondary kaolinites dominate in the examined rocks, so high content of this mineral leads to intensifying the collector properties of rocks. Vice versa, sediment types dominate in chlorites and much more in hydromicaceous minerals. That is why rocks containing increased amounts of these minerals are characterized by low porosity and permeability.

Thus, analyzing the relationships between the reservoir properties of sandstones and siltstones, their granulometric composition and the content of clayey minerals we noticed both positive and negative relationships. It can be explained by the influence of different factors that determine the collector properties of the rocks. They include, on the one hand, sedimentogenesis, diagenesis and catagenesis, and on the other hand - secondary changes of superimposed character that can be connected with deep fluids migration. Most of the identified relationships can be interpreted from the standpoint of mechanogene sedimentation and subsequent diagenesis and catagenesis. The exceptions were revealed in the evaluation of the connection between kaolinite content and reservoir properties of rocks, granulometric coefficients, the content of pelitic fraction, as well as chlorite and hydromicaceous minerals. The results obtained suggest that kaolinite opposite to chlorite, and hydromicaceous minerals, is sedimentary-catagenetic only to a small degree. The greater part of it should be considered as authigenic (secondary) formation, appeared as a result of changes in feldspar (changes of superimposed character).

However, the role of clayey minerals as cement in clastic rocks is not limited to their contribution to the reservoir properties of rocks. They also have a significant influence on the development of the fields, in particular on the economic efficiency of productive strata. Three types were marked out among the reservoir rocks, which differ in quantitative content of the identified clayey minerals of different swellability. It can be explained by structural features of both minerals and their aggregates. Thus, kaolinite and chlorite are formations of lower swellability. Hydromicaceous minerals with swelling interlayers in their structures are characterized by higher swellabilitiy.

On the basis of mineralogic-and-lithological typification of rocks in productive strata and consideration of different swellability of clayey minerals, we suggested their lithologic-technological typification. As a result of the proposed typification of rocks we designed lithologic-technological schemes that allowed us to mark out zones (areas), which differ from each other in terms of the productive strata development. Three zones for rocks of BS_{11}^{1} and JuS_{1}^{1} productive strata were singled out. Zone I is represented by rocks of the highest concentration of hydromicaceous minerals, greater than in other areas. The rocks with such composition of clayey cement are the most swellable. Therefore, we suggest using highly mineralized stratal water for oil expulsion for the process to be more productive. Rocks with intermediate contents of kaolinite are developed in Zone II. The degree of swelling of rocks is lower here than in Zone I. That is why the water which is pumped into the well can be of an intermediate mineralization. The rocks with a high content of kaolinite as compared with other clayey minerals dominate Zone III, i.e. the mineral of lower swellability. This zone is less "risky" for the development. The water of lower degree of mineralization can be used for oil expulsion from the productive layers of rocks with such mineralogic-and-lithological features. It should be specified that the absence of our own experimental material allows us assume that the composition of the water injected into the stratum for oil expulsion should be different for each of the selected zones.

More over having analyzed geological and production data and having considered expenses we established the connection between them and the mineralogic-and-lithological features of rocks in productive layers. It has been determined that the least expensive and the least "risky" is lithologic-and-technological Zone III, the most expensive and the most "risky" is lithologic-and-technological Zone I. This fact can be explained by higher swellability of rocks in Zone I as compared to Zone II and much more to Zone III.

The researches show that it is necessary to take into account mineralogic-and-lithological features of rocks, genesis, structural and physico-chemical properties of clayey minerals to improve the efficiency of productive strata development.

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1. Shmyrina V.A. Vliyaniye vtorichnykh izmenenii porod-kollektorov nz filtratsionno-yomkostnye svoistva produktivhykh plastov BS_{11}^{1} i YuS_{1}^{1}Kustovogo mestorozhdeniya / **V.A.Shmyrina**, V.P.Morozov // Uchyonye Zapiski Kazanskogo Universiteta. Seriya Yestestvennye Nauki. – 2013. – T.155, kn.1. – S.95-100.

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