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DIAGENETIC STAGES OF OIL-SATURATED SANDSTONES OF THE PASHYISKY HORIZON AT THE ROMASHKINSKOYE OIL FIELD

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Abstract

It was identified three stages of reservoir rock formation of the Pashyisky horizon of the Frasnian stage of the Upper Devonian at the Romashkinskoye field, based on optical microscopic studies. The first stage, associated with clastic deposits sedimentation and marked by clastic grains dense structural packing formation, close to cubic. The second diagenetic stage of quartz sandstones is associated with the subsidence stage of sediments into the burial zone. During this period were actively proceeding the processes of grains mechanical deformation, blastesis of quartz clasts, the formation of siderite fragments, and fibrous chalcedony, partially metasomatic replacing clay layers in sandstones. The third diagenetic stage in quartz sandstones is associated with the migration of underground gas-water solutions. Analysis of the transformation degree of the Pashyisky horizon quartz sandstones at different areas of the Romashkinskoye field revealed the relationship between the intensity of secondary diagenetic processes and the degree of rocks oil saturation.

Keywords:
Pashyisky horizon;
Oil;
Sandstone;
Reservoir;
Diagenesis.

1. Introduction

Last time, the stage-by-stage analysis of diagenetic transformations of sedimentary rocks has become a very important direction in petroleum geology [1, 2]. It is used to predict the formation of reservoir rocks in the basins, the possibility of filling them with water-oil fluids, and assess the degree of isolation of oil deposits from subsequent transformations [3-5]. In well-studied oil and gas basins with a long history of the development of hydrocarbon deposits, stage analysis makes it possible to better understand the processes of formation of petrophysical properties of oil-producing formations, consistently reconstructing the dynamics of their change to the current state [6-9]. The practical significance of such studies is the fact that in many hydrocarbon deposits, the distribution of fluids within the formation is controlled by the petrophysical properties of reservoir rocks.

This paper is the study of the stages of diagenetic transformations of the Upper Devonian oil-saturated sandstones from the Pashyisky horizon of the Romashkinskoye oil field [10]. The choice of such an object is due to the need for a more reliable assessment of the prospects for the oil-bearing capacity of reservoir rocks along with the lateral profile of the productive formation D1. For greater coverage of the study area, the sections of wells drilled in different areas of the Romashkinskoye oil field were studied: Zelenogorskaya; Pavlovskaya; Minnibaevskaya; Almetyevskaya (fig.1).

The reservoir initially differed from each other

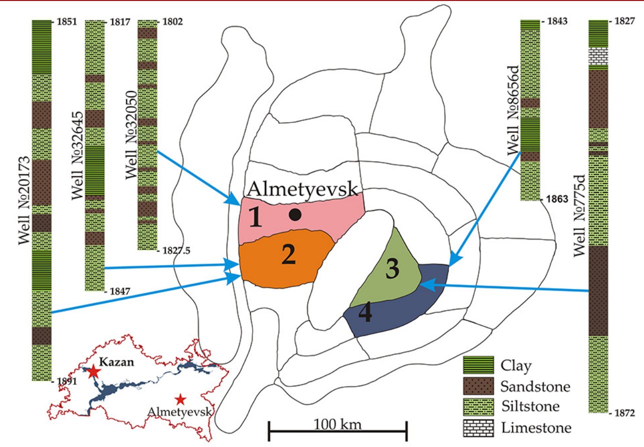

Fig.1. Position of the studied areas with typical sections of the Pashiysky horizon on the structure of the Romashkinskoye dome: 1 - Almetyevskaya; 2 - Minnibaevskaya; 3 - Pavlovskaya; 4 - Zelenogorskaya

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in oil productivity in the selected areas. All of them are currently in the final stages of development. A more detailed approach to gaining knowledge about the structure of reservoir rocks is required for the recovery of residual reserves of oil. For this, in turn, was studied main diagenetic stages of reservoir sandstones D1 from the Pashyisky horizon.

2. Methods

The main research method was optical microscopic analysis, which makes it possible to study both the structural components of sandstones and their interaction in the rock. The studies were on a transmission polarizing microscope Zeiss AXIO Imager. A2. To determine the mineral phases were used objectives with a magnification factor of 2.5, 5.0, and 10.0. This made to evaluate both the general picture of the distribution of mineral phases over the area of thin sections and to consider the areas of contacts between grains.

X-ray analysis was used as an additional method for determining the mineralogical composition of sandstones. The analysis was on a Bruker D2 Phaser diffractometer. The survey was in the following mode: X-ray tube voltage - 30 kV, current - 30 mA, scanning step - 0.02 °, speed - 1 deg/min. The range of scanning angles in the Bragg-Brentano geometry was from 3 to 40 °. This measurement range covers the diffraction reflections of almost all mineral phases of sedimentary rocks.

3. Results

The analysis of the sections of the studied wells of the oil-producing intervals showed that the reservoir rocks are sandstones, the dense rocks are claystones. The top of section sandstones often contains siltstones with varying clay content. In some sections, siltstones are oil-saturated and light brown, in others are water-saturated and light gray. Granulometric studies of rocks have confirmed they are belonging to three genetic groups of various lithological compositions: psammites (0.1-0.25 mm), siltstones (0.01-0.1 mm), and pelites (<0.01 mm).

Claystones are characterized by a pelitic structure, composed of tightly adjoining clay particles with a common axial orientation, which causes the effect of uniform extinction of the rock in the thin section, according to petrographic studies (fig.2A). Clay minerals are represented mainly by chlorite, to a lesser extent by illite, according to the XRD analysis. The unevenly banded distribution of finely dispersed organic matter gives claystone an unclear layered horizontal texture. The clay mass contains from 10 to 25% grains of quartz and feldspars of silts size grains. In some samples, allogenic fragments are scattered, in others, they are concentrated in thin layers. Among authigenic minerals is pyrite aggregates up to 0.1 mm. in some samples are found aggregates of fine-grained chalcedony. The rocks are dense, not porous.

Siltstones are characterized by a coarser-grained structure and a pronounced horizontally layered texture due to the presence of argillite layers (fig.2B). The rocks are 70-85% composed of an allogenic component, 15-30% is cementing substance. The detrital part of 0.01-0.1 mm in size is represented mainly by semi-rounded and angular quartz grains (94-97%), to a lesser extent by angular fragments of feldspars (2-4%), as well as muscovite flakes (1-2%). Fragments of minerals are cemented mainly by clay, lesser extent by siliceous cement. Syngenetic clay cement is lenticular-pore type, pelitic in structure, and illite-chlorite in composition. Silica cement is epigenetic, contact type, quartz in composition. Authigenic minerals are represented by pyrite aggregates up to 0.1 mm. The rocks are dense.

As follows from the description, the structural elements of claystones and siltstones have undergone relatively minor changes, despite the confinement of rocks in the zone of proto-mesocatagenesis (PK3-MK1). The processes of their transformation can be attributed only to compaction under the action of the lithostatic pressure of the overlying rocks. This is especially well visible in clayey rocks and interlayers occurring among siltstones, in which clay particles have acquired a well-defined axially oriented texture. Small changes in the clastic component in the siltstones are apparently due to the plastic properties of the clay component in them. Particles of chlorite and illite were evenly distributed in the intergranular space of siltstones, squeezed out in the compaction stage of clastic rocks. In this case, most of the grains turned out to be enveloped in thin clay «shirts». This prevented contact interactions between allogenic grains, preserving them from subsequent structural transformation. The exception is the contacting fragments of minerals, which partially dissolved at the contacts and grew together due to silica cement. Such structural changes in claystones and siltstones have led to the formation of relatively dense caprocks with very low filtration properties. The inability to filter pore solutions has become one of the reasons for the low degree of diagenetic transformation of minerals, preserving their syndepositional appearance.

Sandstones turned out to be more variable to diagenetic processes, they do not contain clay minerals or contain them from 1 to 3%. Comparison of the similar sandstones from different areas of the Romashkinskoye oil field made it possible to establish the sequence of their diagenetic transformation under the influence of various factors.

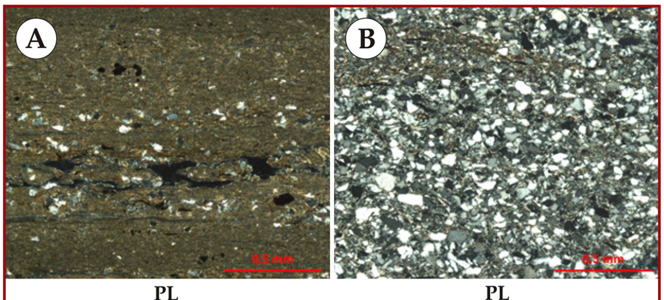

Fig.2. Photo of thin sections of claystones and siltstones of the Pashiysky horizon: A - illite-chlorite claystone; B - siltstone with clay

Sandstones are characterized mainly by a fine-grained structure, according to petrographic studies. Their texture is more diverse, varying from uniform to indistinctly layered and horizontally layered. The last two are due to the presence of siltstones and claystones of various thicknesses into the sandstones. The lesser reservoir properties of siltstones in comparison with sandstones often give the rocks in the sections a banded texture due to ununiform oil saturation. The general shallow-sea origin of the rocks determines the same mineralogical composition of sandstones. The sandstones are dominated by quartz grains (95-97%), feldspars are present by fragments of albites, orthoclases, microcline (2-4%), and muscovite flakes (1%), according to XRD and petrographic data.

Fragments of minerals are 85-90%, cement is 10-15% of the composition of the rock. The size of the fragments varies from 0.01 to 0.3 mm, 0.1-0.25 mm prevails, the silt fraction varies from 10 to 35%. Silt grains (0.01-0.1 mm) are evenly distributed in the rock in low contents of silt fraction and they form small lenses up to 0.2 mm in relatively high contents (> 20%) of silt fraction (fig.3). Stratification of sandstones is often noted, due to the alternation of psammitic, silty, and claystone layers of different thicknesses, at the top of the section. Clastic grains are characterized by similar morphological forms, regardless of the location of the wells. It is predominate semi-rounded, isometric, and elongated grains. Elongated grains are oriented in the rock according to bedding or at an acute angle to bedding, which is due to their adaptation to a lithostatic pressure.

Quartz grains are densely packed in the rock, in contact with each other at the edges. Quartz grains are pressed into fine-silty material on contacts with clayey-silty layers. At the points of contact, the quartz grains acquired extended convex-concave contacts of mutual adaptation (fig.4A). Some of the grains have formed cluster intergrowths, in which all quartz fragments have a common optical orientation. The process of granoblastesis is not developed everywhere, it is focal. On the periphery of quartz grains are the areas of close-contacting contacts and traces of deformations in the form of parallel microcracks. These cracks break the quartz surface into a series of submicroscopic plates, as a result, the grains acquire wavy optical extinction on the contacts.

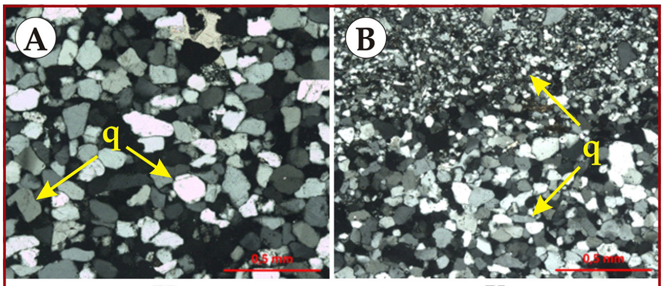

Fig.3. Photo of thin sections of quartz sandstones of the Pashiysky horizon (q - quartz): A - quartz sandstone; B - quartz sandstone with siltstone

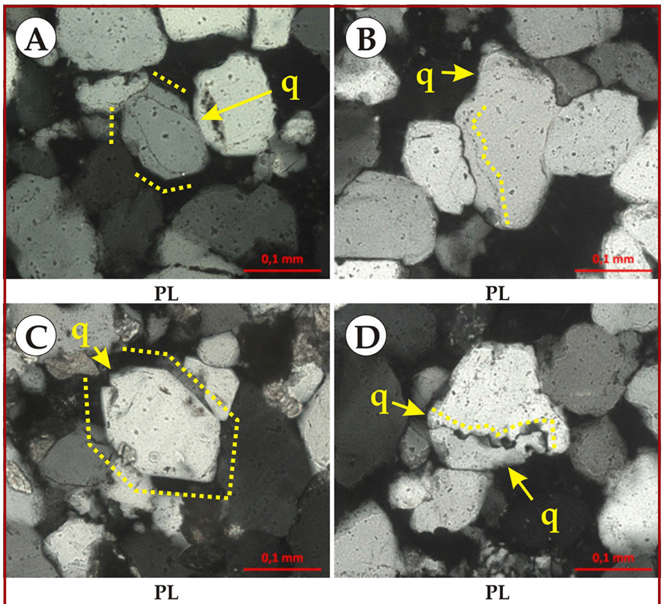

Fig.4. Thin sections photo of quartz sandstones with fragments of micro deformation of grains: A - cluster intergrowth of quartz grains; B - quartz grain with Boehm stripes; C - deformed grain of albite; D - albite grain, split along the periphery

Boehm stripes are noted in the form of parallel chains of fluid and silty microinclusions, on the periphery of many quartz grains (fig.4B). The «Boehm shading» is a slip plane in minerals that arose as a result of micro shears and decorated with inclusions, according to V.Baranov [11]. Similar inclusions are also found in the parts of intergrowth of closely spaced quartz grains, only less pronounced and forming cluster aggregates with uniform extinction. The accretion of individual mineral individuals is also accompanied by the capture of components from the mineral formation substance. Plagioclases gradually split along the boundaries of polysynthetic twins into thinner plates, on contacts with quartz grains (fig.4C). This leads to the formation of a «fringe» along the periphery of albite grains of parallel, weakly curving leaves with a common optical orientation (fig.4D).

The processes of regeneration of mineral grains are intensively manifested in the Pavlovskaya and Minibaevskaya areas of the Romashkinskoye field, where sandstones are maximally oil-saturated (fig.5). Everywhere, around the quartz fragments can observe peripheral rims of similar composition of various thicknesses. The growing quartz rims have a common optical orientation with the primary grain. They are separated from the original fragment by a dark inner boundary consisting of fluid and mineral inclusions which trapped during growth by the regenerated part of quartz grains.

Part of the quartz fragments acquired well-defined habit elements in the form of the faces of the hexagonal prism $\{10\bar{1}0\}$ and rhombohedra $\{10\bar{1}1\}$ and $\{01\bar{1}1\}$, separated by edges, as a result of regeneration. Quartz crystal tends to create relatively even extended boundaries with neighboring grains when growing in confined conditions. If the growth

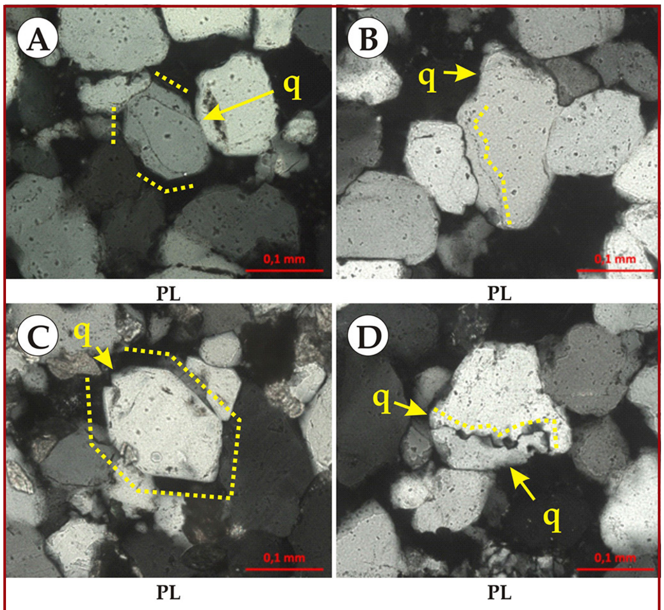

Fig.5. Thin sections photos of quartz sandstones with regenerated quartz grains: A, B - quartz grains with traces of regeneration; C - double-top quartz; D - microstylolite along the boundaries of two quartz grains

occurs in the direction of the free void-pore space of the reservoir rock, the crystal takes the form of a double top, limited on both sides by a hexagonal prism with pyramidal heads. In some cases, the quartz crystal splits, forming two heads, when the growth of rhombohedron faces at the ends of a hexagonal prism is blocked. The regeneration process is accompanied by the development of microstylolites along the boundaries of the contiguous quartz grains. As a rule, microstylolites do not go beyond the boundaries of the contacts of two grains and the height of their teeth does not exceed 0.05 mm. The effect of wavy extinction of intergrown grains appears in the stylolitization zone, due to the increased density of micro stresses and linear defects of quartz grains.

Muscovite flakes in quartz sandstones are at different stages of transformation (fig.6). Mechanical deformations predominate, when the plates under the action of lithostatic pressure bend in waves at the contacts. It is caused by the pressing of quartz grains

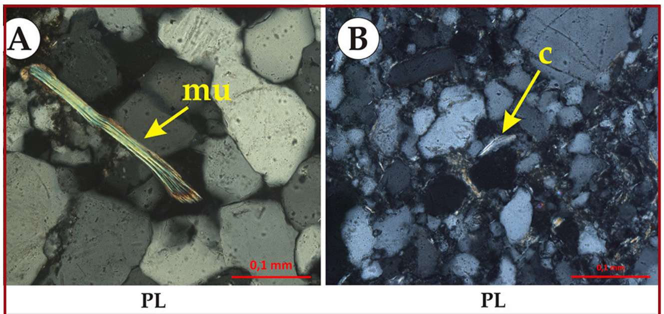

Fig.6. Photo of thin sections of quartz sandstones with transformed muscovite flakes: A - deformed muscovite plates (mu); B - muscovite replaced by chalcedony (c)

to mica. There are less developed processes of splitting of muscovite plates along the periphery to scales. As a result, a kind of «horse tails» are formed along the edges of the muscovites. In some samples, the process of transformation of muscovite plates was even further. On their periphery, the process of siliceous metasomatism is taking place with the replacement of the split «horse tails» with fibrous chalcedony.

Fragments of minerals are cemented with siliceous, carbonate, and siliceous-clay cement. Siliceous cement is contact or contact-regeneration, in the composition is quartz. The regeneration type of cement appears as a regeneration border around the periphery of quartz fragments. As a rule, it is separated from the grains by a black edging. Carbonate cement is represented by authigenic aggregates of siderite and dolomite. Siderite forms isometric, often spherical, nest-like segregations up to 1.0 mm in size. The Dolomites are found in the form of nested and lenticular-veinlet segregations, composed of fine-medium-grained crystals, some of which contain dark-brown oil inclusions. The proportion of carbonate cement does not exceed 10% of the rock. Siliceous clay cement forms lenticular-vein aggregates with a micro-grained structure. The clay component is represented mainly by illite and chlorite, while the siliceous component is represented by fibrous chalcedony, which metasomatically replaces clay aggregates. In some cases, chalcedony is confined to the periphery of clay aggregates, gradually spreading to their central parts. In others, it forms inside clay veinlets, leaving their peripheral areas unaffected. There are areas where newly formed chalcedony aggregates penetrate clay layers in the form of infiltration «tongues», forming uneven sawtooth boundaries at the contact with the primary rocks. In thin sections, siliceous metasomatism is well fixed by the change in interference color from yellowish-brown to light gray, within clay layers with an axially oriented arrangement of illite and chlorite flakes. At the same time, in the zones of silicification, the effect of wavy extinction occurs due to the different optical orientation of chalcedony fibers and their twisting around the L2 axis, if in the initial clay segregations there is a uniform extinction of illite-chlorite aggregates, caused by their axial orientation.

Sandstones are characterized by relatively high values of porosity (12-18%). Intergranular pores are communicating, sinuous, less than 0.05 mm in diameter. In some wells, the pores contain hydrocarbons, in others contain sodium-chloride brines. The density of sandstones is 2.16-2.34 g/cm^3, due to the high porosity.

4. Discussion

The structural and mineralogical features of the sandstones of the Pashiysky horizon make it possible to reconstruct the stages of transformation of terrigenous rocks in the basin. Three stages of the formation are traced of the mineral composition and structural characteristics of quartz sandstones, associated with the depositional stage, burial stage, and fluid superimposed diagenesis.

The first stage, associated with the depositional processes of terrigenous deposits was marked by the accumulation of relatively well-sorted mineral grains. At this time, were created depositional settings of active hydrodynamic wave regimes on the gently sloping shelf of the shallow-water Francian paleo sea. It contributed to the accumulation of well-sorted quartz grains. The average degree of roundness and the predominance of elongated quartz fragments suggest the absence of their long-range transport. This also contributed to the formation of weak mechanical structural bonds at the depositional stage. The process of grains redistribution took place during sedimentation. The fragments acquired a dense structural packing, close to rhombohedra, due to mechanical rotations and sliding relative to each other. Elongated fragments occupied an oriented position in the structure. Mechanical damage on the surface of quartz grains promoted an increase in the adhesion forces between them, gradual removal of water from the pore space, an increase in friction forces. Thus, at the depositional stage and initial diagenesis were formed primary structural bonds of the mechanical type.

The second stage of quartz sandstones is associated with the burial diagenesis stage. Pashiysky horizon entered to protocatagenesis-mesocatagenesis (PK3-MK1), according to the data on the reflectivity of vitrinite. A consistent increase in lithostatic pressure led to the maximum compaction of the grains in the volume of the rock. The process of selective dissolution of quartz grains began to develop at boundaries between grains. Different hardness and coefficient of compressibility of quartz in crystallographic directions contributed to the dissolution of some grains and the growth of others, under the same lithostatic pressure, depending on the spatial crystal-chemical orientation of grains concerning the normal pressure application (according to the Ricke principle). It begins the dissolution of quartz grains and the formation of extended convex-concave contacts of mutual adaptation between them with mechanical deformations. Deformations of structural elements are expressed in the appearance at the contact points of parallel microfractures and translational slips along the crystallographic axis C, which changes the optical characteristics of grains. As a result, wavy extinction occurs under a microscope in the contact zones of quartz grains, and Boehm stripes appear. The increased defectiveness of minerals leads to their more intense dissolution and a gradual transition of point contacts into extended boundaries. In areas where closely spaced quartz grains have approximately the same orientation as the crystallographic axes (for example, due to the piezoelectric effect). Elastic deformations promote turns and slides of minerals relative to each other until the directions of their optical axes coincide. Such distribution of grains leads to the accretion of individuals with the formation of cluster intergrow, with a combination of unidirectional lithostatic pressure. The blastesis process is caused by the activation of the diffusion of silica on the boundaries of closely spaced grains, by the crystal-chemical affinity of minerals, by the identical orientation of the flat networks of the crystal structure of intergrown quartz grains. Relatively large plagioclase grains in contact with quartz grains were also involved in the process of mechanical deformation, although to a lesser extent compared to quartz. Moreover, the intensity of deformations of feldspar grains was determined by their spatial orientation relative to the application of lithostatic pressure. Plagioclases split into thin plates when pressure was applied along the plane of intergrowth of polysynthetic twins. Deformations of the feldspar grains were practically not if the rock pressure was applied along the normal to the cleavage planes of the plagioclases. Muscovite plates were also subject to mechanical deformation. Marine sandstones often experience multidirectional pressure on their basal surface (010) being oriented in the process of sedimentation. Muscovite plates can bend under the quartz grains pressing in local areas, possessing good elastic properties. As a result, undulating bending of muscovite occurs without loss of integrity. Subsequently, contact interactions form at the points of contact of two different minerals. Mechanical types of bonds between mineral grains are gradually transformed into stronger crystallization bonds, during the burial diagenesis. This is facilitated by the simultaneous occurrence of dissolution and crystallization of minerals under the action of lithostatic pressure. As a result, the relatively weakly bounded sand transformation to sandstone. In this state, the rock can exist for a long time and preserve the high reservoir properties obtained at the depositional stage, due to the rigid incompressible skeleton. Pore solutions saturated with quartz give additional resistance to sandstone by the pressure of overlying rocks.

The formation of authigenic minerals is also associated with the stage of burial diagenesis, primarily precipitation of siderite and fibrous chalcedony. The confinement of radial siderite spherulites to areas of sandy-silty strata, enriched with clay material, suggests a paragenetic relationship between $FeCO_3$ and the degree of clay content in terrigenous rocks. This is apparently due to most of the bound iron is concentrated in chlorite, which composes clay layers, including the Pashiysky horizon. Part of the bound iron was released and in the form of bicarbonate and migrated into adjacent sandstones and siltstones, where it was precipitated as siderite.

$$Fe(HCO_3)_2 = FeCO_3 + H_2O + CO_2$$

It was during the compaction and dehydration of claystone. It is not excluded to the participation of microorganisms in the precipitation of siderites. It was shown in [12] that microbes are quite capable of creating siderite crystals and aggregates during their activity. In our case, there is indirect evidence of the biogenic origin of siderite. At the contacts with muscovite flakes are observed dispersed lumpy aggregates, tending to assume a rhombohedral habitus and oval segregations, which have a biogenic origin (fig.7). The conjugation of siderite neoplasms with muscovite is explained by the presence of potassium ions in the structure, which is one of the essential elements in biochemical processes [13].

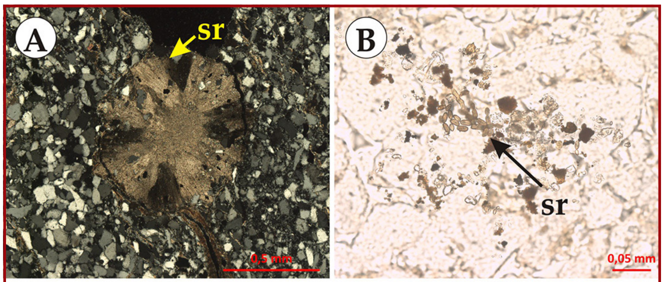

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Fig.7. Photo of thin sections of quartz sandstones with siderite:
A - siderite spherulite (sr); B - biogenic siderite

Authigenic fibrous chalcedony is present in almost all illite-chlorite aggregates, localized in sandstones. In areas of siliceous metasomatism, all chalcedony fibers are oriented strictly parallel to the axial texture of clay minerals. They are developing along the lateral edges of illite and chlorite flakes. Such growth of siliceous minerals is determined by the direction of diffusion supply of nutrients to its growing edges. The axial texture of illite-chlorite flakes creates a condition for directed migration of solutions along their basal planes, i.e., parallel to the bedding of clayey layers. The growth of chalcedony may occur in channels by the diffusion migration of silica. Otherwise, it is difficult to explain their parallel arrangement concerning each other and different growth rate of fibers along {110}, in the same clay aggregate. It determines the formation of infiltration «tongues» of metasomatic replacement in chalcedony. The direction of the process of silicification of illite-chlorite aggregates is determined by the degree of supersaturation of the crystallization medium with migratory of silica, from the periphery to the center or from the center to the periphery. The process of siliceous metasomatism was mainly along the periphery of illite-chlorite aggregates as a result of the intense dissolution of fragments of quartz grains and supersaturation of pore solutions along with chalcedony at the boundaries of clay layers. The growth of fibrous chalcedony began inside illite-chlorite aggregates. The specific of spatial arrangement of newly formed minerals predetermined a different effect on the pore space of sandstones. Siderite aggregates complicate the structure of the porosity because siderite is developing between grains. Fibrous chalcedony practically does not affect the capacity-filtration properties of sandstones and metasomatically replaces clay microlayers. It replaces initially dense illite-chlorite segregations and it is developing in pore space, inaccessible for the penetration of hydrocarbons. The third stage of diagenetic transformations in quartz sandstones is associated with the migration of upward basinal solutions. The peculiarity of this stage is the transformation of reservoir rocks under the influence of water-oil fluids. Within one productive unit occurs very diverse structural and mineralogical changes in the oil-saturated sandstones of the Pashiysky horizon, at small distances. The entrance of aggressive solutions is probably associated with the microstylolites in reservoirs.

Before this stage, in sandstones was a balance between the mineral skeleton and pore solutions. The activation of the processes of selective dissolution of quartz grains can proceed with a slight increase in the alkalinity of the medium [14], with the formation of stylolite structures. Alkalization of pore solutions can be associated with the decomposition of low molecular weight carboxylic acids, according to Taranenko [15]. Sakhibgareev thought that pH changes have a biochemical nature [16]. An excess of silica was used to the formation of regenerative rims around quartz grains, or to the formation of fibrous chalcedony, which metasomatically replaced muscovite. An increase in the alkalinity of pore solutions is evidenced by the secondary carbonate mineralization of reservoir rocks, which begins to occur at pH> 8 [17].

Regeneration of quartz grains is caused by oil-water fluids and accompanying by the high temperatures of homogenization (120-140 °C). This is indicated by many oil inclusions of hydrocarbons in the growth zone of quartz rims. The process of metasomatic replacement of muscovite plates by fibrous chalcedony indirectly indicates the excess content of silica acid in pore solutions associated with the dissolution of quartz grains. This can also be observed higher in the section in the Visean oil-saturated sandstones [18]. The metasomatic replacement does not occur at a slow rate of dissolution of mineral fragments, since all free silica is gradually deposited on the surface of quartz grains, forming habitus elements of minerals. Dolomitization is a typical secondary mineral of the fluid stage of diagenesis (fig.8). Authigenic dolomites show an additional input of alkaline-earth elements by fluids and increased content of carbon dioxide in the system. It should be noted that the content of Ca^{2+} and Mg^{2+} ions in the formation waters is insufficient for the precipitation of carbonate minerals. It indicates reducing fluid-dynamic processes. Small inclusions of hydrocarbons in dolomite crystals indicate the paragenesis of carbonate mineralization with water-oil fluids, which is typical for the studied basin [19]. Different forms of dolomite crystals suggest the presence of several stages of dolomite

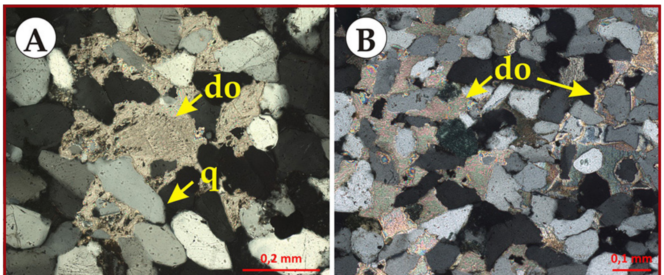

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Fig.8. Photo of thin sections of quartz sandstones with dolomite:
A - dolomite crystals (do); B - dolomite vein

mineralization. Small crystals of dolomite formed at the early stages of the entering of water-oil fluids. In the upper part of the section was created high partial pressure of carbon dioxide.

In the lower parts of the reservoir were concentrated water-oil solutions, gas-depleted. The long period of existence of the gas-water phase and fluctuations of CO_2 in the pore solution contributed to the gradual recrystallization of dolomite grains. Part of the carbonate grains captured small inclusions of hydrocarbons, in the process of growth. Dolomite crystals began to form at the later stages of the water-oil geofluid system, during the time of water-oil contact forming. Their morphology was determined by the relative stabilization and consistency of the position of the water-oil contact, and the size of aggregates and crystals was determined by the intensity of the influx of Ca^{2+} and Mg^{2+} ions. Authigenic dolomites increased the density of rocks due to a decrease in their effective porosity, filling the pore space of oil-saturated sandstones in local areas. However, the mosaic structure of carbonate minerals and their low content practically did not affect the reservoir properties of rocks.

Analysis of the degree of transformation of quartz sandstones made it possible the following features of diagenesis of the Pashiysky horizon in different areas of the Romashkinskoye oil deposit. First, the dynamics of the burial processes of sandstones (burial diagenesis) contributed to identical transformations. It is a common source of terrigenous material and similar hydrodynamic conditions of the depositional environment (sedimentation). Second, all the differences in diagenesis begin at the stage of superimposed fluid diagenesis, in oil-saturated sandstones.

If the mineralogical direction of the transformation of the rocks of the D1 reservoir in all areas is the same, then the intensity differs significantly. So, the most altered are sandstones from Pavlovskaya and Minnibaevskaya areas, where sandstones are characterized by uniform oil saturation. The processes of quartz regeneration and silicification of clay interlayers are intensively done in them. Dolomitization in the top of the oil reservoir is observed only in Pavlovskaya area, while dolomite is absent in Minnibaevskaya area. The processes of redistribution are much less in the sandstones of the Almetyevsk and Zelenogorsk areas with a relatively weak and uneven oil saturation. Regeneration rims around allogenic quartz grains are poorly developed, even though the intensity of silicification of clay layers is comparable to the sandstones of Pavlovskaya and Minnibaevskaya areas. Sandstones of the Zelenogorsk area are distinguished by a higher content of authigenic dolomite, which forms nested and lenticular-bedded segregations. Thus, the main structural and mineralogical differences of sandstones were at the stage of fluid diagenesis.

Conclusions

The following conclusions can be drawn:

1. The least altered in the process of diagenesis are dense claystones and siltstones, in the terrigenous rocks of the Pashiysky horizon of the Romashkinskoye oilfield. Their diagenetic transformations are mainly associated with the compaction processes under the action of the lithostatic pressure of the overlying rocks. Quartz sandstones are the most permeable rocks and obtained strong structural and mineralogical transformations.

2. Oil-saturated sandstones of the Pashiysky horizon have consistently three stages: depositional stage, burial diagenesis, and superimposed fluid diagenesis. In terrigenous sediments was formed a dense structural packing of mineral fragments, close to cubic, at the depositional stage. At the burial stage of rocks were actively proceeding the processes of mechanical deformation of grains, blastesis of quartz fragments, the formation of siderite segregations and fibrous chalcedony, metasomatic replacing clay layers in sandstones. At the stage of fluid diagenesis was a process of redistribution of silica, which realized in the regeneration of quartz fragments and the replacement of muscovite plates with chalcedony, as well as the formation of secondary dolomite. This is associated with the arrival of water-oil solutions into the reservoir rocks.

3. Quartz sandstones from different areas of the Romashkinskoye oilfield are distinguished by the intensity of structural and mineralogical transformations, despite the common conditions of sedimentation and burial process in the PK3-MK1 zone. This is due to the processes of fluid diagenesis, which formed the modern appearance of reservoir strata. On the Pavlovskaya and Minnibaevskaya areas is increased the density of crystallization contacts between quartz grains of sandstones, due to the redistribution of silica. The Zelenogorskaya area was formed dolomite cement of the nested and vein types, due to fluctuations of CO_2 in pore solutions.

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Стадийность литогенеза нефтеносных песчаников Пашийского горизонта Ромашкинского нефтяного месторождения

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Реферат

На основе оптико-микроскопических исследований было выявлено три этапа формирования пород-коллекторов пашийского горизонта франского яруса верхнего девона Ромашкинского месторождения. Первый этап, связанный с процессами седиментации терригенных отложений, ознаменовался формированием плотной структурной упаковки обломочных зерен, приближенной к кубической. Второй этап литогенеза в кварцевых песках связан со стадией погружения отложений в зону катагенеза. В этот период активно протекали процессы механических деформаций минеральных зерен, бластез кварцевых обломков, формирование сидеритовых обособлений и волокнистого халцедона, частично метасоматичеки замещающего глинистые слойки в песчаниках. Третий этап литогенеза в кварцевых песчаниках связан с миграцией подземных газоводных растворов. Особенность этой стадии заключается в неравномерном преобразовании пород коллекторов под действием водонефтяных флюидов. Анализ степени преобразованности кварцевых песчаников пашийского горизонта на различных площадях Ромашкинского месторождения выявил взаимосвязь интенсивности протекания вторичных постседиментационных процессов со степенью нефтенасыщености пород.

Ключевые слова: пашийский горизонт; нефть; песчаник; коллектор; литогенез.

Romaşkin neft yatağının Paşi horizontunun neftli qumdaşlarının litogenezinin mərhələliyi

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Xülasə

Optik mikroskopik tədqiqatlar əsasında Romaşkin yatağının Yuxarı Devonun Frasniya mərhələsinin Paşi horizontunun kollektor-laylarının formalaşmasının üç mərhələsi müəyyən edilmişdir. Terrigen çöküntülərinin sedimentasiya prosesləri ilə bağlı olan birinci mərhələ qırıntı formalı dənəciklərdən ibarət kuba bənzər bərk struktur kipliyinin formalaşması ilə səciyyələndirilmişdir. Kvars qumlarında litogenezin ikinci mərhələsi çöküntülərin katagenez zonasına çökmə mərhələsi ilə bağlıdır. Bu dövrdə mineral dənələrinin mexaniki deformasiyası, kvars qırıntılarının blastezi, siderit arıylmalarının və qumdaşılarında gil təbəqələrini qismən metasomatik əvəz edən lifli xalsedonun əmələ gəlməsi prosesləri fəal şəkildə gedirdi. Kvars qumdaşlarında litogenezin üçüncü mərhələsi yeraltı qaz-su məhlullarının miqrasiyası ilə bağlıdır. Bu mərhələnin özəlliyi su-neft flüidlərinin təsiri altında kollektor laylarının qeyri-bərabər yenidən əmələgəlməsidir. Romaşkin yatağının müxtəlif sahələrində Paşi horizontunun kvars qumdaşılarının yenidənəmələgəlmə dərəcəsinin analizi təkrar postsedimentasiya proseslərinin intensivliyi ilə süxurların neftlə doyma dərəcəsi arasında əlaqəni müəyyən etmişdir.

Açar sözlər: Paşi horizontu; neft; qumdaşı; kollektor; litogenez.