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Genesis of the Void Space and Types of Secondary Processes in the Neoproterozoic Reservoirs of the Moshakovskaya Formation within the Southwest of the Siberian Platform

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Abstract: The oil and gas potential in the southwest of the Siberian Platform is largely associated with Neoproterozoic reservoirs. One of the most promising targets is the deposits of the Taseeva Group, including terrigenous deposits of the Moshakovskaya Formation, widely developed along the periphery of the Baikit anteclise and the adjacent territory of the Angara fold zone. Despite the discovery of industrial gas deposits in them at the Abakanskoye, Imbinskoye, and Ilbokichskoye fields, the degree of investigation of the deposits of the Moshakovskaya Formation remains quite low. The Neoproterozoic deposits of the Moshakovskaya Formation are distinguished by a high degree of geological heterogeneity. It is due to the variability of the textural-mineral and structural characteristics of the rocks composing them, as well as the intensity of secondary alterations. The aim of this research is to assess the impact of secondary processes on the reservoir properties of the reservoir rocks of the Moshakovskaya Formation based on the results of lithological and petrophysical studies. To achieve this goal, the following experimental methods were used: optical polarizing microscopy, scanning electron microscopy, X-ray spectral microanalysis in SEM, and X-ray diffractometry. As a result of the multi-scale studies, post-sedimentary processes were detailed. It was found that the void space of the reservoir rocks of the Moshakovskaya Formation is largely controlled by the manifestation of leaching and authigenic mineral formation processes, which are largely the result of hydrothermal processes occurring in the rocks. Fractures of various origins, such as tectonic, magmatic, and hydrothermal, play an essential role in the filtration system of reservoir rocks. The research results presented in this article can be aimed at improving the efficiency of the development of Neoproterozoic reservoirs within the Siberian Platform.

Keywords: reservoir rocks, hydrothermal processes, secondary alterations, leaching, authigenic minerals, porosity, void space, Siberian Platform, Neoproterozoic, Taseeva Group, Moshakovskaya Formation

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Review

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1. Introduction

Neoproterozoic productive deposits of the Taseeva Group, including terrigenous deposits of the Moshakovskaya Formation, are distributed within the southwest of the Siberian Platform (the territory of the southern periphery of the Baikit anteclise and the adjacent part of the Angara fold zone and partly on the Boguchany-Manzino Uplift of the Sayano-Yenisei syneclise) (Figure 1). They are one of the most promising objects for discovering gas and gas condensate fields. To date, such large fields as Abakanskoye, Imbinskoye, Ilbokichskoye, and others have been identified within the study region in the deposits of the Taseeva Group.

The deposits of the Taseeva Group are represented by a complex of variegated predominantly terrigenous rocks. Their total thickness is about 1300–1500 m. These deposits

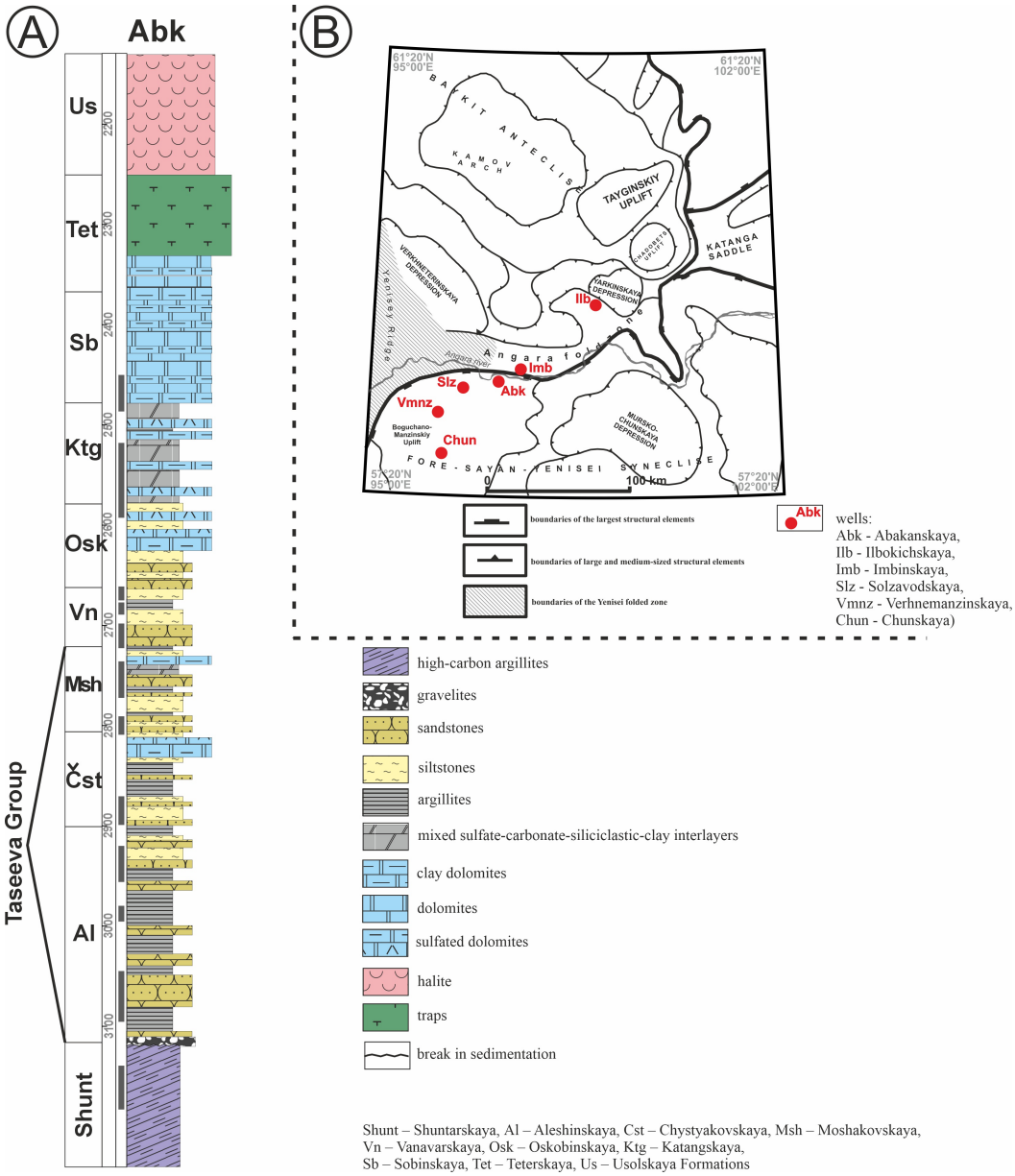


Figure 1. (A) Lithological column (the Abakanskaya-1 well). (B) Tectonic scheme of the southwest of the Siberian Platform [*Postnikov et al.*, 2021].

are distinguished by a high degree of geological heterogeneity, and the deposits discovered in them have a complex geological structure.

Three formations are distinguished in the section of the Taseeva Group (from bottom to top): Aleshinskaya, Chistyakovskaya, and Moshakovskaya. This article considers variegated terrigenous deposits of the Moshakovskaya Formation. They conformably overlie the gray-colored terrigenous and terrigenous-carbonate deposits of the Chistyakovskaya Formation. For a long time, the stratigraphic confinement of the deposits of the Taseeva Group was highly debatable. This was due to the absence or insufficient number of reliable faunal remains, as well as a wide time range of their distribution. However, in 2021, based on the results of U-Pb isotopic dating of zircons, the age of the Moshakovskaya Formation was determined (600 ± 13 Ma) [*Postnikov et al.*, 2021].

The studied deposits were considered in detail in the works of *Anatolyeva* [1968, 1972], *Khomentovsky et al.* [1972], *Sovetov* [2015, 2018], *Melnikov et al.* [2010], *Melnikov and Konstantinova* [2004, 2006], and *Melnikov et al.* [2012], *Kochnev et al.* [2007, 2015, 2020],

and *Gutina et al.* [2003] and *Gutina and Sidoras* [2001]. However, the stages and patterns of the manifestation of secondary processes in the reservoir rocks of the Moshakovskaya Formation remain a poorly studied problem. Secondary processes largely control the reservoir properties of reservoir rocks. This must be considered in the process of exploration work aimed at searching for oil and gas fields. Therefore, conducting detailed multi-scale studies aimed at studying this problem is relevant.

The reservoir rocks of the Moshakovskaya Formation are characterized by a high degree of lithological and petrophysical heterogeneity due to the variability of the facies conditions of sedimentation and, mainly, the manifestation of various secondary processes. These properties of reservoir rocks cause significant difficulties in the exploration and development of gas deposits.

Many years of experience in the study of these reservoir rocks has shown that a significant part of their void space is secondary and is associated with the manifestation of processes such as leaching and fracturing. At the same time, active authigenic mineral formation creates zones of degraded filtration and reservoir properties. In fact, the reservoir rocks of the Moshakovskaya Formation can be classified as unconventional reservoirs created by the manifestation of secondary processes, which often do not coincide with the facies zones.

The aim of the research is to assess the impact of secondary processes on the reservoir properties of the reservoir rocks of the Moshakovskaya Formation based on the results of lithological and petrophysical studies.

The article is based on the results obtained from an extensive amount of factual material, including core material from deep drilling wells in the studied area, archival geological and geophysical data, as well as the results of analytical studies.

2. Materials and Methods

Lithological studies were carried out on 750 samples studied by optical microscopy (500 petrographic thin sections), scanning electron microscopy (150 samples), and X-ray diffraction analysis (100 samples). In addition, the 250 results of petrophysical studies of the core were used.

Studies of the structure and material composition of reservoir rocks were carried out using a polarizing microscope Axio Imager A2m Carl Zeiss (Germany). The structure of the void space was studied using a JEOL JSM-6610LV scanning electron microscope (Japan) with an OXFORD INSTRUMENTS IE350-IW500-HKL microanalysis (UK) attachment. The mineral composition of the rocks was analyzed using a RIGAKU (XRD) SmartLab X-ray diffractometer (Japan). The morphometric characteristics of the void space were obtained from the results of rock image analysis in thin sections using the specialized AxioVision software (Germany).

3. Lithological Characteristics of the Moshakovskaya Formation

The Neoproterozoic Moshakovskaya Formation is predominantly represented by variegated sand-silt and silty-clay varieties and to a lesser extent by carbonate and sulfate rocks.

The clastic part of the sandstones of the deposits is characterized by a polymictic composition with a significant content (more than 20%) of fragments of metamorphic rocks. It is represented by fragments of quartz (40–55%), feldspars (10–15%), micaceous schists (up to 10–15%), quartzites (up to 5–10%) and fragments of volcanic rocks (1–2%), mica flakes (usually 3–5%, sometimes up to 10–12%) (Figure 2). Fragments of feldspars are represented by microcline, less often by orthoclase and albite. Micas are represented by biotite and muscovite. Accessory minerals include zircon, tourmaline, rutile, and monazite. The content of tourmaline fragments reaches 3–5% in some thin sections. Grains typically exhibit angular, subangular, and subrounded shapes. Fragments of quartz and feldspars are much worse rounded than fragments of metamorphic and volcanic rocks.

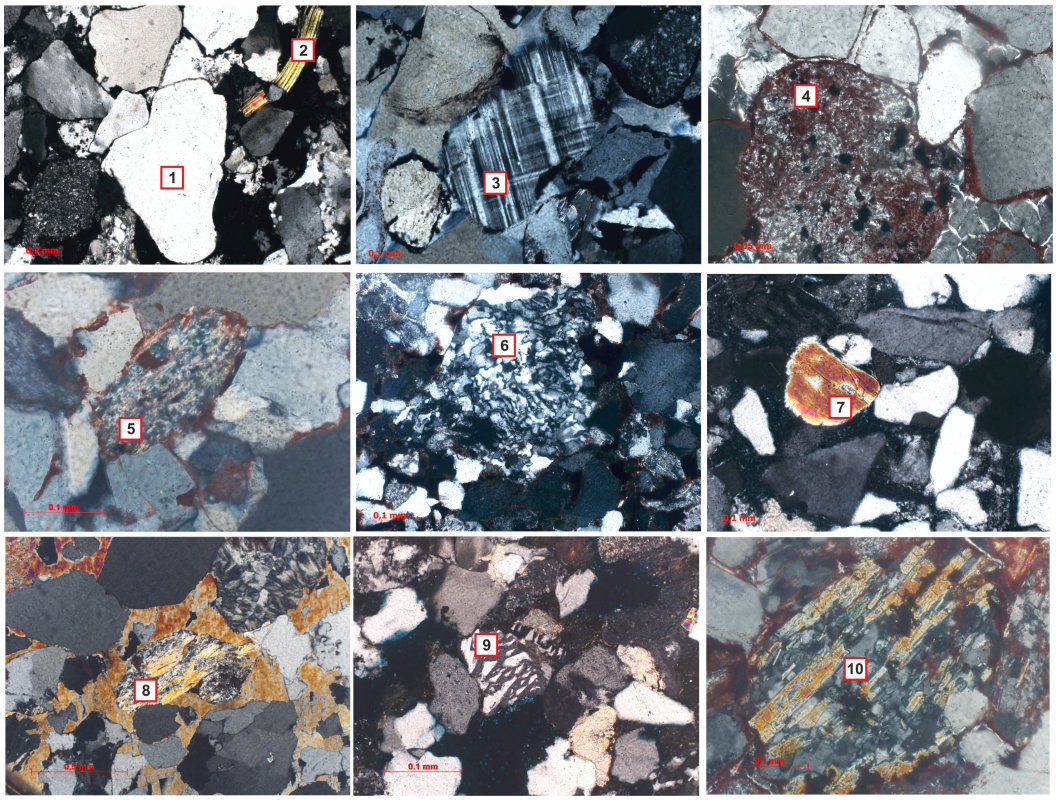


Figure 2. Composition of the clastic part of sandstones. Symbols: fragments of quartz (1), muscovite (2), potassium feldspar (3), volcanic rock (4), biotite-muscovite schist (5), quartzite schist (6), tourmaline (7), biotite schist (8), pegmatite (9), tourmaline schist (10).

The cement composition is highly variable, typically argillaceous (clayey), less often quartz, ferruginous, sulfate, and carbonate.

The results of X-ray diffraction and micro-X-ray spectral analyses indicate that in the deposits the clay component of cement is represented by illite, iron-magnesium and ferruginous chlorite, the ferruginous component is hematite, the carbonate component is calcite, less often dolomite and siderite, the sulfate component is anhydrite, less often barite.

The distribution features and the amount of clay cement vary greatly in the studied rocks (Figure 3). In some samples, it fills the entire intergranular space and the flakes are strongly compacted. Sometimes its content is much less and it is less compacted. Therefore, thin interaggregate voids 1–5 μm in size are noted between the flakes. The sizes of flakes of clay minerals vary from 0.5–1 to 25 μm, and in some samples their sizes reach 50 μm.

Hematite cement is unevenly distributed, partially or completely covers the fragments with films, and also fills intergranular pores (Figure 4). Hematite crystals are 0.5–1 μm in size. In hematite cement, micropores ranging in size from 0.5 to 1 μm are noted.

Sulfate and carbonate cements are evenly distributed and usually completely fill the intergranular pores (Figure 5). The sizes of crystals of calcite, dolomite, siderite, anhydrite, and barite vary from 5–10 to 200–300 μm.

The structural features of the deposits are very diverse and variable both in section and in area. The deposits are characterized by the presence of structures of oblique, oblique wavy, horizontally layered, in some places gently undulating, and gradation bedding. There are bioturbation structures.

Features of the structural and mineral characteristics of the rocks, a sharply different degree of sorting and roundness of clastic material indicate the formation of the Moshakovskaya Formation within the research region within the transition zone from continental to marine [*Antipova et al.*, 2019; *Postnikova et al.*, 2017].

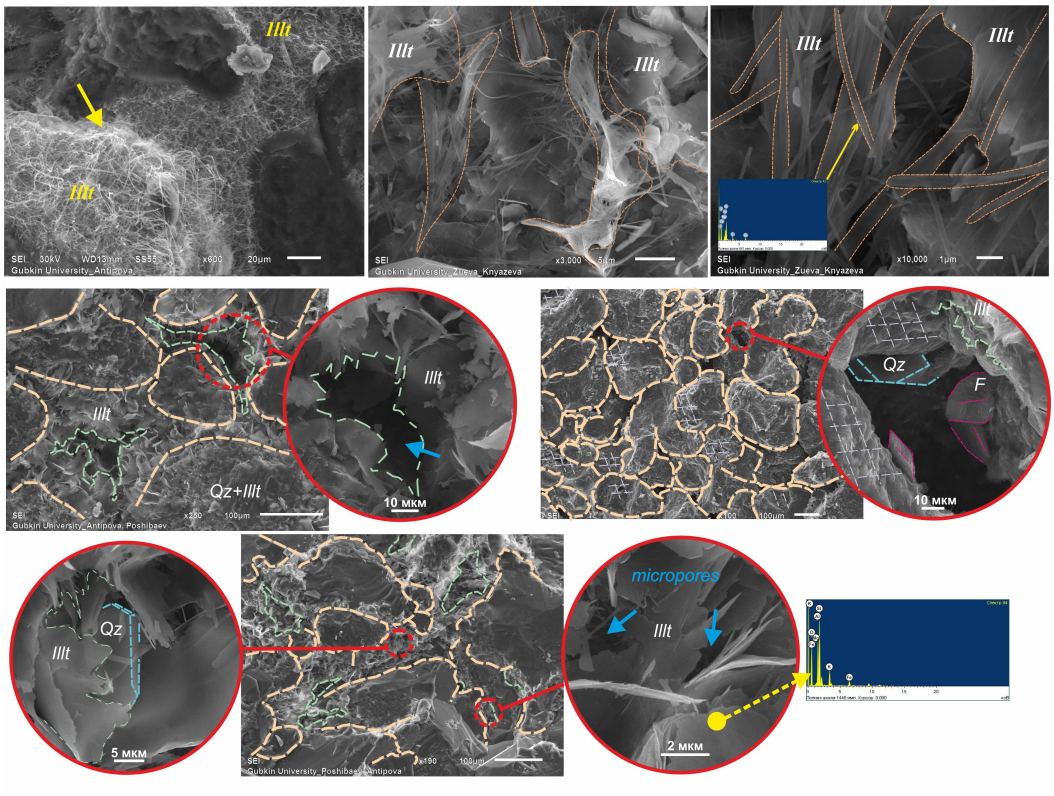


Figure 3. Microstructure of illite cement. Symbols: Qz — quartz, F — potassium feldspar, Illt — illite.

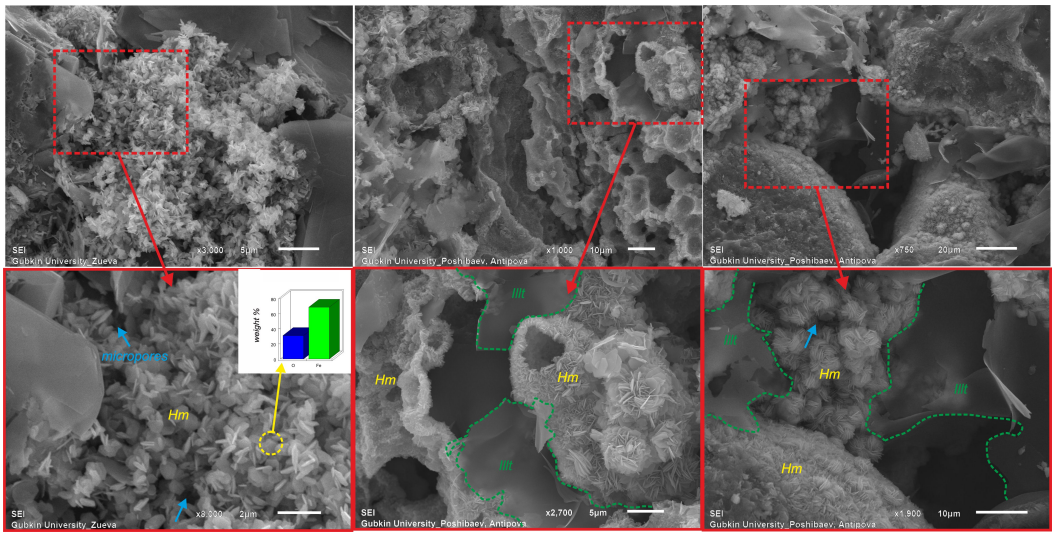


Figure 4. Microstructure of hematite cement. Symbols: Hm — hematite, Illt — illite.

During the deposition of the Moshakovskaya Formation, a narrow marine gulf existed in the southwestern Siberian Platform, framed from the north and south by a zone of deltaic plains with rare lakes and channels. The sandiest deposits were formed in the areas of active streams and beach zones framing the marginal parts of the deltaic plain.

4. Secondary Alterations of Reservoir Rocks of the Moshakovskaya Formation

The reservoir rocks of the Moshakovskaya Formation are characterized by high intensity and variety of secondary alterations. Secondary processes have largely changed the primary structure of the rocks and had a great impact on the reservoir properties of rocks.

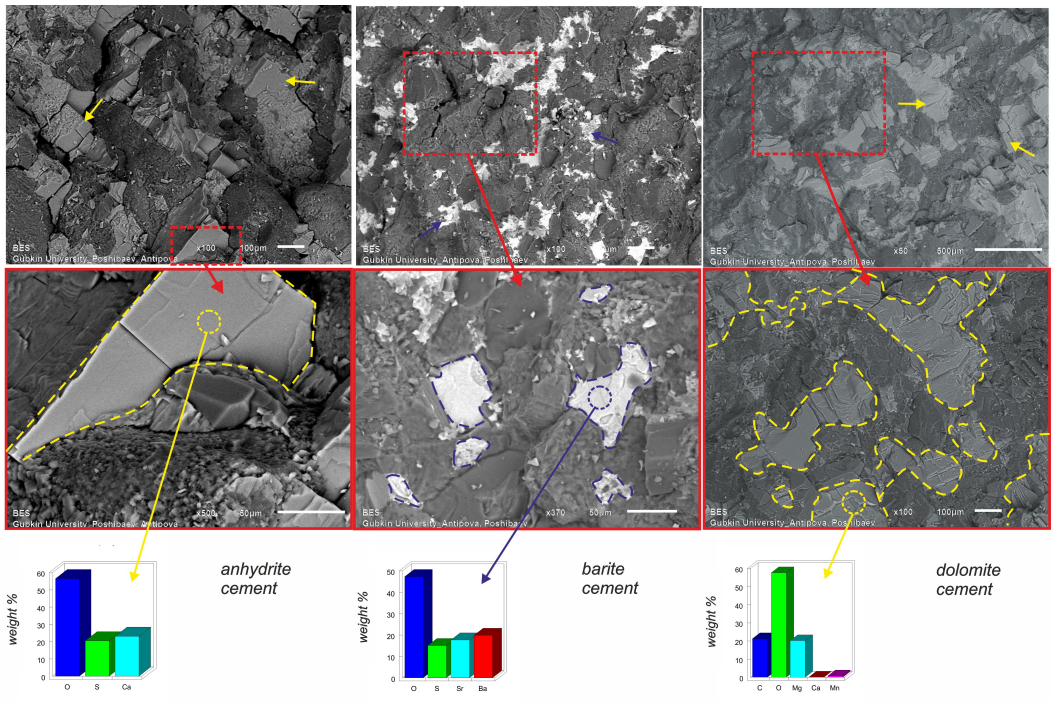


Figure 5. Microstructure of anhydrite, barite, and dolomite cements.

The processes of authigenic mineral formation in void space, pressure solution of clastic grains, their plastic deformations, intense fracturing, sulfatization, and carbonatization are most widely manifested.

The processes of quartz regeneration had the most significant effect on the decrease in porosity values. It manifests itself in the partial restoration of the shape of crystals. In some layers, regeneration rims almost completely fill the void space of sandstones (Figure 6). In such layers, the porosity values are 1–2%.

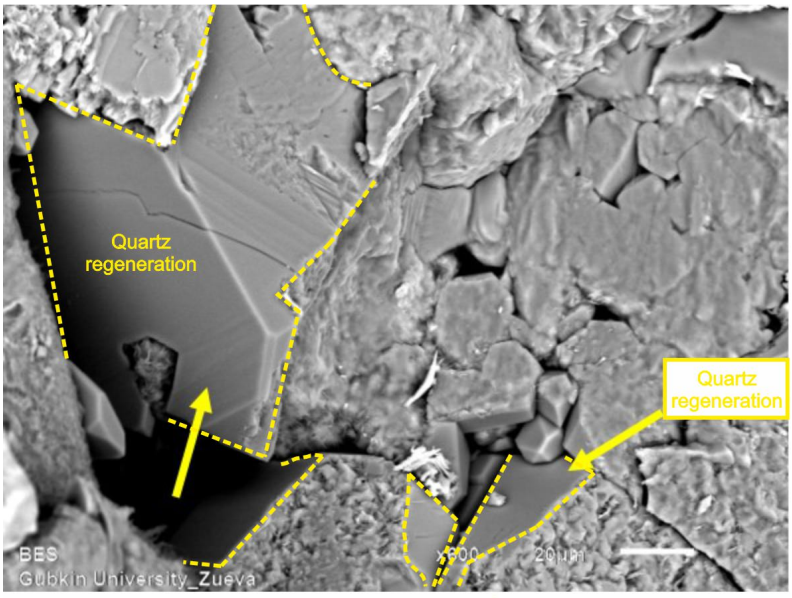


Figure 6. Intensive regeneration of quartz grains.

The formation of regeneration rims around quartz grains occurred in several stages. On average, 3–4 regeneration rims can be distinguished in those interlayers that contain an insignificant amount of clay cement. In interlayers where the content of clay cement is more than 10–15%, grain regeneration is not so intense. Apparently, this is due to the fact

that clay cement in the void space largely prevents the migration of fluids saturated with silica.

Traces of quartz regeneration are usually interconnected with the pressure solution of clastic grains: conformal, incorporation, and microstylolite contacts (Figure 7). The intensity of these processes is largely due to the structure of the clastic part of the rock, especially the degree of sorting of the fragments.

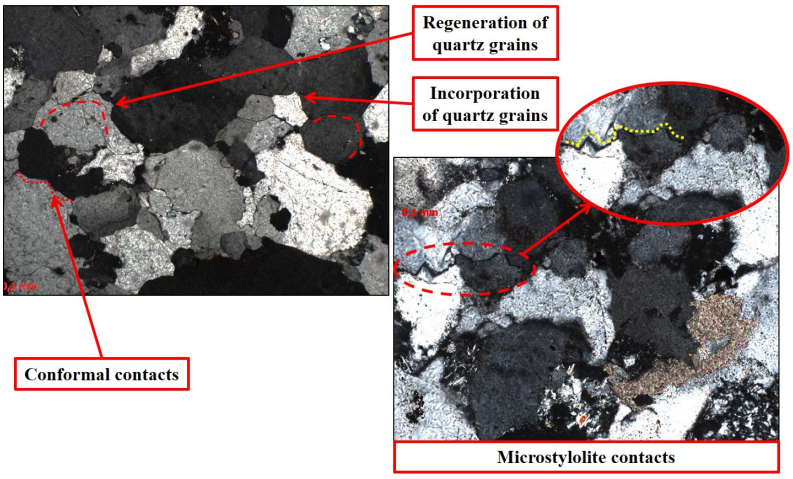


Figure 7. Some secondary alterations (late catagenetic – early metagenetic changes) of reservoir rocks.

The decrease in porosity values is also associated with the process of regeneration of fragments of potassium feldspars. However, this process is manifested on a smaller scale compared to the regeneration of quartz (Figure 8).

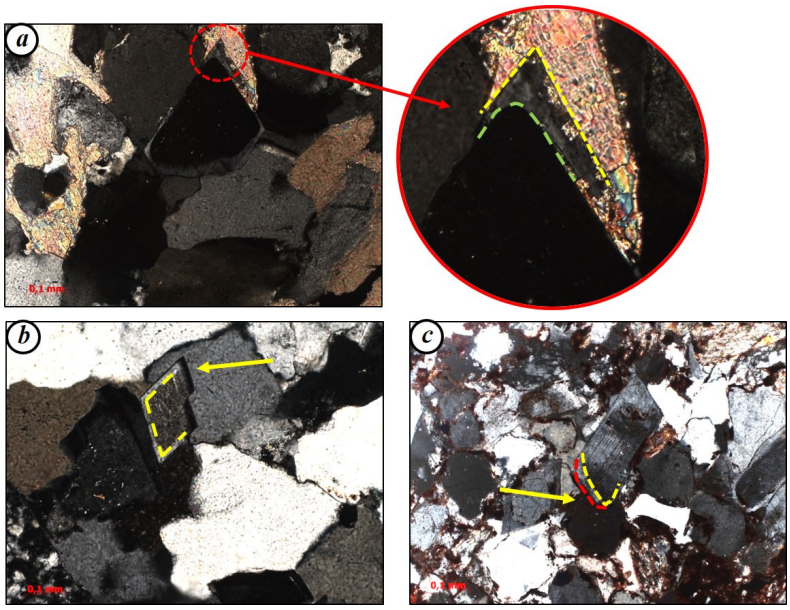


Figure 8. Regeneration of potassium feldspar grains. Corrosion of regeneration rims by later carbonate secondary cement (a) and incorporation of regenerated potassium feldspar fragments into quartz fragments (b, c).

Recrystallization-granulation blastesis of quartz is often superimposed on the regeneration rims of quartz. The phenomenon of recrystallization-granulation blastesis of quartz consists in the local replacement of allothigenic and authigenic quartz by metamorphogenic quartz in the form of a partial displacement of the boundary of a mineral grain into a grain adjacent to it.

The signs of the process of metamorphogenic "self-purification" of quartz, diagnosed by numerous Böhm lamellae, also testify to the transformation of rocks at the stage of early metagenesis (Figure 9). They are filamentous chains of gas–liquid inclusions that cross quartz grains [*Yapaskurt*, 2008].

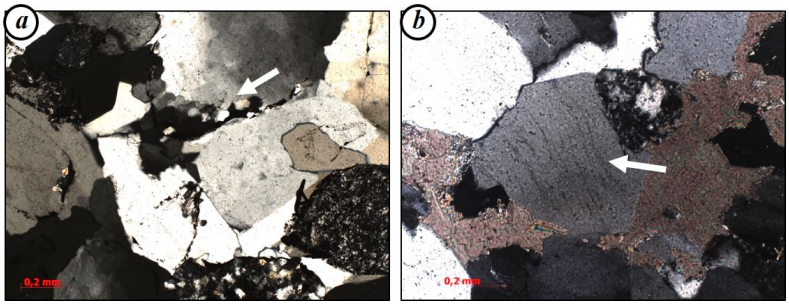


Figure 9. Microstructure of recrystallization-granulation blastesis on the periphery of a quartz grain (a). Böhm lamellae in a quartz grain (b).

Optical and electron microscopic studies have revealed numerous signs of plastic deformation of clastic grains. The fragments of micaceous schists are most intensively deformed. The fragments of micaceous schists are often so severely deformed that it is often difficult to diagnose them as fragments, and not as clay cement, even with the help of electron microscopic studies.

In the void space, authigenic crystals of quartz and potassium feldspars are often observed ranging in size from 3–5 μm to 40–50 μm, in some cases up to 200–300 μm (Figure 10). The surface of the newly formed crystals is practically not changed by the processes of pressure solution, which indicates their later generation.

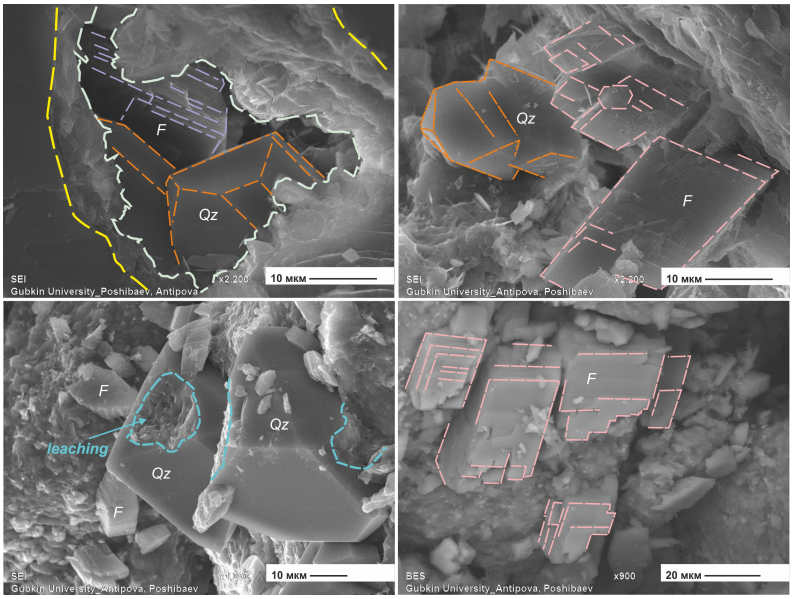


Figure 10. Authigenic quartz and potassium feldspar crystals. Symbols: Qz — quartz, F — potassium feldspar.

The authigenic micas are very numerous in the void space of the sandstones of the Moshakovskaya Formation. They belong to the illites of the 2M1 polytype modification with a high iron content [*Yudovich and Ketris*, 2008]. These authigenic minerals have a scaly or foliated microstructure and often form transverse ingrowths into the edges of regenerated quartz fragments. Newly formed clayey illite flakes greatly complicate the configuration of intergranular voids and reduce the diameter of pore channels.

Authigenic carbonates are represented by crystals of calcite, dolomite, ankerite, magnesite, and siderite. They partially or sometimes completely fill the residual void space of reservoir rocks. These processes are most widely developed in rocks that initially had a significant amount of void space. Secondary carbonate crystals corrode regenerated quartz and feldspar grains. Secondary carbonate cement usually has a patchy distribution, sometimes lenticular or layered. Fractures are often filled with carbonate minerals, usually siderite or dolomite. Corrosion of regeneration quartz borders with ingrowths of authigenic micas by carbonate minerals, filling of fractures with dolomite, siderite, and ankerite gives grounds to consider the processes of carbonatization to be later in relation to the formation of regeneration quartz and authigenic micas.

Authigenic sulfates are represented by anhydrite, barite, and celestine. Anhydrite is frequently found together with secondary carbonate minerals.

Crystals of sulfides such as pyrite, chalcopyrite, and cobaltite are found in the void space of the sandstones of the Moshakovskaya Formation.

In the well Abakanskaya-1 (the central part of the Angara fold zone), such minerals as barite, celestine, siderite, ankerite, magnesite, hematite, magnetite, chalcopyrite, and cobaltite were found in the deposits of the Moshakovskaya Formation. Vanadium and nickel impurities were found in magnetite and titanomagnetite. Tungsten impurities were found in barite (Figure 11).

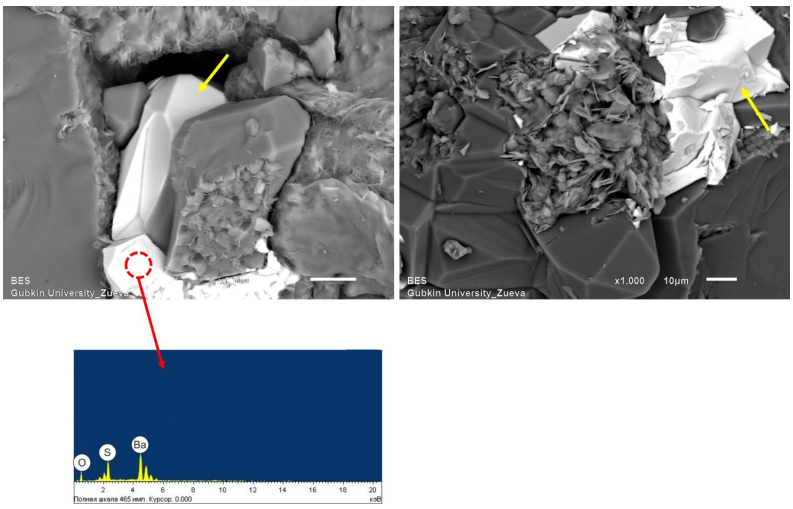


Figure 11. Authigenic crystals of barite.

Newly formed hematite, siderite, magnesite, barite, and ankerite were found in the Ilbokichskaya-3 well (north-eastern part of the Angara fold zone).

In the well Chunskaya-1 (slope of the Boguchany-Manzino Uplift), such a mineral as tungstenite (tungsten disulfide from the molybdenite group) was found. The crystals have a thin-lamellar, scaly, pinnate shape (Figure 12). The mineral is considered rare and occurs exclusively in hydrothermal deposits.

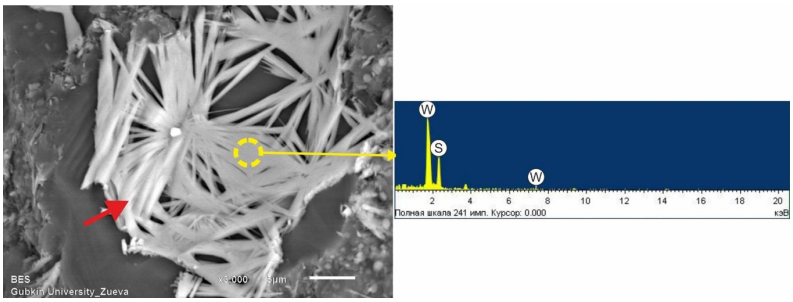


Figure 12. Authigenic tungstenite crystals.

The coexistence of such newly formed minerals suggests that the latest stages of authigenic mineralization are associated with hydrothermal processes.

Sulfate and carbonate mineralization are noted in many fractures identified throughout the section, especially in the Abakanskaya-1 well [*Poshibaev*, 2014]. Minerals were found in the same fractures, which are indicators of hydrothermal processes.

Hydrothermal minerals have been found in core samples taken from wells drilled in various structural zones (Figure 13). However, signs of the most active hydrothermal-metasomatic changes were revealed in the central zone of the Angara fold zone (in the Abakanskaya-1 well).

The intensity of these processes in reservoir rocks is very heterogeneous. The regeneration of quartz and potassium feldspar grains, the formation of conformal and incorporation contacts is most intensively manifested on the slope of the Boguchany-Manzino Uplift (in the Chunskaya-1 well). Intensive sulfatization and carbonatization are characteristic of deposits in the central part of the Angara fold zone (in the Abakanskaya-1 well). And leaching processes are most strongly detected in the northeastern part of the Angara fold zone (in the Ilbokichskaya-3 well).

The differentiation of the secondary processes by area is probably related to the distance from the source of hydrothermal solutions and the patterns of fracturing, as well as the lithological heterogeneity of the distribution of initially highly porous and highly permeable rocks.

5. Types of Void Space of Reservoir Rocks of the Moshakovskaya Formation

The reservoir rocks of the Neoproterozoic Moshakovskaya Formation are represented by polymictic coarse-, medium-, fine- and mixed-granular sandstones.

The reservoir rocks are distinguished by a high degree of lithological and petrophysical heterogeneity due to paleogeographic conditions, as well as the intensity and direction of secondary processes.

The most high-porosity reservoir rocks were formed in the areas of development of accumulative sand bodies in zones of active watercourses and beach formations in coastal areas (Figure 14).

As a result of the studies, it was found that the reservoir rocks of the deposits of the Moshakovskaya Formation belong to porous and porous-fractured types. Numerous subvertical extended partially mineralized fractures connect thin granular reservoir interlayers, thereby forming a complex reservoir system.

Several types of voids are distinguished in the reservoir rocks of the Moshakovskaya Formation: intergranular pores, voids of leaching cement, and clastic component (Figure 15).

Leaching voids are of the greatest practical interest (Figure 16). Their share of the total void space is sometimes more than 50–60%. These voids are associated with leaching processes that accompany all stages of hydrothermal-metasomatic processes. Thus, leaching is the main void-forming factor.

Analysis of reservoir characteristics of rocks showed that the range of change in the porosity coefficient ranges from 0.37 to 20.61%, averaging 5.54%, gas permeability from impermeable rocks to 300 mD, averaging 2.67 mD (Figure 17). For a porous-fractured reservoir, the values of the permeability coefficient for gas are up to 100–140 mD.

A strong variation in the values of the porosity coefficient in the same lithological types is mainly due to the intensity of the manifestation of certain secondary processes.

For example, the distribution features and the amount of illite cement well explain the differences in the values of the porosity coefficient within the same lithotype. For example, in samples with low porosity (1–2%), illite cement often fills the entire space of the intergranular void. In them, illite flakes are often strongly compacted. In porous sandstones (the porosity is 10–15%), illite cement is much less, and it is less compacted in the intergranular space.

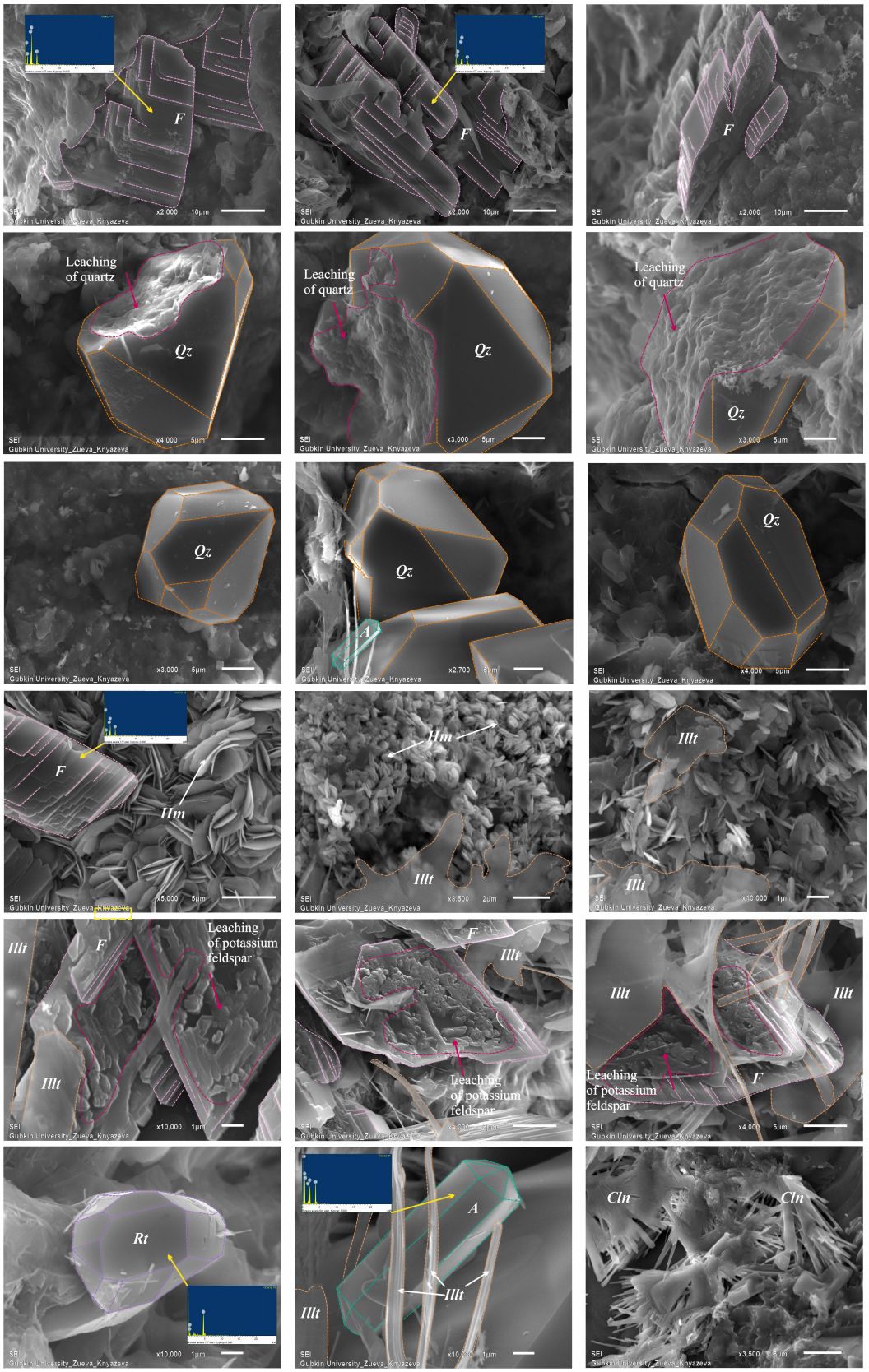


Figure 13. Some hydrothermal minerals in the void space of reservoir rocks. Symbols: Qz — quartz, F — potassium feldspar, Hm — hematite, Illt — illite, A — apatite, Rt — rutile, Cln — celestine.

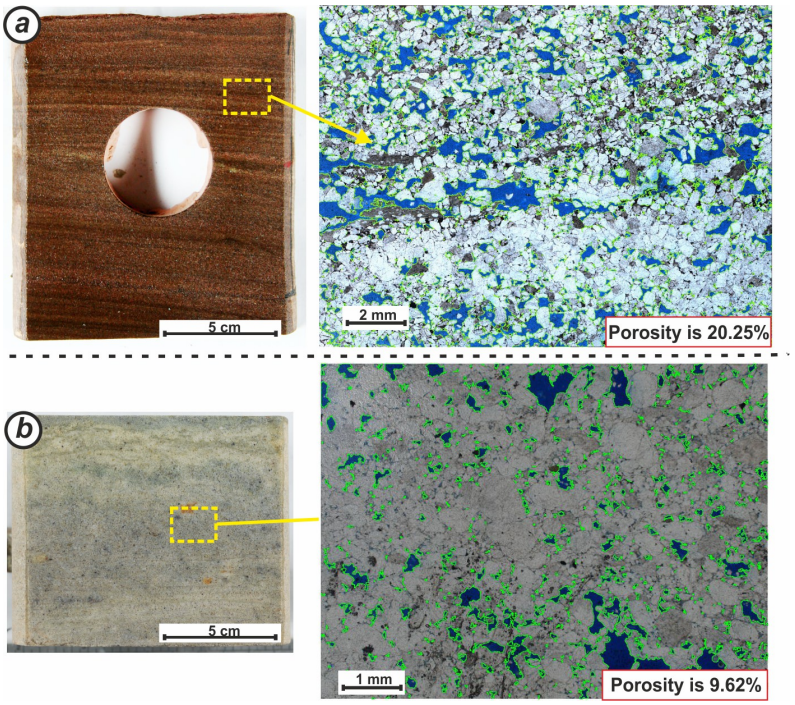


Figure 14. High-porosity reservoir rocks in the areas of development of accumulative sand bodies in zones of active watercourses (a) and beach formations (b) in coastal areas. Porosity according to rock image analysis.

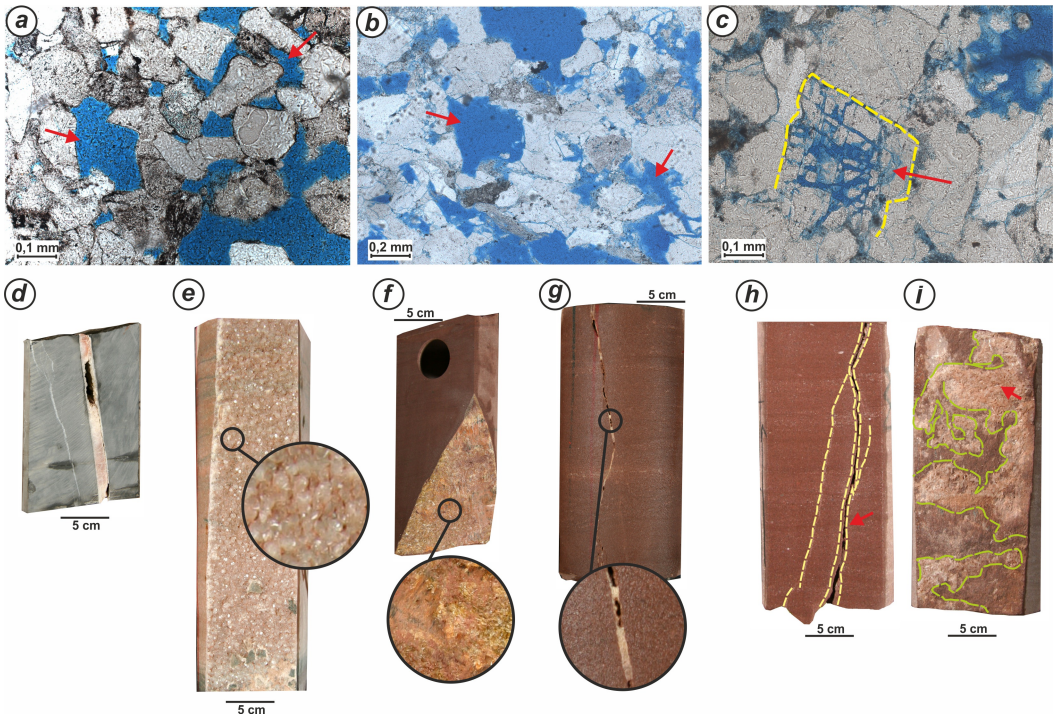


Figure 15. The main types of void space in productive deposits of the Moshakovskaya Formation: intergranular pores (a), leaching voids of cement (b) and clastic component (c), fractures partially filled with dolomite (d, e), slip surface and authigenic ankerite crystals on it (f), fracture partially filled with ankerite (g), system of open subvertical partially mineralized fractures (h), surface of partially mineralized fracture (i).

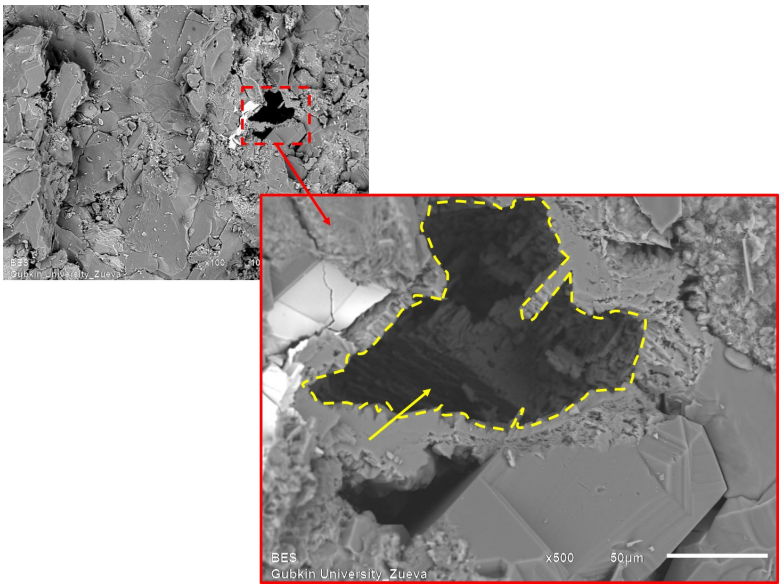


Figure 16. Intensive leaching of a fragment of potassium feldspar.

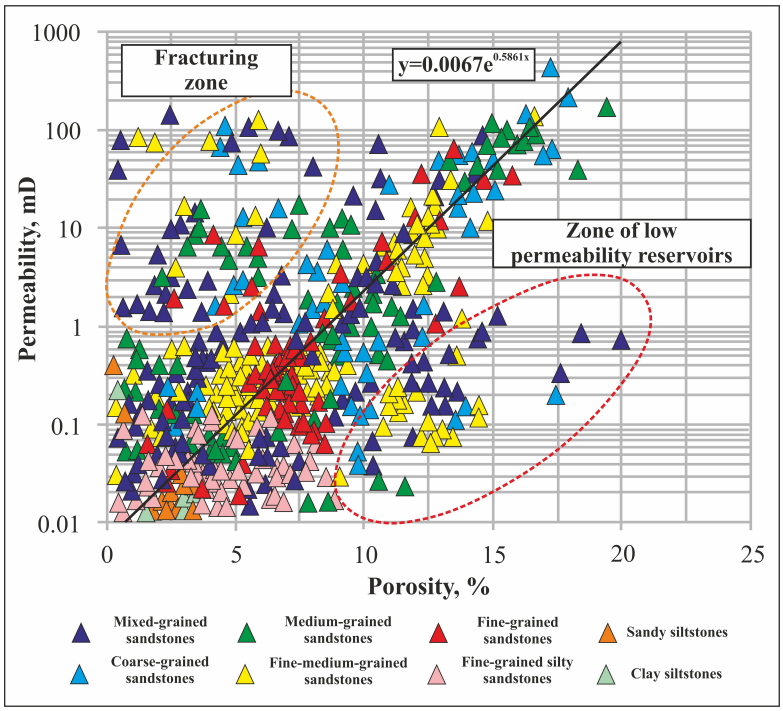


Figure 17. Petrophysical dependency Permeability–Porosity for different lithotypes according to the results of laboratory studies.

The sizes of flakes of clay minerals also explain the differences in porosity and permeability properties. In samples with smaller flakes, the values of the porosity coefficient are much higher.

Secondary sulfate and carbonate minerals usually completely fill the entire void space. Therefore, in such samples, the values of the porosity usually do not exceed 1–3%. However, if the leaching of sulfate and carbonate cement occurs, then in such samples the values of the porosity can reach 12–15%.

In sandstones with hematite cementation, the values of the porosity coefficient are usually high, which is explained by its microporous structure.

6. Discussion

One of the main factors of authigenic mineral formation in the deposits of the Moshakovskaya Formation was hydrothermal processes. They were most active at the final stages of lithogenesis, during periods of magmatic activations associated with manifestations of kimberlite and trap magmatism [*Alekseeva et al.*, 2016; *Kargin et al.*, 2016].

Hydrothermal processes dominated the trap development zones at the postmagmatic stage. They occurred both in near-surface zones and were confined to the supply channels of basalt covers and intrusions. Ore-conducting channels do not contain ore bodies everywhere, but at the same time they bear traces of hydrothermal mineralization.

The early tectonic-hydrothermal stage took place under conditions of high tectonic tension, a sharp pulsating stress regime, as well as high aggressiveness of solutions, which led to the predominant dissolution of rocks. The initial hydrothermal fluids were alkaline. Upon cooling to 450–300 °C, they became acidic. The reason for these changes lies in the T–P dependence of the dissociation of hydrolysis products and the state of aggregation of fluids. Fluids evolve over time from essentially sub-neutral or alkaline through alkaline to acidic. Then back to late low-temperature alkaline and sub-neutral fluids [*Kigai and Tagirov*, 2010; *Korzhinsky*, 1951, 1953, 1958, 1982]. Each of these cycles corresponds to a certain stage of mineralization. The beginning of each stage is characterized by a sharp increase in alkalinity or acidity, which leads to metasomatic changes in the host rocks. The composition of the resulting authigenic minerals is determined primarily by the temperature of the incoming solution, and not by the composition of the host rocks.

At the early high-temperature (alkaline) stage of hydrothermal processes, the first generations of potassium feldspar and pyrite crystals were formed. The surface of the newly formed crystals is not changed by pressure solution processes. Tabular crystals of potassium feldspar can most likely be attributed to high-temperature sanidine. Their sizes are 10–50 μm.

At the next medium-temperature (acid) stage, the formation of the second generation of pyrite, the first generation of apatite and rutile, hematite, and quartz crystals occurred. Hematite flakes form thin brushes on the surface of grains and often fill pores. The sizes of apatite and rutile crystals do not exceed 10 μm. The sizes of quartz crystals are 10–50 μm.

At the next medium- and low-temperature (late alkaline) stage, the second generation of potassium feldspar crystals, carbonate minerals (ankerite, siderite, dolomite, and magnesite), ore sulfide minerals (pyrite, chalcopyrite, cobaltite, and tungstenite), barite, and celestine were formed.

The stages of formation of carbonate minerals can be presented as follows: the first generation of calcite, followed by ankerite, siderite, dolomite, and magnesite. The process is completed by the second generation of calcite. The sizes of the crystals of carbonate minerals vary from 10 to 150 μm, barite and celestine — up to 200 μm.

At the final stage of hydrothermal processes, residual neutral solutions affected the rock and anhydrite crystals formed in the void space.

The manifestation of halitization refers to the latest stages of secondary processes. In general, the halite content in rocks is small and reaches no more than 1–3%. Halite crystals are noted as minor clusters in the void space of reservoir rocks.

One of the most important secondary processes that had a significant impact on the texture of the void space of reservoir rocks is leaching. Leaching processes affect both the clastic and cementing parts of the rocks, creating additional porosity and filtration channels. Their share of the total volume of void space sometimes exceeds 80%. It can be stated with a high degree of probability that leaching accompanied hydrothermal-metasomatic processes that worked the entire section of the Moshakovskaya Formation with varying degrees of intensity. Indicators of various stages of hydrothermal-metasomatic processes are complexes of authigenic minerals described earlier. Leaching is a multi-stage process that accompanied various stages of hydrothermal-metasomatic development of the section.

As a result, the stages of the secondary processes were quite clearly established, as shown in Figure 18.

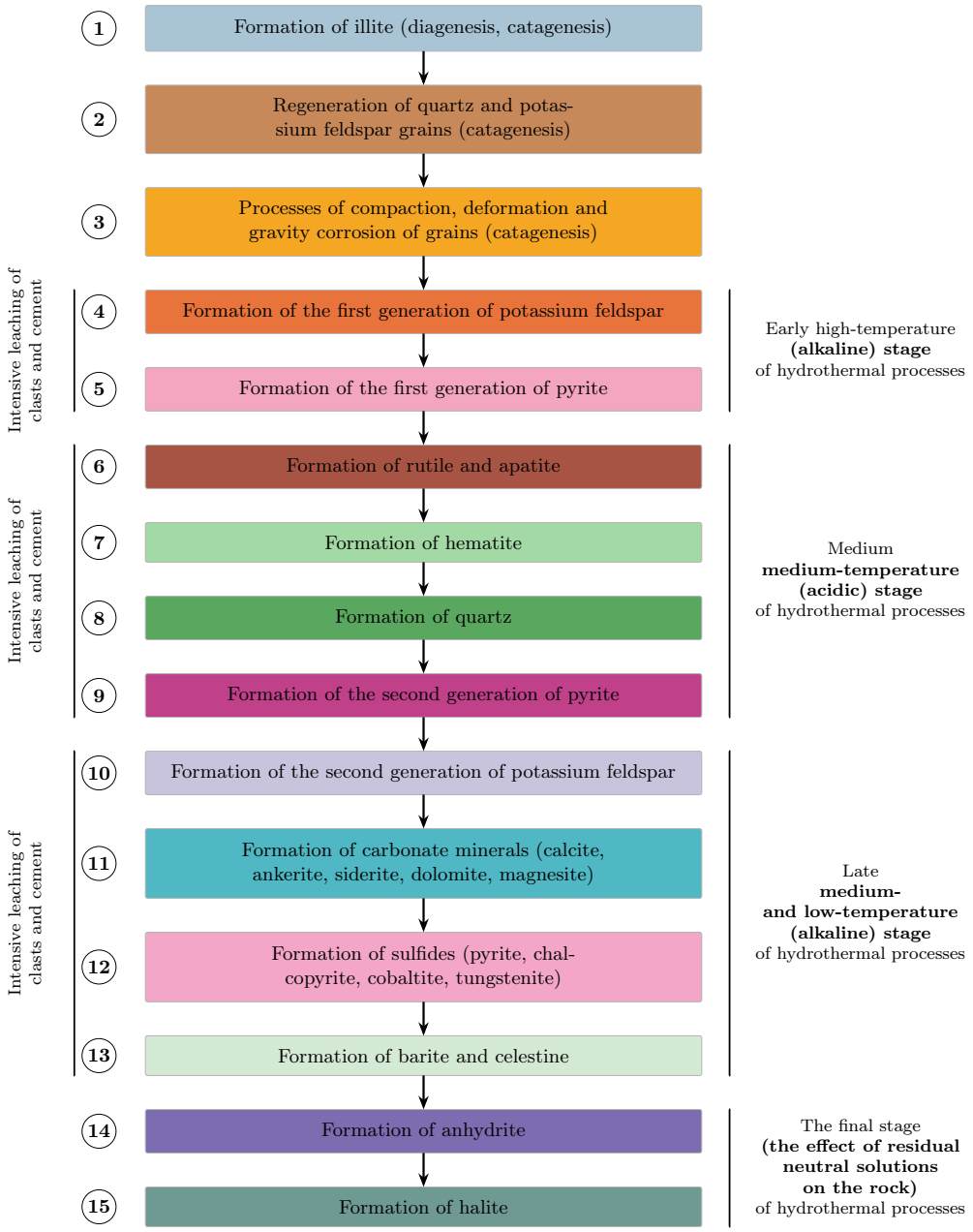


Figure 18. The stages of the secondary processes of reservoir rocks.

7. Conclusions

The reservoir rocks of the Moshakovskaya Formation are represented by polymictic coarse-, medium-, fine- and mixed-granular sandstones. The most high-porosity reservoir rocks were formed in the areas of development of accumulative sand bodies in zones of active watercourses and beach formations in coastal areas [*Antipova et al.*, 2019].

The reservoir rocks are of porous and porous-fractured types. The void space in reservoir rocks is due to intergranular pores, as well as leaching voids of cement and clastic component, united by a system of tectonic fractures.

The rocks that make up the productive deposits of the Moshakovskaya Formation are characterized by high intensity and a variety of secondary alterations.

As a result of the complex optical, electron microscopic, and X-ray diffraction studies, a wide range of secondary alterations in the Neoproterozoic reservoir rocks of the Moshakovskaya Formation was revealed.

The processes of authigenic mineral formation in void space, pressure solution of clastic grains, their plastic deformation, leaching, and intense fracturing are most widely manifested.

The presence of such newly formed minerals as barite, celestine, calcite, siderite, ankerite, magnesite, dolomite, hematite, magnetite, pyrite, chalcopyrite, cobaltite, and tungstenite in the void space of clastic rocks suggests that the latest processes of authigenic mineral formation are associated with hydrothermal activity. Each of the stages of the hydrothermal process was accompanied by intensive leaching.

The processes of carbonatization, sulfatization, and leaching had a significant impact on the reservoir properties of rocks. Carbonatization and sulfatization are the causes of local deterioration of reservoir properties. Leaching is the cause of the formation of interlayers with significant porosity.

Thus, one of the main factors of authigenic mineral formation in the deposits was hydrothermal processes. They were most actively manifested at the final stages of lithogenesis during periods of magmatic activation associated with manifestations of kimberlite and trap magmatism.

The facies factor and secondary processes mainly determined the distribution of the pore component of the reservoir rocks. At the same time, fracture zones play the most important role in the filtration system of Neoproterozoic reservoirs. Thickening and mutual intersection of faults (zones of modern geodynamic extension) in facies zones favorable for the formation of reservoir rocks is an additional positive factor for improving reservoir properties, since in these zones the most permeable sections of the section are formed.

Thus, it should be noted that currently the reservoirs of the Moshakovskaya Formation are a complex system of voids and filtration channels characterized by a high degree of heterogeneity of petrophysical characteristics, morphometric parameters, and mineral composition of the void space. All these factors largely determine the effectiveness of their development.

The study of the manifestation of various kinds of secondary processes allows us to conclude that the primary structures of rocks, their mineral composition, and the structure of the void space were significantly changed by complex multifactorial processes accompanying tectonic events and hydrothermal manifestations.

A new type of pore space has been identified in Neoproterozoic deposits. It is leaching voids. This type of voids may be associated with the discovery of new levels of reservoir development associated with leaching processes.

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