Structure and composition of the Sarailinsky depression oil source strata in territory of the Tatarstan Republic

Eduard Korolev[1], *Vladimir* Morozov[1], *Aleksey* Eskin[1*], *Anton* Kolchugin[1], and *Alexey* Khauzkin[1]

[1]Kazan Federal University, 420008, Russia

Abstract. The work carried out a study of core material from oil source rocks of the Sarailinsky depression, located between the southern and northern domes of the Tatar arch within the Tatarstan Republic. The well sections of the Sarailinsky strata are dominated by carbonate rocks, represented by packstones, wackestones and mudstones. Among the limestones lie interlayers of carbonate-siliceous rocks and mudstones. All rock lithotypes are enriched to varying degrees in sapropelic organic matter, which allows them to be classified as oil source deposits. There is a tendency for the relative content of organic matter to increase in the series: limestone → carbonate-siliceous rocks → mudstones. Judging by the interlayering of rocks of different composition in the section, the formation of the Sarailinsky strata took place in a marine sedimentation basin, with periodically changing environmental conditions. Under normal conditions, limestone was formed, under abnormal conditions, carbonate-siliceous rocks enriched in organic matter were formed, and when the removal of terrigenous material from the continent intensified, argillites were formed.

1 Introduction

The decrease in the resource potential of hydrocarbons in the old oil-producing regions of Russia stimulates oil companies to search for new objects for development. In recent years, much attention has been paid to shallow terrigenous bitumen deposits and the Domanik black shales deposits [1-2]. The development of successful technologies for the extraction of high-viscosity bitumen has led to a decrease in preferential taxation in this industry due to the exclusion of bitumen deposits from the register of unconventional hydrocarbon resources. Due to the fall in global oil prices, this has led to the unprofitability of most bitumen deposits. Currently, many oil producing companies have focused their attention on the source rocks of the Domanik formation, which in the future may become a new source of oil. The impetus for geological research in this direction was the successful development of high-carbon deposits of the Bakken field (USA), from which shale oil is extracted [3-4]. On the territory of the Volga-Ural anteclise, deposits of the Domanik formation are confined to the Kama-Kinel system of depressions [5-6]. One of the structural-tectonic

* Corresponding author: eskin.aleksey@gmail.com

elements of the depression system is the Sarailinsky depression, which separates the Southern and Northern domes of the Tatar arch [7]. Within its boundaries lie thick strata of terrigenous rocks, which, in terms of organic matter content, belong to oil source deposits [8]. The presence of oil deposits in the Sarailinsky depression suggests that the source of hydrocarbons was the original rocks enriched in sapropelic substance. However, to determine the potential significance of the Sarailinsky terrigenous strata in oil generation processes, it is necessary to conduct lithological and mineralogical studies of rocks in order to determine their structure, mineral composition, and organic matter content.

2 Methods

The object of the study was the core material of wells that exposed the Sarailinsky strata in the axial and slope parts of the depression of the same name. After a macroscopic description of the core and determination of the main rock lithotypes, samples of limestone, siltstone, marl and argillites were selected. Subsequently, all samples were sent to laboratories for the production of preparations for optical microscopy, X-ray and thermal analysis.

Optical microscopic studies were carried out using a polarizing optical microscope Axio Imager A2 manufactured in Germany. To do this, thin sections were made from the most representative rock samples, which were then studied in transmitted and polarized light. X-ray analysis was carried out on a Bruker D2 Phaser X-ray diffractometer (Germany). Powder preparations were used. X-ray diffraction patterns were interpreted using the DIFFRAC.EVA and TOPAS software. Thermal analysis was carried out on an STA 449 Jupiter F3 device with a firing range from 30 to 1000°C, heating step – 10 deg/min with constant air blowing. The main purpose of the analysis was to determine the relative content of organic matter and the ratio of fractions that boil away at different temperatures

3 Research results

The study of core material from wells that penetrated the terrigenous strata in the Sarailinsky depression made it possible to identify the main lithotypes of sedimentary rocks and the features of their occurrence in the sections. According to optical microscopy, it was established that the sections are dominated by light and dark gray limestones, as well as dark gray to black carbonate-siliceous rocks of mixed composition, among which there are small layers of black argillites. The contacts between layers of different facies rocks are sharp and clear, indicating sharp changes in sedimentation conditions. Limestones are represented by three facies of carbonate rocks in accordance with the classification of R.J. Dunham [8]. These are mudstones, wackestones and packstones.

Mudstones are composed of micro-fine-grained calcite, the grains of which form dense irregular aggregate intergrowths (Figure 1A). In the intergranular space of calcite aggregates there are dark brown inclusions of syngenetic organic matter, which gives the rock a dark tint. Organic matter is coagulated into isometric aggregates or forms thin films around calcite grains. Limestones show uneven layer-by-layer recrystallization. Areas enriched in organic matter retained the primary microgranular structure of calcite, areas depleted in organic matter underwent more intense recrystallization with the formation of fine-grained calcite. The alternation of micro- and fine-grained calcite layers determines the horizontally layered texture of the rock. The granular mass contains up to 10% inclusions of organic and represented by fragments of calcispheres and radiolarians. Among the diagenetic minerals, pyrite is present, metasomatically developing after calcite.

Wackestones are similar in structure, composition, and structural-textural features to mudstones (Figure 1B). The difference lies in a slightly higher content of syngenetic planktonic organic matter and fragments of calcispheres, radiolarians, and blue-green algae. Among the diagenetic minerals, in addition to pyrite, there are aggregates of fine-grained chalcedony, which indicates the dissolution of radiolarians and redeposition of silica.

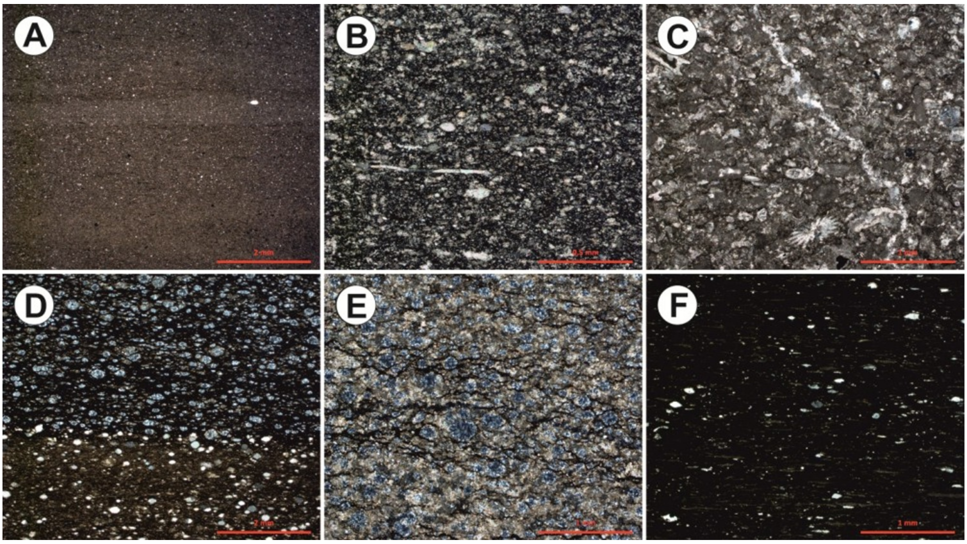

Fig. 1. Photo of thin sections the Sarailinsky depression rocks in polarized light: A – mudstone; B – wackestone; C – packstone; D,E – carbonate-siliceous rocks; F – argillite.

Packstones are composed mostly (75-80%) of organic remains (Figure 1C). They represented by microgranular lumpy aggregates of spheroidal shape (80%), fragments of crinoids (15%) and calcispheres (5%). Bioclasts form a dense structural packing in contact with each other. Fragments of marine organisms are cemented with calcite cement of the pore type with a microgranular structure. In the intergranular space of calcite cement there are numerous black and dark brown inclusions of condensed organic matter, giving the rock a dark tint. The limestone contains black carbonate-siliceous layers (Figure 1D) composed of aggregate intergrowths of micro-fine-grained calcite with chalcedony and radiolarian inclusions (Figure 1E). Due to the higher content of syngenetic sapropelic substance, carbonate-siliceous layers are characterized by a black color. They contain diagenetic pyrite grains about 0.05 mm in size, which metasomatically replace rock calcite.

The argillites are composed of highly altered clay minerals that have undergone processes of transformation of the crystalline structure (Figure 1F). Under the influence of pressure, clay minerals are compacted, their particles come into contact by the basal planes. Between the particles of clay minerals there are coagulated aggregates of organic matter. Some of the organic matter is concentrated in the form of lens-shaped segregations, and some - in the form of thin films on the surface of clay minerals. The relatively high content of organic matter causes the black color of the rock, and the predominance of lenticular segregations causes a lenticular-layered microtexture. The argillites contain 5-10% clastic quartz grains and radiolarian fragments composed of fine-grained chalcedony. Rare grains of diagenetic pyrite and aggregates of fine-grained chalcedony are also present.

X-ray studies have shown that each lithotype is characterized by its own individual composition of mineral associations. In limestones, the main rock-forming mineral is calcite, often in association with dolomite. In some layers of carbonate rocks, small admixtures of chalcedony, pyrite and halite are noted. Carbonate-siliceous rocks of mixed

 https://doi.org/10.1051/e3sconf/202452403014

composition are represented by grains of calcite and chalcedony in various proportions. Dolomite, pyrite, illite and kaolinite are present as trace minerals. In argillites, the rock-forming minerals are chalcedony, a mixed-layer phase of illite-montmorillonite composition, kaolinite and calcite. Pyrite and dolomite are present in small quantities.

Determination of the content of the syngenetic organic component using thermal analysis made it possible to establish the features of the distribution of kerogen along the section of the Sarailinsky strata (Figure 2). A tendency was noted for an increase in the relative content of kerogen in the series: limestone → carbonate-siliceous rocks → argillites. On differential thermal analysis curves, organic matter produces three exothermic effects in the temperature range 240-480°C. The first effect is due to the thermal destruction of low molecular weight organic components, the second and third – high molecular weight. That is, syngenetic organic matter refers to biogenic polymers of complex composition. Based on changes in the thermogravimetry curve in the range of exothermic effects, it was found that in limestones the kerogen content is 0.2-1.5%, in carbonate-siliceous rocks – 1.0-4.2%, in argillites – 3.2-5.1%.

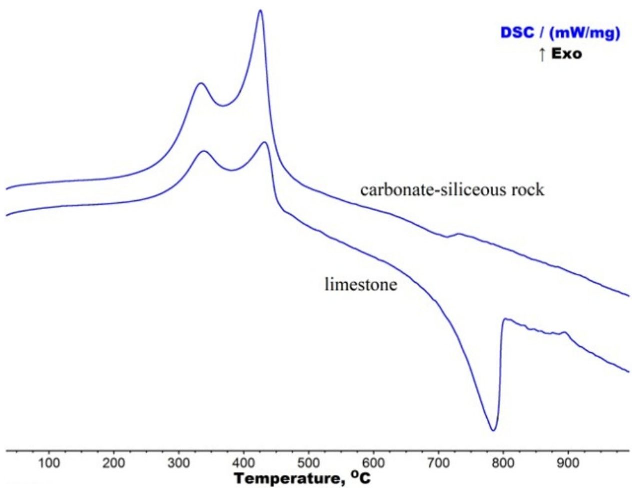

Fig. 2. Thermograms of carbonate-siliceous rocks and limestone of the Sarailinsky strata.

4 Discussion

Analysis of the research materials obtained suggests that the terrigenous strata of the Sarailinsky depression formed in a marine sedimentation basin with an anomalous gas regime. Judging by the association of organic remains in limestones, most carbonate rocks, with the exception of packstones, were formed under conditions of oxygen deficiency. This is, in particular, indicated by the presence of syngenetic organic matter in the rocks and the absence of remains of benthic marine organisms. At the same time, fragments of nekton (floating organisms) indicate that the water column above the bottom layer of the sea basin was saturated with oxygen. The horizontally layered texture of the rocks is a consequence of their accumulation in relatively deep-sea depressions, where calm hydrodynamic conditions of the water column prevailed. Sharp transitions of limestone into carbonate-siliceous rocks and argillites along the section indicate rapid changes in the geochemical parameters of the water column within the Sarailinsky depression. The higher content of sapropel residues in rocks of mixed composition is caused by a surge in the vital activity of phyto- and zooplankton. Moreover, in the ecological niche of this biotope, siliceous organisms (radiolaria) predominated among planktonic organisms. When plankton died, organic matter and mineral skeletons of radiolarians fell to the bottom of the sea basin, forming silts enriched with biogenic material. The calm hydrodynamic regime in the deep areas of the seabed contributed to the saturation of the bottom layer of water with carbon dioxide and depletion of oxygen. As a result, the benthic organisms were suppressed and the silts were enriched with nekton fragments (conodonts). Probably, at this time, terrigenous material was being removed from the coastline, which, accumulating in the axial part of the Sarailinsky depression, formed layers of argillites. The systematic entry of planktonogenic material into muddy sediments and the lack of oxygen in the bottom layer of the marine paleobasin created conditions for the burial of syngenetic organic matter [9]. During the subsidence of sedimentary deposits, organic matter was redistributed, forming films around mineral grains and coagulated aggregates. Based on the relative content of organic matter (<5%), most of the rocks belong to the Domanikoids [10]. Syngenetic organic matter is characterized by a relatively low degree of transformation [11]. That is, the rocks have not reached the stage of oil generation. At the same time, the presence of oil deposits in the side parts of the Sarailinsky depression allows us to assume the presence of a source of hydrocarbons in the axial part of the negative structure. The prerequisite for this is the increased thermal background within the regional tectonic faults at the base of the depression [12]. The presence of sapropelic organic matter in sedimentary rocks contributed to the development of diagenetic mineralization. By releasing carbon dioxide and saturating pore solutions with carbon dioxide, organic matter activated the processes of recrystallization of the original micro-grained calcite into fine-grained calcite. Variations in acidity-alkalinity in the pore environment led to the dissolution and subsequent precipitation of silica [13]. As a result, diagenetic aggregates of fine-grained chalcedony were formed in rocks of mixed carbonate-siliceous composition, the source of which was the siliceous skeletons of radiolarians. Part of the active silica filled the cavities of previously formed tectonic cracks. Increased partial pressures of carbon dioxide were created in certain layers of sedimentary rocks. This led to the formation of rhombohedral grains of authigenic dolomite. The suppressed activity of oxygen in the presence of sulfur-organic compounds caused a surge in the vital activity of sulfate-reducing microbial communities, saturating pore solutions with hydrogen sulfide [14]. The latter, binding with divalent iron ions, formed grains and aggregates of pyrite. Since sulfate-reducing microorganisms led an attached lifestyle, diagenetic pyrite developed along previously formed calcite grains. Features of accumulation and post-sedimentary transformations of organomineral matter over a long geological history have shaped the modern appearance of the Sarailinsky terrigenous strata. Judging by the maturity of sapropelic organic matter, the sedimentary rocks of the Sarailinsky depression have not currently entered the stage of oil generation, although the presence of local sources of hydrocarbons near regional tectonic faults cannot be ruled out.

5 Conclusion

Considering the above, the following conclusions can be drawn:

- The Sarailinsky terrigenous sequence was formed under the conditions of a depression valley in the sea basin of the Tournaisian-Visean age.
- In the bottom layer of the depression, sedimentation conditions changed periodically. Under normal marine conditions, layers of different-facial limestones accumulated; under anomalous conditions, carbonate-siliceous rocks accumulated; during the active removal of terrigenous material from the continent, argillites accumulated. Anomalous conditions are associated with a violation of the gas regime in the bottom layer of the sea basin, caused by the decay of planktonic microorganisms.

- Based on the content of syngenetic organic matter, sedimentary rocks can be classified as domanikoids; based on the degree of maturity of organic matter, they can be classified as rocks with a low regeneration potential of hydrocarbon
- The rocks of the Sarailinsky strata have undergone various post-sedimentary transformations under the influence of geochemical destruction of sapropelic organic matter. Decaying organic matter, supplying carbon dioxide into pore solutions, contributed to the recrystallization of microgranular calcite in limestones and the formation of diagenetic dolomites in carbonate-siliceous rocks. Suppression of oxygen activity caused a surge in the activity of sulfate-reducing microorganisms forming pyrite grains
- Currently, the generation of hydrocarbons in the Sarailinsky depression may be associated with rocks located along regional tectonic faults along which there is an ascending heat flow from the crystalline basement.

Acknowledgement

This work was funded by the subsidy allocated to Kazan Federal University for the state assignment in the sphere of scientific activities, project No. FZSM-2023-0014.

References

1. E.A. Korolev, A.I. Bakhtin, A.A. Eskin, R.R. Hanipova, Neftyanoe khozyaystvo - Oil Industry **10** (2016)
2. V.P. Morozov, A.S. Khayuzkin, E.A. Korolev, A.N. Kolchugin, A.N. Mukhamediyarova, E.V. Morozova, A.A. Eskin, N.A. Nazimov, F.M. Gazeeva, N.S. Zakharova, Georesources **24,** 4 (2022)
3. J.W. Schmoker, AAPG Mem. **60**, 19 (1994)
4. A.V. Stoupakova, N.P. Fadeeva, G.A. Kalmykov, A.Kh. Bogomolov, T.A. Kiryukhina, N.I. Korobova, T.A. Shardanova, A.A. Suslova, R.S. Sautkin, E.N. Poludetkina, E.V. Kozlova, D.V. Mitronov, F.V. Korkots, Georesources **61**, 2 (2015)
5. T.A. Kiryukhina, N.P. Fadeyeva, A.V. Stoupakova, E.N. Poludetkina, R.S. Sautkin, Oil and gas geology **3** (2023)
6. X.P. Liang, G.A. Galushyn, V.P. Filippov, Georesources **62**, 3 (2015)
7. I.P. Kosachev, G.P. Kayukova, E.M. Kosacheva, Oil and gas geology **12**, 3 (2017)
8. R.J. Dunham, Bull. Amer. Assoc. Petrol. Geol. **1** (1962)
9. D.A. Bushnev, N.S. Burdelnaya, E.S. Ponomarenko, T.A. Zubova, Lithology and minerals **4** (2016)
10. N.P. Fadeeva, E.V. Kozlova, E.N. Poludetkina, T.A. Shardanova, N.V. Pronina, A.V. Stupakova, G.A. Kalmykov, A.N. Khomyak, Vestn. Mosc. un. ser. 4. Geol. **6** (2015)
11. M.I. Zaidelson, S.Ya. Weinbaum, N.P. Koprova, Formation and oil and gas potential of domanikoid formations (M.: Nauka, 1990)
12. N.N. Khristoforova, A.V. Khristoforov, M.A. Bergman, Georesources **26**, 3(2008)
13. A.V. Stoupakova, G.A. Kalmykov, N.I. Korobova, N.P. Fadeeva, Yu.A. Gatovskii, A.A. Suslova, R.S. Sautkin, N.V. Pronina, M.A. Bolshakova, A.P. Zavyalova, V.V. Chupakhina, N.N. Petrakova, A.A. Miftakhova, Georesources **1** (2017)
14. R.T. Wilkin, H.L. Barnes, S.L. Brantley, Geochem. et Cosmochim. Acta **60**, 20 (1996)