The Lithology of the Eocene-Paleocene Reservoirs of the Central and Eastern Ciscaucasia

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Abstract: The article presents the results of lithological and petrophysical investigations of reservoir rocks of the Eocene-Paleocene Formations, which is one of the main hydrocarbon prolific horizons in the Central and Eastern Ciscaucasia. These results include lithological characteristics and pore space parameters for reservoir rocks of these stratigraphic intervals.

1 INTRODUCTION

The geological study of the Eastern and Central Ciscaucasia began in the 19th century. The first brief lithological characterization of rocks was carried out based on the results of a study by G.V. Abikh, who laid the foundation for the oil geology of the Ciscaucasia. A great contribution to further geological research was made by A.L. Karpinsky (1883), N.I. Andrusov (1888), K.A. Prokopov (1908), IM. Gubkin (1920 - 1940), A.D. Arkhangelsky (1920, 1927), I.O. Brod (1934), N.B. Vassoevich (1948), V.E. Khain (1948), A.I. Letavin (1970, 1972), and M.S. Burshar (1969) [1,2].

As an example, in the thematic collection "*Experience in the study of geological and geophysical data for the study of the geology of the Apsheron Peninsula, Eastern and Central Ciscaucasia*" published in 1960, the lithology, facies changes and stratigraphy boundaries were presented and unified. It was found that, within the study area, the Khadum Formation consists ofmarls,silty-sandy-clayey and clayey mudstones with an Ostracodalimestonelayer in the middle part.

Even though the study of this area and the lithological analysis of the Eocene-Paleocene Formation have been carried out at a high level, many questions still remain here. They are connected with the hydrocarbon potential and reservoir properties of these rocks.

Since the regions of the Central and Eastern Ciscaucasia have significant potential for replenishing the hydrocarbon resource base, it is particularly important to determine the main geological factors which control hydrocarbon formation and distribution. A significant part of this potential falls on unconventional reservoirs in clayey sediments of the Paleogene complex. The search and exploration of promising areas with such reservoirs are complicated by the specifics of their properties, but a comprehensive interpretation of the results of seismic exploration, well logging and core studies can significantly improve the forecast quality [3,4].

The novelty of this work lies in the comprehension of the analytical results from the new drill core investigation. These results include a detailed study of the lithology and pore space and identification of connectivity between the pore space configuration and the fracturing propagation direction depending on the change in mineral composition.

This studywas aimed to identify the influence of mineral composition variance on the rock reservoir properties. A detailed lithological characterization ofreservoir rocks in the Eocene-Paleocene deposits was a base for reservoir properties deducing.

2 Methods

There were67 samples from all 240 meters of core investigated with the following methods and techniques.

Visual analysis of rock structure with samples.

Light microscopy techniques (based on thin sections analysis):

- Identification of the lithological types.
- Characterization of the pore space parameters.
- Identification of the pore space distribution patterns.
- IMAGE-analysis of the photographs under SEM.

The method of IMAGE-analysis of the images obtained using SEM in the secondary electron mode is based on the fact that secondary electrons are generated by near-surface layers and are very sensitive to the state of the surface. The smallest changes in surface topography are reflected in the number of collected electrons. Thus, this type of electrons carries information about the relief of the sample, the depth of the voids, and the structure of the pore walls. Deeper voids will have a darker glow relative to shallow pores [5,6].

Quantitative characteristics of pore space were calculated in the AxioVision (ZEISS) software. Application-specific modules allow to measure geometry parameters of each pore such as maximum length, area and aspect ratio. These parameters are particularly important for geomechanical rock properties.

3 Results

The investigated well section is in the Prikumskaya system of uplifts, Praskoveyskaya area. The object of the study is the Eocene-Paleocene deposits, widespread in the Ciscaucasia region (Fig. 1). The Goryachy Klyuch, Cherkess, Kumsko-Kerestinsky, Beloglinsky and Khadumsky suits were considered [7].

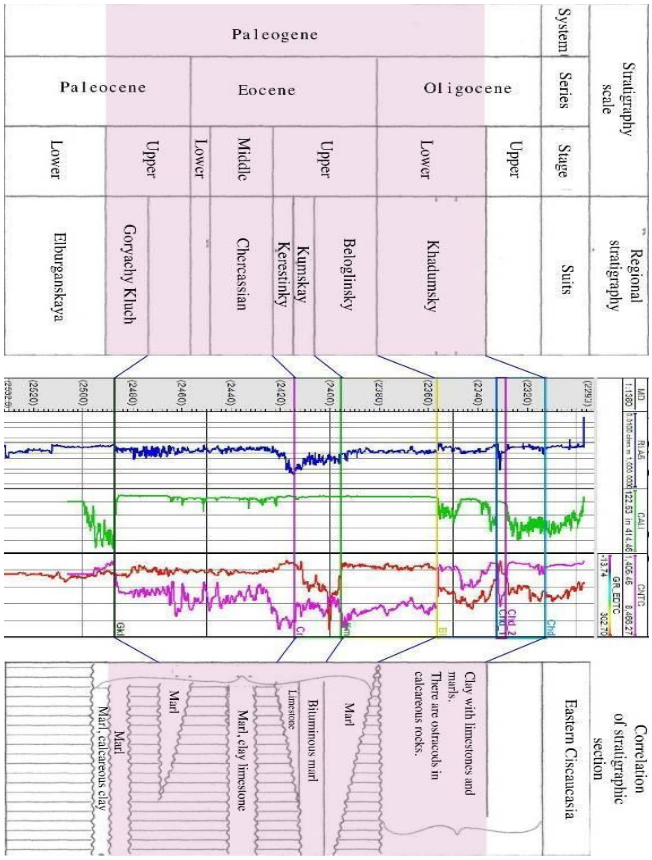

Fig. 1. Stratigraphy section of the Eocene-Paleocene deposits of the Eastern Caucasus region.

3.1. Lithology

As a result of the lithological analysis, the nine main lithotypes (Table 1) were identified.

Table 1. Lithotypes.

Suite	Sample depth, m	Lithotyp	Color	Structure	Microstructure	Texture
The Khadumsky	2311,40 – 2356,50	Thin laminated mudstones.	brown, grayto black	laminated,	horizontal laminated, laminated	lenticular-pelitic
		Thin laminated - calcareous mudstones.	-		horizontal laminated	lenticular-laminated, laminated
		Clay limestones (mudstones).	taupe to black	thin laminated, lenticular-laminated, mottled, bioturbation	-	pelitic

The Beloglinsky	2356,00 – 2395,40	Clay limestones withglobigerines (mudstones and wackestones).	gray, light gray, taupe, dark gray	mottled, bioturbated, thin laminated	mottled, pelitic, bioturbated, detrial, thin laminated
The Kumsko-Kerestinsky	2395,40 – 2415,00	Bituminous limestones with globigerines (wackestones, packstones).	brown, gray, dark gray to black	horizontal laminated, laminated	lenticular-laminated, laminated, pelitic
The Chercess	2415,00 – 2487,60	Globigerina clayey limestones (packstones)	gray, light gray, beige, taupe, dark gray	mottled, bioturbated, thin laminated	mottled, bioturbated, thin laminated, pelitic, detrial
		Laminated silty mudstones	light brown, brown	laminated, cross-bedded, bioturbated	pelitic, silty
The Goryachy Klyuch	2487,60-2550,00	Silty calcareous mudstones	light brown, brown to black	thithin laminated, spotty	pelitic, laminated, silty, mottled
		Clay silty limestones	brownish gray, brown, gray	laminated, cross-bedded, bioturbated	mottled, bioturbated, thin laminated, pelitic

3.1.1 The GoryachyKlyuch Suit

The analyzedpart of the GoryachyKlyuch Suit is composed mainly of silty calcareous mudstones interbeddedwith clayey siltylimestones.

Lithotype 1. Silty calcareous mudstones

The rocks (Fig. 2) consist of peliticclay, calcareous and siliceous components. In addition, thereis a considerable admixture of quartz, glauconite, feldspars grains, and flakes of mica (15-20%). Grains are characterized by size range from 0.02 to 0.1 mm,wide types of roundness, and uniform distribution.

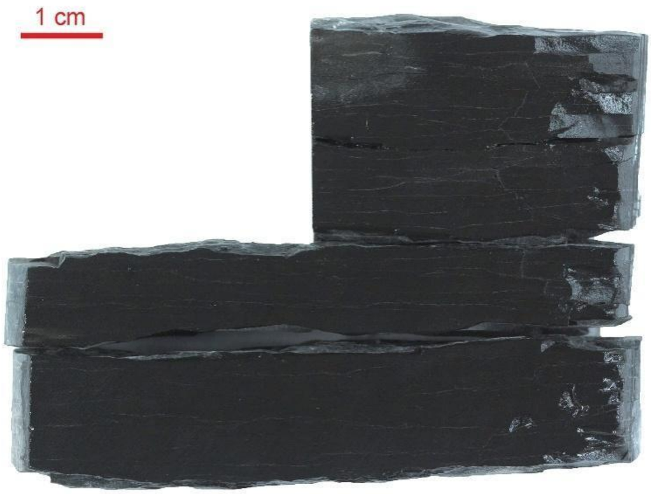

Fig. 2. Silty calcareous mudstones.

Foraminifera shells filled with calcite, and sometimes pyrite,are rarely found. Their Size Has a range of 0.05-0.2 mm.

Organic matter is present as a dispersed inclusion, sometimes it has a filamentary shape.

Secondary rock changes:

- pyritization – scattered roundshape spots(from 0.02 to 0.5 mm), one piece rarely fills the cavity of the shells

- calcite filling of shell cavities by micro-, fine-grained crystals.

Porosity: undistinguishable with optical methods.The fractures opening up to 0.3 mm are present in the rock.Predominantly, fractures are aligned with the rock bedding, but sometimes they cross the primary structure of the rock.

Lithotype 2. Clay siltylimestones

The rock contains considerable admixture of quartz, glauconite grains, feldspar, and mica flakes (25-35%). Their size has a range of 0.02 - 0.08 mm; subrounded shapes.

Organic detritus is presented by scarce gastropod shells (about 0.25 mm) and recrystallized undistinguishable fragments (about 0.2 mm).

Organic matter (up to 20%) is presented as scattered inclusions, sometimes as filamentary shapes.

Secondary rock changes:

- pyritization, i.e., – rounded spots of 0.01-0.03 mm in range size and aggregates up to 1.5 mm.Pyritespots are distributed predominantly at the lamination and rarely cross the laminas. The amount of pyrite is about 1-2%.

Porosity: rocks are dense. Fracturing is not observed.

3.1.2 The CherkessSuite

The Cherkess Suites divided into two parts by rock composition: the lower part is predominantly siliciclastic, and the upper part is predominantly calcareous.

Lithotype 3. Globigerina clayey limestones (packstones).

The rocks (Fig. 3) are composed of foraminifera shells and their fragmentsin clayey calcareous matrix. The matrix has apelitic texture. A clay admixture approximately amounts up to 10-15%.

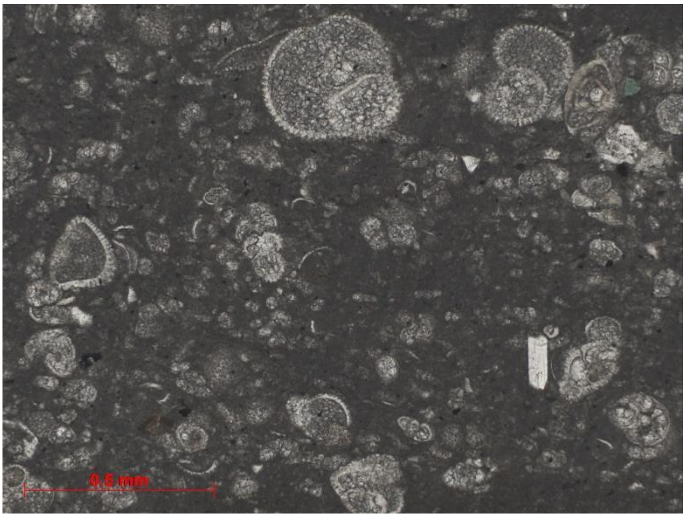

Fig. 3. Foraminifera shells and single grain of glauconite.

Organic detritus is presented by foraminiferashells and their fragments (0.05-0.6 mm) and gastropods (0.05-0.5 mm). A consistent pattern in sorting is not detected. Safety varies poor to good. Shells are filled with microgranular calcite, rarely quartz, pyrite, kaolinite. The distribution of detritus in the rocks is uneven, mainly layered. The amount of detritus is up to 35-55%.

The rock contains grains of quartz and plagioclase up to 0.3 mm in size and single grains of round-shaped glauconite up to 0.05 mm in size.

Secondaryrock changes:

- pyritization–rounded spots up to 0.01-0.075 mm in range size, one piece rarely forms a cluster of up to 2 mm in size. The amount of pyrite is 2-3%.
- filling of shell cavities with micro-grained crystals of calcite.

Porosity: indistinguishable with optical methods. There areahorizontal fractureopening up to 0.15 mm in the rock.

Lithotype 4. Laminated siltymudstone.

The rocks mainly consist of clay components. In addition, there is a considerable admixture of quartz, glauconite, feldspars grains and mica flakes (15%). Grains are characterized by size range from 0.02 to 0.1 mm and wide types of roundness. There is an admixture of organic matter and pyrite. The quantitative content of various rock components is indistinguishable with optical methods.

Foraminifera, calcisphere, and gastropods shells filled with calcite, and sometimes pyrite, are rarely found. Their size has a range of 0.05-0.3 mm. A consistent pattern in sorting is not detected. Fish bones up to 1 mm in size are also found.

Organic Matter Has scattered or filamentary spots.

Secondary rock changes:

- pyritization –scattered round shape spots (from 0.005 to 1 mm). One rarely fills the cavity of the shells.

- filling of shell cavities with micro-, fine-grained crystals of calcite.

Porosity: undistinguishable with optical methods. Opening fractures (up to 0.1 mm) are present in the rock. Predominantly fracturesare aligned with the rock bedding, but sometimes they cross the primary structure of the rock.

3.1.3 The Kumsko-Kerestinsky Suite

The deposits of the Kumsko-Kerestinsky Suite are composed mainly of bituminous limestones.

Lithotype 5. Bituminous limestones with globigerines (wackestones, packstones).

The rocks (Fig. 4)consist of pelitic calcite andclay admixture (up to 15%).

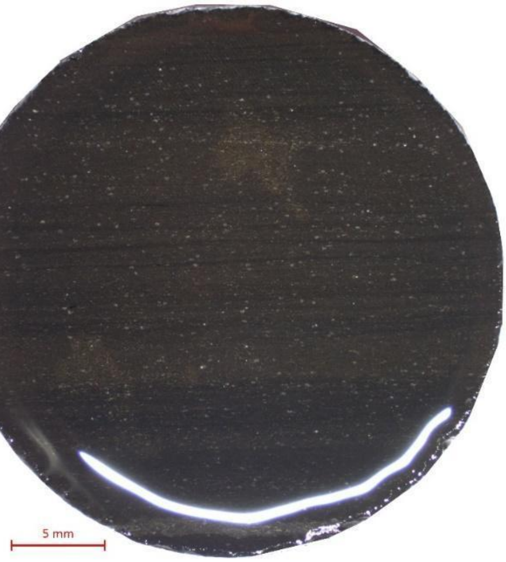

Fig. 4. Fine parallel lamination in the limestones.

Organic detritus is presented by foraminifera shells and their fragments (0.05-0.6 mm). Preservation of shells is mostly good and only occasionally bad. Detritus is distributed randomly, less often is aligned with the rock bedding. The amount of detritus is up to 20-50%. Shells are filled with calcite, rarely kaolinite.

Remains of bones and fish scales (from 0.1 to 15.0 mm) are found.

Organic matter is in scattered spots, sometimes they have a filamentary shape. The amount of organic matter is about 25%.

Secondary rock changes:

- pyritization – scatted round shape spots(0.01 mm). Pyrite rarely fills organic detritus. The amount of pyrite is about 7%.

- filling of shell cavities with micro-grained crystals of calcite.

- substitution of fish scales by dolomite.

Porosity: rocks are dense. There is a horizontal fracture with an opening up to 0.075 mm.

3.1.4 The Beloglinsky Suite

The Beloglinsky Suite is composed of clay limestones (mudstones and wakestones).

Lithotype 6. Clay limestones with globigerina (mudstones and wakestones).

The rocks consist of pelitic calcite and clay admixture (5-10%). In addition, there are quartz grains (0.3 mm).

Organic detritus is characterized by ununiform distribution, basically laminated. The amount of detritus is mainly 5-20% and about 45-50%. Is located at the depth of 2359.10 m.

Detritus is presented by foraminifer shells and their fragments(0.05-0.6 mm) and gastropods (0.05-0.5 mm). A consistent pattern in sorting is not detected. Shells are located by banding or in large clusters that create a lenticular structure.Preservation of shells varies from poor to good. Shells are filled with microgranular calcite, rarely quartz, pyrite, and kaolinite.

Few fragments of a significant part of the rock were composed of coccolithophoreshells, that were set by SEM.

Secondary rock changes:

- pyritization –round shapespots (0.01-0.075 mm), which rarely form clusters bigger than 2 mm in size. The amount of pyrite is 2-3%.
- fillings of shell cavities with microgranular crystals of calcite.
- fillings of shellcavities with quartz crystals.

Porosity: undistinguishable with optical methods. There arehorizontal fractures with openings up to 0.15 mm.

3.1.5 The Khadumsky Suite

According to by its lithological composition, the KhadumskySuitis divided into 3 horizons.

The Pshekhsky horizon consists of thin laminated calcareous mudstones (in the lower and upper parts) and bituminous clay-carbonate rocks in the middle part.

The Polbinsky horizon is presented by clay limestones (mudstones).

The horizon of the MorozkinaBalika consists of thin laminated calcareous mudstones.

Lithotype 7. Thin laminated mudstones.

The rocks mainly consist of clay components in addition to pelitic siliceous, organic,andsiliciclastic admixtures. The latter is presented by single quartz grains of fine silt dimension. The quantitative content of various rock components is undistinguishable using optical methods.

Pelitic clay and siliceous admixtures are in the lenses which form a lenticular-laminated microstructure. Lenticular isolations are bordered by organic matter and pyrite globules. Lens sizes is up to 0.25 mm.

Organic matter (5-10%) is aligned with the rock bedding, that form a laminated microstructure, and sometimes it has filamentary shape.

Secondary rock changes:

- pyritization –spots(0.01 mm), one form clusters up to 0.5 mm in size. The amount of pyrite is 4-5%.
- dolomitization – lenses (0.05-1.5 mm), substitution of fish scales by dolomite.

Porosity: undistinguishable using optical methods. Open(up to 0.1 mm) fractures with length 1.0-29.0 mm. Predominantly fractures are aligned with the rock bedding, but sometimes they cross the primary structure of the rock.

Lithotype 8. Thin laminated calcareous mudstones.

The rocks consist of pelitic clay, carbonate and siliceous components. In addition, there is admixture of organic matter, pyrite, and a siliciclastic admixture presented by single grains of quartz and feldspar. Quantitative content of various rock components is undistinguishable using optical methods.

Pelitic clay, carbonate and siliceous materials forms lenses and thin laminated structures. They are forming a lenticular-laminated and laminated microstructure.Lens sizes are up to 0.1-1.5 mm.

There are foraminifera shells, gastropods filled with calcite, rarely kaolinite (0,05-0.25 mm). Preservation of shells is good to poor. Consistent pattern in sorting is not detected. The amount of shells is up to 5-25% in the depth interval 2334.63-2346.20 m. There are fish scales up to 3 mm in size (Fig. 5).

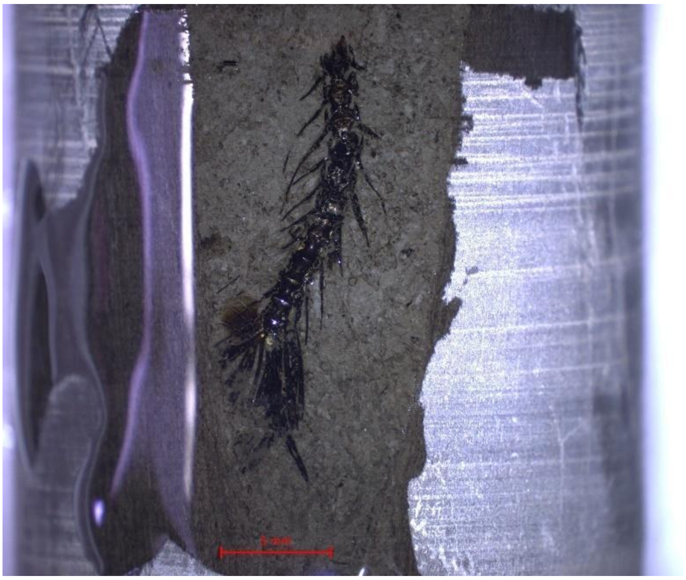

Fig. 5. Fish tail in thin laminated calcareous mudstone.

Organicmatteris presented by filamentaryspots. The amount is about 5-30%.

Secondary rock changes:

- pyritization – scattered round shapespots(0.005-0.2 mm), which rarely form clusters up to 1 mm in size. One emphasizes lenticular-laminated and laminated microstructure of the rock. The amount of pyrite is about 3-4%.
- filling of shells cavities with micro-, fine-grained crystals of calcite.
- dolomitization – single idiomorphic dolomite crystals (1 mm in size), substitution of fish scales and foraminifera shells by dolomite.

Porosity: undistinguishable using optical methods. The open (from 0.02 to 0.1 mm) fractures are present in the rock. Fractures are aligned with the rock bedding, but sometimes they cross the primary structure of the rock.

Lithotype 9.Clay limestones (mudstones).

The rocks consist of pelitic calcite and clay (10-15%) admixture, rarely unit quartz grains of fine silt dimension.

Organic detritus occurs in the form of single hard-to-determine remains and bones and scales of fish.

There is organic matterpresented by laminated form up to 5 mm long.

Secondary rock changes:

- pyritization –round shape spots (0.01-0.03 mm), which form clusters up to 1 mm in size and lenses up to 2 mm in size.They are aligned with the bedding. The amount of pyrite is about 3-4%.
- dolomitization– isometric crystals up to 0.3 mm in size.

Porosity: undistinguishable using optical methods. Open (up to 0.03 mm) fractures occurein the rock.

3.2 Pore space Parameters and fracture distribution

The pore space investigation was performed for the following samples: thin-laminated calcareous mudstones of the Khadumsky Suite, bituminous limestone of the Kumsko-Kerestinsky suite, clayey limestones with globigerines of the Beloglinsky and Cherkessian Suite.

Inter- and intraparticle and interlayer pores are predominant in the studied samples.

A sample from the upper part of the Cherkassian Suite (depth 2436.56 m) has average porosity of 9.19%, and isometric shape of pores (Fig. 6). The pores with an area of less than $10^{-5}mm^2$ are quantitatively prevalent (95.12%). The average pore size is 0.003 mm.

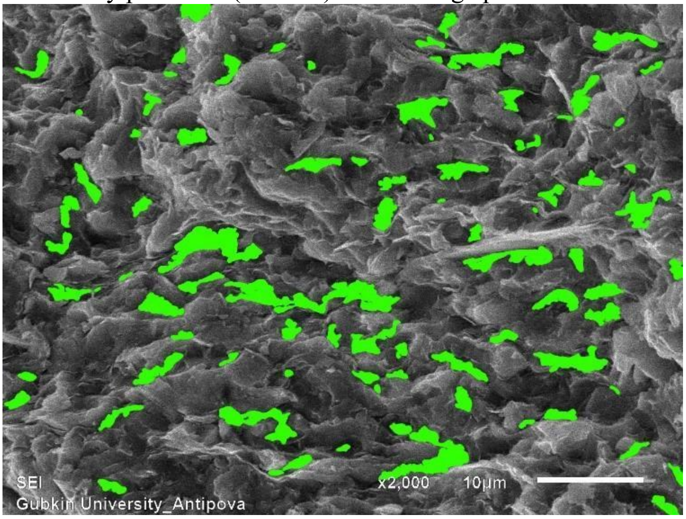

Fig. 6. Pore space of globigerina clayey limestones.

The pore space of the bituminous limestones of the Kumsko-Kerestinsky Suite (depth 2401.12 m) consists of elongated, sometimes isometric, micropores less than 0.008 mm in size. Their amount is 7,19%. The pores with an area of less than $10^{-5}mm^2$ are prevalent(96.05%).

The Beloglinsky Suite is composed of clay limestones (depth 2358.53 m) which have predominantly isometric micropores (average size of 0.004 mm). Their amount does not exceed 10.04%. Predominantly the pores have poor connectivity and are less than $10^{-5}mm^2$ (78.26%).

A thin-layered calcareous mudstone of the Khadumsky Suite (depth 2349.36 m have mesh-shape micropores distributed in a clayey matrix. Their average size is 0.006 mm, and the amount is 11.6%. The size less than $10^{-5}mm$ is dominating(69.70%).

Fracturing is the main factor that provides connectivity of pores. Subvertical fracturing can be traced throughout the whole interval, except for thin-layered calcareous mudstones of the Pshekhsky Horizon and the Morozkina Balka Horison (Khadumsky Suite).Subvertical fractures are attenuated in limestone interlayers with increasing clay content.

The tectonic origin of subvertical fractures is proved by calcite mineralization and oil saturation. Subvertical fractures are most developed in the lower part of the section (Goryachy Klyuch Suite, Cherkessian and Kumsko-Kerestinsky Suites). There is a system of subparallel and subvertical fractures with a distance of 4-10 cm between fractures.

Subhorizontal fracturing, mostly developed in mudstones and clayey limestones, is observed throughout the section. Probably subhorizontal fracturing is the result of rock pressure release since there are no visible traces of secondary mineralization and leaching along the fracture sides. However, oil saturation/effusion is noticed along with subhorizontal fractures in the Kumsko-Kerestinsky Suite (Fig. 7).

Fig. 7. Hydrocarbon effusion along the fracture.

Inclined fractures are also present in the rocks (angle is 45-50 °). Striae and slickensides are common for their surfaces. That indicates such fractures do not contribute to the pore space formation being in a state of geodynamic compression.

4 Conclusion

The deposits predominantly consist of multicomponent siliceous-carbonate-clayey rocks, mainly containing in situ hydrocarbons.

The section is built up of thin-layered calcareous and clayey mudstone, clayey and bituminous globigerina limestone, and laminated silty mudstones intercalation.

A conclusion can be made that the average porosity is generally good (7-11%) but pores have a very small size (0.003-0.008 mm) and poor connectivity.

The increase of carbonate content results in a more rounded and isometric pore shape as in calcareous mudstones of the Khadumsky Suite and globigerina limestone of the Cherkess Suite.

The direction of fracture propagation is controlled by mineral contents and connected pore space pattern. There is an obvious example of horizontal fracturing in mudstones and clayey limestones throughout the section. These rocks have predominantly elongated pores in the clayey matrix.

As a fact, subvertical fractures are attenuated in limestone interlayers with increasing clay content but are most developed in the lower part of the section (Goryachy Klyuch Suite, Cherkessian and Kumsko-Kerestinsky Suites), where carbonate mudstones are prevalent.

It leads to the conclusion that although the fractures are developed at all hierarchical levels (micro-, macro- and meso), their presence is often confined to an increase of carbonate and siliceous component in the rock composition. When the clay components predominates, fracture attenuation is observed.

These results allow deducing of the intervals with higher reservoir potential. It will be the layers of the bituminous limestones of the Kumsko-Kerestinsky Suite and calcareous mudstones of the Khadumsky Suite. They might be considered unconventional reservoirs which susceptible to horizontal fracturing.

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