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Modeling of geological features and hydrocarbon potential of the Maikop series of Black sea-Crimea region

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SUMMARY

Geological structure and composition of the Maikop series as well as geochemical and petrophysical properties of the Maikop series clay rocks of the southern margin of the East European Platform are considered. The sections of the Maikop series of Black Sea and the Crimean region, including the north-western area of the Black Sea shelf (wells Arkhangelsk-21, Golitsyn-1, 6, 7, 9, 12, 28); the central part of the Crimean peninsula (Dzhankojsk-1); the Kerch Peninsula (Fontanovsk-6, 12); the Azov Sea shelf (Nord-Kazantip-3); Near-Kerch area of the Black Sea shelf (Subbotin-1) are described. Comparative analysis is made between the Maikop series depositions that occur in following regions – the Kerch-Taman trough, the eastern part of the Black Sea, the Indol-Kuban Trough, West, Central and East Caucasus, the Middle Caspian, West Azerbaijan, South-Caspian depression.

Introduction. The Oligocene-Miocene sequences of the Maikop series form important units in the geological sections of the southern frame of the East European Platform. It is a complex of predominantly argillaceous depositions up to 4-5 km thick, which is considered as a regional oil-producing stratum. Therefore, their compositional and structural features petrophysical and geochemical characteristics, and oil and gas generation potential are of great interest. All these geological evidences make it necessary to study the Maikop series.

The Maikop series is mapped and described in details over the various regions of the southern frame of the East European Platform, however, geological and geochemical features and petroleum characteristics are described in relatively few works (Distanova, 2007; Guliyev et al., 2001; Nadezhkin, 2011). Comprehensive review of the series depositions with characteristics of their features and oil and gas potential is absent for many regions. In addition, the oil-generation potential of the series as to unconventional sources of hydrocarbons, in particular, shale oil, has not been practically studied.

Oligocene-Miocene Maikop series is widely distributed over the south area of East European Platform in the Black Sea-Caspian region (Figure 1). The series accumulations are formed within the sea basin under reducing conditions as result of large-scale regional anoxic events occurred in Neo and Paratethis.

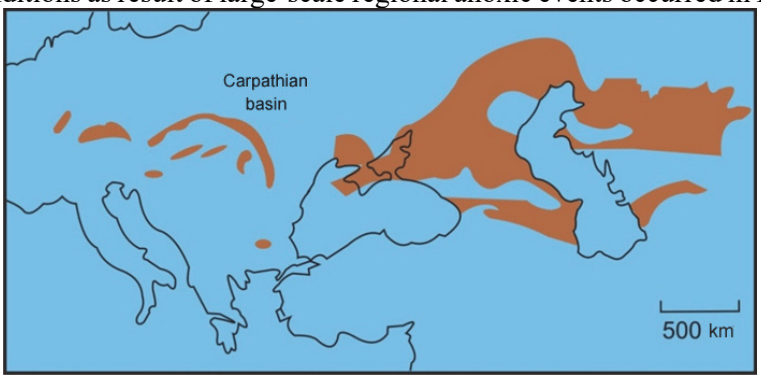

Figure 1 *Distribution of black shale deposits in Parathetis; Oligocene-Early Miocene (Mykhailov et al., 2014)*

Maikop formations of the Black Sea-Crimean region have wide distribution, and they are absent only within the local areas of Dobruja, Crimea Mountains, the domal zone of the Central Crimean megauplift. The most complete sections of the series were found on the Kerch Peninsula (4000 m thick and more) and within the north-west area of the Black Sea shelf (over 1600 m). In the western and northern Black Sea coastal area, the Plain Crimea, the central and northern parts of the Azov Sea, of the Maikop series does not exceed 300–400 m in thickness. Within the deep-water part of the Black Sea, the Maikop section has been studied only by geophysical methods; here its thickness exceeds 5000 m. On the Earth's surface, these formations extend as sublatitudinal zone (Belogorsk town - Nasypnoe village) and on the Kerch peninsula.

The Maikop series occurs as monotonous stratum of Oligocene-Lower Miocene age and comprizes mostly gray, dark gray faintly calcareous mudstones with rare interlayers of siltstones, sandstones, fine-grained sands. The series sequences are widespread over the Karkinitsa-Severokrymsky trough (North-Western Crimea) and the Indolo-Kuban trough (the Kerch Peninsula), where they show thickness of 900–1100 m and 3000–4000 m, correspondingly. In the section of the series, mudstones predominate. The siltstone does not exceed 20 %, but it is sandstones, siltstones and sands, whose layers have a thickness of 10 to 100 m, are treated as collector rocks. Clay units with a thickness of 15–100 m, which separate them, play the role of caprocks. In general, the Maikop sand and clay sequences is a regional seal for reservoirs confined to the underlaying formations.

So, the Maikop depositions are represented by series of gray and dark gray siltstone, weakly calcareous argillites, sometimes interbedded with siltstone, sandstone, fine-grained sands, rich in organic matter (from 0.69 to 10.23 %), C_{org} (2.20–16.70 %), the porosity of which varies widely – from 0.3 to 31.7 %. They are associated with numerous hydrocarbon accumulations s, as well as phosphorus, REE – uranium deposits. Argillites dominates in the geological section of the series , where the amount of sand and silt material does not exceed 20 %. But it is sandstone, siltstone and sand layers that ranging from 10 to 100 m in width are treated as reservoir rocks for conventional hydrocarbon fields. Clay units

that are 15–100 meters thick and separate them commonly form caprock. As a whole Maikop sandy clay series occurs as regional seal for collectors confined to the underlaying formations .
C_{org} enriched lithotypes are unevenly distributed in the Maikop section and their occurrence is primarily influenced by paleooceanographic features of sedimentation. It is possible to predict the formation of several differently aged levels of sedimentations with enrichment in C_{org}. They form rock series ranging from 20 to 100 m in thickness and, occurrence depths from 300 to 1500 m. However, the degree of thermal transformation of rocks is extremely low. Organic matter of Maikop series is typically immature and, shows relatively low temperatures of pyrolysis (418–423 °C) that indicates on shallow subsidence of host rocks (up to 1.5–2.0 km), while the main zone of oil formation is located at depths of 3–6 km.

The geochemical features are studied for core samples of the Maikop series collected along column of the wells drilled in the north-west area of the Black Sea shelf, the central part of the Crimean Peninsula, Kerch Peninsula, the Azov Sea shelf, Near-Kerch part of Black Sea shelf (Mykhailov and Zagnitko, 2017).
As a result high content of C_{org} (2.26–16.70 %) and TOC (0.69–10.2 %) are established for the rock units of the Maikop series (Table 1). However, they usually are thermally immature and cannot be treated as promising for prospection on oil shale. Among the exceptions are rocks found in the wells Golitsyn-1, 9, where the vitrinite reflectivity index reaches values that is typical of the lower zone of oil formation (0.8–1.8). It can testify for favorable thermal conditions at the lower levels of the Maikop series and their possible oil-and-gas generation potential.

Table 1. Content of organic matter in Maikop rocks of Black See-Crimea region

Well	№ sample	Interval, m	Rock	$C_{org.}$, %	H_2O^-, %	$U \cdot 10^{-4}$, %	$CO_{2carb.}$, %	TOC, %	R_0
Black See NW shelf									
Arkhangelsk-21	171AX	867	Argillite	3.84	3.20	2.3	0.71	4.08174	0.42
Arkhangelsk-21	172AX	872	Siltstone	3.46	3.40	2.3	0.05	4.77720	0.43
Arkhangelsk-21	173AX	877	Siltstone	2.26	1.86	2.3	0.05	1.89870	-
Arkhangelsk-21	174AX	878	Siltstone	2.62	2.18	2.5	0.66	2.57813	0.43
Golitsyn-1	165GL	1034	Marlstone	3.36	3.20	2.3	0.22	4.24242	
Golitsyn-6	162GL	1812	Marlstone	2.20	0.46	2.2	22.00	0.69517	1.64
Golitsyn-7	163GL	570	Argillite	4.42	0.90	3.4	9.07	2.98883	-
Golitsyn-9	164GL	2100	Argillite	3.60	3.24	2.5	1.15	3.97606	0.84
Golitsyn-12	161GL	2710	Argillite	2.90	0.76	1.6	16.0	1.55922	-
Central part of the Crimea Peninsula									
Dzhankojsk-1	166DZ	845	Siltstone	5.24	4.0	4.0	1.43	6.96021	0.57
Dzhankojsk-1	167DZ	866	Argillite	4.84	3.22	2.3	0.05	5.58562	0.36
Dzhankojsk-1	168DZ	876	Marlstone	16.70	1.34	1.9	14.85	10.22793	-
Dzhankojsk-1	169DZ	885	Argillite	4.80	2.82	2.4	0.82	6.04519	0.51
Dzhankojsk-1	170DZ	892	Sandstone	4.32	2.50	3.0	0.11	5.09043	0.46
Kerch Peninsula									
Fontanovsk-6	180FN	3292	Argillite	4.02	1.40	1.8	1.2	3.8974	0.59
Fontanovsk-12	179FN	3695	Sandstone	3.20	1.70	1.6	1.15	2.9374	0.60
Azov shelf									
Nord-Kazantip-3	151PK	1042	Siltstone	4.88	3.16	2.4	0.5	6.62876	-
Nord-Kazantip-3	152PK	1100	Argil	6.26	2.52	2.4	2.58	6.24480	-
Nord-Kazantip-3	155PK	1420	Siltstone	4.96	2.82	2.9	0.1	5.39351	0.37
Nord-Kazantip-3	156PK	1550	Siltstone	7.36	2.02	2.2	3.74	7.64596	-
Nord-Kazantip-3	158PK	2250	Argillite	3.86	2.16	2.3	0.16	4.67209	-
Nord-Kazantip-3	159PK	2587	Siltstone	5.76	1.50	2.0	2.91	6.07009	0.52
Nord-Kazantip-3	157PK	2590	Siltstone	4.66	1.00	2.0	2.25	6.52520	0.37
Nord-Kazantip-3	160PK	2597	Siltstone	3.52	1.24	1.9	0.11	4.48698	0.44
Near-Kerch part of the Black Sea shelf									
Subbotin-1	176SB	1363	Argillite	5.62	3.54	3.7	1.37	6.51382	0.51
Subbotin-1	178SB	1960	Argillite	3.56	2.26	3.1	0.11	5.77810	0.50
Subbotin-1	177SB	2330	Argillite	7.18	3.54	3.9	0.11	5.98207	0.59

It is additionally proved by the results of speciation analysis of gas collected from wells Golitsyn-1, Arkhangelsk-21, Dzhankojsk-1, Severokazantipskaya-3, Subbotin-1. Gas-pyrochromatographic analysis has shown that hydrogen, carbon monoxide and carbon dioxide are predominate in the core samples of Maikop series (Mykhailov and Zagnitko, 2017). Based on the 9 samples analyzed, the total amount of gas components range from 7.0 % to 14.0 % in wells Subbotina-1 and reaches 10.2–12.1 % in other wells ; methane (CH_4) ranges from 0.006 in North-Kazantipska-3 well to 0.1 in Subbotina-1 well. As a whole, with the exception of several samples collected from Subbotin-1, Arkhangelska-21, and Dzhankoyskaya-1 wells, results of study of gas components distribution, over the cores samples of Maikop series have shown their relatively small saturation in methane. The high content of "heavy" homologues found in these samples can indicate the possibility of accumulation of oil components in these sections.

Here, moderately and high gas-bearing rocks that occur in depths are characterized by average recovery rate, significant contents of contaminating homologues and slight enrichment in hydrogen sulfide. Despite of thermal immaturity of these rocks, all the above mentioned evidences can indicate their favorable prospects for gas-and-oil content. This discrepancy may be caused by the migration of gas and oil components from underlying strata into the overlaying horizons.

Thus, deposits of the Maikop series that occurs at depths more than 2000 m can be treated as perspective for searches on oil shale in case of proving of the presence of large amount of rocks rich in organic matter. As to evaluation of shale oil prospects of Black Sea and the Crimean regions, it may be noted that the discovered oil deposits can be treated as indicator of sufficient oil-and-gas potential and optimal degree of thermal maturity of deeply occurred black shale deposits of Albian and Maikop series. Their y parameters corresponds to the main zone of oil formation, and so these strata may be prospective for shale oil exploration because of their wide distribution over the geologic section and laterally.

Petrophysical properties of the argillaceous rocks of the Maikop series occurred in NW shelf of the Black Sea; the central part of the Crimean Peninsula; Kerch Peninsula; Kerch shelf of the Azov Sea; the northern shelf of the Azov Sea; Near Kerch section of the Black Sea shelf are studied (Vyzhva et al., 2017). The correlative relations between porosity coefficient and porosity parameter of oil-and-gas saturation and coefficient of water saturation, porosity ratio over time interval of samples saturated with kerosene are established.

Unconventional reservoirs (clays, siltstones) are characterized by wide range of petrophysical parameters (Vyzhva et al., 2017), that is clearly associated with varying degrees of sample jointing. Thus, the bulk density of argillaceous rocks of the Maikop series varies from 1313 to 2621 kg/m^3 (average 1729 kg/m^3) in dry samples, from 1728 to 2708 kg/m^3 (average 2081 kg/m^3) in samples saturated with kerosene and the apparent mineralogical density ranges from 2434 to 3022 kg/m^3 (average 2584 kg/m^3). The coefficient of open porosity varies from 0.3 % to 31.7 % (average 19.6 %). Open porosity on nitrogen varies from 6.6% to 38.1% (average 25.7 %).

Conclusion. Studies of the Maikop series of the southern margin of the East European Platform have revealed its distinct heterogeneity as to the concentration of organic matter and other gas components (Guliyev et al., 2001; Hudson et al.; 2008; Saint Germes et al., 2002). It was found that the Oligocene-Early Miocene might be treated as global scale epoch of carbon accumulation. Formation of high-carbon strata is associated with anoxic conditions of hydrogen sulfide contamination within water column . Usually, Maikop sediments are characterized by high degree of bituminisation. It is believed that lower Maikop (Oligocene) deposits of the West Black See basin are graded at MK_4-AK_1, and sediments of Tuapse, Sorokin and Guria depression are graded at MK_3 (Main Zone of oil Generation – MZG), Upper Maikop (Lower Miocene) of the east part of the Black Sea are graded at MK_1, and sediments of Tuapse, Sorokin depression, the Shatsky Swell does not reach MZG. On land Lower Maikop deposits (Khadum suite of the Northern Precaucasia, sequences of the Kerch-Taman and West Kuban depression) show high oil source potential. In the Kerch Peninsula and Sochi-Adler depression Maikop deposits occurred at katagenesis grade PK – early MK_1, that is maturing stage when the mass generation of liquid hydrocarbons has not started yet.

In the Black Sea and the Crimean region the Maikop series is represented by thick layers of clay and siltstone interbedded with siltstones and sandstones, rich in organic matter (from 0.69 to 10.23 %), C_{org} (2,20–16,70 %). They are associated with numerous hydrocarbon fields. However, the degree of thermal

transformations of rocks is very low – reflectivity of vitrinite almost everywhere does not exceed 0.36–0.60 (protocatagenesis), only rarely reaching 0.84–1.64. Thus, organic matter of the Maikop series is usually immature and characterized by relatively low temperature of pyrolysis (418–423 °C). This fact can testify for shallow occurrence of the host rock (up to 1.5–2.0 km), but MZG occurs at the depths of 3–6 km.

Thus, the rocks of the Maikop series, that are commonly occurred at depths of up to 2000–3000 m are thermally immature and cannot be treated as prospective for oil shale research (Mykhailov, 2018). At the same time at the depth level more than 2000–3000 m the degree of thermal maturity increase and they might be considered as prospective for oil shale research at condition of enrichment in organic matter (Figure 2).

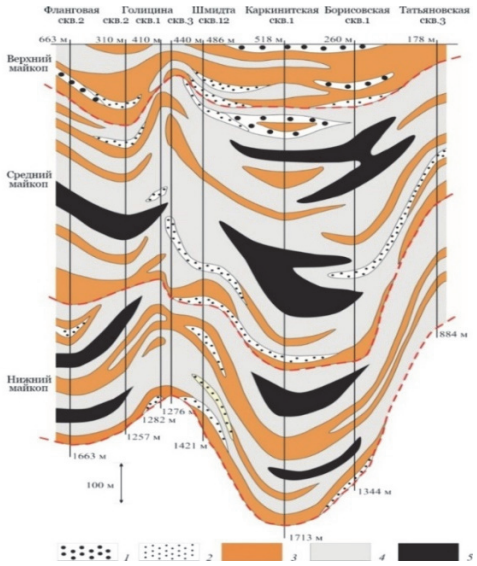

Figure 2 *Sedimentologic-paleoceanographic section. Maikop sediments. North-Black Sea shelf (Mykhailov et al., 2014) 1-3 - clastogenic accumulative bodies; shelf silt; 4 - background level of organic matter; 5 - high content of organic matter*

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