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CAUCASUS MAYKOPIAN KEROGENOUS SHALE SEQUENCES: GENERATIVE POTENTIAL

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Abstract. *The generative potential of kerogenous shale sequences in the Caucasus Maykopian series, the southern part of European Russia, is evaluated. The Khadum and Batalpashin sediments in the Eastern and Central Fore-Caucasus include three types of kerogen: I, II and III. The Khadum sediments are dominated by a more "noble" type II kerogen, mixed humic-sapropelic organic matter (OM). The Maykopian series may be attributed to the category of "rich" and "very rich" ("outstanding") oil source rocks. The maturity extent of the subject sediments within the region varies between the grades of protokatagenesis (maximum pyrolysis temperature (T_{max}) = 390 °C) and MC_4 (T_{max} = 471 °C). Based on the pyrolytic studies, the Khadum and Batalpashin sediments are distinct from other pelitic rocks in rather high generative potential values. The average value of the total generative potential (S_1 + S_2) in the studied samples from the Khadum and Batalpashin Formations is 4.83 mg HC/g rock. The quantitative estimate of the hydrocarbon generative potential of the Khadum and Batalpashin sediments in this region was conducted for the first time. The total initial generative hydrocarbon potential of the sediments is 133.4 BT, being 92.7 BT for the Khadum Formation, and 40.7 BT for the Batalpashin Formation.*

Keywords: *organic carbon, katagenesis, generation potential, source rock, Khadum Formation, Batalpashin Formation, shale strata.*

1. Introduction

The Maykopian sedimentary series is broadly developed over the entire Caucasus territory (Fig. 1). It includes marine Oligocene-Lower Miocene rocks of the Cenozoic Paleogene erathem. By their lithofacies features, the

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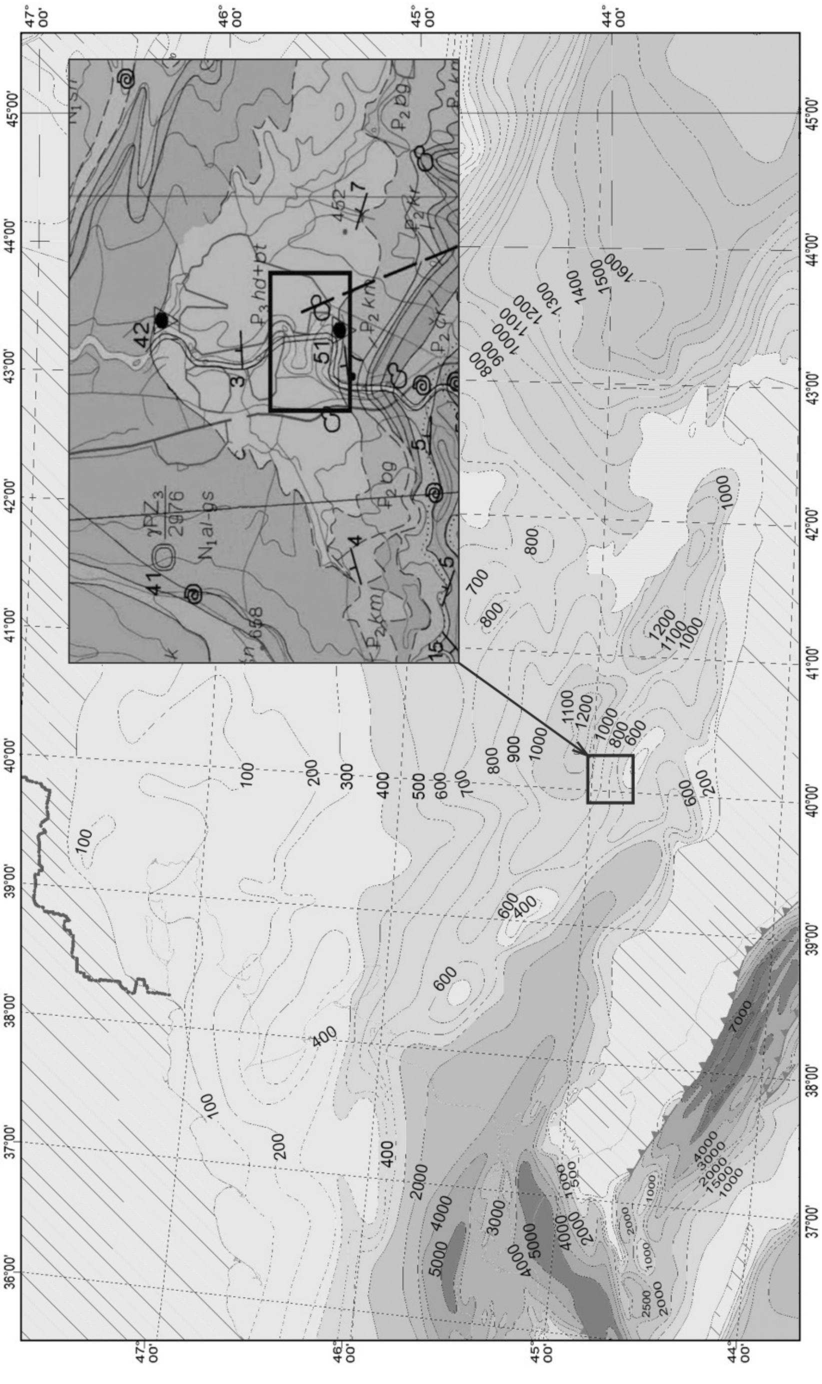


Fig. 1. Composite thickness map of Maykopian rocks. The sampling zone, the canyon portion of the Belaya River, Adygea Republic, is marked by a rectangle.

Maykopian series rocks are subdivided into three subseries, which in their turn include a number of formations and subformations. The Lower Maykopian subseries rocks correspond to the Khadum Formation, Batalpashin Formation and Septarium Formation and are clearly identified in the section by both lithology and microfauna. The Khadum Formation is subdivided by its lithological parameters into three subformations: the lower Pshekh subformation, the middle Polbin or ostracod subformation and the upper Morozkin ravine subformation.

Kerogenous shale sequences are composed of a variety of solid, multilayer pelitic rocks (clay, marl, clayey limestone, argillite, siltstone and the shale proper) containing all possible forms of organic matter (OM) at different maturity stages [1–4]. Being distinct from other pelitic rocks in texture features (mode of arrangement), shales are capable of splitting into lamina. The Khadum rocks in the Fore-Caucasus are found at a wide range of depths (0 to 4,500 m) and are exposed on the surface in the canyon area of the Belaya (White) River, 30 km south of the city of Maykop, Adygea Republic. The Khadum rocks there acquire typical shale features and are represented by fractured, thin, slabby, foliated argillite-like clay and marl alternating with compact clay and marl varieties. In the Azerbaijan territory, the study of organic matter concentration and type distribution in the Maykopian Series was conducted based on the results of the pyrolytic analysis of mostly rock material from outcrops and cores with the utilization of mud volcano ejecta [5–7]. The interest in the Caucasus Maykopian rocks has increased in recent years due to the so-called “shale revolution” occurring in the world. The conducted studies testify to a high generative potential of the Maykopian series whereas the Khadum and Batalpashin rocks are the sections where nonconventional (shale) hydrocarbon accumulations and oil shales formed.

2. Study methodology

The void space and its mineral fill-up microstructure studies of rocks of the Khadum and Batalpashin Formations were carried out by way of electron-microscopic and X-ray microanalyses, using a JSM 6610 LV scanning electron microscope (Jeol, Japan) equipped with an IE350 energy dispersive spectrometer (Oxford Instruments, Great Britain).

For the OM study of shale sequences the Rock-Eval pyrolysis, a technique for determining the direct rock hydrocarbon (HC) potential and the zone of oil-gas generation (rock maturity level), was applied. Pyrolytic studies were performed using the Rock-Eval 6 analyzer (Vinci Technologies, France).

Thermal maturity is one of most important parameters used for the evaluation of hydrocarbons (HCs) in shale deposits. The commonly used parameter to evaluate the OM thermal maturity of rock is vitrinite reflectance (R_O). For optical studies under reflected and luminescent light at quantitative determinations of coal macerals (under reflected light) and for the determination of R_O and OM type (under luminescent light) an Axio Scope A1 binocular microscope (Switzerland) was employed.

Coal petrography studies were conducted using the D1302 equipment (Craic Technologies, USA). Four polished sections under simple white light were examined. The studies included the preparation of descriptions of sections and measurements of R_O, as well as observation of the sections under ultraviolet (UV) light.

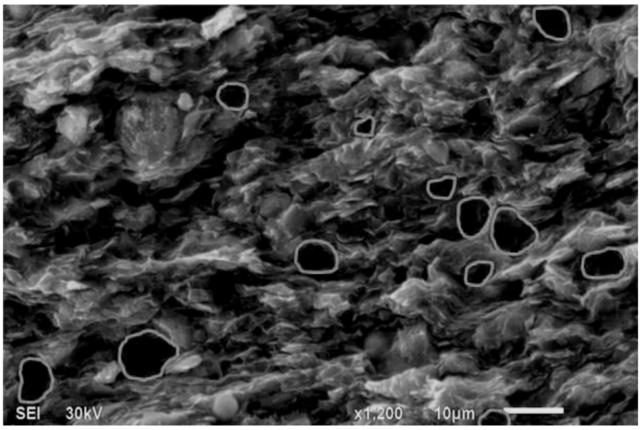
The generative potential of Khadum and Batalpashin rocks in the Caucasus Maykopian series was evaluated based on the results of pyrolytic studies: OM total organic carbon (TOC) content, maximum pyrolysis temperature (T_{max}), realized, residual and total OM generative potential (S_1, S_2, ($S_1 + S_2$)) and hydrogen index (HI). Computations for the Khadum Formation rocks were done in oil and gas areas in the Eastern Fore-Caucasus, Stavropol and the Tersk-Caspian Trough, and for the Batalpashin Formation rocks, in the Eastern Fore-Caucasus oil and gas area. The volume and mass of oil source rocks for the Khadum and Batalpashin rocks were calculated.

3. Study results

The results of lithologic-sedimentological and X-ray structural analysis indicated that the shale sequences in the Khadum and Batalpashin Formations of the Maykopian series are dominated by bituminous siliceous-clayey and carbonaceous-clayey rocks, and argillites and siltstones with clayey-carbonaceous cement (Fig. 1). The rocks of the lower part of the Khadum Formation, underneath the ostracod layer, are represented mostly by argillites and bituminous-carbonaceous-clayey rocks. These rocks are composed of the clayey hydromicaceous material with lenses and interbeds of organic detritus, mostly Globigerina foraminiferal shells. Both bituminous-carbonaceous-clayey rocks and argillites include organic matter in the form of thin interbeds. The upper portion of the Khadum Formation and the lower portion of the Batalpashin Formation are dominated by bituminous-siliceous-clayey rocks. These rocks are composed of the clayey hydromicaceous material with an admixture of organic matter. The content of organic matter (TOC = 2–5%) and its structural interrelation with other components allow the rocks to be identified as “bituminous”. Being different from other pelitic rocks in texture characteristics, the shales are capable of splitting into laminae. The rock void space is represented by two types, pores and open fractures. The fractures account for 10 to 30% of the total rock volume. Fracture opening is 0.1–3 mm. It may be assumed that the fractures are of natural origin and provide for pore connectivity in the clayey matrix.

Raster electron microscopy (REM) study of the rocks of the Khadum and Batalpashin Formations showed for the first time that there existed voids of various morphological types in their microstructure, often filled with hydrocarbons. Among these voids, organic vacuities which resulted from OM transformation stood out. Porosity in the kerogen texture (organic porosity) developed during the rock OM thermal maturation is capable of affecting adsorption of the generated oil. The space between the pores in low-permeability shale sequences is often filled with hydrocarbons and varies in size from dozens to hundreds of microns (Fig. 2). Hydrocarbons are retained in these pores not only by the mineral rock portion but also by its organic component, which has adsorption capability. The organic porosity

(a)



(b)

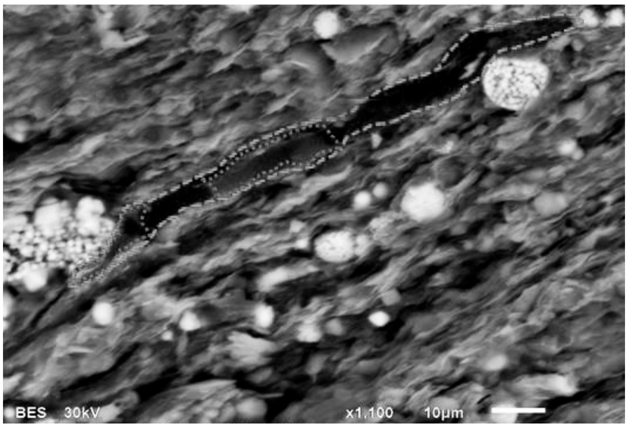


Fig. 2. Organic pores: (a) isometric, in the clayey rock mass, filled with hydrocarbons (the sample from a depth of 2,305 m, well South Ostrogorskaya), (b) lit-like, partially filled with hydrocarbons (the sample from a depth of 2,307 m, well South Ostrogorskaya).

not only may be identified and measured by electron microscopy, but also estimated on the basis of pyrolytic parameters as determined by the Rock-Eval technique.

The integrated studies show the physicochemical parameter values of the shale sequences of Khadum and Batalpashin rocks in the Maykopian series in the Central and Eastern Fore-Caucasus to widely vary. Based on chemical-bituminological studies, the TOC content in the samples of Khadum and Batalpashin sediments varies between 0.26% for the Pshekh limestone in well Dovsunskaya-4 and 8.35% for the ostracod horizon clays in well Emelyanovskaya-1.

The modal value of TOC for all the studied samples is 2.11%. The average TOC content in the Batalpashin Formation rocks is 1.41, in those of the Khadum Formation, 2.26%. With increasing rock carbonization, the TOC content declines. Minimum values have been recorded for limestones and siltstones. The highest average TOC values are noted in clays and marls of the ostracod horizon (4.46%). According to Peters [8], the Khadum and Batalpashin sediments in the Eastern and Central Fore-Caucasus may be attributed to "rich" (TOC > 1%) and "very rich" (TOC > 3%) oil source rocks.

The studied rocks are distinct from other pelitic rocks in high bitumoid content. The bitumoid texture is mostly uniform, rarely lens-shaped. A regular increase of the bitumoid content in rocks with depth has been recorded. This is caused by the increasing sediment katagenesis and hydrocarbon generation. High rock bituminosity and the domination of lubricants in the group composition of the dispersed organic matter chloroform bitumoid is indicative of the beginning of intense generative processes in the studied sediments and their approach at the present time to the oil window.

The bitumoids are dominated by chloroform extracts. The chloroform bitumoid group composition has the following average contents of components: lubricants, 57.5%; resins, 39.3%; asphaltenes, 3.2 %. The elementary composition of chloroform bitumoids and crudes from the Oligocene sediments is practically identical: bitumoids, C = 82.3%, H = 10.2%; crudes, C = 80.6%, H = 11.8%.

Based on the pyrolytic studies, the Khadum and Batalpashin rocks are distinct in sufficiently high generative potential values. The free HC content (S_1) describing the value of realized generative potential varies within the range of 0.04–9.44 mg HC/g rock. The content of hydrocarbons, products of kerogen pyrolysis and resin-asphaltene compounds describing their residual generative potential (S_2), varies within a wider range, from 0.18 to 47.77 mg HC/g rock.

The spatial pattern of S_2 concentration variations is much similar to that of S_1. The average value of the total generative potential ($S_1 + S_2$) in the samples of Khadum and Batalpashin Formations is 4.83 mg HC/g rock, being for the Batalpashin rocks 1.62 mg HC/g rock and for the Khadum rocks, 7.85 mg HC/g rock. The range of the total generative potential values is quite wide, between 0.3 and 50.89 mg HC/g rock. Maximum ($S_1 + S_2$)

values have been recorded for the sediments of the ostracod subformation in the Pri-Kuma zone. According to Tissot and Welte [8], the Khadum sediments may be attributed to oil source rocks with a high total generative potential ((S_1 + S_2) > 6 mg HC/g rock), and the Batalpashin sediments, to low potential gas source rocks.

The OM genetic and katagenetic characteristics are illustrated by various correlation diagrams of such pyrolytic parameters as HI, OI, S_1 + S_2, T_{max}, TOC, etc. (Figs. 3–5). Varying between 18 and 580 mg HC/g TOC, the HI value for the Khadum sediments averages 188 mg HC/g TOC. Maximum HI values have been recorded in marls of the ostracod subformation, the average value being 338 mg HC/g TOC.

For the evaluation of the oil source rock quality a correlation diagram of S_1 + S_2 vs TOC content was used (Fig. 3). A substantial part of the studied samples in the diagram is in the field of "good", "very good" and "outstanding" oil source rocks.

Kerogen types were identified using a modified Van Krevelen correlation diagram of HI vs T_{max} (Fig. 4). The diagram enables the identification of the field of different kerogen types following their katagenetic evolution. The three aggregates of points in the diagram correspond to three kerogen types. Type I kerogen is represented mostly by alkane structures with a small admixture of cyclomethylene and aromatic compounds. The source material of type I kerogen is mostly microalgae and bacteria. It is typical of bituminous and oil shales. Type II kerogen is dominated by cyclic (naphthene and aromatic) structures, and derived from a mix of algal, grassy and woody remains.

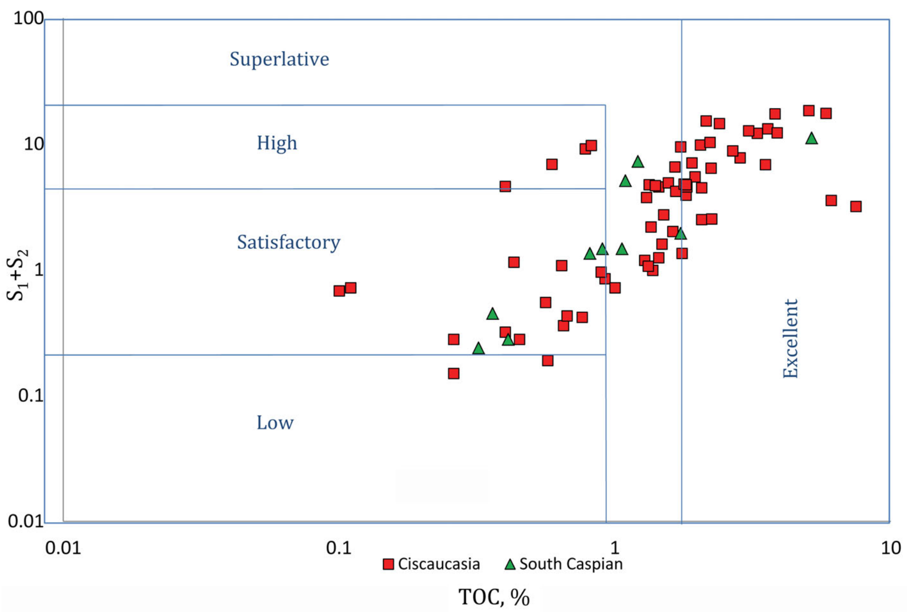


Fig. 3. Generative potential diagram for the Maykopian rocks of the Caucasus.

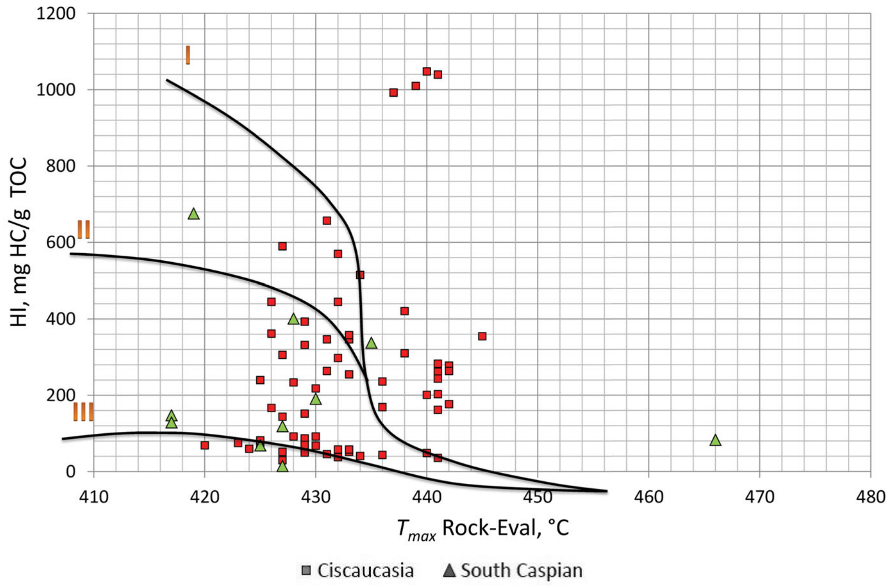


Fig. 4. Van-Krevelen diagram of HI vs T_{max} for the Maykopian rocks of the Caucasus.

Type III kerogen includes mostly acyclic aromatic structures and oxygen functional groups as well as high-molecular alkanes. The woody-inertinite organic matter served as its source material. The kerogen type may be reliably determined only at the protokatagenesis and MC_1–MC_2 stages. At higher stages, as the generative potential gets exhausted and the HI value declines, distinguishing between type I and II kerogens becomes difficult, which makes their plotting and analysis unreasonable. Figure 4 illustrates the HI-T_{max} relationship for all the studied samples of the Caucasus Maykopian rocks. Obviously, most of the rock samples are within the field of type II–III and III kerogens. However, some samples are represented by type IV kerogen and are in the non-generative area. Rock samples with the highest oxygen index (OI) have the lowest content of the organic component, type IV kerogen. This suggests their high degree of oxidation and increase in the formation of the inorganic CO_2 due to decomposition of the calcareous matrix. The values of T_{max} and the production index (PI) ($S_1/(S_1 + S_2)$) are also supportive of the thermal maturity of core samples containing type II and III kerogens. The samples capable of generating hydrocarbons are within the T_{max} zone 435–445 °C and their OM is mature. Out of the 16 studied wells, samples from only 6 (all from well Vorobyevskaya) contain thermally mature kerogen.

According to Peters [9] and Espitalier [10], the intervals containing liquid oil or high concentrations of mobile bitumoid have an anomalously low maximum pyrolysis temperatures T_{max}. The derived T_{max} values mostly fall in the range of 425–433 °C, which is traditionally attributed to the beginning of the oil window – the katagenesis grade PC_3–MC_1, while low T_{max} values are indicative of the migratory nature of bitumoid.

In the above temperature range, the OM katagenetic maturity is quite low. Despite the low OM maturity, it is likely that the hydrocarbon generation already occurs in the T_{max} range of 430–440 °C, which is evidenced by the elevated S_1 content (appearance of parautochthonous bitumoids) in the samples. For mature samples in the T_{max} range of 440–452 ºC, the OM katagenetic permutation corresponds to the middle and final grades of the oil window, MC_2–MC_3.

In the T_{max} vs PI diagram (Fig. 5), rock samples are positioned in the immature OM area. The OM katagenetic maturity grade is quite low. The T_{max} value varies within a narrow range, the lowermost values are typical of migratory bitumoid. Most values are within 425–433 °C, which corresponds to the beginning of the oil window. This is also supported by a low productivity index of up to 0.20. An increase in PI to 0.52 at low T_{max} values demonstrates the migratory nature of bitumoid.

According to T_{max} vs R_O data [10], the following interrelation between these parameters and generative zones was established [11]. T_{max} < 430 °C corresponds to the zone of immature kerogen (protokatagenesis grades PC, R_O < 0.5), the T_{max} interval of 430–465 °C is attributed to the oil window (grades MC_1–MC_3, R_O = 0.5–1.3), T_{max} > 465 °C is ascribed to the gas window (R_O > 1.3).

The studies showed that T_{max} values for the Khadum and Batalpashin rocks varied from 390 °C (Black Earth, Karpinsky Ridge) to 471 °C (Tersk-Caspian Trough, Belorechenskaya district). The average T_{max} for all samples

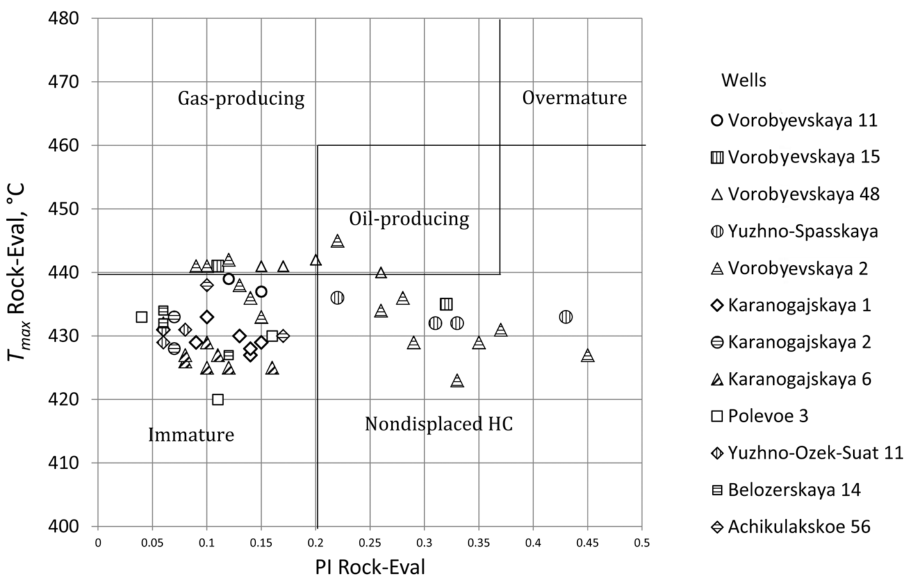


Fig. 5. T_{max} vs PI for the Maykopian rocks of the Caucasus.

is 423 °C, which corresponds to the late protokatagenesis grade PC_3. The T_{max} ranges for individual tectonic zones are as follows: Tersk-Caspian Trough 431–471 °C (grades MC1–MC4); Scythian Plate 412–447 °C (grades PC–MC2); Karpinsky Ridge 390–435 °C (grades PC–MC1). The highest maturity (grades MC2–MC4) has been recorded in the Khadum rocks within the folded flank of the Tersk-Caspian Trough (Belorechenskaya, Bragunskaya, Gudermesskaya districts). Regionally, the grade of katagenesis of Khadum rocks becomes higher toward southeast.

The kerogen depletion degree is reflected in the production index, PI = $S_1/(S_1 + S_2)$, whose values equal to 0.1–0.4 correspond to the oil window environment (in the absence of migration). Therefore, PI may serve as a relative measure of katagenesis. The rocks in the oil-gas-saturated reservoir have high S_1 values, while oil source rocks have high S_2 values. Almost all the studied samples have PI values between 0.1 and 0.4. Only some samples from Chanty-Argun, Andreyevskaya, Khankala, Dovsunskaya and Emelyanovskaya prospects have PI values greater than 0.4. In combination with high T_{max} values this indicates high maturity of these samples and possible oil occurrence “in situ”.

The Khadum Formation sediments currently reached the oil window. Therefore, the HC generation and emigration had already occurred (or are occurring), the initial values of TOC content and HI could have been higher, according to our estimate, by a factor of approximately 1.3 to 1.5, viz. at least 3–4% and 400–500 mg HC/g TOC, respectively.

Vitrinite (Vt) fragments redeposited along with other rock fragments are very rare and small. Measurements of R_O, %, were performed for a sample from well Ozek-Suat-5. The histogram is not representative as it displays a wide scatter of R_O values. The value of $R_O > 0.75\%$ is characteristic of vitrinite carrying information about the erosion zone whereas R_O values lower than 0.30% are attributable to the sapropel-type amorphous OM. These parameters could be used as “vitrinite equivalents”, after the appropriate recalculation.

The studied sample from the given area (Fig. 1) has the following pyrolytic parameters values: TOC content 40.69%, free crude oil content S_1 3.52 mg/g, and kerogen potential S_2 123.98 mg/g. Thus, according to Peters [8], these rocks may be ascribed to very good oil source rocks. Besides, its HI of 305 also indicates that the sample belongs to good oil source rocks. Despite its elevated TOC content as an indication of a good source rock, the generative carbon content of the sample does not exceed 25%. The low PI, 0.03 m, suggests the poor maturity of rock organic matter, while T_{max} of 379 °C suggests its thermal immaturity. If $S_1 <$ TOC, the absence of superposition of the migratory processes is quite likely. The OI value of 65 is a testimony to a certain manifestation of the oxidizing processes.

The Maykopian series rocks in Azerbaijan are distinct from other pelitic rocks in high TOC content, and include amorphous algal matter [12, 13]. HI varies between 15 and 676 mg HC/g TOC. The content and quality of the sediments OM improve eastward, toward the Caspian Sea (Figs. 2, 3). Therefore the OM quality is higher in the offshore part of the Caspian Sea Basin.

Geochemical studies of the low-permeability Maykopian series shale rocks show their organic matter to be mostly relatively immature and in the early stage of oil generation. Based on the study of maturity parameters R_O, T_{max} and PI, the oil generation in the OM of Miocene rocks begins at depths of 2,500 to 3,000 m. At the same time, none of these parameters reveal peak oil generation down to a depth of 5,000 m [14–18]. Within such beds, which have not reached sufficient subsidence depth and temperature peak, the HC generation still occurs. The conducted studies established that the oil source rock properties of the Maykopian series rocks in the Azerbaijan territory were very good. Due to the studies carried out, there is a high potential for discovering both conventional and unconventional shale HC resources in the region.

The generative potential of Khadum and Batalpashin rocks in the subject region was evaluated using the results of pyrolytic studies. The initial generative potential of the rocks was computed utilizing an IFP-developed technique based on the derived S_1 and S_2. The technique is based on a concept that S_1 reflects the amount of “free” hydrocarbons per unit mass (1 ton) of source rock and S_2 corresponds to the potential (residual) amount of kerogen hydrocarbons per unit mass of source rock. The total initial hydrocarbon generative potential of Khadum and Batalpashin rocks in the region was determined to be 133.4 BT, being 92.7 BT for the Khadum Formation, and 40.7 BT for the Batalpashin Formation.

4. Discussion

The probability of HCs formation in shales and their quality is defined by kerogen type, katagenesis kinetics and thermobaric environment. Depending on these factors, solid, liquid or gaseous fossil fuels may be formed in shale sequences. An important distinctive feature of accumulations in shale and tight reservoirs is that HCs are dispersed in rocks of low matrix permeability. The HC resources in low-permeability clayey shale sequences are associated with the areas of occurrence of immature “rich” and “very rich” potential oil source rocks at the initial stage of the oil window or upon approach to it. The TOC content in them may reach a few dozen percent. Due to the katagenetic expense of OM for the formation of hydrocarbons and non-hydrocarbons, its mass during katagenesis decreases. Thus, at each stage of transformation of OM we are dealing with its residual concentrations. The greater the difference between the initial and current TOC values, the higher the source rock maturity. Due to the OM mass loss during the maturation process, the determination of the initial TOC content is important to evaluate the shale HC generative potential and resources.

Of great significance in the kerogen texture is porosity which develops during the process of rock thermal maturation and is capable of affecting the adsorption of the generated oil. Organically originated void spaces formed upon OM thermal maturation and HC generation may be called organic porosity. An example of organic porosity is nanopores in the kerogen texture of low-permeability shale sequences. The porous kerogen surface has an elevated adsorption activity, it retains the generated hydrocarbons and plays an important role in determining their total amount accumulated. For instance, in the Mowry Shale sequence (Powder River Basin, USA), the kerogen type is II, the initial organic carbon content is 6%, vitrinite reflectance 1.2% and organic porosity about 5%.

Indicatively, the generative capability of various kerogen types is different. Thus, type I kerogen is capable in the process of katagenesis of a practically total conversion of hydrocarbons whereas type III kerogen is mostly composed of nongenerating matter and releases their small amount only. Comparison of source rocks having different types of kerogen but equal initial TOC contents at its maximum maturity reveals that the current TOC content of kerogen which generated the highest amount of HCs is the lowest. Therefore, the significance of kerogen generative capability may be underestimated. As a result of permutation, the kerogen capable of generating the highest amount of HCs has the lowermost current TOC values. And vice versa, the kerogen which generated the smallest amount of HCs has the highest current TOC values.

Having determined the kerogen type (there are three kerogen types identified), it is possible to suggest the percentage of TOC to be converted in HCs: type I kerogen up to 80%, type II kerogen up to 50% and type III kerogen up to 20% [19]. Thus, knowing the current values of OM content in the source rock, HI and S_1, as well as OM maturity degree, it is possible to compute the initial TOC and HI values.

A key parameter describing the kerogenous shale generative potential is organic carbon content. TOC in its turn depends on kerogen type. Similarly important are parameters expressing the yield of shale oil from kerogen, which is obtained by thermal treatment in the absence of oxygen. The aforementioned parameters describing the shale oil yield from kerogen depend on kerogen genesis. The kerogen kinds identified after the dissolution of most of the rock mineral matter in hydrochloric (HCl) and hydrofluoric (HF) acids are the following: algal, amorphous, grassy, woody and coaly (inertinite).

At heating the amorphous kerogen the amount of liquid hydrocarbons released is almost twice that released upon heating the grassy kerogen. The grassy kerogen, in turn, yields more liquid hydrocarbons than the woody and coaly kerogens. The high oil yield at oil shale distillation is due to the high amorphous kerogen content in most shales. An example of marine and lacustrine amorphous kerogen is the kerogen of Green River Formation oil shale, Uinta Basin, Utah, USA. The amorphous kerogen of the Green River

Formation and the overlying Uinta Formation migrated over a short distance from the source beds and formed asphalt accumulations in the form of veins and fracture fills and as bituminous sands. Commercial interest in the oil shale deposit development is driven not so much by the elevated content of oil shale OM as by its properties. These properties include the enrichment in hydrogen, poor katagenetic alteration and the possibility of obtaining from it, after thermal treatment, a high yield of petroleum hydrocarbons, up to 70% [20]. Shale oil is a major product of thermal treatment. For estimating the amount and quality of shale oil it is very important to determine the type of kerogen. The use of shale is technically and economically feasible when at least 20% of its kerogen is converted to oil after the thermal treatment [21]. The oil shale treatment is economically justified only if it provides for a potentially high synthetic oil yield. For instance, in Estonia, oil is produced only from one oil shale type, kukersite, due to its satisfactory yield (23%), whereas the processing of graptolite argillite, the other type of oil shale, gives but a low yield of the target product (1–2%) [22].

The content of shale oil in kerogen may vary from 45.5 to 273 liters of oil per ton of oil shale. The experience in the development of known shale formations in North America shows that such sequences are hybrid accumulations of both conventional and unconventional hydrocarbons. Examples of such sediments are shale formations of the US Eagle Ford Shale Play in the West Gulf Basin of South Texas, the Bakken Formation in the Williston Basin of Montana and Dakota, the Barnett Formation in the Fort Worth Basin of Texas, etc., which are similar in several parameters to the oil shale sequences in the Caucasus Maykopian series.

5. Conclusions

The results of the conducted geochemical studies allow the following conclusions to be made:

1. The Khadum and Batalpashin sediments of the Eastern and Central Fore-Caucasus contain three types of kerogen – I, II and III. The Khadum rocks are dominated by a more “noble” type II kerogen, mixed humic-sapropelic organic matter.
2. By geochemical parameters like total organic carbon, hydrogen index and total generative potential, the Khadum and Batalpashin rocks may be attributed to “rich” and “very rich” (“outstanding”) oil source rocks. The rocks of the Khadum ostracod subformation have the most favorable geochemical characteristics.
3. The maturity extent of the subject rocks within the region varies between the grades of protokatagenesis (T_{max} = 390 °C) and MC_4 (T_{max} = 471 °C). Regionally, an intensification in the katagenesis southeastward, from the Karpinsky Ridge toward the most subsided portion of the Tersk-Caspian Trough, has been recorded. Over the

most of the subject territory, the Khadum sediments are located within the oil window. The Khadum Formation exhibits a higher generative capability in the Pri-kuma zone, the Nogay Step and the northern flank of the Tersk-Caspian Trough.

4. The total initial generative hydrocarbon potential of the Khadum and Batalpashin rocks within the study region is 133.4 BT, being for the Khadum Formation 92.7 BT and for the Batalpashin Formation, 40.7 BT. It should be noted that the quantitative estimate of the hydrocarbon generative potential of Khadum and Batalpashin rocks in the given region was conducted for the first time.

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