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Thermal maturity of organic matter and type of kerogen of Mesozoic sediments, Aryskum depression

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Annotation
This work is devoted to the study of the oil and gas source potential of the Mesozoic deposits of the Aryskum depression of the South Turgay oil and gas basin and aims to study the features of the geological structure, determine the facial-genetic type and degree of maturity of organic matter. Geochemical methods play an important role in assessing oil and gas source potential, one of which is pyrolytic core analysis to determine the type of organic matter and thermal maturity of the studied rock material samples. To achieve this goal, the results of pyrolytic analysis of stone material from Neocomian and Jurassic deposits were used. Analysis of geological and geophysical materials made it possible to trace the pattern of distribution over the area of oil and gas-bearing sandy layers and the underlying clay layers with high insulating properties in the Aryskum horizon. The results obtained show that the total organic carbon content ranges from 0.47 to 1.41 wt%. To establish the type of kerogen and its position relative to the zones of oil and gas formation, the Van Krevelen diagram was used in the coordinates of atomic ratios of the elemental composition of kerogen and its modification for pyrolytic data, indicating that the kerogen of the studied samples is a mixture of types I, II and III, facies-genetic the type of organic matter of which belongs to humic, humic-sapropelic, and the sedimentation conditions are coastal-marine environment in moderately reducing conditions.

Keywords: Aryskum depression, South Turgay oil and gas basin, oil and gas content, organic matter, hydrocarbons, type of kerogen

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Introduction

The question of the source of hydrocarbons finds wide practical application in predicting the oil and gas potential of the subsurface, in solving which it is difficult to overestimate the role of modern methods of geochemical research [1]. The pyrolytic method is a widely used and highly valued tool used by petroleum geochemists, the purpose of which is to assess the oil and gas generation potential of rocks, the type of kerogen, and the thermal maturity of organic matter, where stepwise heating modes of core samples are used. The samples are initially pyrolyzed in an inert atmosphere and then oxidized in an oxidizing medium. The method of rock assessment in one full cycle of analysis allows us to obtain several important indicators related to the formation of oil, such as the amount of free hydrocarbons present in the sample, the residual content of hydrocarbons, the TOC content, the level of thermal maturity of the sample, the amount of chemically active

organic matter, the presence of carbonate minerals and the quality/type of organic matter present in the samples [[2], [3]].

It is known that the characteristics of the parent rocks are evaluated according to the level of thermal maturity and the amount of organic matter and the type of kerogen [[4], [5], [6], [7], [8]]. Thus, the total organic matter content (TOC) is estimated by the amount of organic matter in a rock sample. Geochemical parameters such as hydrogen, oxygen indices (HI, OI), temperature (T_{max}) and productivity index (PI) obtained as a result of Rock-Eval pyrolysis allow us to evaluate the type of kerogen and determine the thermal maturity of organic matter [[6], [7], [8], [9], [10], [11]].

The purpose of this work is to determine the facies-genetic type and degree of maturity of organic matter, to achieve which the following tasks were solved (1) to study the history of the formation of the tectonic structure of the South Turgay oil and gas basin, the regularities of the distribution of hydrocarbons; (2) assessment of the oil-generation potential of Jurassic and Neocomian deposits, the type of kerogen and thermal maturity by pyrolytic method of core samples.

Geological settings. The South Turgay oil and gas basin, with a total area of about 60 thousand square kilometers, is a large linear structure of the northwestern strike and represents the southeastern margin of the Turgay depression (Figure 1). According to the thickness of the sedimentary cover, the peculiarities of tectonic and lithological-stratigraphic characteristics, the basin belongs to the intracontinental. The oil and gas potential of the basin was established in 1984 by the discovery of the Kumkol deposit. Intensive geological exploration began to be carried out since the late 1970s.

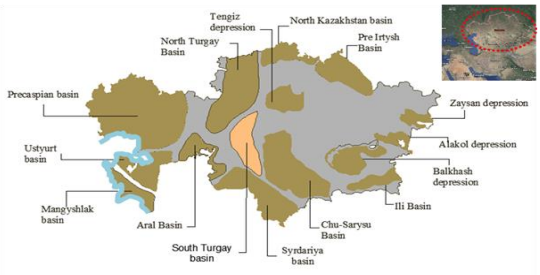

Figure 1 - Map of the sedimentary basins of Kazakhstan [12]

The basin is divided into three structural floors such as characteristic structural and material features of microcontinents. The lower floor is a crystalline foundation consisting of Archean-Lower Paleozoic metamorphic gneisses and various shales that occur at adjacent elevations and are opened by some wells inside and near the edge of the syneclise [13]. The Middle-quasi-platform complex of the Middle and Upper Paleozoic consists of intermittent Devonian, Carboniferous, and Permian deposits up to 1.5-2 km thick. In accordance with the drilling and seismic survey materials in the South Turgay oil and gas basin, there is a wide development of quasi-platform formations of the Upper Paleozoic of considerable power, the distribution of which on its individual geostructural elements is quite complex. The upper platform cover is represented by sedimentary deposits of Triassic-Jurassic, Cretaceous-Miocene, and Pliocene-Quaternary age [14].

The upper structural floor, the most studied by geophysical methods and deep drilling, includes all the sediments of the Mesozoic and Cenozoic and splits into two tiers: the lower-rift, the upper-epirift.

According to the hypsometric position of the foundation, three large structures are distinguished: the Zhylanshik and Aryskum depression with the Mynbulak uplift separating them, complicated, in turn, by structural elements of lower orders.

All the identified deposits are confined to the Aryskum depression, the tectonic characteristics of which are covered in detail in the works of Abdullin A.A., Daukeev S.Zh., Kuandykov B.M., Zholtaev G.Zh., Nazhmetdinova A.Sh., Puzanova I.V., Sapozhnikov R.B., Votsalevsky E.S., Bulekbaev Z.E., etc.

The Aryskum depression is characterized by a complex tectonic structure, has fairly well-defined raised horst–anticlines and lowered foundation blocks - graben-synclines (Figure 2) in length from 100 to 200-250 km and in width up to 25-50 km of north-westerly strike on the western side of the depression, and northerly direction on the eastern side, expanding in width to the northern part of the depression [15].

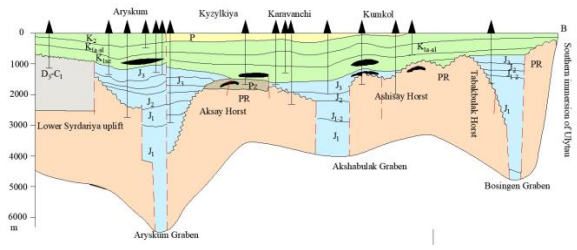

Figure 2 - Geological section of the Aryskum depression [15]

Within the deflection, the Aryskum, Akshabulak (Besoba-Terensai), Sarylan, Bozingen, Daut and Zhinishkekum graben - synclines are distinguished, which are separated by Aksai, Aschisai and Tabakbulak horst - anticlines.

Hydrocarbon systems and deposits. One of the main oils and gas bearing complexes in the section of the Aryskum depression are sandy-clay Mesozoic deposits, within which the Lower Cretaceous (Aryskum horizon), Middle-Upper Jurassic, and Lower Jurassic complexes are distinguished, in addition to which the Upper Paleozoic promising oil and gas complex is also distinguished [16].

The prospects of pre-Mesozoic formations are based on the presence of manifestations of hydrocarbons from weathered basement rocks up to industrial oil inflows (Kyzylkia, Karavanchi, Kenlyk).

Upper Jurassic and Cretaceous sandstones and siltstones deposited in delta and river facies are the main reservoirs in which most of the oil discovered to date is distributed [17].

Within the Jurassic complex, a series of local and zonal clay fluidopores are distinguished [18].

Chalk deposits in the South Turgay oil and gas basin are ubiquitous and are overlain, in turn, by younger Paleogene-Quaternary sediments. They are represented by all age subsections, the deposits are facially sustained over a large area, which allows them to be correlated fairly confidently by logging wells drilled without core sampling.

Oil-producing complexes-sources of hydrocarbons. The forecast hydrocarbon resources are determined based on the reconstruction of the entire complex of natural processes that cause the formation of oil and gas from organic substances of oil and gas mother rocks [19].

Within the South Turgay oil and gas basin, there are effective oil-producing strata of Jurassic sediments, where graben-synclines are associated with lake sedimentation conditions, whose hydrocarbons migrated and accumulated in nearby deposits of the Jurassic and Cretaceous complexes. For the migration of hydrocarbons into Paleozoic traps, sedimentation occurred by overflows from graben along carbonate rocks. Bitumen was found in Devonian carbonate rocks that came to the surface within the Greater Karatau, which indicates the effective migration of hydrocarbons along this complex over a long distance [[20], [21]].

The experimental part

The pyrolytic method on the analyzer of the initial rocks of the samples of stone material of the Kumkol formation of the Upper Jurassic (J_3km) and the Aryskum formation of the Lower Cretaceous (K_1nc1ar) from the wells of the Aryskum depression of the South Turgay oil and gas basin allowed to determine the type of kerogen, hydrocarbon potential and the stage of maturity of organic matter, the geochemical parameters of which are presented in the table below.

Discussion of the results

Generation potential. The results of the study show that the concentration of total organic carbon (TOC) ranges from 0.47 to 1.41%, the parameter S_2 varies from 1.6 to 3.1 mg HC/g of rock in the samples of the Lower Cretaceous and from 1.1 to 9 mg HC/g of rocks of the Kumkol formation of the Upper Jurassic, where values below 2.5 have a low (poor) potential, and above 6 have a good (rich) potential.

Table 1 - Geochemical characteristics of pyrolytic analysis of deposits of the Aryskum depression

Formation	Depth	TOC	S_1	S_2	S_1+S_2	T_{max}	HI	OI	PI
K_1nc_1ar	1682.9	0.52	0.97	1.6	2.57	413.02	298	198.1	0.385
K_1nc_1ar	1686.4	0.53	0.57	2.2	2.77	437.49	417	141.5	0.205
K_1nc_1ar	1687.43	1.12	2.05	3.1	5.15	445.16	277	22.3	0.398
J_3km	1880.45	0.67	0.3	2.6	2.9	434.19	388	16.4	0.103
J_3km	1883.85	0.47	0.24	1.1	1.34	440.33	238	87.2	0.176
J_3km	1887.67	0.57	0.37	2.3	2.67	432.6	407	61.4	0.138
J_3km	1896.54	0.68	0.49	2.8	3.29	330.67	412	47.1	0.149
J_3km	1897.19	0.71	0.22	2	2.22	437.8	283	66.2	0.099
J_3km	1897.36	1.41	1.65	9	10.65	434.11	640	70.2	0.155

Type of kerogen. The dependence of TOC on the hydrocarbon potential indicates type II and type III kerogen of the vast majority of the samples studied, however, the sample from a depth of 1897.36 m is attributed to type I kerogen.

In the studied samples according to the HI hydrogen index, the range of values from 200 to 300 indicates kerogen of type II-III, probably with the generation of oil and gas; from 300 to 600 - kerogen of type II, possible oil and gas generation. However, it should be noted the difference in the sample taken from a depth of 1897.36 m, where the HI value of 640 corresponds to type I kerogen.

The value of the hydrogen index HI, which characterizes the facies-genetic type of organic matter, indicates the humus origin and, less often, the coastal (humus-sapropel) genesis of the studied samples, the organic matter that accumulated under moderately reducing conditions and correspond to kerogen types III and II. In the Van Crevelen diagram (Figure 3), two composite indicators are used to characterize the type of kerogen – the hydrogen index HI and the oxygen index OI, the results of which allow us to draw similar conclusions [22].

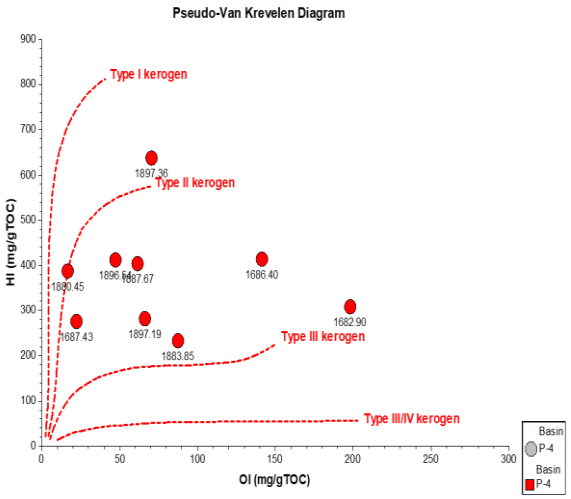

Figure 3 - Correlation between the hydrogen index (HI) and the oxygen index (OI) of the Aryskum depression

Determination of thermal maturity. To determine the thermal maturity, the range of T_{max} values of the studied samples from 435 to 445^{0}C is acceptable for the conditions of the oil window, i.e. oil generation, and allows them to be classified as mature; low T_{max} values are defined as low degree of maturity of organic matter in the studied core samples from a depth of 1682.9 m (Daul formation) and 1896.54 m (Kumkol formation) [23].

The ratio S_1 / S_1+S_2 is the productivity index PI, where the degree of realization of the organic matter of the samples under study varies from 0.103 to 0.398. Thus, samples with a Max in the range of values 435-445^{0}C, as well as PI with more than 0.1 coefficient have an oil-generating potential. However, an indicator of the industrial oil-bearing capacity of the reservoir is a PI value of more than 0.5.

Conclusion

The analysis of the obtained data of the geochemical study of the stone material of the Mesozoic deposits of the South Turgay oil and gas basin allows us to draw the following conclusions:

1. As a result of the study, the studied samples have a rich and very rich generation potential in terms of the content of C_{org} in the range from 0.47 to 1.41, as well as in the parameter S_2 (from 1.1 to 9 mg of HC /g of rock).
2. Most of the studied samples belong to type II and III kerogen, one sample from a depth of 1897.36 m with maximum TOC and S_2 is within the limits of type I kerogen; according to pyrolytic parameters HI, T_{max}, the studied samples belong to type II-III and type I kerogen with probable oil and gas ineftegeneration, respectively;
3. The hydrogen and oxygen indices determining the facies-genetic types of organic matter indicate mainly humus and less often humus-sapropel origin, thereby allowing us to conclude that oil accumulation occurred in moderately reducing conditions and coastal-marine environment.
4. The organic matter in the studied samples is thermally mature according to the T_{max} index. However, there is a low degree of maturity of the organic matter of the Tula formation and the Kumkol formation from a depth of 1682.9 m and 1896.54 m, respectively.

Conflict of interest. On behalf of all the authors, the corresponding author declares that there is no conflict of interest.

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Арысқұм иілуінің Мезозой шөгінділеріндегі органикалық заттардың термиялық пісіп-жетілуі және кероген түрі

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ТҮЙІНДЕМЕ

Бұл жұмыс Оңтүстік Торғай мұнай-газ бассейнінің Арысқұм иілуінің мезозой шөгінділерінің мұнай-газ аналық әлеуетін зерттеуге және геологиялық құрылымның ерекшеліктерін зерттеуге, органикалық заттардың фациалды-генетикалық түрін және жетілу дәрежесін анықтауға арналған. Геохимиялық әдістер мұнай-газ-аналық әлеуетті бағалауда маңызды рөл атқарады, олардың бірі органикалық заттардың түрін және зерттелетін тас материал үлгілерінің термиялық жетілуін анықтау үшін негізгі пиролитикалық талдау болып табылады. Осы мақсатқа жету үшін неоком мен юра шөгінділерінің тас материалын пиролитикалық талдау нәтижелері қолданылды. Геологиялық-геофизикалық материалдарды талдау Арысқұм көкжиегінде жоғары оқшаулағыш қасиеттері бар мұнай-газды құмды қабаттар мен олардың үстіндегі сазды қабаттардың ауданы бойынша таралу заңдылығын байқауға мүмкіндік берді. Алынған мәліметтердің нәтижелері органикалық көміртектің жалпы мөлшері массаның 0,47-ден 1,41%-на дейін екенін көрсетеді. Керогеннің түрін және оның мұнай-газ түзілу аймақтарына қатысты орналасуын анықтау үшін керогеннің элементтік құрамының атомдық қатынастарының координаттарында Ван-Кревелен диаграммасы және оның пиролитикалық деректер үшін модификациясы пайдаланылды, бұл зерттелетін үлгілердің керогені I, II және III типтердің қоспасы екенін көрсетеді. Фациалды-генетикалық түрі органикалық заттар гумусты және гумусты-сапропелге жатады, ал шөгу жағдайлары орташа қалпына келтіру жағдайында жағалау-теңіз ортасы болып табылады.

Түйінді сөздер: Арысқұм ойпаңы, Оңтүстік Торғай мұнай-газ алабы, мұнай-газдылық, органикалық заттар, көмірсутектер, кероген түрі

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АННОТАЦИЯ

Данная работа посвящена исследованию нефтегазоматеринского потенциала мезозойских отложений Арыскумкого прогиба Южно-Торгайского нефтегазоносного бассейна и ставит целью изучение особенностей геологического строения, определение фациально-генетического типа и степени зрелости органического вещества. Геохимические методы занимают важную роль в оценке нефтегазоматеринского потенциала, одним из которых является пиролитический анализ керна для определения типа органического вещества и термической зрелости исследуемых образцов каменного материала. Для достижения этой цели были использованы результаты пиролитического анализа каменного материала отложений неокома и юры. Анализ геолого-геофизических материалов позволил проследить закономерность распространения по площади нефтегазоносных песчаных пластов и залегающих над ними глинистых прослоев с высокими изолирующими свойствами в Арыскумском горизонте. Результаты полученных данных показывают, что общее содержание органического углерода составляет от 0,47 до 1,41% масс. Для установления типа керогена и его положения относительно зон нефтегазообразования использовалась диаграмма Ван-Кревелена в координатах атомных отношений элементного состава керогена и ее модификация для пиролитических данных, свидетельствующая о том, что кероген исследуемых образцов представляет собой смесь типов I, II и III, фациально-генетический тип органическое вещество которых относится к гумусовой, гумусово-сапропелевой, а условия осадконакопления - прибрежно-морская среда в умеренно восстановительных условиях.

***Ключевые слова**:* Арыскумская впадина, Южно-Тургайский нефтегазоносный бассейн, нефтегазоносность, органическое вещество, углеводороды, тип керогена

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