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ORIGINAL ARTICLE

Geochemical prerequisites for the formation of oil and gas accumulation zones in the South Turgay basin, Kazakhstan

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Abstract This study predicts favorable oil and gas source-rock formation conditions in the Aryskum Depression of the South Turgay Basin, Kazakhstan. This study assesses the thermal maturity and characteristics of organic matter by determining its environmental conditions using data from geochemical analysis of core (pyrolysis) and oil (biomarkers and carbon isotopic compositions) samples. According to the geochemical parameters obtained by pyrolysis, the oil generation potential of the original rocks of most studied samples varies from poor to rich. The facies–genetic organic matter is predominantly humic and less frequently humus–sapropel, indicating organic matter accumulation in the studied samples were under moderately reducing conditions (kerogen III and II types) and coastal–marine environments (kerogen type I). The carbon isotopic compositions of oils derived from the Jurassic deposits of the Aryskum Depression also indicate the sapropelic and mixed humic–sapropelic type of organic matter (kerogen II and I). Biomarker analysis of oils indicates original organic matter formation in an anoxic environment.

Keywords South Turgay Basin · Oil and gas potential · Source rock · Organic matter · Kerogen

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1 Introduction

The assessment of the oil and gas generation potential of sedimentary basins is primarily based on identifying oil source rocks that generated hydrocarbon accumulations. In this regard, it is challenging to overestimate the importance of organic geochemistry methods, the results of which are critical and associated with increasing effectiveness of prospecting and the quality of prediction of new oil and gas accumulation zones. Geochemical methods are an obligatory criterion for assessing oil and gas potential during geological prospecting, forecasting, exploration, and development of oil and gas fields (Kontorovich 1976).

The South Turgay Basin is one of the primary oil and gas basins in the southeast of Kazakhstan. In the depletion conditions of the identified hydrocarbon reserves and a decrease in oil production, the assessment of the oil and gas generation potential of the basin, the study of various types of kerogens and the degree of their maturity, and the study of the facies environment of organic matter accumulation are relevant.

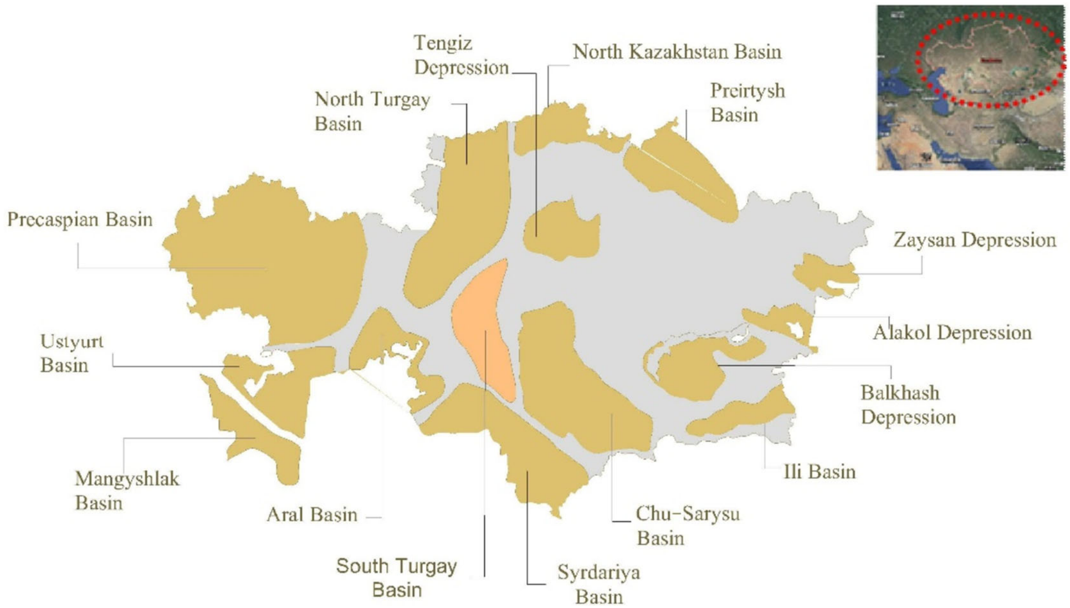

Fig. 1 Simplified tectonic map of the getic depression and the South and East Carpathians, with the studied area marked as rectangular; modified from Azhgaliev et al. (2013)

This study identifies possible source rocks to clarify their evolution, development, distribution, and nature of possible hydrocarbon generation centers considering the results of pyrolytic analysis, chromato-mass spectrometer studies, carbon isotopic composition of oils, and gathered geochemical data in recent years (Kontorovich 1976; Kryukov et al. 1987).

Therefore, we solved such problems that can be divided into four parts:

(1) Identification and characterization of oil source strata according to pyrolytic analysis and assessment of their oil and gas generation potential.
(2) Characteristics of organic matter, stage of maturity, features of its catagenetic transformation, and facial–genetic type, and determining the kerogen type.
(3) Reconstruction of the composition of the original oil for organic matter and the conditions of its accumulation according to the individual composition and distribution of chemofossils.
(4) Identification of the features of the formation of oils by the isotopic composition of carbon.

2 Geological settings

Tectonically, the South Turgay Basin (Fig. 1) is characterized by a northwestern strike, has an area of 8×104 km^2, and is a rift-like depression formed between the lower Syrdarya VAULT and the Ulytau Massif. Over 50 oil and gas fields have been discovered in the South Turgay Basin. For the first time, the productivity of the region was proved by the receipt of oil in 1984 in the first exploration well in the Kumkol area. The industrial oil and gas potential of the South Turgay Basin dates back to the late 1990s (Kryukov et al. 1987).

The modern structural plan of the South Turgay Basin has been determined and sufficiently and fully characterized by seismic survey and deep drilling data. Two subsidence areas (the Aryskum and Zhylanshik Depressions) were distinguished according to the features of the structural plan, and the Mynbulak Saddle is distinguished between them. The primary lower-order structural elements are grabens and horsts (Fig. 2) (Ozdoev et al. 2020; Smabaeva 2015). From west to east, the Aryskum, Akshabulak, Sarylan, and Bozingen grabens are distinguished, connected by the Aksai, Ashchisai, and Tabakbulak horsts.

The Aryskum depression is characterized by the densest distribution of hydrocarbons per unit area and a well-defined two-story structure. At the lower level, deep grabens are made by terrigenous Jurassic sediments and hump-shaped ledges separate ledges, represented by formations of the pre-Jurassic age (Fig. 3). In some cases, the tops of the Paleozoic ledges comprise disintegrated rocks and conditions favorable for the formation of oil and gas accumulations (Paragulgov et al. 2013a, b).

The upper floor comprises terrigenous rocks, primarily of Cretaceous and Cenozoic ages, covering the underlying complexes of sediments in a cloak-like manner. A sharp disagreement occurs on contact with the protrusions of pre-Jurassic formations and a consistent occurrence regarding Jurassic sediments. (Fig. 3). The depth mark of the

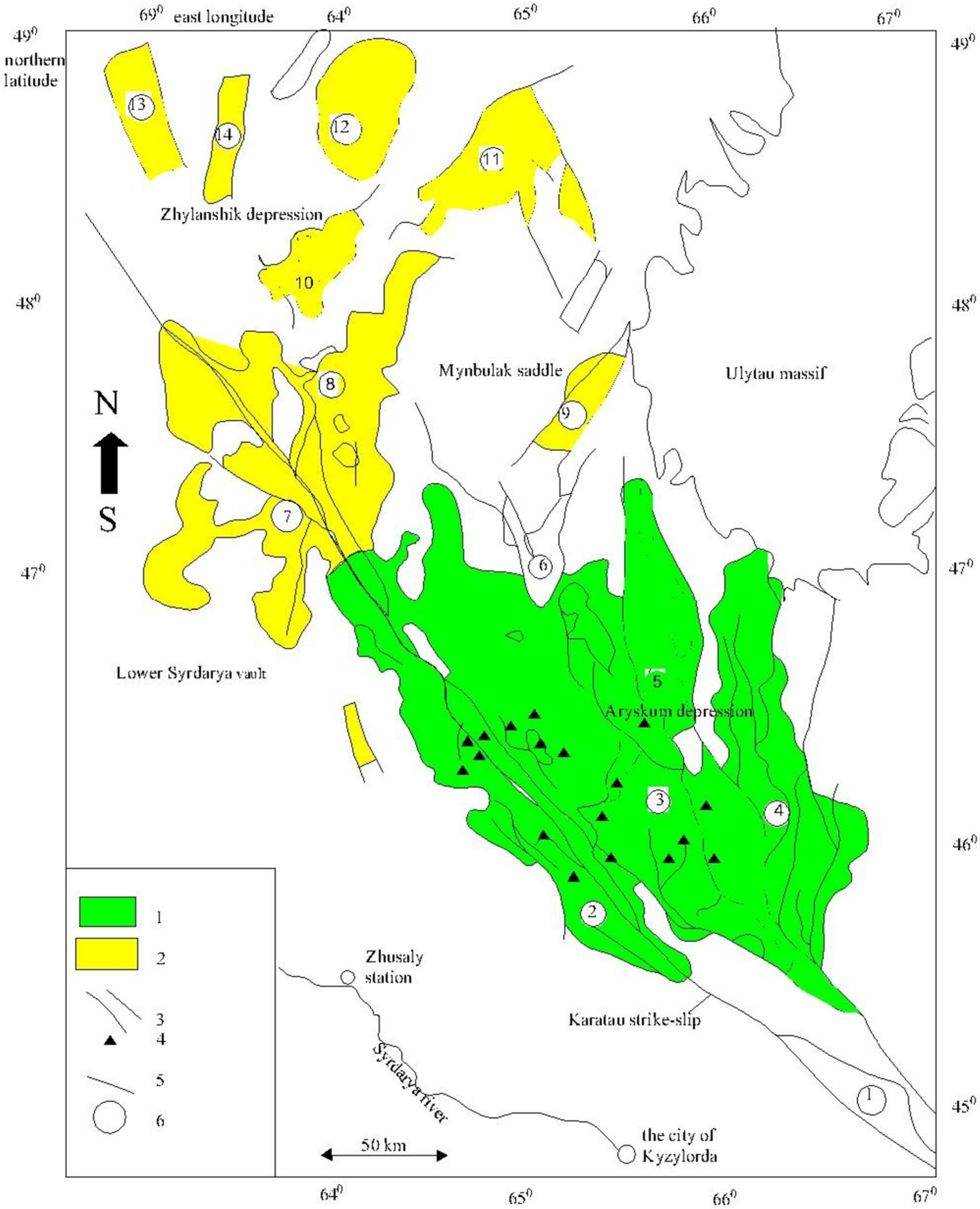

Fig. 2 Aryskum depression of the South Turgay basin, Kazakhstan. Tectonic framework of the South Turgay basin (Bolat 2020). 1—oil- and gas-bearing territories; 2—oil and gas-prospective territories; 3—aults; 4—oil fields; 5—Syrdarya river; 6—Jurassic grabens: ①. Daut, ②. Aryskum, ③. Akshabulak; ④. Bozingen, ⑤. Sarylan, ⑥. Kulsay, ⑦. Zhinishkekum, ⑧. Cherkitau, ⑨. Jimykin, ⑩. Kulagak, ⑪. Boshakul, ⑫. Zhanakural, ⑬. Aschisay, ⑭. Baymurat

foundation roof decreases in the northern direction; the greatest depth of the foundation is noted in the central part of the South Turgay Basin in the stretch of the Karatau Regional Fault (Turkov 2020; Zholtaev 2018).

As a rule, the raised areas of the horst are promising for detecting zones with hydrocarbon traps. From a hydrocarbon potential viewpoint, researchers in the foreground, considering the exploratory drilling data, consider the Aksai and Aschisai horsts since the bulk of significant oil and gas fields are concentrated within their limits. Thus, the horst–graben nature of the macropattern and development of the South Turgay Basin is a factor according to

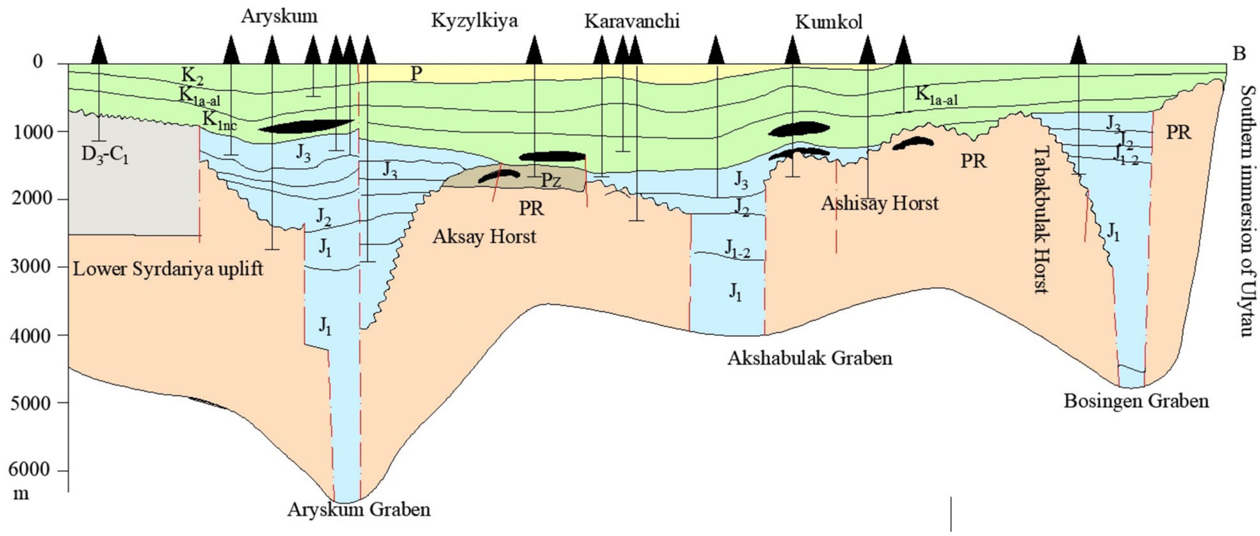

Fig. 3 Geological profile of the Aryskum depression of the South Turgay basin, Kazakhstan (Turkov 2020). Symbols: J_1—Lower Jurassic, J_2—Middle Jurassic, J_3—Upper Jurassic, K_1—Lower Cretaceous, K_2—Upper Cretaceous, Pz—Paleozoic, PR—Proterozoic, D_3–C_1—Upper Devonian–Lower Carboniferous

which this territory is differentiated by the level of hydrocarbon potential, including in the territory by the degree of prospects and in importance regarding the directions and placement of exploration works.

In most of the South Turgay Basin, the Proterozoic and Lower Paleozoic basement, represented by metamorphic rocks (shales of various compositions, gneisses, and porphyrites), is overlain by Upper Paleozoic deposits, a quasiplatform complex (Paragulgov et al. 2013a; Nukenov and Bolat 2015). Weakly metamorphosed and less dislocated deposits of the quasiplatform complex are represented by red-colored formations of the Middle and Upper Devonian (Famennian age) and undivided rocks of the Middle and Upper Carboniferous (Bisengaliev and Temirkhasov 2015).

The Jurassic sediment complex is a rift complex of sedimentary filling of the entire Mesozoic Depression and includes three subcomplexes that appeared successively in the Early, Middle, and Late Jurassic ages. The Lower Jurassic is represented by the Sazymbai and Aibolin Formations, the Middle Jurassic includes the Doshchan and Karagansai Formations, and the Upper Jurassic is characterized by deposits of the Kumkol and Akshabulak Formations. The Lower and Upper Neocomian continental deposits are represented by individual cycles of sandy and clayey rocks (Kryukov et al. 1987; Bolat 2020; Daukeev et al. 2002).

2.1 Ideas about the formation of oil and gas systems and complexes

Jurassic and Cretaceous Deposits in the Aryskum Depression are the primary oil- and gas-containing reservoirs, represented by terrigenous differences (sandstones and siltstones), the accumulation of which occurred in delta and river conditions (Fig. 4). A powerful layer of Lower Cretaceous mudstones K_1nc_1 is a regional cover for them (Bolat 2020). Reservoir rocks in the Upper Jurassic and Lower Cretaceous sediments are characterized by sufficiently high filtration and capacitance properties, open porosity in places of approximately 30%, and permeability in some cases of 6md. Clay deposits are frequently regional and zonal fluid-resistant (Iskaziev and Azhgaliev 2009). However, as evidenced by new data (Azhgaliev and Bigarayev 2023) obtained in recent years, the productivity of clay deposits is noted at the Aibolin, Karagansay, and Doschan Formation levels.

The South Turgay Basin is an illustrative example of which the sedimentary migration theory of the origin of oil and gas has been proven and scientifically substantiated. As the preliminary research results show, the maximum oil and gas saturation of the section is characteristic of grabens, where the highest concentration of organic matter in the rocks of the oil and gas source strata and a significant amount of these rocks that took part in generating hydrocarbons are noted. In this regard, the Aryskum and Akshabulak grabens are distinguished by their large size and area and the thickness of the Jurassic and Lower Cretaceous Deposits. Most deposits are confined to them, concentrated on slopes and sides (Doschan, Tuzkol, Karavanchi, and Nuraly), junctions with horsts (Kumkol, Akshabulak, and Bestobe), and axial central zones of grabens (Aryskum, Konys, and Maibulak).

The lateral and vertical migration of hydrocarbons from the axial parts of the mentioned grabens contributed to the filling of anticline and nonanticline traps and oil and gas

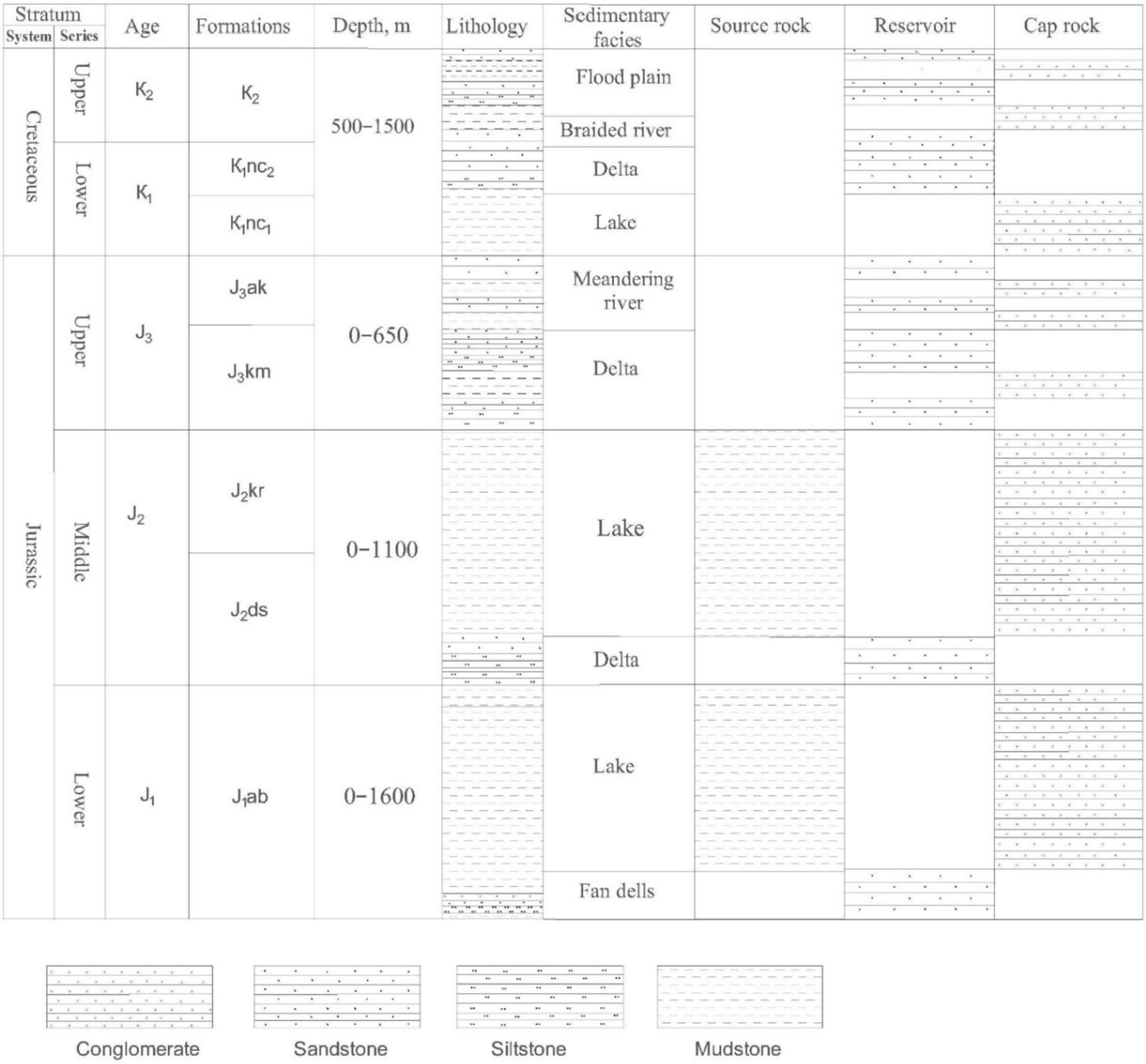

Fig. 4 Schematic section column of the reservoir part of the Aryskum depression of the South Turgay Basin, Kazakhstan (Yin et al. 2012)

deposit formations (Bolat 2020; Kaishybai 2020). Accordingly, in the South Turgay Basin section, potential oil and gas traps accumulated and formed in the conditions of the horst (anticlines and uplifts) and the graben slope (traps of lithological and stratiplotic screening) (Kuandykov et al. 1992; Bolatet al. 2015).

Studies of the geochemical characteristics of the sedimentary cover have shown that the Jurassic–Cretaceous Formations have various organic matter types, mainly sapropelic. Consequently, the Lower and Middle Jurassic strata were considered the most probable generation strata, which could generate liquid hydrocarbons considering the thermobaric condition of the basin (Kryukov et al. 1987; Ozdoev et al. 2020; Zholtaev 2018). The Lower Cretaceous and Upper Jurassic sediments are not considered oil-producing because their average values of total organic matter are beyond the lower threshold of concentrations accepted for oil-producing source rocks, and they were not included in the oil formation zone.

The facies–genetic organic matter can be considered a crucial basic parameter in solving problems of assessing the generation potential of hydrocarbons in oil and gas basins. It is with the chemical–genetic organic matter, considering the paleo and existing barothermal conditions of the impact on organic matter and the reliability of oil and gas complex screening, that the phase state and ratio of hydrocarbons are determined in the latter (Tissot and Welte 1984).

Thus, studies of past years have established (Tissot and Welte 1984) that in the Lower Jurassic Sazymbai Formation, the sediment accumulation occurred in a weakly reducing environment, changing into an oxidizing one. In the overlying Aibolin Formation, the gelified matter accumulating in a reducing environment is 70 %–75 %, forming interlayers of coals of the claren type formed in the anaerobic environment of stagnant swamps. In the closed reservoirs of the Doschan Formation of the Middle Jurassic, the material of higher plants accumulated, and endangered plankton was deposited. In the sediments of the Karagansai Formation, the proportion of alginite and leiatinite increased, amounting to 6 %–8 %, and the content of fusenite ranges from 8 % to 40 %. The gelified substance makes up 60 %–80 % of the dispersed organic matter mass. The predominance of mixed humus–sapropel forms of a lake reservoir in the dispersed organic matter composition with the development of lake–marsh facies of sedimentation is noted. Various sedimentation conditions and lithological complexes characterize the deposits of the Kumkol Formation of the Upper Jurassic. Within the Doschan area, concentrated organic matter has been isolated as interlayers of claren and ultraclaren coals, formed at sharply increased sedimentation rates. In the Karavanshi and Maibulak areas, organic matter is dominated by fused matter, with a sharply subordinate value of gelified and leuptinite components. In the deposits of this suite, an increase in the organic matter composition of algal material occurs by 1 %–8 %. Sediments accumulated in the deposits of the Akshabulak Formation during a sharply increased continental character of the climate under oxidizing conditions (Daukeev et al. 2002).

3 Materials and methods

(1) Geochemical studies of organic matter include pyrolytic analysis on the Source-rock Analyzer [SRA—total petroleum hydrocarbons (TPH)/total organic carbon (TOC)] at the Weatherford Laboratories Instruments Division. The core was crushed and sifted through a 40-mesh sieve. The amount of free (S_1) and generated (S_2) hydrocarbons and the amount of TOC and temperature (T_{max}) during pyrolysis were also determined.

(2) The alkane composition separation and identification were conducted using gas–liquid chromatography (Model 3700) and Perkin–Elmer Sigma 2B using a flame ionization detector; helium was used as the carrier gas. The capillary column with the SE-52 phase was 33 m long. Shooting-mode linear temperature programming at 4 °/min from the initial temperature of 100 to 290 °C was selected. The relative biomarker compositions (hopanes, gammacerane, diasterane, and regular steranes) in oils were determined by chromatography-mass spectrometry using a Trace-DSQ magnetic chromatography-mass spectrometer from Thermo Scientific (Germany).

(3) The carbon isotope composition analysis of oils in the accredited laboratory of isotope methods of the Tomsk branch of the Joint-Stock Company, Siberian Research Institute of Geology, Geophysics and Mineral Raw Materials on the DELTA V ADVANTA mass spectrometer was used.

Also, published sources on the geochemistry of sedimentary deposits were used, performed by researchers at previous stages of studying the region.

4 Discussion

The available factual materials on the geochemical characteristics of the South Turgay Basin (Kryukov et al. 1987; Bolat 2020; Iskaziev and Azhgaliev 2009; Azhgaliev and Bigarayev 2023) indicate that the average TOC correlates with the lithological types of rocks (clays, siltstones, sandstones, and oil shales). It has been established that Jurassic–Cretaceous sediments are characterized by sufficiently high organic matter contents of various types (humic and sapropelic type), the concentration of organic matter exceeds the Clark value, and in the Jurassic sediments, the organic matter type is primarily represented by the humus variety.

The TOC content in siltstones, mudstones, and sandstones of the Lower–Middle and Upper Jurassic sediments of the Aryskum Depression of the South Turgay sedimentary basin shows that in the sediments of the Akshabulak Formation of the Upper Jurassic, the value of C_{org} is below the lower concentration, and the maximum indicators are characteristic of the Doschan Formation of the Middle Jurassic. Depending on the TOC concentration, oil-producing source rocks (clays, mudstones, clayey siltstones, and clayey limestone) vary from poor to excellent generative potential.

The uneven distribution of organic matter in Mesozoic sediments was noted according to the results of a chemical–bituminological study. Thus, the minimum organic matter from 0.01 to 0.53 is observed in the Upper Jurassic variegated thickness, and the maximum (avg. 13%) in the underlying gray-colored formation, with layers of oil shale, and the average organic matter concentration in the Jurassic section is 2 %–3 %. The average organic matter concentration in the Lower Cretaceous complex is 0.01 %–1.9 %.

According to biomarker studies and the fingerprinting of oil deposits of the Akshabulak graben of the Aryskum depression, the organic matter formation in terrigenous (clay) strata deposited in the lacustrine environment was previously established (Seitkhaziyev et al. 2021a, b, c).

4.1 New geochemical data

The amount of organic matter in rocks, kerogen, and hydrocarbons in the sample is determined using the TOC, and the relative ability of the source rock to generate hydrocarbons is determined by the quality and quantity of its organic matter (Tissot and Welte 1984; Waples 1994). The geochemical section of the core material samples from the well of the field in the southern part of the Akshabulak graben–syncline of the Aryskum Depression of the South Turgay Basin (Fig. 5), determined by the pyrolytic method on the SRA, enables us to assess their hydrocarbon potential, the stage of maturity of organic matter, and determine the kerogen type.

4.1.1 Generative potential of the oil-producing rock

The geochemical study results of the core material of the Kumkol Formation of the Upper Jurassic (J_3km) and the Aryskum Formation of the Lower Cretaceous (K_1nc_1ar) presented in Table 1 indicate that the TOC concentration varies from 0.47 % to 1.41 %. Since the correctness of the results depends on the TOC in the rock under study, samples with low TOC values (< 0.5) were not used for the correct interpretation of pyrolysis data. Based on the TOC values (Lidong et al. 2023), the generative potential of source rocks ranges from poor to good.

The sum of $S_1 + S_2$ (mg of HC/g of rock), which represents the genetic potential of the rock, makes it possible to classify the studied samples as oil-producing rocks with moderate (satisfactory) potential, except for the sample of the Kumkol Formation from a depth of 1883.85 m, which, according to the sum of $S_1 + S_2$ of less than 2 mg/g, most likely does not belong to oil-producing. According to the $S_1 + S_2$ range from 1.31 to 1.78, this sample can be attributed to gas-generating.

In addition to determining the TOC, the amount of generated hydrocarbons released during thermal pyrolysis (parameter S_2) (Ghiran et al. 2023) is also crucial for determining the petroleum potential of the rock. Figure 6 shows that the plot of the dependence of TOC on S_2, demonstrating a linear relationship of TOC = $f(S_2)$, has a small correlation coefficient of $R_2 = 0.7838$. In the analyzed samples of the Daul Formation of the Lower Cretaceous, the parameter S_2 is 1.6–3.1 mg of HC/g of rock and 1.1–9 mg of HC/g of the rocks of the Kumkol Formation of the Upper Jurassic, where the values in the studied samples below 2.5 have a poor (poor) potential, and above 6.0 have a good potential.

4.1.2 Determination of kerogen type

Determining the kerogen type is crucial for identifying the hydrocarbon types generated from the rock (Seitkhaziyev 2023; Shnip 2005). According to the plot of the dependence of TOC on the hydrocarbon potential, most studied samples belong to type II and III kerogen, and only a

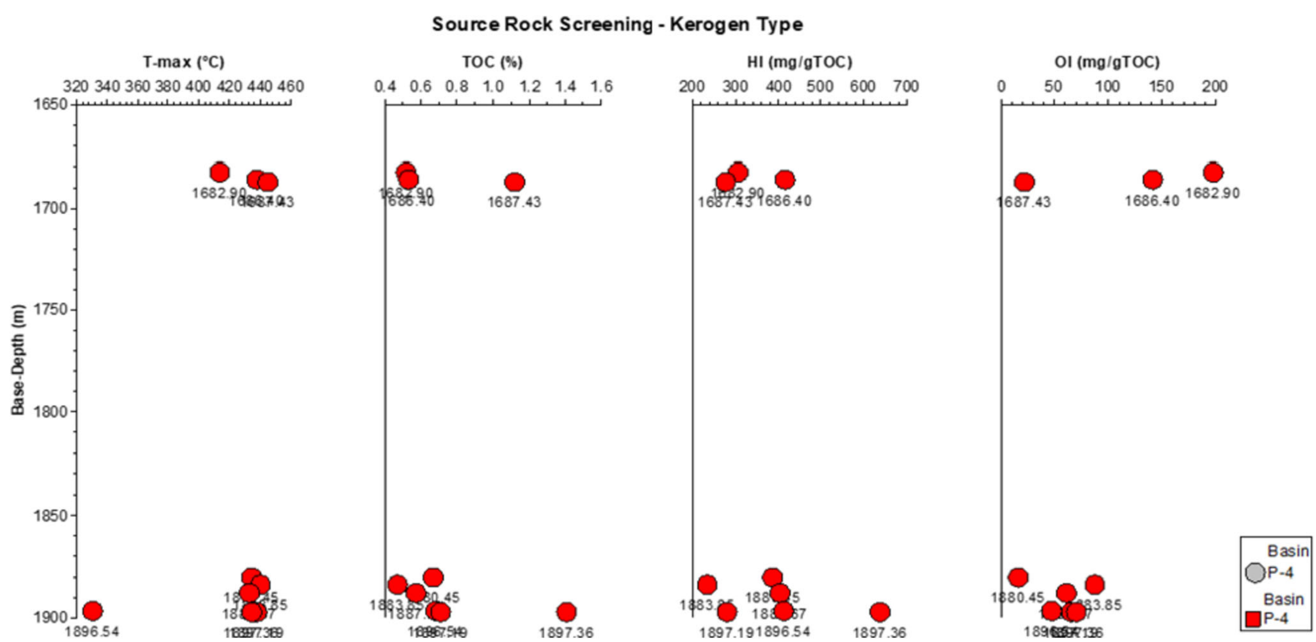

Fig. 5 Geochemical section of the initial rocks of the core material samples of the well P-4 of the Aryskum depression of the South Turgay Basin, Kazakhstan

Table 1 Geochemical data derived from pyrolysis analysis of the formations of the Aryskum depression of the South Torgay Basin, Kazakhstan

Formation	Depth	TOC	S_1	S_2	$S_1 + S_2$	S_3	T_{max}	HI	OI	S_2/S_3	S1/TOC*100	PI
K_1nc_1ar	1682.9	0.52	0.97	1.6	2.57	1.3	413.02	298	198.1	2	187	0.385
K_1nc_1ar	1686.4	0.53	0.57	2.2	2.77	0.75	437.49	417	141.5	3	108	0.205
K_1nc_1ar	1687.43	1.12	2.05	3.1	5.15	0.25	445.16	277	22.3	12	183	0.398
J_3km_2	1880.45	0.67	0.3	2.6	2.9	0.11	434.19	388	16.4	24	45	0.103
J_3km	1883.85	0.47	0.24	1.1	1.34	0.41	440.33	238	87.2	3	51	0.176
J_3km	1887.67	0.57	0.37	2.3	2.67	0.35	432.6	407	61.4	7	65	0.138
J_3km	1896.54	0.68	0.49	2.8	3.29	0.32	330.67	412	47.1	9	72	0.149
J_3km	1897.19	0.71	0.22	2	2.22	0.47	437.8	283	66.2	4	31	0.099
J_3km	1897.36	1.41	1.65	9	10.65	0.99	434.11	640	70.2	9	117	0.155

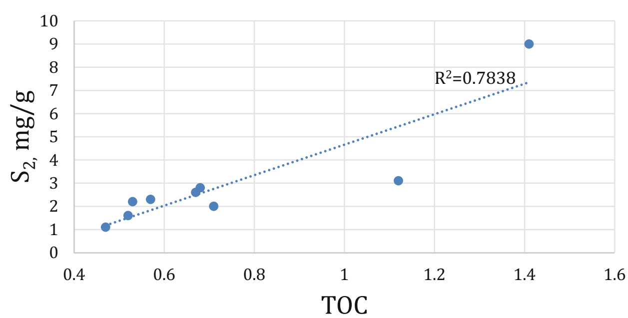

Fig. 6 Plot of the total organic carbon (TOC) dependence on parameter S_2 of the Aryskum depression of the South Turgay Basin, Kazakhstan

sample from a depth of 1897.36 m, with a maximum TOC and S_2, is in the range of type I kerogen (Fig. 7).

This study characterized the kerogen and the initial organic matter by pyrolytic parameters hydrogen index (HI), T_{max} (Fig. 8). According to the HI, most samples can be attributed to kerogen types II–III; therefore, the HI values from 200 to 300 indicate kerogen types II–III, presumably with oil and gas generation; from 300 to 600, indicates kerogen type II with oil generation. However, a significant difference is noted in the sample from the depth of 1897.36 m, whose high HI value (640) corresponds to kerogen type I.

According to the elemental analysis results of oil shales and rocks enriched with organic matter, the diagram of evolutionary curves shows that the South Turgay kerogens are assigned to kerogen type III by the oxygen index and HI values, indicating the initial organic matter formation of the Aryskum Depression in terrestrial continental conditions, and types II and I, which are characteristic for coastal–marine and lake environments of initial organic matter accumulation.

Thus, the change in the HI values in the studied samples, which characterizes the facies–genetic organic matter (Tissot et al. 1974; Waples 1985; Peters and Cassa 1994), indicates a predominantly humus origin and less often a coastal genesis (humus–sapropel), where organic matter accumulated under moderately reducing conditions, corresponding to kerogen types III, II, and I, which is characteristic of the coastal–marine environment of the initial organic matter accumulation.

Attributing a kerogen to a particular type according to pyrolytic data is frequently an ambiguous task, for which a Van Crevelen diagram is used (Fig. 9). To characterize the kerogen type in the pyrolytic analysis of rocks, two composite indicators are used, the HI and oxygen index (OI), the results of which can lead to a similar conclusion.

4.1.3 Determination of thermal maturity

The T_{max} values allow an assessment of the thermal maturity of organic matter regarding the ability of oil and gas generation of rocks. Thus, the T_{max} value range of the studied samples from 435 °C to 445 °C is acceptable for the oil window (oil generation) conditions and allows them to be classified as mature. Low T_{max} values (less than 435 °C) determine the degree of maturity of the organic matter of the studied core samples from a depth of 1682.9 m (Daul Formation) and 1896.54 m (Kumkol Formation) as low (Fig. 10).

In the absence of hydrocarbon migration in the oil source rock, the ratio $S_1/S_1 + S_2$ is a productivity index (PI), of which the value indicates the maturity of organic matter (Peters 1986; Zhuravlev 2009). The degree of realization of organic matter or the PI of the studied samples varies from 0.103 to 0.398. Thus, samples with a T_{max} of 435–445 °C and a PI greater than 0.1 might have oil-generating potential (Fig. 11). However, an indicator of the industrial oil-bearing capacity of the reservoir is a PI value of more than 0.5 (Serebrennikova 2004).

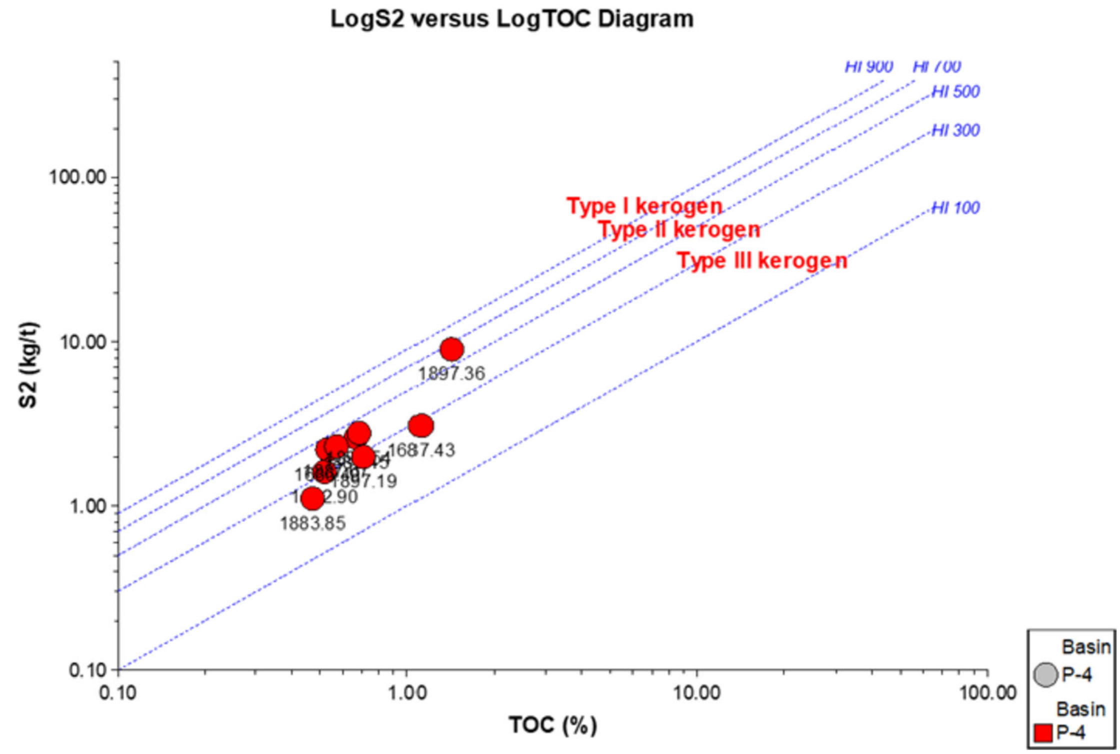

Fig. 7 Plot of the dependence of the total organic carbon (TOC) on the hydrocarbon potential in the core samples of the Aryskum depression of the South Turgay Basin, Kazakhstan

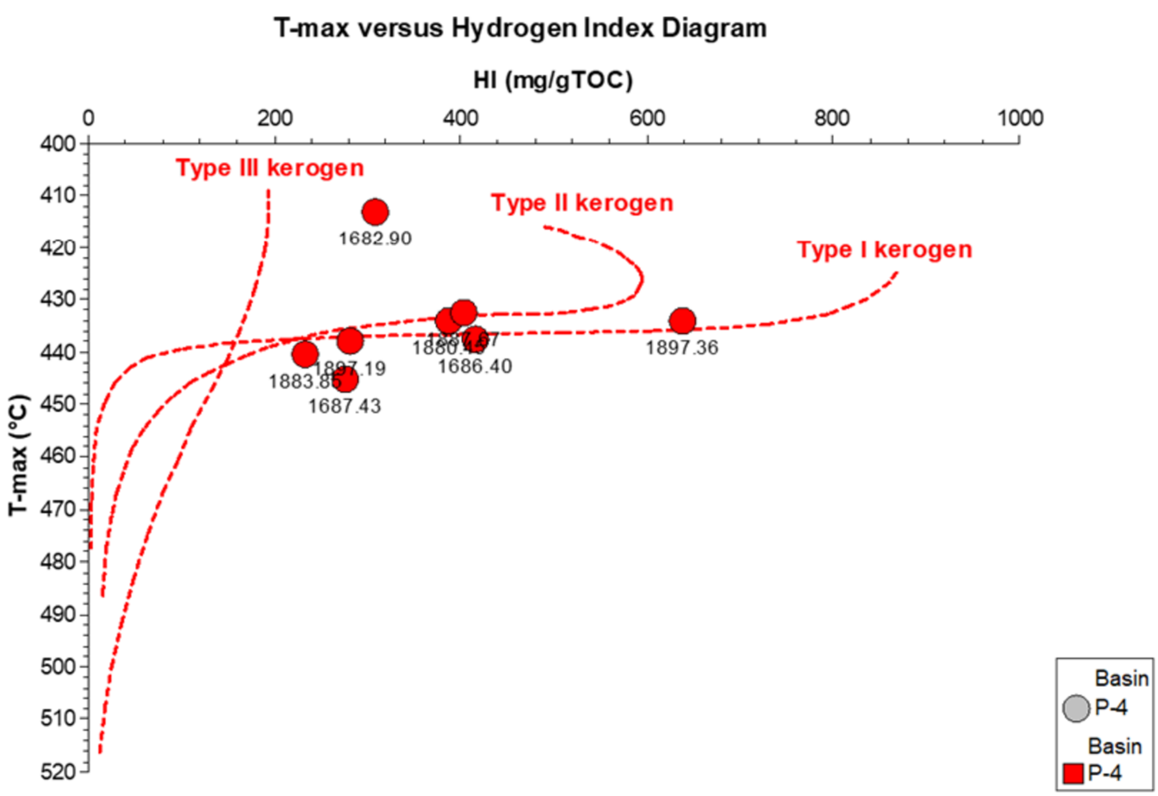

Fig. 8 Dependence of the hydrogen index (HI) on T_{max} of the Jurassic–Cretaceous sediments of the Aryskum depression of the South Turgay Basin, Kazakhstan

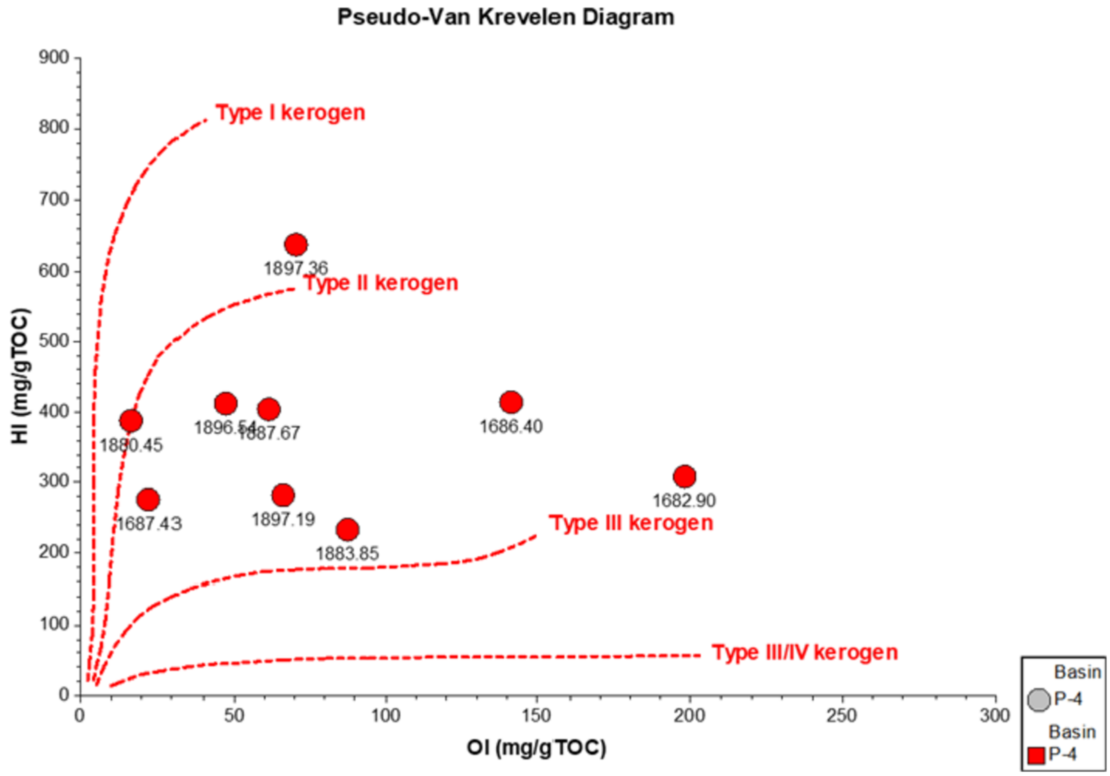

Fig. 9 Correlation between the hydrogen index (HI) and oxygen index (OI) of the Aryskum depression of the South Turgay Basin, Kazakhstan

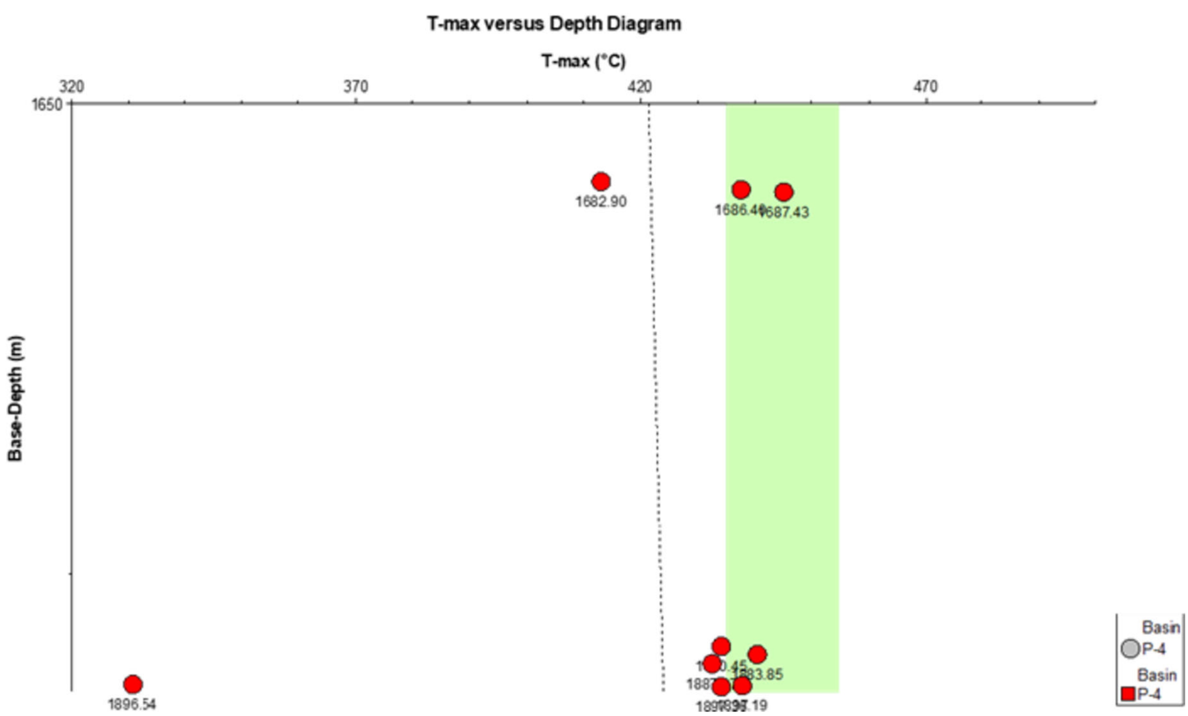

Fig. 10 Diagram of the T_{max} dependence on the depth of the Aryskum depression of the South Turgay Basin, Kazakhstan

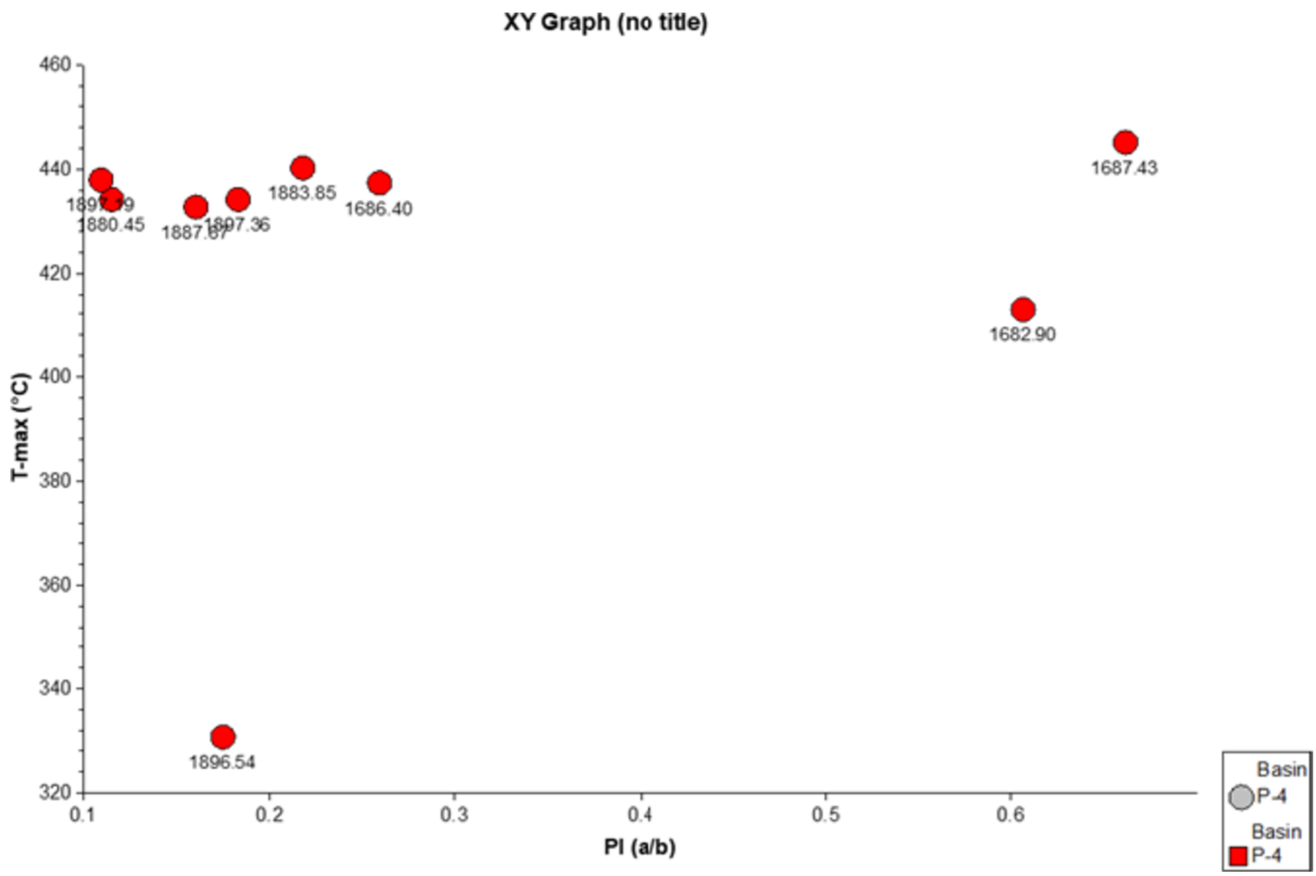

Fig. 11 Diagram of the dependence of the T_{max} on the productivity index (PI) of the Aryskum depression of the South Turgay Basin, Kazakhstan

Table 2 Values of genetic parameters of the composition of biomarkers of the Aryskum depression by gas–liquid chromatography and chromatography-mass spectrometry, according to the Institute of Petroleum Chemistry of the Siberian Branch of the Russian Academy of Sciences (Peters and Moldowan 1993)

Oil index	Boz-J_1	Aksh-K_1	Aksh-PR	Akc-K_1	Akc-Pz
Pr/Ph	3.1	1.6	1.8	2.6	2.7
Sts	C27 < C29	C27 < C29	C27 < C29	C27 < C29	C27 < C29
Sts27/ Sts29	0.5	0.66	0.77	0.64	0.63
Dst27/St29	0.36	0.29	0.31	0.47	0.46
St29/H30	0.31	0.15	0.19	0.24	0.3
G/H30	0.04	0.08	0.07	0.16	0.13

4.2 Types and conditions of organic matter formation by hydrocarbon biomarkers (chemofossils)

Data on the composition of hydrocarbon biomarkers represented in oils by alkanes (n-alkanes, isoprenoids), polycyclic naphthenes (heylantanes, steranes, and hopanes,) and arenes (naphthalenes and phenanthrenes) allow us to judge the source of oils, the accumulation conditions, and transformation of the initial organic matter (Table 2) (Peters and Cassa 1994; Peters et al. 2005; Peters and Moldowan 1993).

The studied samples are represented by oil samples from sediments of the Lower Jurassic of the Bozingen graben (Boz-J_1), Proterozoic (Aksh-PR), and Lower Cretaceous (Aksh-K_1) of the Akshabulak graben, and Paleozoic (Akc-Pz) and Lower Cretaceous (Akc-K_1) of the Aksai horst. The Pr/Ph value indicates that the initial organic matter that produced the oil of the Akshabulak graben was formed under suboxidative conditions. Organic matter for the

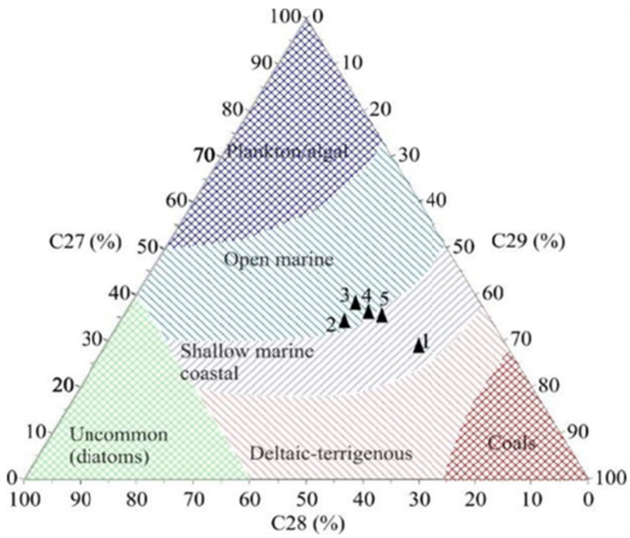

Fig. 12 Trigonogram of the composition of isosteranes (m/z 218) of oils from the Aryskum depression of the South Turgay Basin, Kazakhstan (Madisheva et al. 2020)

Aksai horst and the Bozingen graben was formed in an oxidizing environment.

For the Aksai horst oil, a moderately increased content of gammacerane was recorded (the gammacerane index, G/H30, is 0.13–0.16), indicating a higher salinity of the basin area where the accumulation of their initial organic matter occurred. The minimum G/H30 value and at the same time the maximum value of Pr/Ph is oil from the Lower Jurassic (Table 2), indicating the accumulation of its initial oil-producing substance in the conditions of a desalinated reservoir.

The sterane compositions, one of the primary biomarker groups, despite their low content in the oils of the Aryskum Depression, indicate the identity of paleogeoplotic conditions for the initial oil-producing substance formation of oils from Cretaceous sediments deposited, apparently in marine, possibly shallow conditions, and oils from adjacent basement reservoirs (Fig. 12).

Analysis of the data obtained allows us to conclude that the oil-producing strata, most likely of Cretaceous age, within the Akshabulak graben accumulated in a deeper part of the sea than the same-age sediments of the Aksai horst, deposited, apparently, in lagoon conditions, and the Lower Jurassic sediments of the Bozingen graben in the desalinated delta zone.

5 Genesis of hydrocarbons by the isotopic composition of the carbon of oils

Since two sources of oil carbon (organic matter of marine and continental origins) differ markedly in isotopic compositions, they should have affected the carbon isotopic composition of oils belonging to different facies (Yuandong et al. 2019; Galimov 1968). Table 3 presents the isotopic composition results of the carbon of the Aryskum Depression oils, established by isotope–mass chromatography in the Tomsk branch of the Siberian Research Institute of Geology, Geophysics, and mineral raw materials, which allows the identification of the genesis of hydrocarbons. Thus, $\delta^{13}C$ of the Jurassic–Cretaceous oils of the South Turgay Basin allowed us to assume a genetic relationship of the studied oil samples with sapropel-type organic matter (kerogen types I and II) and their formation from organic matter of mixed humus–sapropel type (Madisheva 2020; Golyshev et al. 2020).

The variation of the carbon isotope composition of the $\delta^{13}C$ oils of the Jurassic deposits of the Aryskum Depression ranges from − 28.0% to − 30.3% (Fig. 13). The $\delta^{13}C$ value shows the difference between the isotopic composition of the sample and the Vienna Peed Dee Belemnite standard—Late Cretaceous Belemnite calcium carbonate (Pee Dee Formation, South Carolina). According to the plot, there is a slight relief of $\delta^{13}C$ with increasing depth.

6 Conclusions

The following conclusions can be drawn from summarizing the analysis of new data on the geochemistry of hydrocarbons in the South Turgay Basin:

1. Based on the results of pyrolytic analysis of core samples, which allow assessing the generative potential of oil-bearing rocks, it has been established that the studied samples exhibit a potential ranging from poor to good in terms of their TOC (ranging from 0.47 to 1.41) and S_2 parameter (ranging from 1.1 to 9 mg HC/g rock).

2. Determination of kerogen type based on the correlation between TOC and hydrocarbon potential has shown that the vast majority of the examined samples belong to kerogen types II and III. Only the sample from a depth of 1897.36 m, with maximum TOC and S_2 values, falls within the kerogen type I category. Additionally, the characteristics of kerogen and the original organic matter based on pyrolytic parameters HI and T_{max} indicate that most samples correspond to kerogen types II-III, suggesting the potential for oil and gas generation, while the kerogen type I sample likely has the potential for oil generation.

The hydrogen index (HI) and oxygen index (OI) of the examined samples, which allow determining facies-genetic types of organic matter, indicate predominantly humic and occasionally humus-sapropelic origins. This leads to the conclusion that the organic matter in the studied samples accumulated under moderately reducing conditions (kerogen types III and II) and in a nearshore-marine environment (kerogen type I).

Table 3 Isotopic composition of the carbon of the Aryskum depression of the South Turgay Basin, Kazakhstan (Golyshev et al. 2020)

Group	Sampling interval	Formation	Collector lithology	Reservoir temperature (°C)	$\delta^{13}C$ (‰)
Akshabulak	1623.0–1633.0	K1nc	Alternation of sandstones and conglomerates	68	− 30.7
Aschisay	1291.4–1295.0	J-0	Variegated clays and siltstones with layers of lightly cemented sand	52.3	− 30.3
	1300.0–1306.0				
	1310.8–1313.4				
Bozingen	1703.3–1713.7	J_{1-2}	Sandstones, siltstones, mudstones	73.7	− 28.3
	1649.0–1662.0	J_{1-2}	Sandstones with interlayers of mudstones, gravelites, and shales	73.2	− 28.9
	905.0–911.0	J_{1-2}	Sandstones, siltstones, mudstones	44.1	− 28
Aksay	1468.0–1474.0	K1nc	Mudstones, siltstones, sandstones	62.1	− 28.7
	1884.0–1885.5	J3	Sandstones, siltstones	75.2	− 29.7
	1889.5–1892.5				
	1415.0–1417.0	K1nc	Limestones are gray, dark gray with veins of calcite	57.4	− 28.7
	1418.5–1420.5		Limestones are gray, dark gray with veins of calcite		

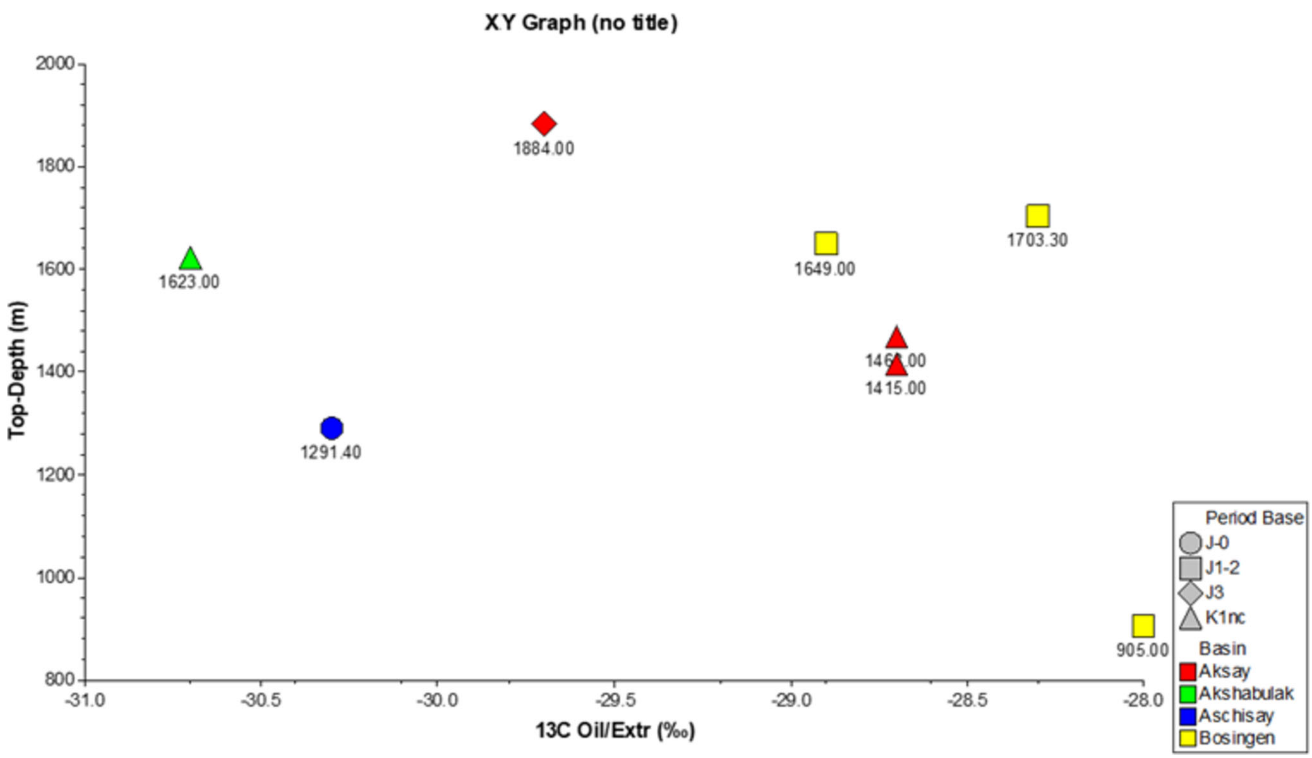

Fig. 13 Isotopic composition of the carbon of oils $\delta^{13}C$ of the Jurassic deposits of the Aryskum depression of the South Turgay basin, Kazakhstan

The organic matter in the examined samples, based on the Tmax parameter, is considered thermally mature; however, the degree of maturity for core samples from depths of 1682.9 m (Daul Formation) and 1896.54 m (Kumkol Formation) is lower and is assessed as low.

3. The Pr/Ph values suggest that the primary petroleum generation in the Akshabulak graben occurred under sub-oxidizing conditions, while in the Aksai horst and Bozingen graben, it occurred under oxidizing conditions.

The initial organic matter of the Aksai horst oils shows an elevated content of gammacerane, indicating a higher basin salinity. It is suggested that the initial oil-prone material formed from Cretaceous deposits, likely deposited in marine, possibly shallow-water conditions.

4. The carbon isotopic composition ($\delta^{13}C$) of the oils allowed for the identification of a genetic link between the examined samples from the Aryskum Depression and sapropelic-type organic matter (kerogen types I and II), as well as their formation from mixed humic-sapropelic organic matter.

5. The results of the present geochemical studies suggest the possibility of predicting new oil and gas accumulation zones in the Lower and Middle Jurassic deposits, which occupy significant volumes of sedimentary fill in the grabens. This, in turn, expands our understanding of the hydrocarbon potential of these deposits within the South Turgay Basin.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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