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Paleothermicity and hydrocarbons generation modelization in the eastern part of the Precaspian Basin and Pre-Uralian Basin (Kazakhstan)

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Abstract. The Precaspian basin is the main oil province in Kazakhstan, where there are such giant fields as Tengiz, Karachaganak, Astrakhan and Kashagan. In previous works have been identified source rocks associated mainly with the sub-salt complex. However, the issue of such parameters as the depth of the oil window remains unresolved, because the geothermal gradient is low and the studied source rocks have a low maturity. By the study of the organic matter in these sediments and simulation of genesis of hydrocarbons by Petromod 1D software (IES GmbH; now SLB), we wanted to determine the depth range of oil window for essential source rocks. This area is composed of three parts from Devonian to late Carboniferous: the Precaspian Basin subdivided into a basin (claystones, mudstones and calciturbidites) and a platform (limestone and storm sandstones), and the Pre-Uralian Basin (turbidite sandstones). For the studied sector the values of the R_o are low and varies from 0.4 to 0.7 and T_{max} lies between 420 and 445°C. The simulation of the heat flow was calibrated by Vitrinite reflectance with different kinetics according to the type of organic matter – Vandenbroucke et al. (1999)'s model was chosen for the type III (Brent) and for the type II (KCF). The low value of the heat gradient can be compensated by the geological duration during which source rock undergoes the transformation. In the sector studied the phase of generation of oil can correspond to the level of evaluation, corresponding to value 0.5% of R_o and even 0.4% for the algal type or mixed OM II/III. For the studied formations, the major part of hydrocarbons was generated from the maximal phase of burial. We can distinguish four zones in which the depths of the beginning and end of the oil window are different: the western zone (basin) from 4-4.5 km to 7-9 km, the zone of slope and border from 3-3.7 km to 4.5-5 km, the zone of Preuralian basin from 2.8-3.3 to 4.5-5 km, and the eastern zone under the thrust of Ural (Izembet) from 2-2.8 to 3.5-4 km.

Keywords: Precaspian basin, Pre-Uralian Basin, organic matter, simulation, heat flow, petroleum system, maturity, calibration.

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1. Introduction

The Precaspian Basin contains substantial prospective hydrocarbon resources, estimated at 10-12 billion tonnes of oil and condensate and 5-6 trillion cubic metres of natural gas. However, the origin of these hydrocarbons remains insufficiently understood because the basin is characterized by a low geothermal gradient and generally low source-rock maturity. Therefore, this study examines the organic matter in the sedimentary succession to identify the principal source rocks and assess their thermal maturity.

The study area comprises three principal geological domains developed from the Devonian to the Late Carboniferous: the basinal zone of the Precaspian Basin, composed predominantly of claystones, mudstones, and calciturbidites; its platform zone, represented by limestones and storm-generated sandstones; and the Pre-Uralian Basin, dominated by turbiditic sandstones. From the Asselian to the Artinskian,

turbidites and claystones accumulated throughout the eastern Precaspian Basin and the Pre-Uralian Basin, followed by evaporite deposition during the Kungurian [1]. These sedimentary successions occur at depths ranging from 1700 to 4500 m.

The samples were analyzed using organic petrography, including maceral analysis and vitrinite reflectance measurements; geochemical methods, including Rock-Eval pyrolysis and extract analysis; and molecular analysis by gas chromatography-mass spectrometry (GC-MS).

To investigate hydrocarbon generation and migration, one-dimensional (1D) basin modeling was performed to reconstruct the evolution of the sedimentary basin during subsidence. This approach enables the positions of the oil and gas windows to be reconstructed throughout the basin's geological history. The modeling was conducted for five wells representing five distinct tectonic zones using version 9 of PetroMod 1D, developed by IES GmbH (now SLB).

The models integrate geological and geochemical data, subsidence and thermal histories, the kinetics of organic matter transformation, and hydrocarbon generation and expulsion. Together, these parameters define the physical framework for simulating the basin's thermal evolution and hydrocarbon generation history. To obtain an acceptable agreement between the modeled and measured thermal indicators, the heat-flow history of each well was calibrated using vitrinite reflectance data, present-day temperatures, and paleotemperatures derived from fluid inclusion microthermometry.

2. Materials and methods

2.1. Principles and background

2.1.1. Model parameters

1D modeling was performed for wells representing different tectonic zones: the western part of the basin, the slope, the platform zone of the Caspian basin, the Cis-Ural zone, and the reverse-thrust junction zone with the Urals under cover, respectively.

The calculations were performed using the PetroMod 1D model. This model was used to reconstruct the subsidence history, thermal evolution of the basin, and hydrocarbon generation. The model was calibrated by changing the heat flow and the degree of erosion until an acceptable agreement between the modeled and actual thermal indicators was achieved.

2.1.2. Physical parameters

The thicknesses and lithologies of the various geological formations were specified for each well. The lithologies used in the calculations were defined as mixtures of pure components with specified volume percentages.

The geological history of the eastern Caspian Basin has been dominated by subsidence, but there were also isolated periods of tectonic inversion at the end of the Bashkirian, the end of the Carboniferous, and the end of the Asselian-Artinskian. The thicknesses and lithologies of the various geological formations were specified for each well (an example of the well representing the middle position within the territory under consideration is given in Table 1).

Table 1. Input table with stratigraphic data for the Loktybai 14G well (Case of a model with small amplitude erosion)

Age	Top, m	Bottom, m	Present thickness, m	Eroded thickness, m	Deposition age, MPa		Erosion age, MPa		Lithology
					from	to	From	to	
Quaternaire	0	10	10		65	0			
Cretaceous	10	500	490		135	65			Clastic
Jurassic	500	630	130		203	135			Clastic
Triassic	630	950	320		250	203			Clastic
Permian Sup.	950	1250	300		274	250			Clastic
Kungurian	1296	3442	2146		277	274			Salt-bearing rocks+clastic
Asselian-Artinskian	3442	3685	243		296	277			Clastic
Upper Carboniferous-Podolskian	0	0	0	130			305	296	Limestones+ evaporites
Myachkovian	3685	3721	36		307	305			Limestones
Lower Podolskian	3721	3813	92		308	307			
Upper Visean	3813	4005	192		337	308			Clastic
Lower Moscovian									
Lower-Middle Visean	4005	5250	1245		360	337 Middle-Devonian			Limestones
Middle-Upper Devonian	5250	6200	950		390	360 Devonian			Clastic
Lower Devonian	6200	6750	550		410	390			Limestones
Lower Paleozoic	6750	7500	750		540	410			Clastic
Basement	7500					540			Clastic-limestone
									Volcanic, metamorphic rocks

The lithologies used in the calculations were defined as mixtures of pure components with specified volume percentages. The geological history of the eastern Caspian Basin has been dominated by subsidence, but there were also isolated periods of tectonic inversion at the end of the Bashkirian, the end of the Carboniferous, and the end of the Asselian-Artinskian.

2.1.3. Thermal indicators of the model

The thermal markers used in this study are vitrinite reflectivity (VR), current temperatures and fluid inclusion entrapment temperatures.

Thermal history reconstructions are based on vitrinite reflectance measurements (VR, % Rr). The VR measurements were primarily performed on samples from potential source rocks of the Visean, Serpukhovian-Moscovian, and Asselian-Artinskian successions. In general, the measured VR values are consistent with previously reported data for the eastern

part of the Precaspian Basin [2]. The values are relatively low and generally do not exceed 0.7%. Only the reverse-thrust zone beneath the allochthonous strata shows VR values in the range of 1-1.25. Thermal history was reconstructed based on these parameters.

For one-dimensional modeling, wells with a sufficient number of vitrinite reflectance (VR) measurements over the investigated depth intervals were selected. Where direct VR measurements were unavailable, three types of maturity proxies were used: VR-equivalent values derived from non-vitrinite macerals, such as alginite and tasmanite; VR values estimated from the methylphenanthrene index (MPI-1); and VR values estimated from Rock-Eval T_{max} . The latter two were calculated using the corresponding empirical relationships between MPI-1 or T_{max} and vitrinite reflectance.

The measured VR values were plotted against depth for each well and compared with the corresponding vitrinite

reflectance profiles simulated using the Easy%Ro model

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2.1.4. Hydrocarbon genesis modeling

This study also considers the conditions of hydrocarbon formation. The model uses parallel-reaction kinetic models to simulate hydrocarbon generation (oil and gas) and includes the secondary cracking of compounds formed during primary cracking. These reactions are described by the Arrhenius Equation (1) and are assumed to follow first-order kinetics:

$$\frac{dX}{dt} = X A_0 \exp\left(-\frac{E_a}{RT}\right), \quad (1)$$

where X is the fraction of the substance reacted; A_0 is the pre-exponential factor, s^{-1} ; E_a is the activation energy, cal/mol; R is the universal gas constant; T is the absolute temperature, K; t is time, s.

Equation (1) can also be written in differential form as:

$$dX = X A_0 \exp\left(-\frac{E_a}{RT}\right) dt, \quad (2)$$

Knowing the change in temperature with time, this equation allows one to calculate the fraction of reacted substance in a given time interval. Most modern kinetic models use distributions of activation energies, but with a single pre-exponential factor. Each fraction is assigned a fraction of the original carbon (IH) determined for the reference sample.

Thus, for the same thermal history and a given activation energy, the fraction of reacted substance can be determined. Models with parallel reactions also allow the distribution of part of the IH to different compounds, which makes it possible to quantitatively estimate the number of compounds generated (oil, gas, etc.) during kerogen cracking.

Numerous kinetic models have been reported in the literature [4]. However, whenever possible, the model should incorporate kinetic parameters specific to the source rocks under investigation.

This study focuses on the different phases of hydrocarbon generation and the possibilities of secondary cracking. The quantitative aspect is considered only indicatively.

2.1.5. Thermal regime of the basin

According to **Ошибка! Источник ссылки не найден.** the threshold for the onset of oil formation depends on the geothermal gradient, depth and time of burial. The temperature at which oil begins to form varies from 50°C in Paleozoic basins to 115°C in Mio-Pliocene deposits. The time of oil generation also varies: the main phase may follow the deposition of source rocks with a delay of several million to 300 million years.

The temperature corresponding to the onset of the oil window decreases from approximately 120°C for 12-million-year-old deposits to 60-62°C for deposits aged 180-359 million years. This relationship is expressed as:

$$T = 164.4 - 19.39 \ln t, \quad (r = -0.89) \quad (3)$$

where T is the threshold temperature for oil generation, °C; t is geological time, million years; r is the correlation coefficient.

An alternative time-temperature relationship is given in [6]:

$$\log_{10} t = \frac{3014}{T} - 6.498 \quad (4)$$

where t is geological time, million years, and T is the absolute temperature, K.

These equations were used to determine the threshold temperature for the onset of oil generation in different source-rock series. For the Lower-Middle Visean rocks (345.5-334 Ma), the estimated temperatures are 50-51°C according to the Pigott model [7] and 60-61°C according to the Connan model [6]. For the Serpukhovian-Moscovian rocks (326.5-305 Ma), the corresponding temperatures are 52-54°C and 62-63°C, while for the Lower Permian rocks (296-278.5 Ma), they are 55-56°C and 64-65°C. These temperatures were used to estimate the depth of the onset of the oil window in the source rocks of the pre-salt complex. The resulting temperature and depth estimates helped to select the most appropriate kinetic model for the organic matter types and basin conditions.

2.1.6. Kinetic model

Several kinetic models are available in PetroMod 1D. The following criteria were used to select the most suitable models. First, models related to type II or type III organic matter (OM) were selected. PetroMod 1D includes 27 models for type II OM and 10 models for type III OM.

A comparison of the hydrocarbon generation phases obtained using different models showed that the T2(KCF)-CS model of Vandenbroucke et al. (1999) [8] best meets the selection criteria. According to this model, the temperature of oil generation onset varies from 72°C in the Devonian to 63°C at present. The PRV value remains relatively stable from the Devonian to the present (0.45-0.49%). The present-day depth of the onset of the oil window is approximately 2800-3000 m.

The T2(KCF)-CS model of Vandenbroucke et al. (1999) [8] was developed for the Portlandian-Berriasian Elgin Field in the North Sea. The studied Kimmeridge Clay Formation is characterized by the following parameters: type II OM; TOC – 8.2%; HI – 567 mg hydrocarbons/g TOC; T_{max} – 420°C.

In the Kumsai well, type III organic matter occurs in the Sakmarian-Artinskian sediments, whereas mixed type II/III organic matter occurs in the Asselian sediments. The Sakmarian sediments are characterized by TOC – 1.13%, HI – 49 mg/g TOC, and T_{max} – 425°C, indicating type III OM. The Asselian sediments are characterized by TOC – 3.49%, HI – 512 mg/g TOC, and T_{max} – 441°C, indicating type II or mixed type II/III OM.

2.1.7. Current heat flow

Heat flows from the Cenozoic to the present were determined by calibration against present-day temperatures. The results show that the temperature curve in the PetroMod 1D depth-temperature plot depends exclusively on the heat flow during the latest stratigraphic period, which corresponds to the Cenozoic in the present models. The present-day heat flow of 35-37 mW/m² was used as a reference for the paleo-heat-flow evolution curve.

3. Results and discussion

The Rock-Eval analysis identified two groups of kerogen in the slope and basin sediments: type III (humic) kerogen with a low HI (<150 mg/g TOC) in the Permian and Visean sediments, and type II (algal) kerogen with a high HI (>250 mg/g TOC) in the Serpukhovian-Moscovian sediments. Type III kerogen has the lowest oil-generation potential, whereas type II kerogen has the highest.

The Visean, Serpukhovian-Moscovian, and Asselian-Artinskian samples generally show low thermal maturity, with vitrinite reflectance (VR) values below 0.65% and $T_{\max}$ values below 435°C. The VR-depth diagrams show three types of gradients: the lowest in the western part and platform zone of the Precaspian Basin (Figure 1a), intermediate in the Pre-Uralian Basin, and the highest in the eastern suture zone overthrust by the Ural nappes (Figure 1b).

The heat-flow model was calibrated using vitrinite reflectance data. Three periods of erosion were identified in the study area: at the end of the Bashkirian, at the end of the Carboniferous, and before the Kungurian. The estimated erosion thickness ranges from 100 to 700 m. In the suture zone, the thickness of the nappes thrust over the autochthonous deposits of the Pre-Uralian Basin is approximately 4500 m.

The simulated heat-flow values are low in the western part of the Precaspian Basin (15-25 mW/m²) and increase to 40-50 mW/m² in the eastern part of the Pre-Uralian Basin within the suture zone. The maximum heat flow occurred during the period of maximum burial in the Early Permian, reaching 30 mW/m² in the west and 65 mW/m² in the east.

Hydrocarbon generation in the source rocks was simulated using different kinetic models according to the type of organic matter. The models of Vandenbroucke et al. (1999) [8] were selected for type III (Brent) and type II (KCF) organic matter.

The majority of hydrocarbons were generated during burial without any additional thermal event. In the eastern part of the Precaspian Basin (Akjar well), the low heat flow explains why the source rocks are either immature or within the oil window, from the Devonian to the base of the Permian succession (Figure 2).

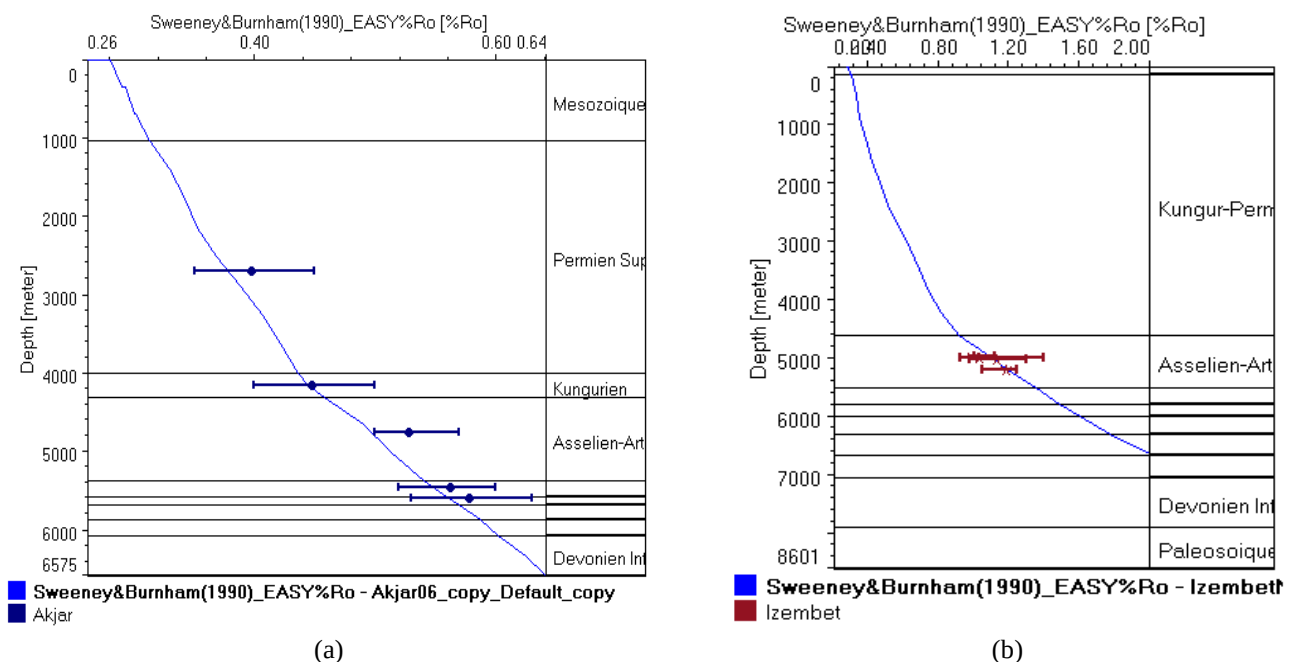


Figure 1. Calibration of the thermal history using vitrinite reflectance data for the: (a) – Akjar well; (b) – Izembet well

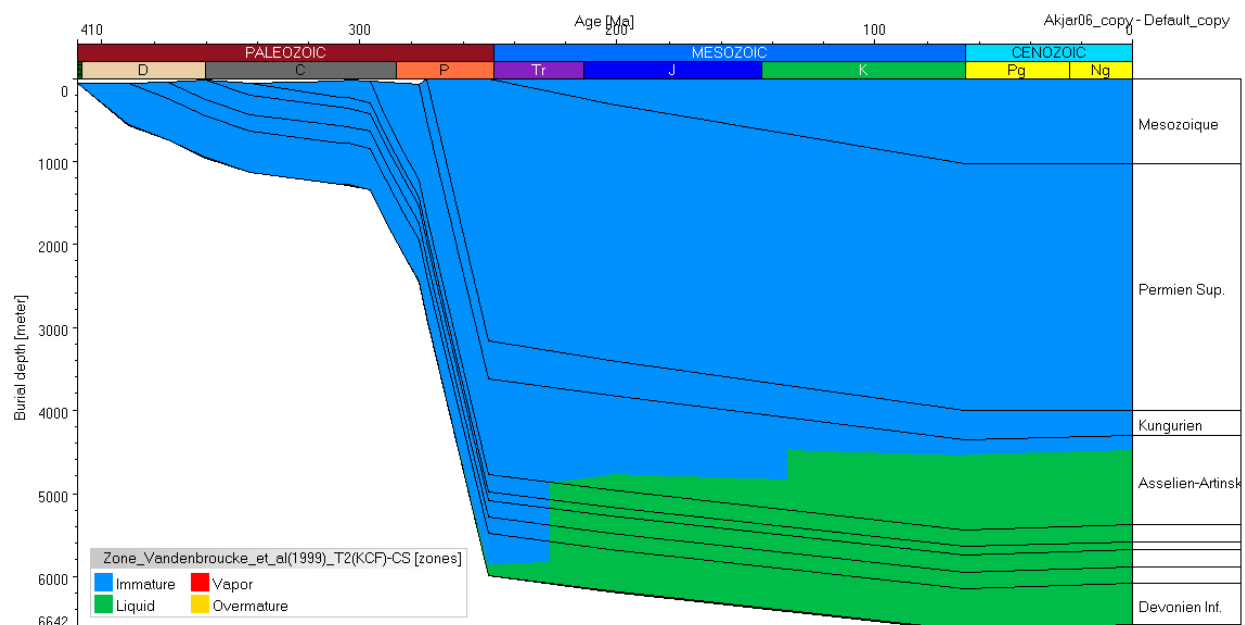


Figure 2. Simulation of hydrocarbon zones in the Akjar well (liquid represents oil)

In the suture zone of the Pre-Uralian Basin, the high heat flow explains the presence of the oil window in the Visean to Early Permian rocks and the wet-gas window in the Devonian rocks of the Izembet well (Figure 3), as well as the dry-

gas window in the Devonian rocks of the Belogorskaya well. The onset of the oil window occurs at depths of approximately 4000-5000 m in the basal part of the Precaspian Basin and 3500-4000 m in the suture zone.

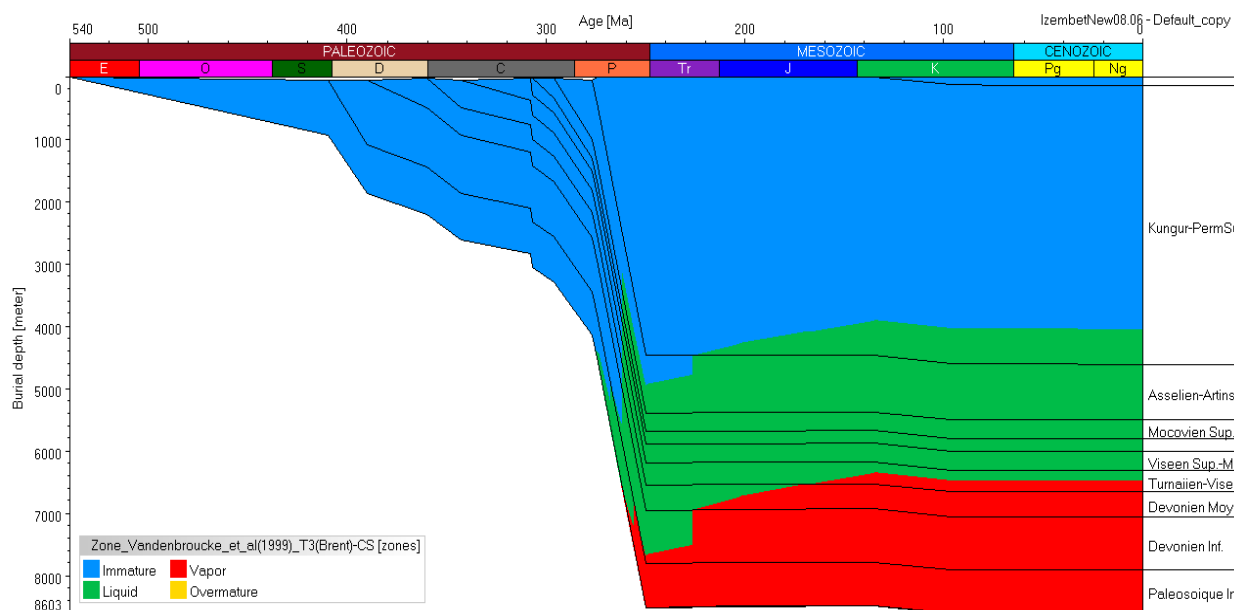


Figure 3. Simulation of hydrocarbon zones in the Izembet well (liquid represents oil; vapor represents wet gas)

The modeling results demonstrate that the thermal maturity and hydrocarbon generation history vary considerably between the tectonic zones of the study area. In the Akjar well, the low heat flow and thermal gradient resulted in the preservation of largely immature source rocks, while oil generation was restricted to the deepest parts of the sedimentary succession (Figure 2). By contrast, the higher heat flow in the Izembet well promoted more advanced organic matter transformation, resulting in oil generation within the Visean to Lower Permian rocks and gas generation within the deeper Devonian succession (Figure 3).

The depths of the oil window estimated from the PRV-depth relationships and the T2(KCF)-CS kinetic model [8] are generally comparable. Its onset is estimated at approximately 2100-3100 m in the overthrust zone (Izembet) and the Pre-Uralian Basin (Bajjaryk), 3000-3700 m in the platform (Kumsai) and slope (Loktybai) zones, and 3800-4300 m in the western basal zone (Akjar). The greater depth of the oil window at Akjar is consistent with the lower thermal gradient of approximately 12-20°C/km.

The vertical extent of the oil window follows the same regional pattern. It is smallest in the eastern overthrust zone, increases in the Pre-Uralian, platform, and slope zones, and reaches 5000-5500 m in the western basal zone. Thus, the east-west differences in hydrocarbon generation can be explained primarily by spatial variations in heat flow, burial history, and tectonic setting, without requiring an additional regional thermal event.

4. Conclusions

The modeled heat flow decreases from the eastern overthrust zone toward the central and western parts of the Precaspian Basin. The lowest heat-flow values and thermal gradients were identified in the basal zone, whereas the highest values occurred in the suture zone of the Pre-Uralian Basin.

Thermal gradients within most of the Precaspian Basin generally do not exceed 23-25°C/km. Consequently, the studied source rocks are predominantly immature or within the oil window. This thermal regime is consistent with the predominance of oil and mixed oil-condensate-gas accumulations and the absence of known dry-gas fields in the central and western parts of the basin.

The PetroMod 1D simulations indicate maximum formation temperatures of 69-106°C, whereas fluid-inclusion trapping temperatures range from 82 to 138°C. This difference may reflect the circulation of hot hydrothermal fluids through relatively cooler formations. However, the discrepancy becomes considerably smaller if the fluid inclusions formed during the Kungurian-early Late Permian, when the modeled heat flow was higher.

The onset of the oil window varies from approximately 2100-3100 m in the eastern overthrust and Pre-Uralian zones to 3800-4300 m in the western basal zone, with intermediate depths of 3000-3700 m in the platform and slope zones. These results confirm that regional variations in heat flow and burial history controlled the spatial distribution of the oil and gas windows in the eastern Precaspian and Pre-Uralian basins. The developed models provide a basis for assessing source-rock maturity and identifying prospective hydrocarbon generation zones during further exploration of the region.

Author contributions

Conceptualization: TY, BK, MS; Data curation: TY; Formal analysis: TY, BK, MS; Funding acquisition: TY; Investigation: TY; Methodology: TY; Project administration: TY; Resources: BK, MS; Software: TY; Supervision: TY; Validation: TY; Visualization: TY, BK, MS; Writing – original draft: TY; Writing – review & editing: TY, BK, MS. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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Каспий маңы және Орал алды бассейндерінің шығыс бөлігіндегі палеотермиялық жағдайлар мен көмірсутектердің түзілуін модельдеу (Қазақстан)

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Андатпа. Каспий маңы бассейні Қазақстанның негізгі мұнай-газды провинциясы болып табылады, мұнда Теңіз, Қарашығанақ, Астрахан және Қашаған сияқты алып кен орындары орналасқан. Алдыңғы зерттеулерде негізінен тұзасты кешенімен байланысты мұнай түзуші жыныстар анықталған. Алайда мұнай терезесінің тереңдігі сияқты параметрлерді анықтау мәселесі әлі де толық шешілмеген, себебі геотермиялық градиент төмен, ал зерттелген мұнай түзуші жыныстардың жетілу дәрежесі төмен. Осы шөгінділердегі органикалық заттарды зерттеу және PetroMod 1D бағдарламалық жасақтамасы (IES GmbH; қазіргі уақытта SLB) көмегімен көмірсутектердің түзілуін модельдеу негізінде негізгі мұнай түзуші жыныстар үшін мұнай терезесінің тереңдік аралығын анықтау көзделді. Зерттелетін аумақ девоннан кейінгі карбонға дейін қалыптасқан үш құрылымдық-фациялық бөліктен тұрады: Каспий маңы бассейні, ол бассейндік бөлікке (сазды жыныстар, аргиллиттер және кальцитурбидиттер) және платформалық бөлікке (эктастар мен дауылдық құмтастар) бөлінеді, сондай-ақ турбидиттік құмтастардан тұратын Орал алды бассейні. Зерттелген секторда витриниттің шағылу қабілеті Ro төмен мәндермен сипатталып, 0.4-тен 0.7%-ға дейін өзгереді, ал Tmax 420-445°C аралығында болады. Жылу ағынын модельдеу органикалық заттың түріне байланысты әртүрлі кинетикалық модельдерді қолдана отырып, витриниттің шағылу қабілеті бойынша калибрленді: III типті органикалық зат (Brent) үшін Vandenbroucke et al. (1999) моделі, ал II тип үшін KCF моделі таңдалды. Геотермиялық градиенттің төмен мәні мұнай түзуші жыныстардың трансформацияға ұшырайтын геологиялық уақыт ұзақтығымен өтелуі мүмкін. Зерттелген секторда мұнай генерациясы фазасының басталуы шамамен 0.5% Ro жетілу деңгейіне, ал балдырлық немесе аралас II/III типті органикалық заттар үшін тіпті 0.4% Ro мәніне сәйкес келуі мүмкін. Зерттелген формациялар үшін көмірсутектердің негізгі бөлігі максималды көмілу кезеңінде түзілген. Мұнай терезесінің басталу және аяқталу тереңдіктері әртүрлі төрт аймақ бөлінді: батыс аймақ (бассейндік бөлік) – 4.0-4.5 км-ден 7-9 км-ге дейін; беткей және жиектік аймақ – 3.0-3.7 км-ден 4.5-5.0 км-ге дейін; Орал алды бассейні аймағы – 2.8-3.3 км-ден 4.5-5.0 км-ге дейін; Орал жапсарлы жылжуының астындағы шығыс аймақ (Изембет) – 2.0-2.8 км-ден 3.5-4.0 км-ге дейін.

Негізгі сөздер: Каспий маңы бассейні, Орал алды бассейні, органикалық зат, модельдеу, жылу ағыны, мұнай-газ жүйесі, жетілу дәрежесі, калибрлеу.

Палеотермичность и моделирование генерации углеводородов в восточной части Прикаспийского и Предуральяского бассейнов (Казахстан)

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Аннотация. Прикаспийский бассейн является основной нефтегазоносной провинцией Казахстана, где расположены такие гигантские месторождения, как Тенгиз, Карачаганак, Астраханское и Кашаган. В предыдущих исследованиях были выявлены нефтематеринские породы, преимущественно связанные с подсолевым комплексом. Однако вопрос определения таких параметров, как глубина нефтяного окна, остается нерешенным, поскольку геотермический градиент здесь низкий, а изученные нефтематеринские породы характеризуются невысокой степенью зрелости. На основе изучения органического вещества в этих отложениях и моделирования генерации углеводородов с использованием программного обеспечения PetroMod 1D (IES GmbH; в настоящее время SLB) была предпринята попытка определить диапазон глубин нефтяного окна для основных нефтематеринских пород. Исследуемая территория включает три структурно-фациальные области, сформировавшиеся в период от девона до позднего карбона: Прикаспийский бассейн, подразделяемый на собственно бассейновую часть (глинистые породы, аргиллиты и кальцитурбидиты) и платформенную часть (известняки и штормовые песчаники), а также Предуральский бассейн, представленный турбидитовыми песчаниками. Для исследуемого участка значения отражательной способности витринита R_o являются низкими и варьируют от 0.4 до 0.7%, а T_{max} находится в диапазоне 420-445°C. Моделирование теплового потока было откалибровано по отражательной способности витринита с использованием различных кинетических моделей в зависимости от типа органического вещества: для органического вещества III типа (Brent) была выбрана модель Vandembroucke et al. (1999), а для II типа – модель KCF. Низкое значение геотермического градиента может компенсироваться продолжительностью геологического времени, в течение которого нефтематеринские породы подвергаются преобразованию. В исследуемом секторе начало фазы генерации нефти может соответствовать уровню зрелости около 0.5% R_o и даже 0.4% R_o для водородослевого либо смешанного органического вещества II/III типов. Для исследованных формаций основная часть углеводородов была сгенерирована в период максимального погружения. Выделены четыре зоны, различающиеся глубинами, начала и завершения нефтяного окна: западная зона (бассейновая часть) – от 4.0-4.5 до 7-9 км; зона склона и борта – от 3.0-3.7 до 4.5-5.0 км; зона Предуральского бассейна – от 2.8-3.3 до 4.5-5.0 км; восточная зона под Уральским надвигом (Изембет) – от 2.0-2.8 до 3.5-4.0 км.

Ключевые слова: Прикаспийский бассейн, Предуральский бассейн, органическое вещество, моделирование, тепловой поток, нефтегазовая система, зрелость, калибровка.

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