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MODELING OF HYDROCARBON GENERATION ZONES AND MIGRATION PATHWAYS OF AN OIL FIELD OF PRECASPIAN REGION, KAZAKHSTAN


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This article highlights the features of geological (basin) modeling of various zones and migration routes and presents the assessment of resources of the oil field in the Precaspian region in western Kazakhstan. A brief overview of geochemical features of the basin is presented using modern assaying and visualization software packages. The preferred method of constructing 1D models is indicated, and the results of such 1D modeling derived from the results of basin modeling are presented. Additional data points (including paleowater depths, sediment-water interface temperatures and heat flows) as boundary conditions were collected and included in the modeling software for data calibration and cross-checking purposes. For all 1D models produced in this study, Jurassic source rocks were deemed to have entered the oil window in Cretaceous time with the critical moment occurring in Late Cretaceous and Early Paleogene. The implied tectonic history of the basin suggests two possible periods of trap formation: tectonic inversion in the Middle Jurassic and possible folding during late Alpine orogeny which began in Late Cretaceous or early Eocene. While the Middle Jurassic traps can undoubtedly be filled with hydrocarbons, there is no such high degree of certainty with regards to traps formed after Late Cretaceous, as those traps were formed after peak migration periods.

KEY WORDS: *Precaspian region, modeling, basin, geochemical, PetroMod, geothermal gradient.*

КӨМІРСУТЕКТЕРДІ ӨНДІРУ АЙМАҚТАРЫН ЖӘНЕ КӨШІ-ҚОН ЖОЛДАРЫН МОДЕЛЬДЕУ, КАСПИЙ МАҢЫ ӨҢІРІНІҢ МҰНАЙ КЕН ОРНЫНЫҢ РЕСУРСТАРЫН БАҒАЛАУ, ҚАЗАҚСТАН

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Бұл мақалада әртүрлі көші-қон аймақтары мен жолдарын геологиялық (бассейндік) модельдеудің ерекшеліктері баяндалады және Батыс Қазақстандағы Каспий маңы өңіріндегі мұнай кен орнының ресурстарын бағалау ұсынылады. Бассейннің геохимиялық ерекшеліктеріне қысқаша шолу заманауи талдау және визуализация бағдарламалық пакеттерін пайдалану арқылы берілген. Бір өлшемді модельдерді құрудың қолайлы әдісі көрсетілген және бассейнді модельдеу нәтижелерінен алынған осындай бір өлшемді модельдеудің нәтижелері келтірілген. Қосымша деректер нүктелері (палео жетектерінің тереңдігі, шөгінділер мен су интерфейсіндегі температура және жылу ағындары) шекаралық шарттар ретінде жиналып, деректерді калибрлеу және Кросс-тексеру мақсатында модельдеу бағдарламалық жасақтамасына енгізілді. Осы зерттеуде жасалған барлық бір өлшемді модельдер үшін Юра көздерінің жыныстары Бор дәуірінде мұнай терезесіне кірді деп есептелді, ал маңызды сәт кеш бор мен ерте палеогенде болды. Бассейннің болжамды тектоникалық тарихы тұзақтың пайда болуының екі мүмкін кезеңін болжайды: орта юрадағы тектоникалық инверсия және кеш Бор дәуірінде немесе ерте эоценде басталған альпілік тау құрылысының ықтимал қатпарлануы. Ортаңғы юра тұзақтары көмірсутектермен толтырылуы мүмкін болса да, кеш бор дәуірінен кейін пайда болған тұзақтарға деген сенімділіктің жоғары деңгейі жоқ, өйткені бұл тұзақтар көші-қонның ең жоғары кезеңдерінен кейін пайда болды.

ТҮЙІН СӨЗДЕР: *Каспий маңы аймағы, модельдеу, бассейндік, геохимиялық, PetroMod, геотермиялық градиент.*

МОДЕЛИРОВАНИЕ ЗОН ГЕНЕРАЦИИ И ПУТЕЙ МИГРАЦИИ УГЛЕВОДОРОДОВ, ОЦЕНКА РЕСУРСОВ НЕФТЯНОГО МЕСТОРОЖДЕНИЯ ПРИКАСПИЙСКОГО РЕГИОНА, КАЗАХСТАН

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НАО «КАЗАХСКИЙ НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ ТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ ИМ. К.И. САТПАЕВА»,
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В данной статье освещаются особенности геологического (бассейнового) моделирования различных зон и путей миграции и представлена оценка ресурсов нефтяного месторождения в Прикаспийском регионе в Западном Казахстане. Краткий обзор геохимических особенностей бассейна представлен с использованием современных программных пакетов для анализа и визуализации. Указан предпочтительный метод построения одномерных *моделей, и представлены результаты такого одномерного моделирования, полученные на основе результатов моделирования бассейна. дополнительные точки данных (включая глубины палеовод, температуры на границе раздела донных отложений и воды и тепловые потоки) в качестве граничных условий были собраны и включены в программное обеспечение для моделирования для целей калибровки данных и перекрестной проверки. Для всех одномерных моделей, созданных в этом исследовании, считалось, что юрские породы-источники вошли в нефтяное окно в меловое время, а критический момент пришелся на поздний мел и ранний палеоген. Предполагаемая тектоническая история бассейна предполагает два возможных периода формирования ловушки: тектоническую инверсию в средней юре и возможную складчатость во время позднеальпийского горообразования, которое началось в позднем мелу или раннем эоцене. В то время как среднеюрские ловушки, несомненно, могут быть заполнены углеводородами, нет такой высокой степени уверенности в отношении ловушек, образовавшихся после позднего мела, поскольку эти ловушки были сформированы после пиковых периодов миграции.*

КЛЮЧЕВЫЕ СЛОВА: *Прикаспийский бассейн, моделирование, бассейн, геохимический, PetroMod, геотермический градиент.*

Introduction. The establishment of giant reservoirs with good filtration and capacitance properties in a number of well-known oil and gas basins of the world under conditions of abnormally high reservoir pressures and elevated temperatures at depths of 8,000–10,000 m or more has renewed interest in the search for large accumulations of hydrocarbons in the deep layers of the Caspian Depression. [2] The oil and gas potential within the northern and middle parts of the Caspian Sea has been positively assessed by many scientists. [5] The access of oil prospecting operations to new territories allowed us to obtain fundamentally new data on the conditions of occurrence of hydrocarbon deposits, which cannot be explained from the standpoint of the currently prevailing sedimentary-migration hypothesis of the origin of oil. [7] Traditionally, the main share of hydrocarbons in the Precaspian basin is currently associated with the Paleozoic complex in its near-shore zones, primarily with the largest carbonate objects of reef genesis. [1] The idea of migration routes and unloading zones of deep hydrocarbon systems in the upper part of the Earth's crust ("degassing pipes", "through range", "foundation faults") was formulated by P.N. Kropotkin, the author of the fundamental idea: oil and gas accumulation is the result of the hydrocarbon branch of the degassing of the Earth. [6] Currently, the strategy of studying the subsalt deposits of the Precaspian Basin is based on the search for large carbonate bodies of the Lower Permian-Devonian age, which occupy the main place in the provision of the oil and gas industry of the Republic of Kazakhstan and with which the bulk of the explored reserves and forecast hydrocarbon resources are associated. [3] The Middle Devonian deposits in large areas of the side parts of the Precaspian Basin may have the same composition and represent a promising direction of oil and gas exploration at accessible depths.[4]

Accumulation of hydrocarbons in traps can occur both in the generation zones and in the marginal, most elevated parts and separating ledges in the presence of favorable conditions for lateral migration of hydrocarbons.

Petroleum System Modeling (PSM), often referred to as basin modeling (when performed at the basin scale), is a method used to represent the history of a sedimentary basin, including the processes and components necessary for oil formation: oil source rock, reservoir, trapping mechanism, pressure of overlying rocks and the corresponding relative timing of their formation. Using geological, geophysical and engineering data, a 3D model of the subsurface is created. It can be used to understand whether oil is present and how much of it may be in potential traps.

The resulting models are valuable during exploration to identify favorable places where oil could migrate and get trapped.

Methodology. PSM was performed in 1D mode using the PetroMod software and the PSQL (Petroleum system quick look) tool in the Petrel software.

The following workflow was applied to study the petroleum system:

1) Stratigraphy and facies were analyzed in the selected wells,

2) 1D models created in PetroMod based on these wells,

3) The thermal regime was calibrated based on vitrinite temperature and reflectivity data found in external sources for one well,

4) 1D models were created to understand the zones of HC generation in the vertical section,

5) The processes of generation and migration of HC were modeled in Petrel (using the PSQL tool) to understand the migration paths and highlight possible accumulations.

The Jurassic interval is the only one proven at the deposit and in the neighboring part of the basin.

Results: 1D models

Figures 1, 2, 3 show the final lithostratigraphic columns created for the selected wells using the results of petrophysical interpretation. The intervals of the source rocks were selected in the intervals of shales, the type of kerogen was taken as type III based on the regional database of Jurassic SR obtained from the IHS source (*Figure 1*). The hydrogen indicators were taken on the basis of geochemical data recorded in a well located in the western part. The lower Cretaceous SR intervals have also been investigated in order to understand the upper limits of HC generation windows.

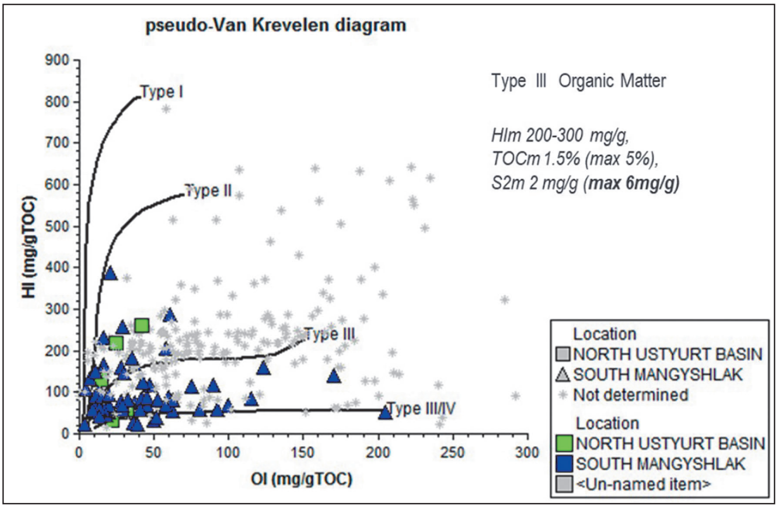

Figure 1 - **Samples of source rocks plotted on the Van Krevelen diagram (IHS database for sedimentary basins of Western Kazakhstan)**

Age [Ma]	Name top/well pick	Depth [m]	Thickness [m]	Event type	Name layer/event	Paleodeposition/ erosion [m]	Lithology	PSE	Kinetic	TOC [%]	HI [mgHC/gTOC]
0.00	C1 seal	0	430	Deposition	C1 seal		Sh80_Sst20	Overburden Rock			
66.00	K2 seal	430	455	Deposition	K2 seal		Chalk70_Sh30	Seal Rock			
90.00	K2 res	885	415	Deposition	K2 res		Sh40_Sst60	Reservoir Rock			
95.00	K1 seal	1300	280	Deposition	K1 seal		Sh65_Sst35	Seal Rock			
105.00	K1 res	1580	700	Deposition	K1 res		Sh70_Sst30	Reservoir Rock			
140.00	K1 source	2280	130	Deposition	K1 source		Sh60_Sst40	Source Rock	Pepper&Corvi(1995)_TIIIH(DE)	1.00	300.00
145.00	J3 seal	2410	170	Deposition	J3 seal		Sh59_Lst25_Sst14_Anh2	Seal Rock			
156.00	J2b res	2580	50	Deposition	J2b res		Sh40_Sst60	Reservoir Rock			
157.90	J2b source	2630	170	Deposition	J2b source		Sh70_Sst30	Source Rock	Pepper&Corvi(1995)_TIIIH(DE)	1.50	250.00
163.90	J2a res	2800	220	Deposition	J2a res		Sh60_Sst40	Reservoir Rock			
172.00	J2a source	3020	215	Deposition	J2a source		Sh90_Sst10	Source Rock	Pepper&Corvi(1995)_TIIIH(DE)	3.00	300.00
180.00	J1b res	3235	220	Deposition	J1b res		Sh20_Sst80	Reservoir Rock			
201.00	J1 source	3455	75	Deposition	J1 source		Sh90_Sst10	Source Rock	Pepper&Corvi(1995)_TIIIH(DE)	3.00	300.00
208.50	J1a res	3530	20	Deposition	J1a res		Sh10_Sst90	Reservoir Rock			
210.00	Base Jur	3550									

Figure 2 - **Lithostratigraphic column of the Arystan well**

Age [Ma]	Name top/well pick	Depth [m]	Thickness [m]	Event type	Name layer/event	Paleodeposition/ erosion [m]	Lithology	PSE	Kinetic	TOC [%]	HI [mgHC/gTOC]
0.00	Surface	0	750	Deposition	1		Sh80_Sst20	Overburden Rock			
66.00	Cretaceous	750	423	Deposition	2		Chalk (typical)	Seal Rock			
100.50	Top Lower Cret	1173	921	Deposition	3		Sh60_Sst40	Reservoir Rock			
122.70	Top K1 SR	2094	164	Deposition	3a		Sh80_Sst20	Source Rock	Pepper&Corvi(1995)_TIIIH(DE)	1.00	300.00
126.60	Bot K1 SR	2258	763	Deposition	3b		Sh60_Sst40	Reservoir Rock			
145.00	Top Jurassic	3021	411	Deposition	4		Sh59_Lst25_Sst14_Anh2	Seal Rock			
165.10	Top Middle Jurassic	3432	75	Deposition	5		Sh40_Sst60	Reservoir Rock			
168.80	Top J2 SR	3507	164	Deposition	5a		Sh60_Sst40	Source Rock	Pepper&Corvi(1995)_TIIIH(DE)	1.50	250.00
176.80	Top Lower Jurassic	3671	226	Deposition	6		Sh40_Sst60	Reservoir Rock			
187.90	Top J1 SR	3897	103	Deposition	6a		Sh90_Sst10	Source Rock	Pepper&Corvi(1995)_TIIIH(DE)	3.00	300.00
192.90	Base J1 SR	4000	171	Deposition	6b		Sh20_Sst80	Reservoir Rock			
201.30	Base Jurassic unc.	4171	0	Erosion	7er	0					
202.00	Top Triassic	4171	549	Deposition	7	0	Siltstone (organic lean)	Underburden Rock			
237.00	Top Mid Triassic	4720	608	Deposition	8		Siltstone (organic lean)	Underburden Rock			
247.20	Top Lower Triassic	5328	652	Deposition	9		Siltstone (organic rich, typical)	Source Rock	Pepper&Corvi(1995)_TII-S(A)	1.00	600.00
323.20	Basement	5980									

Figure 3 - **Lithostratigraphic column of the pseudo-well Kitchen-1**

Boundary conditions. A critical stage in the construction of the oil system model is the establishment of boundary conditions of the thermal regime. The boundary conditions are as follows:

- Paleo Water depth (PWD),
- Sediment-water interface temperature (SWIT),
- Heat flow.

SWIT and heat flow are upper and lower boundary conditions that change over the course of the basin's evolution history and must be reconstructed for the period under study, i.e. from the beginning of the Jurassic Period to the present day.

Paleo Water depth

PWD is used to calculate SWIT by applying corrections for the water layer to the surface temperature. PWD was reconstructed based on the previous work done for the district. Note that the model only takes into account values after the base Jurassic period (~200 million years ago).

Sediment-water interface temperature

SWIT is calculated from the surface temperature by applying corrections to the water layer (PWD). The surface temperature was reconstructed using the global average temperature model Wygrals (1989), which is available in Petrel. This tool uses as input the location (set in the Northern Hemisphere > Central Asia > 45 deg. latitude) to reconstruct the surface temperature curve (*Figure 4*).

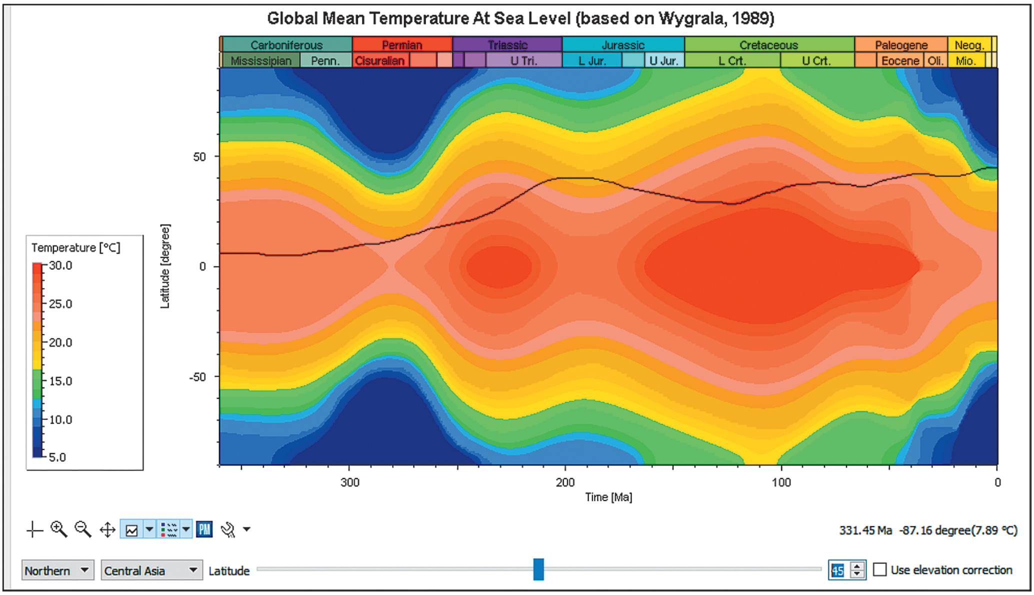

Figure 4 - **The global average temperature model according to Weigrals (1989)**

Heat flow

Heat flow is the movement of heat (energy) from the bowels of the Earth to the surface. The heat flow is calculated using the thermal conductivity of the rock multiplied by the temperature gradient.

Knowing the lithological column of the well, PetroMod reconstructs the thermal conductivity profile of the corresponding 1D model.

The digitized data set of the well did not contain temperature logs and the reflectivity coefficient of vitrinite. The source of the thermal data was external data sources. The Tereshkovskaya-1P well is located within the research area with only known samples of vitrinite reflectivity (VR) (from the IHS database - *Figure 7*). This well was used to calibrate the heat flow. Note that there are only two VR values in this well.

The current temperature gradient is known as 33 degrees Celsius/km from the same IHS database (*Figure 5*).

The value of the heat flow of 55 MW/m2 converts the Tereshkovskaya-1P model into a temperature logging corresponding to a gradient of 33 ° C/km (*Figure 5*, left). This value correlates with the modern map of heat flows, found on a well-known Internet resource www.earthbyte.org (*Figure 6*). Since the heat flow curve must be reconstructed in the past, this value can only be relevant to the end of this curve (i.e. today).

The rest of the curve was iteratively adjusted to match the VR values of the Tereshkovskaya-1P well. Unfortunately, it was not possible to compare the two values, preserving a geologically significant section, so priority was given to the lower VR sample taken from the Jurassic section (*Figure 7*, right).

Figure 8 shows the final boundary conditions calibrated for the Tereshkovskaya-1P well. They were used to run all PetroMod 1D models, as well as generation and migration models in Petrel.

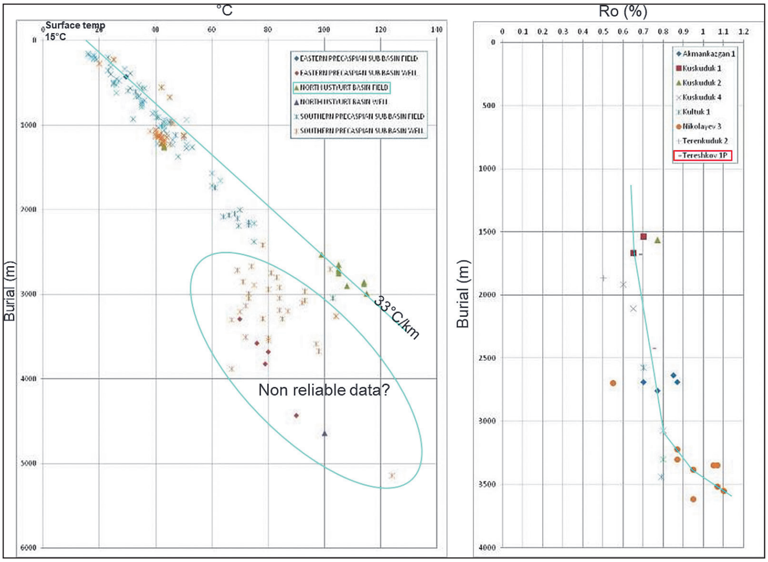

Figure 5 - **Regional calibration data (IHS database)**

Due to an unknown source of calibration data (an external database available only in image format), the accuracy of the data cannot be verified, the reader should bear in mind the uncertainties that are unavoidable in such circumstances.

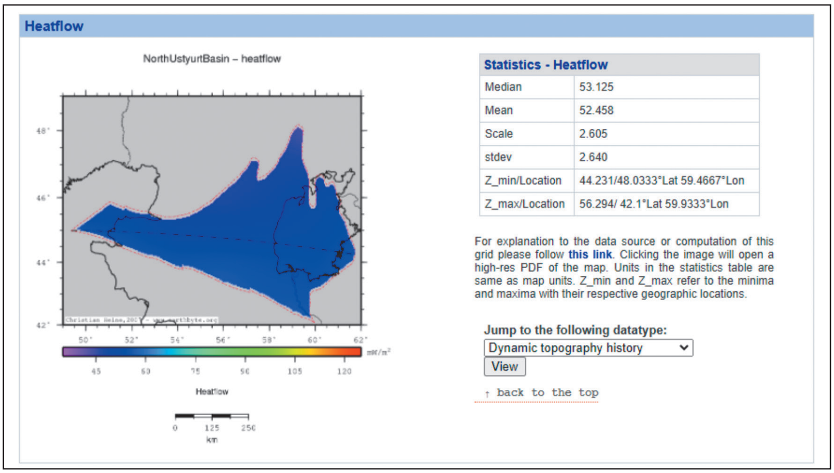

Figure 6 - **Modern heat flow map of the Northern Ustyurt basin (www.earthbyte.org)**

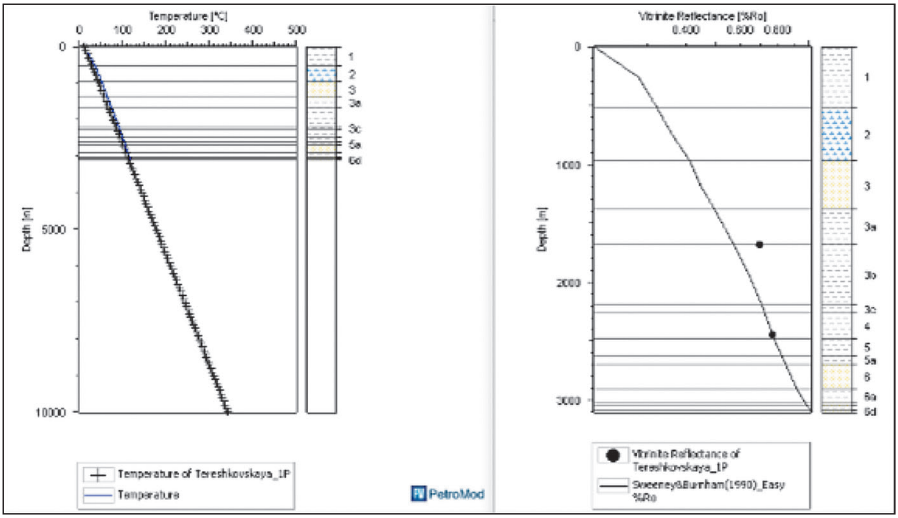

Figure 6 - **Modern heat flow map of the Northern Ustyurt basin (www.earthbyte.org)**

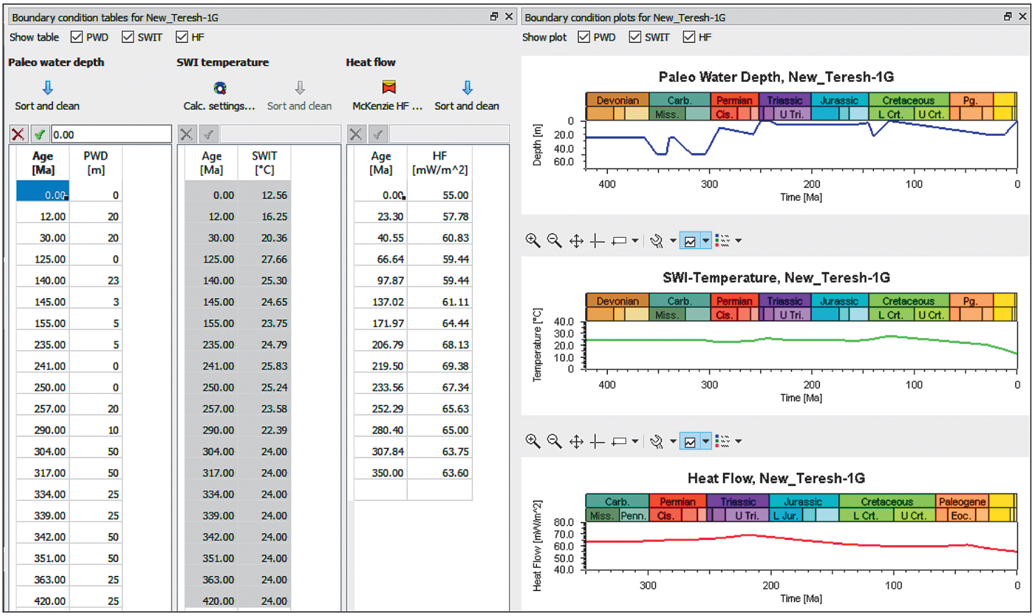

Figure 8 - **Final boundary conditions calibrated by the Tereshkovskaya-1P well**

Analysis. *Figures 9* to *12* show the results of modeling created 1D models in PetroMod. Two burial sites and a diagram of geological events are shown for each model.

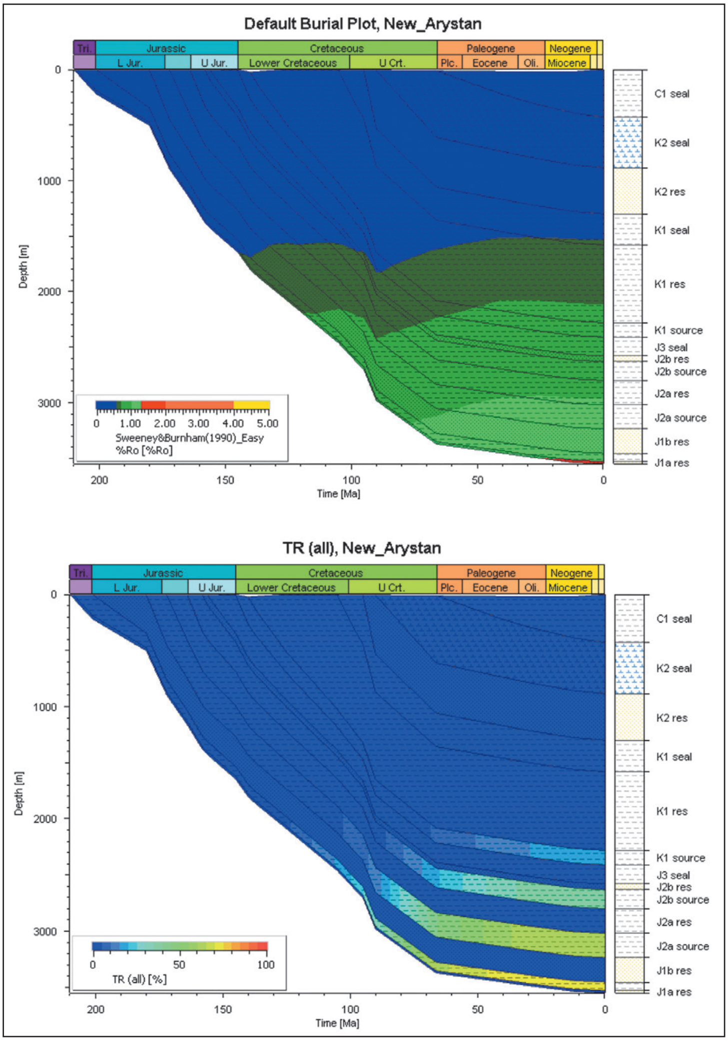

Figure 9 - **1D burial sites with superimposed values of VR and TR, Arystan well**

The upper graph shows the value of the vitrinite reflection coefficient, grouped by the oil window (from 0.6 to 1.2%, green colors) and the gas window (from 1.2 to 4.0%, red colors). This graph shows the maturity level for all intervals in the simulated section. Blue color corresponds to immaturity conditions, dark green – early/paraffin oil, medium green – basic oil, light green – late/light oil, dark red – wet gas, light red – dry gas.

The lower burial site is covered by the transformation coefficient (TR). This value means the percentage of organic matter converted into liquid hydrocarbons, and is calculated only for the intervals of the oil source rock where the kinetic model was installed (see lithostratigraphic columns, *Figures 9-12*). The TR value of 50% is usually considered as a critical moment for the generation process – the time when migration is at its peak.

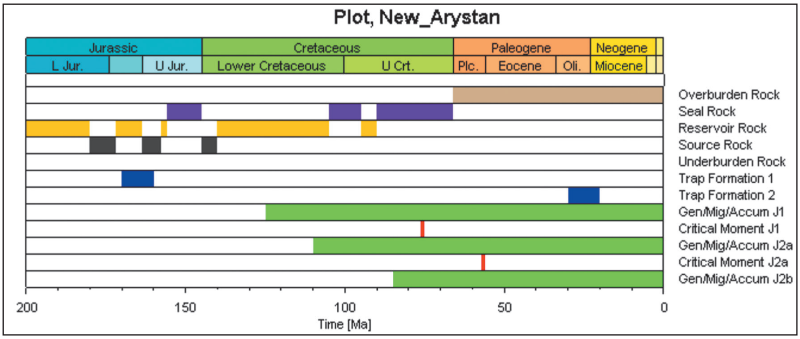

Figure 10 - **Diagram of geological events, Arystan well**

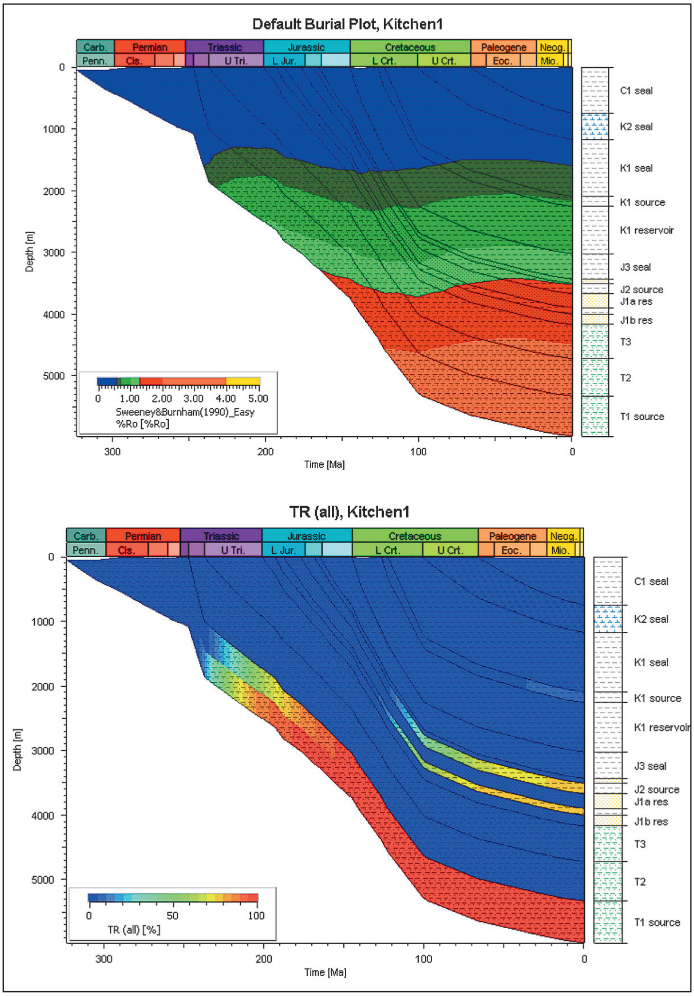

Figure 11 - **1D burial sites with superimposed values of VR and TR, Kitchen-1 pseudo-well**

Conclusion. The diagram of geological events summarizes the oil system of the 1D model, superimposing its key processes on the timeline: deposition of the oil source rock, reservoir, seal, pressure of the overlying strata, generation time, critical moments for each source rock and the hypothetical time of trap formation. This diagram is used to understand whether the petroleum system is working, i.e. the source rock was deposited before the reservoir rocks were covered with a seal, and the formed hydrocarbons began to migrate after the traps were formed so that they could be filled.

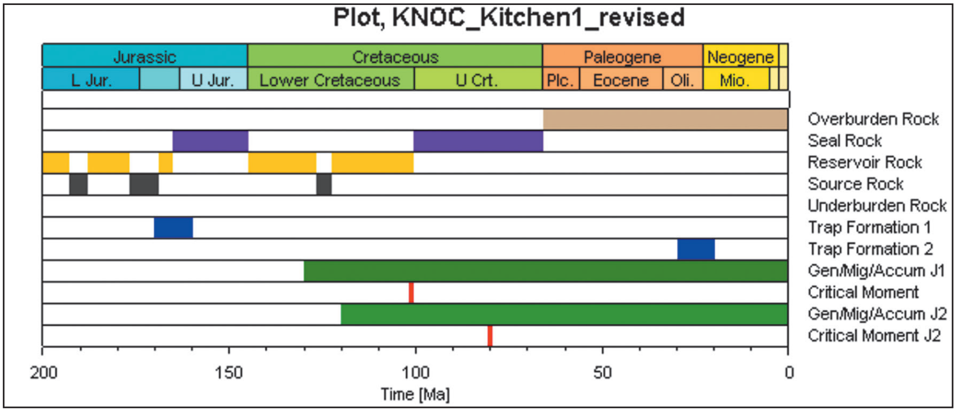

Figure 12 - **Diagram of geological events, Kitchen-1 pseudo-well**

For all 1D models (wells/structures), Jurassic source rocks entered the oil window in Cretaceous time (intervals J1, obviously earlier than J2), the critical moment occurred in the Late Cretaceous - Early Paleogene. The tectonic history of the basin suggests two possible periods of trap formation: tectonic inversion in the Middle Jurassic and possible folding during the late Alpine orogeny, which began in the Late Cretaceous - Eocene period. While the Middle Jurassic traps can undoubtedly be filled, given that generation began in the Cretaceous period, traps formed after the Late Cretaceous period have a high risk of missing the peak of migration.

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