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ASSESSMENT OF GEOLOGICAL RISKS IN GEOLOGICAL EXPLORATION FOR OIL AND GAS IN THE SOUTH CASPIAN BASIN

The article examines the results of geological risk assessment during geological exploration for oil and gas in the South Caspian Basin using the Monte Carlo method. The modeling was performed in the risk analysis module of the Petromod software based on the methodology of the Chevron company. As a result of modeling the hydrocarbon systems of the South Caspian Basin, three generation–migration hydrocarbon systems are distinguished: Eocene–Pliocene, Maikop–Pliocene and Miocene–Pliocene. To assess the probability of success and geological risks during geological exploration for oil and gas, the main stage was the analysis of the elements of the hydrocarbon system: oil and gas source strata, reservoir rocks, seals, hydrocarbon traps, as well as the processes of generation, migration and accumulation of hydrocarbons. The results of calculations of the probability of geological success for the South Caspian Basin showed the following values: for the Eocene–Pliocene hydrocarbon system–30.9%, the Maikop–Pliocene hydrocarbon system–65.6%, the Miocene–Pliocene hydrocarbon system–46.1%. The obtained data indicate low geological risks in the studied region. The hydrocarbon saturation of the productive strata section is controlled by mud volcanoes and associated faults and ruptures, and their distribution over the area spatially corresponds to the zones of their development, ensuring the migration connectivity of the oil and gas source strata of the Paleogene-Miocene and the accumulating hydrocarbon intervals of the Pliocene.

Keywords: *geological risks, geological exploration, oil, South Caspian gas, hydrocarbon systems, geological success*
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Introduction

The aim of the work is to assess geological risks during geological exploration for oil and gas in the South Caspian Basin (SCB) using modern methods, including probabilistic modeling using the Monte Carlo method. The calculations were performed in the risk analysis module of the Petromod software based on the methodology of the Chevron company [1–3].

Geological risks characterize the probability of a negative result during geological exploration work for oil and gas. The reciprocal of geological risk is *probability (coefficient) of exploration success*. The creation of reliable models of hydrocarbon systems (HS) helps to reduce geological risks in geological exploration for oil and gas, consisting of such elements as the oil and gas source rocks (OGSR), reservoir rock, seals, hydrocarbon traps, as well as the processes of generation, migration and accumulation of hydrocarbons [3]. The presence of active hydrocarbon reserves within the South Caspian Basin is confirmed by numerous identified deposits (**Fig. 1**).

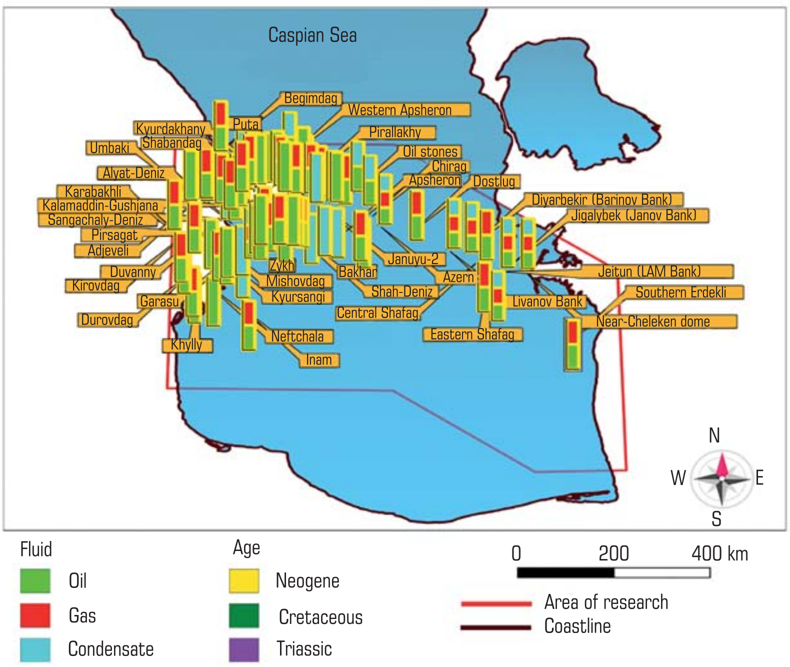

Fig. 1. Scheme of distribution of hydrocarbon deposits and pools in the South Caspian Basin

Geological risk assessment methodology

Geological risk assessment by the Monte Carlo method. The Monte Carlo method was implemented in the risk analysis module of the Petromod software (Schlumberger company)—a software package that allows assessing geological risks through the analysis of uncertainties in the structure and processes of a hydrocarbon system [4]. First, a 3D model is built, lithology, reservoir properties and geochemical parameters are specified. Uncertainties are then analyzed: tectonic history, source composition, porosity–permeability and migration pathways using Monte Carlo and sensitivity analysis methods. The thermal history, generation, migration and accumulation of hydrocarbons are calculated, the volume of hydrocarbon resources and the phase composition of fluids are estimated [5]. Based on all the obtained results, an assessment of geological risks is carried out, for which the input data are the zero model and the input data uncertainty list. For those input data that, for a number of reasons, are not well supported by actual geological data, it is necessary to specify the range of values and the nature of the distribution. It is important to remember that the analyzed uncertain parameters must be independent. Then a Monte Carlo simulation is run [6].

The assessment of geological risks in Petromod is based on the integration of the results of modeling the processes of generation, migration and accumulation of hydrocarbons. The key point is to adapt the models to the specifics of the research area. Geological risk assessment in SCB using Petromod software was carried out designed taking into account the unique features of the region—a powerful Mesozoic-Cenozoic sedimentary cover, active tectonics, mud volcanism and a complex history of thermal evolution [7–10].

Assessment of geological risks using the Chevron methodology. Technology Chevron (Chevron Risk Segment Mapping (CRSM) + Basin Modeling) is particularly useful in complex regions such as the South Caspian, where traditional methods can produce high uncertainty. Thus, CRSM is a risk segmentation method that allows assessing the probability of success of geological exploration work and analyzing the risks associated with it. The probability formula in CRSM gives a quantitative estimate of their combination [11]. Thus, CRSM represents a method for quantitative risk assessment in hydrocarbon exploration. It includes dividing the Basin into segments (based on structural and lithological criteria), assessing the probability of success (POS) for each segment, and taking into account several independent risks (e.g. presence of a reservoir, seal, hydrocarbon generation). To assess geological risks, a probability formula is used that quantitatively takes into account a combination of different risk factors:

$$P_{risk} = 1 - ((1 - P_{1risk})(1 - P_{2risk})(1 - P_{3risk})(1 - P_{4risk})), \quad (1)$$

where $P_{risk.}$ is the overall probability of failure; P_{1risk}–P_{4risk} are the probabilities of individual risks (for example, the absence of a reservoir, migration, trap).

The formula is based on probability theory. If the risks are independent, then the probability of their joint non-occurrence is multiplied. The formula is derived from the principle:

P (at least one risk) = 1 – P (no risk) P (at least one risk) = 1 – P (no risk whatsoever).

Table 1. Checklist for evaluation of geological information

OGSR	Reservoir
1. Ability to release hydrocarbons: • power; • square; • the number of individual horizons enriched with organic matter (OM); • continuity; • oil and gas shows; • C_{org} content; • type of kerogen. 2. Maturity of OGSR: • results of analytical studies; • location of the generation source	1. Availability: • lithology; • spreading; • sedimentation model (sequence stratigraphy). 2. Quality: • lateral continuity and area; • heterogeneity; • porosity (type and range); • permeability (type and range); • jointing
Trap	**Migration, the time factor**
1. Defining the trap (data quality): • number of seismic profiles, quality (resolution) of seismic data; • velocity model, lateral velocity gradient; • correlation with other geophysical data. 2. Characteristics of the trap: • type, presence of four-way closure; • the presence of isolated blocks. 3. FluID stops: • lithology, thickness, continuity, presence of faults; • screening fault; • type, time, pressure, number of layers crossed	1. Time factor: • time relationship, organic matter maturation model, temperature gradients, heat flow. 2. Migration routes: • vertical, lateral, location of the trap in relation to migration routes, migration shoulder, presence of barriers on migration routes. 3. Preservation of deposits: • tectonic activity, biodegradation, thermal cracking, displacement of oil by water and gas

Table 2. Volume of generated hydrocarbons in OGSR in SCB

OGSR	Volume of generated hydrocarbons, Btoe	Oil content, %	Gas component, %	Residual potential, Btoe
Eocene	55.15	79.78	20.22	20
Maikop	83	82.88	17.12	20.9
Tarkhan–Chokrak	7.7	86.15	13.85	6.7
Diatomaceous	29.5	85.36	14.64	19.8
Total	175.35	83.54	16.46	67.4

In complex regions such as the SCB, where traditional methods can produce high uncertainty, Chevron's technology (CRSM + Basin Modeling) is particularly useful.

Geological information is assessed using a checklist to standardize assessment methods and to eliminate as much as possible the influence of the human factor (subjectivity) and the convenience of the geologist [12]. The checklist is divided into blocks corresponding to four risk factors (**Table 1**).

Geological risk assessment in SCB using the Monte Carlo method: Results

The main procedure was the analysis of the reservoir elements, which included the assessment of the reservoir properties, the quality of the seals, and the characteristics of the hydrocarbon traps. The modeling was carried out taking into account the key geological features of the South Caspian Basin, characterized by a thick sedimentary cover (up to 25 km), active tectonic processes (including subduction of the oceanic crust under the Apsheron threshold with the development of thrusts and folding), injection phenomena, intense mud volcanism, which significantly affects the migration processes of hydrocarbons, as well as abnormally low heat flow values (~20–30 mW/m²), which leads to slow maturation of organic matter (OM) [13].

Adaptation of the Petromod software package for modeling SCB HS included:

—calibration of thermal history by introducing reduced heat flow values (20–35 mW/m²), consistent with regional geothermal studies;

—taking into account adiabatic heating caused by exceptionally high rates of sedimentation (up to 2 km/million years in the Pliocene);

—verification of the model using independent geothermal indicators—data on vitrinite reflectivity R_o and results of apex analysis.

When modeling the processes of generation and migration of hydrocarbons, the presence of specific kinetics of organic matter (sapropelic substance predominates in Maikop clays) and the predominant development of vertical migration through faults and mud diapirs (Fault Analysis Module) were taken into account [14–16].

Quality assessment OGSR. The results of pyrolytic studies were used to determine the main pyrolytic parameters: TOC (Total Organic Carbon), *Tmax*, HI, S_1—realized potential of OGSR, S_2—residual, that is, kerogen not transformed into hydrocarbons, $S_1 + S_2$, indicators of quality assessment of OGSR, PI (Production Index) = $S_1 / (S_1 + S_2)$—degree of kerogen depletion. The results of the study of these parameters were presented by the authors in a number of publications, as well as in works and were included in the basis of the created models of generation (catagenetic evolution), the analysis of which made it possible to evaluate the generation potential of OGSR [17]. Based on the models of generation of the main Eocene OGSR (**Fig. 2*a***), Oligocene–Miocene (**Fig. 2b**), Tarkhan–Chokrak (**Fig. 2*c***) and Diatom (**Fig. 2*d***) the generation potential and the total volume of generated hydrocarbons in the South Caspian Sea Basin were determined, which is 175.35 billion tons (**Table 2**) [18]. This procedure allowed us to evaluate the OGSR factor for the Eocene OGSR as "encouraging"—**0.7**, for the Maikop OGSR—"favorable"—**0.9** and for the Miocene OGSR—"favorable"—**0.8**.

Model constructions indicate that the South Caspian Basin is a multi-focal Basin, within which several stratigraphically, hypsometrically and laterally isolated autonomous foci of hydrocarbon generation are distinguished in the Eocene, Oligocene–Miocene and Miocene hydrocarbon systems [19, 20].

The oil of the Pliocene reservoir is a mixture of various oil source strata of Eocene, Oligocene–Miocene (Maikop), Miocene (Tarkhan–Chokrak and diatomaceous) age, the role of which in each specific geological situation is different. The volume of generated hydrocarbons in the South Caspian Sea is 175.35 billion tons, and the remaining potential is 67.4 billion tons.

Reservoir quality assessment. The productive stratum is characterized by sharp lithofacies and poro-perm heterogeneity of the section, built up in individual Cenozoic intervals in a setting of nonequilibrium avalanche sedimentation; rhythmicity, expressed in the periodic replacement of

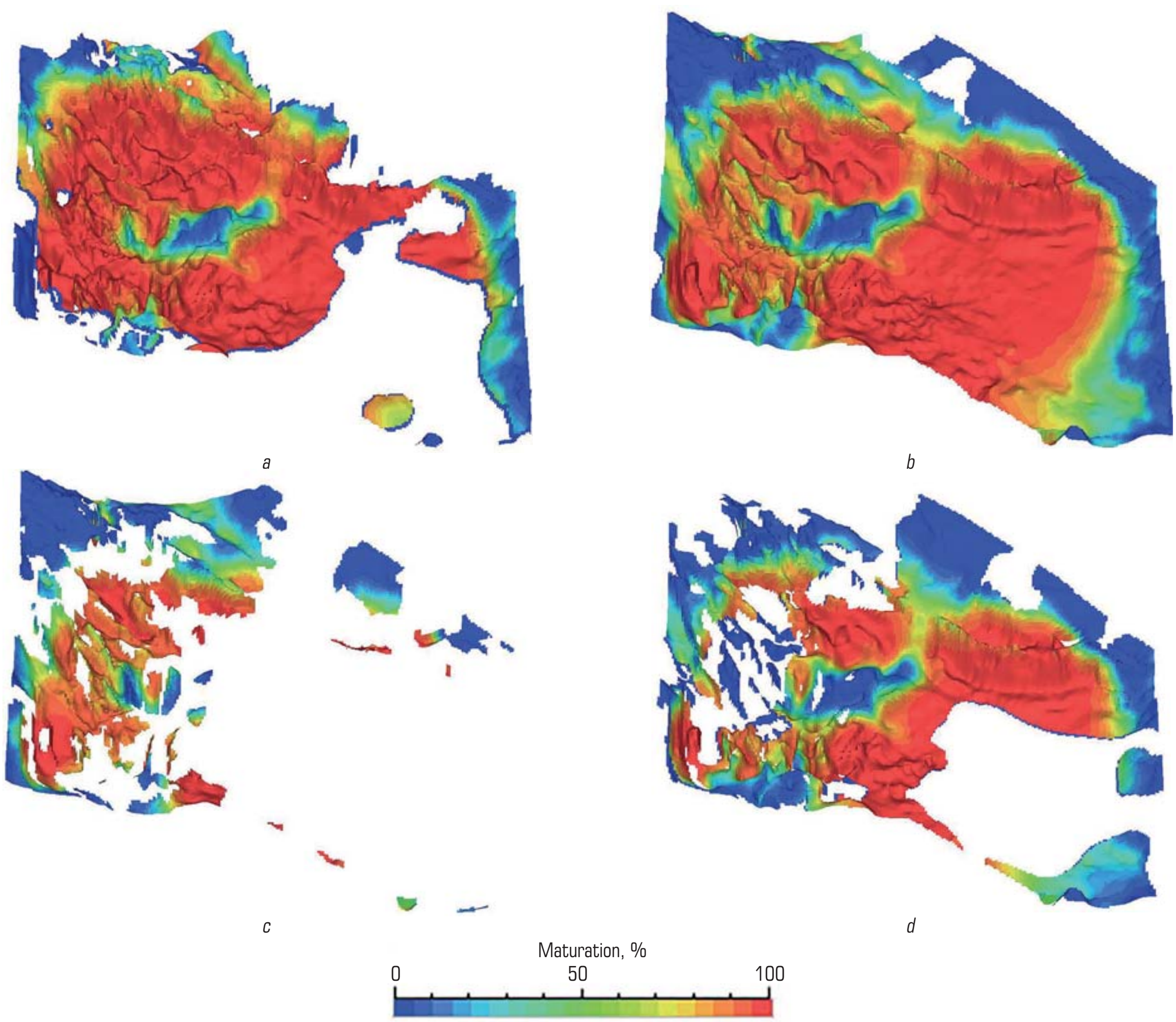

Fig. 2. Models of generation (catagenetic evolution) and volumes of generated hydrocarbons in OGSR in SCB:
a–Eocene OGSR (volume of generated hydrocarbons–55.15 Btoe); *b*–Maikop OGSR (volume of generated hydrocarbons–83 Btoe); *c*–Tarkhan–Chokrak OGSR (volume of generated hydrocarbons–7.7 Btoe); *d*–Diatomaceous OGSR (volume of generated hydrocarbons–29.05 Btoe)

clayey varieties by sandy ones in the vertical direction; lens-forming in the regional plan, successive wedging out of the stratigraphic components of the section both in the direction of the rise and subsidence of the general folding; inversion of the density characteristics of the sedimentary strata, accompanied by the spread in individual Cenozoic intervals of powerful series of unconsolidated ("undercompacted", often quasi-liquefied) highly porous, extremely water-saturated, plastic, highly dynamic (mainly montmorillonite) clays [21]. The formation of the main oil and gas-bearing object of the Lower Pliocene age of the productive strata is associated with three large rivers (Paleo-Volga, Paleo-Uzboy and Paleo-Kura) and dozens of small rivers. Within the South Caspian Basin, reservoirs are sandstone formations present in the productive strata deposits and possessing good reservoir properties. The most productive horizons of the formation were identified as the Kalinian, Over-Kirmaki, Sabunchi, and Surakhany suites. To study the reservoirs, distribution models and lithological-facies schemes of natural reservoirs were developed (**Fig. 3**).

Depending on the intensity of hydrocarbon generation, thermobaric conditions and other factors, hydrocarbons that have penetrated into the reservoir may be in a free or dissolved state in water. Moving up the rise of the layers in the reservoir bed due to changes in thermobaric conditions, some of them are released into a free phase and, in the presence of traps, can form accumulations of oil and/or gas. In the zone of oil and gas accumulations in the chain of traps, the distribution of hydrocarbon accumulations of different phase states, formed according to the principle of "differential capture" is quite often observed [22].

Table 3. Quantitative assessment of accumulated hydrocarbons in the productive strata

Suite	Volume of hydrocarbons accumulated in reservoirs, billion tons of EF	
	Total for reservoirs	
Sabunchi	111.49	
Fasila	1.8	
Over-Kirmaki	0.9	
Kalinian	36.06	
Total for productive thickness		150.25

Modeling made it possible to identify oil and gas accumulation zones (accumulation zones) in reservoirs of the productive stratum (**Fig. 4**). Quantitative assessment of the volume of hydrocarbons accumulated in reservoirs is shown in **Table 3**.

The conducted studies allowed us to classify the reservoir assessment factor as:

- encouraging (0.7)—for the Eocene OGSR;
- favorable (0.9)—for the Maikop;
- favorable (0.8)—for the Miocene.

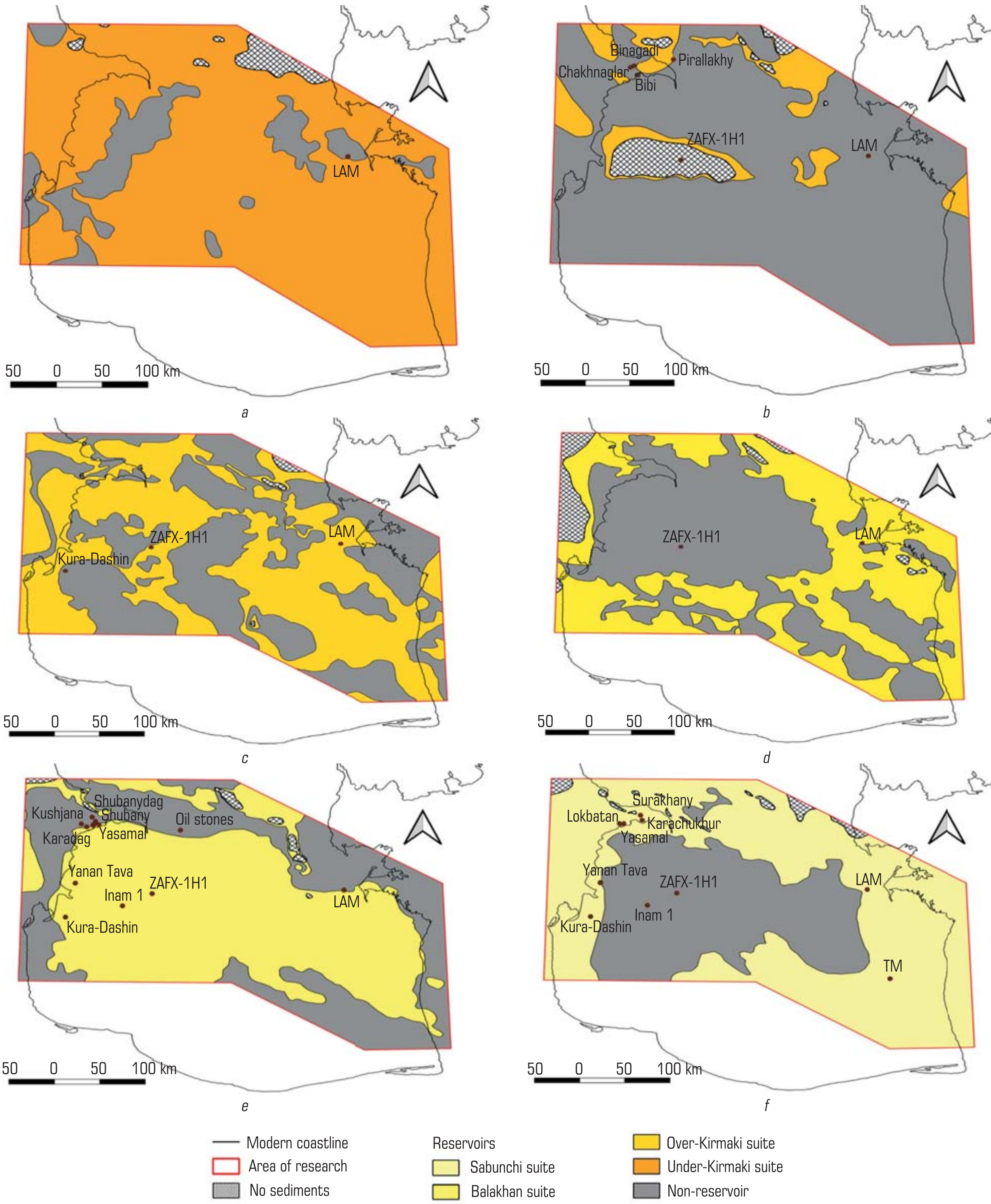

Fig. 3. Reservoir distribution models:
a–Under-Kirmaki suite; *b*–Kirmaki suite; c–Over-Kirmaki suite; *d*–Fasila suite; *e*–Balakhan suite; *f*–Sabunchi suite

The most productive horizons of the formation were identified as the Kalinian, Over-Kirmaki, Sabunchi and Surakhany suites. The main mechanism for hydrocarbon migration in SCB are mud volcanoes, the eruptive channels of which serve as channels for hydrocarbon migration. Migration processes are also ensured by a network of extension cracks created by the process of formation of diapiric structures developed over more than a century of deposits located in the zone of development of mud volcanism [23].

Evaluation of the quality of traps. An important element in the process of accumulation and formation of hydrocarbon deposits is the formation of traps closely related to the folding of the region. The results of the

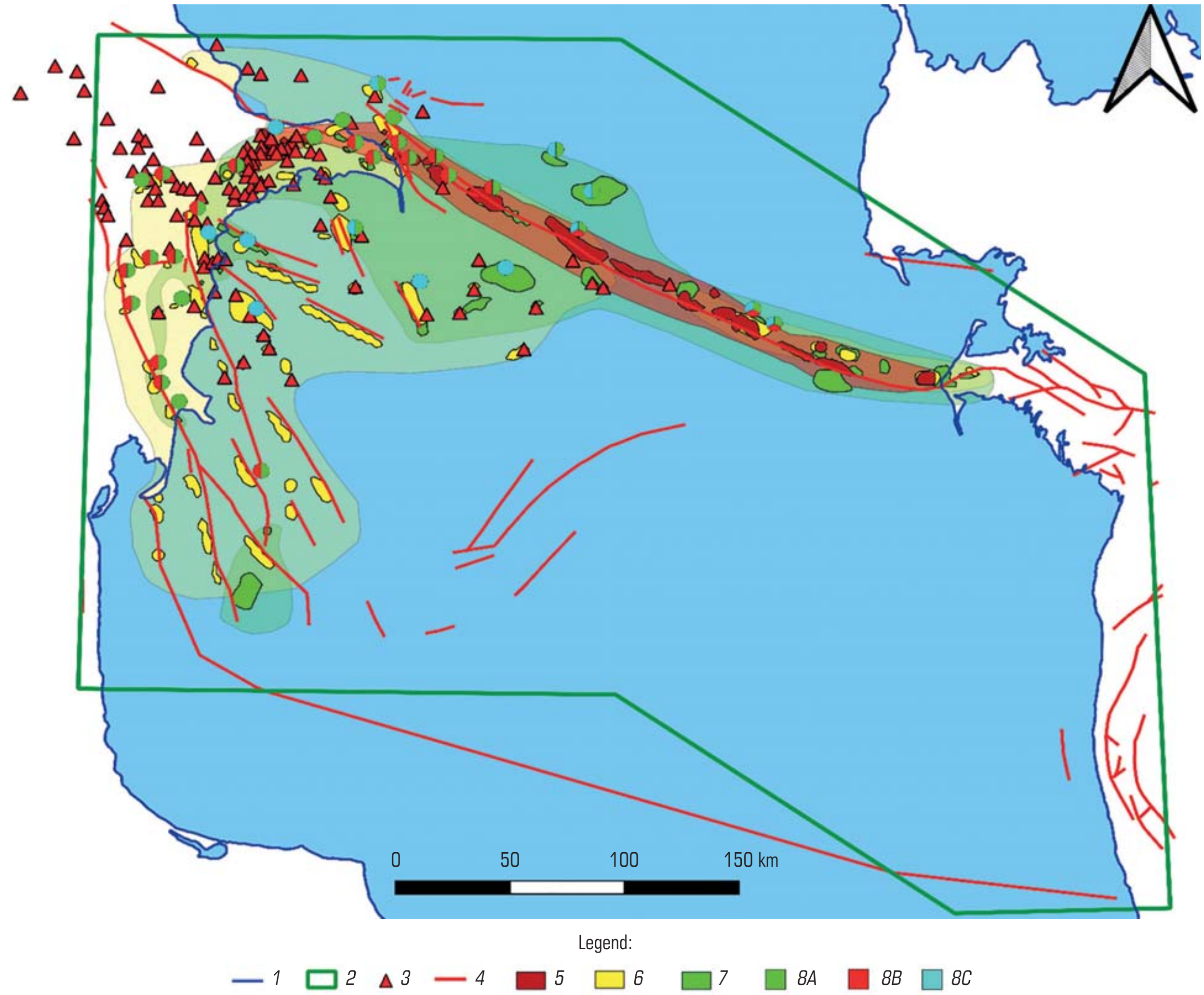

Fig. 4. Maps of oil and gas accumulation zones (hydrocarbon accumulation zones) in reservoirs of productive strata of SCB:
1–coastline; *2*–area of study; *3*–mud volcanoes; *4*–fractures; *5*–Eocene–Pliocene HS; *6*–Maikop–Pliocene HS; *7*–Miocene–Pliocene HS; *8*–deposits: *A*–oil, *B*–gas, *C*–gas condensate

performed modeling showed a relatively high density and, at the same time, significant unevenness in the distribution of folded dislocations at the level of deposits from the surface of the Mesozoic to ground surface in the South Caspian Basin (**Fig. 5**). The folding in the South Caspian Basin is characterized by uniform structural plans common to the entire deep interval of its development and the conformity of the structural elements that form them, which is evidence of its belonging mainly to the Pliocene–Pleistocene cycle of structure formation. The leading folding mechanism in the South Caspian Basin is the redistribution of volumes of low-viscosity clay horizons of the Maikop age present in the layered section of the Basin, which are prone to plastic flow under the load of the powerful overlying strata of the Upper Miocene, Pliocene and Pleistocene.

The analysis and classification of hydrocarbon traps and deposits in the South Caspian Basin shows that the entire set of characteristics reflecting the belonging of a deposit to one class or another is distributed in relation to two factors—structural and sedimentary (lithological–stratigraphic). The structural factor determines the complete configuration of the deposit in geological space (that is, the generalized morphology of the part of this space it occupies), the second, together with the first or independently, determines the internal structure of the deposit, formed by one or several deposits.

Table 4 shows quantitative assessment of accumulated hydrocarbons in traps.

Table 4. Quantitative assessment of accumulated hydrocarbons in traps

OGSR	The volume of accumulated hydrocarbons in traps, Mtoe				
	Sabunchi suite	Fasila suite	Over-Kirmaki suite	Kalinian suite	Total for productive thickness
Eocene	1395.19	19.76	3.88	27.98	1446.81
Maikop	3937.94	45.99	23.16	215.74	4222.83
Tarkhan–Chokrak	572.67	13.31	11.92	266.74	864.64
Diatomaceous	1341.08	39.86	16.52	1824.58	3222.04
Total for suites	7246.88	118.92	55.48	2335.04	9756.32
Accumulated in traps of the productive layer ≈ 9.8–15.2					

The sedimentation (lithology–stratigraphy) factor is represented by three main types of elementary (single) deposits: lithologically limited, lithologically screened, and stratigraphically screened. In this case, lithologically screened deposits, together with lithologically limited ones, are included in the combined conditional group of lithologically determined ones during analysis. In the section of the productive strata of SCB, wedging (clinoform) bodies, lithological and stratigraphic traps are widespread [24].

The presence of a system of mud volcanoes and wedging zones in combination with structural elements also suggests the widespread development of complex combined traps—structural–stratigraphic and structural–lithological.

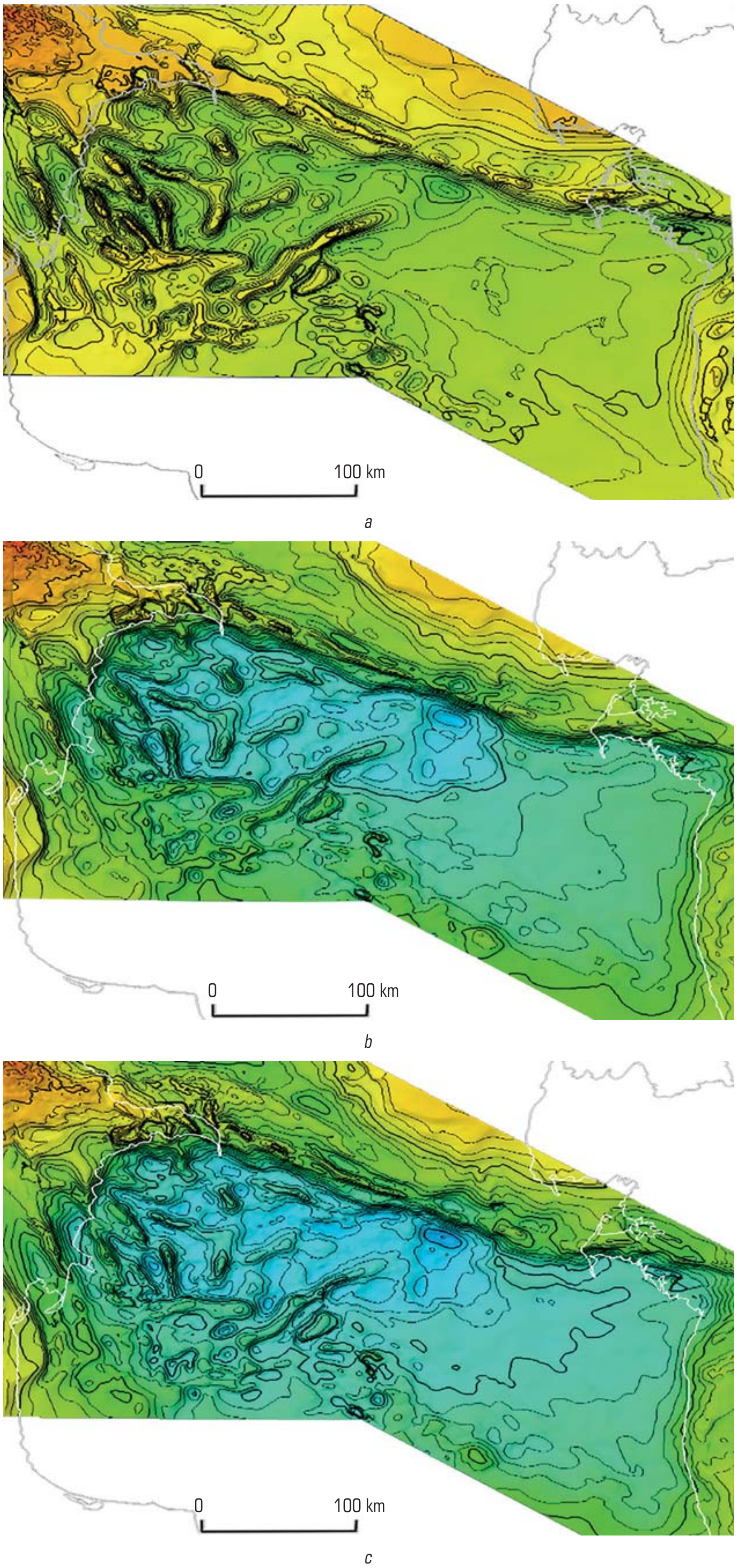

Fig. 5. Models of distribution of folds—structural traps in productive strata:
a—upper section roof; *b*—lower section roof; *c*—floor

Table 5. Geological success probabilities for generation–accumulation hydrocarbon (GAHS) systems of SCB

<table>
<tr><th colspan="14">Eocene–Pliocene GAHS</th></tr>
<tr><th rowspan="3">Discovery probability criteria</th><th colspan="2">Mesozoic</th><th colspan="11">Cenozoic</th></tr>
<tr><th colspan="2">Cretaceous</th><th colspan="3">Paleogene</th><th colspan="8">Neogene-Quarter</th></tr>
<tr><th>K_1</th><th>K_2</th><th>Pg_1</th><th>Pg_2</th><th>$Pg_3N_1^1mk$</th><th>N_1^2tar-cho</th><th>N_1^{2-3}dt</th><th>N_2^1pn</th><th>N_2^2kal</th><th>N_2^2nas</th><th>N_2^2per</th><th>N_2^2sab</th><th>N_2^3Q</th></tr>
<tr><td>OGSR</td><td></td><td></td><td></td><td>0.7</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Reservoirs</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">0.8</td><td></td></tr>
<tr><td>Traps</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="6">0.8</td></tr>
<tr><td>Geochronology</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5">0.9</td></tr>
<tr><td>Discovery probability</td><td colspan="13">0.309</td></tr>
</table>

<table>
<tr><th colspan="14">Maikop–Pliocene GAHS</th></tr>
<tr><th rowspan="3">Discovery probability criteria</th><th colspan="2">Mesozoic</th><th colspan="11">Cenozoic</th></tr>
<tr><th colspan="2">Cretaceous</th><th colspan="3">Paleogene</th><th colspan="8">Neogene-Quarter</th></tr>
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<tr><td>Discovery probability</td><td colspan="13">0.656</td></tr>
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<table>
<tr><th colspan="14">Miocene–Pliocene GAHS</th></tr>
<tr><th rowspan="3">Discovery probability criteria</th><th colspan="2">Mesozoic</th><th colspan="11">Cenozoic</th></tr>
<tr><th colspan="2">Cretaceous</th><th colspan="3">Paleogene</th><th colspan="8">Neogene-Quarter</th></tr>
<tr><th>K_1</th><th>K_2</th><th>Pg_1</th><th>Pg_2</th><th>$Pg_3N_1^1mk$</th><th>N_1^2tar-cho</th><th>N_1^{2-3}dt</th><th>N_2^1pn</th><th>N_2^2kal</th><th>N_2^2nas</th><th>N_2^2per</th><th>N_2^2sab</th><th>N_2^3Q</th></tr>
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<tr><td>Discovery probability</td><td colspan="13">0.461</td></tr>
</table>

The results of the HS modeling allowed us to estimate the volume of accumulated hydrocarbons in traps (Table 4) and the trap assessment factor for the Eocene OGSR as "encouraging"—**0.7**, for the Maikop OGSR—"favorable"—**0.9** and for the Miocene OGSR—"favorable"—**0.8**.

"Geochronology" Factor. The analysis of the geochronology factor, that is, the degree of favorability of the relationship between the time of the processes of trap formation and migration, accumulation of hydrocarbons, was carried out using Basin modeling, the results of which are well demonstrated in the diagrams of the probability of geological success and geological risks for the GAHS SCB (**Table 5**).

Results of geological risk assessment in the South Caspian Basin using the Chevron methodology

To assess geological risks in the South Caspian Basin using the Chevron methodology, a table or risk statement was first compiled. The entries in the statement (assessment of each of the risk factors) are characterized as "unfavorable," "controversial," "neutral," "encouraging," and "favorable" (**Table 6**).

The folding in the South Caspian Basin, which played a decisive role in the formation of traps, is characterized by a single and common geological time for the entire deep interval of the formation and development of structural plans and structural elements, and indicates the formation of traps in the Pliocene before the start of the processes of hydrocarbon emigration from the parent strata. In this regard, the "Geochronology" factor is assessed for the Eocene OGSR as "favorable"—**0.9**, for the Maikop OGSR—"favorable"—**0.9** and for the Miocene OGSR—"favorable"—**0.8**.

Thus, the probability of geological success in carrying out geological exploration work in SCB in the Eocene–Pliocene HS is 0.309, in the Maikop–Pliocene HS—0.656 and in the Miocene–Pliocene HS—0.461, which indicates low geological risks (see Table 5).

Risks were categorized based on empirical data. As a rule:

—**very low risk (0.5–0.99)**—all geological risk factors are assessed as "favorable";

—**low risk (0.25–0.5)**—all geological risk factors are assessed as "encouraging" and "favorable";

—**moderate risk (0.125–0.25)—**two or three factors—from "encouraging" to "favorable", one or two—from "encouraging" to "neutral";

—**high risk (0.063–0.125)—**one or two factors are "encouraging", two or three are "neutral", or from "neutral" to "encouraging";

—**very high risk (0.01–0.063)—**from two to three factors no higher than "neutral" with one or two "questionable" or "neutral".

Below are the calculations of the probability of geological success and the assessment of risks during geological exploration, the results of which are summarized in **Table 7**.

Calculation of geological success probability and risk assessment in geological exploration in the Eocene–Pliocene HS:

$P_{risk} = 1 - (1 - P_{1risk})(1 - P_{2\,risk})(1 - P_{3risk})(1 - P_{4\,risk}) = 1((1 - 0.3)\times$
$\times(1 - 0.3)(1 \cdot 0.3)(1 - 0.1) = 0.6913 \cdot 100\% = 69.13\%;$

$R_{v.o.} = R_{1v.o}R_{2v.o}R_{3v.o}R_{4v.o} = 0.7 \cdot 0.7 \cdot 0.7 \cdot 0.9 = 0.3087 \cdot 100\% =$
$= 30.87\%;$

$R_{risk} + R_{v.o} = 1.$

Calculation of geological success probability and risk assessment in geological exploration work in the Maikop–Pliocene HS:

$P_{risk} = 1 - (1 - P_{1risk})(1 - P_{2\,risk})(1 - P_{3risk})(1 - P_{4\,risk}) = 1((1 - 0.1)\times$
$\times(1 - 0.1)(1 - 0.1)(1 - 0.1) = 0.3439\ 100\% = 34.39\%;$

$R_{v.o.} = R_{1v.o}R_{2v.o}R_{3v.o}R_{4v.o} = 0.9 \cdot 0.9 \cdot 0.9 \cdot 0.9 = 0.6561 \cdot 100\% =$
$= 65.61\%;$

$R_{risk} + R_{v.o} = 1.$

Table 6. Assessment of geological success probability using the Chevron method (Otis, 1997)

Miocene–Pliocene HS	Unfavorable	Controversial	Neutral	Encouraging	Favorable	Overall
Oil source strata appraisal						0.7
Saturability with HS				0.7		
Maturity					0.8	
Reservoir appraisal						0.7
Presence				0.7		
Quality				0.7		
Trap appraisal						0.7
Trap identification reliability				0.7		
Trap characteristic				0.7		
Seal quality					0.8	
Geochronology						0.9
Factor of time					0.9	
Migration paths					0.9	
Reservoir integrity					0.9	
Geological success probability						0.39

Miocene–Pliocene HS	Unfavorable	Controversial	Neutral	Encouraging	Favorable	Overall
Oil source strata appraisal						0.9
Saturability with HS					0.9	
Maturity					0.9	
Reservoir appraisal						0.9
Presence					0.9	
Quality					0.9	
Trap appraisal						0.9
Trap identification reliability					0.9	
Trap characteristic					0.9	
Seal quality					0.9	
Geochronology						0.9
Factor of time					0.9	
Migration paths					0.9	
Reservoir integrity					0.9	
Geological success probability						0.656

Miocene–Pliocene HS	Unfavorable	Controversial	Neutral	Encouraging	Favorable	Overall
Oil source strata appraisal						0.8
Saturability with HS					0.9	
Maturity					0.8	
Reservoir appraisal						0.8
Presence					0.9	
Quality					0.8	
Trap appraisal						0.8
Trap identification reliability					0.8	
Trap characteristic					0.8	
Seal quality					0.8	
Geochronology						0.9
Factor of time					0.9	
Migration paths					0.9	
Reservoir integrity					0.9	
Geological success probability						0.461

Table 7. Resultant estimates of risk assessment and geological success probability

HS	Geological risks $P_{risk} = 1 - (1 - P_{1risk})(1 - P_{2\,risk}) \times (1 - P_{3risk})(1 - P_{4\,risk})$, %	Probability of success $R_{v.o.} = R_{1v.o}R_{2v.o} \times R_{3v.o}R_{4v.o}$, %
Eocene–Pliocene	69.13	30.87
Maikop–Pliocene	34.39	65,61
Miocene–Pliocene	53.92	46.08

Calculation of geological success probability and risk assessment in geological exploration in the Miocene–Pliocene HS:

$P_{risk} = 1 - (1 - P_{1risk})(1 - P_{2risk})(1 - P_{3risk})(1 - P_{4risk}) = 1((1 - 0.2) \times (1 - 0.2)(1 - 0.2)(1 - 0.1) = 0.5392 \cdot 100\% = 53.92\%$;

$R_{v.o.} = R_{1v.o}R_{2v.o}R_{3v.o}R_{4v.o} = 0.8 \cdot 0.8 \cdot 0.8 \cdot 0.9 = 0.4608 \cdot 100\% = 46.08\ \%$;

$R_{risk} + R_{v.o.} = 1$.

Conclusions

The Southern Caspian Basin contains three generation–migration hydrocarbon systems: Eocene–Pliocene, Maikop–Pliocene and Miocene–Pliocene. These systems were identified based on the results of hydrocarbon modeling.

The analysis covered the characteristics of OGSR, assessment of reservoir properties of rocks and seals, study of hydrocarbon traps, and time parameters of formation of HS elements. Particular attention is palD to the analysis of geochronological relationships of hydrocarbon feedstock components development. The degree of development and efficiency of hydrocarbon migration channels are considered as an additional criterion of success probability.

As a result of the calculations of the probability of geological success of geological exploration work in the South Caspian Basin, the following values were obtained for the three hydrocarbon systems: Eocene–Pliocene — 30.9%, Maikop–Pliocene — 65.6% and Miocene–Pliocene — 46.1%. Such indicators indicate minimal geological risks during exploration work in the region.

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HYDROCARBON ORIGIN AND PETROLEUM SYSTEM FRAMEWORK OF THE CUU LONG BASIN SHELF (VIETNAM)

This study examines the origin and mechanisms of hydrocarbon accumulation in the Cuu Long Basin (offshore Vietnam), with particular emphasis on oils hosted in fractured and cavernous granitoids of the crystalline basement. A comprehensive set of molecular geochemical analyses was performed, including gas chromatography (GC), gas chromatography–mass spectrometry (GC–MS), and high-performance liquID chromatography (HPLC), in accordance with ASTM and ISO standards. The distribution patterns of n-alkanes, isoprenoids, steranes, and terpanes revealed identical biomarker profiles for basement-hosted oils and oils associated with Oligocene–Miocene reservoirs. The absence of regular C_{12} and C_{17} isoprenoids, together with the lack of C_{22} and C_{27} cheilanthanes, as well as elevated cheilanthane indices and high hopane/sterane ratios, confirm the biogenic origin of these oils and indicate a significant bacterial contribution to the initial organic matter. The findings support a two-stage migration model: lateral migration within carrier beds, followed by downward migration along fault and fracture zones into the basement. It is established that hydrocarbons in the crystalline basement occur in secondary accumulations and are derived from Oligocene–Miocene source rocks. These results refine the petroleum system model of the basin and substantiate the priority of future exploration for new accumulations in basement reservoirs.

Keywords: *Cuu Long Basin, crystalline basement, biomarkers, n-alkanes, steranes, terpanes, hydrocarbon migration, petroleum system, offshore Vietnam, basement reservoirs*
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Introduction

The problem of oil occurrence in crystalline basement rocks, particularly when they are closely associated with overlying sedimentary source rock intervals, remains one of the key issues in petroleum geochemistry and basin analysis. The composition of oils and organic matter, together with biomarker distributions at the molecular level, are essential factors for reconstructing hydrocarbon generation conditions and migration pathways [1].

The Cuu Long Basin is among the most prolific petroleum provinces of the Vietnamese continental shelf. One of its most important discoveries is the Bạch Hổ (White Tiger) oil field, where a substantial portion of reserves is hosted in fractured and cavernous granitoids of the crystalline basement, overlain by Oligocene–Miocene sediments. These