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Effect of Temperature and Pressure on the Composition of Oils from the Bazhenovskaya Formation in the Latitudinal Segment of the Ob River Area

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Abstract—Detailed data obtained on surface oil samples from the Bazhenovskaya Formation in the latitudinal segment of the Ob River area indicate that the composition of the oil is largely controlled by the P–T conditions in the reservoir. It was determined that the generation of hydrocarbon fluids starts at higher temperatures ($T_f >$ 100°C) if the fluid reflux is hindered and the formation pressures are anomalously high. In systems with the free reflux of hydrocarbon fluids, the processes generating oil and gas are different. The composition of oil in the Bazhenovskaya Formation with the free reflux of hydrocarbon fluids is largely controlled by migration processes, which determine, along with the P–T parameters, the physicochemical characteristics of the oils and their concentrations of hydrocarbon groups and individual hydrocarbons.

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INTRODUCTION

The Bazhenovskaya Formation was first distinguished as an individual stratigraphic unit by Gurari [1] in 1959. The formation is a carbon-rich sandy–clayey–carbonate unit characterized by a significant oil-generating potential. According to Acad. A.E. Kontorovich [2], the rocks of this formation are the source of hydrocarbons for fields that currently yield >75% of the economic oil resources in western Siberia. The uniqueness of this formation also stems from the fact that the hindered fluid reflux due to the isolation of the formation by effective fluid-impermeable beds is favorable for the in situ generation of oil reserves [3]. The identification of the characteristics of oil- and gas-generating processes in the Bazhenovskaya Formation is a problem important for the further development of the sedimentary–migration theory of naphtidegenesis [4]. From this standpoint, the detailed study of oils from the Bazhenovskaya Formation seems to be of much importance.

BRIEF CHARACTERIZATION OF THE OILS

Our research was centered on oils from the Salym district and the hydrocarbon (HC) fluids of the Bazhenovskaya Formation found in the western and northern limbs of the Surgut arch.

Materials on oils from the western limb of the arch (Ai-Pimskaya, Kamynskaya, Alekhinskaya, and Maslikhovskaya fields) indicate that the Bazhenovskaya Formation is characterized by a high formation pressure (K_{an} = 1.1–1.6), and its formation temperatures are often higher than 100°C (T_f = 81–105°C). The composition of fluids from the Kamynskaya field is closely similar to that of the group of oils from the Salymskii district, where the effect of temperature is counterbalanced by the high formation pressure. These are the oils of the Khanty-Mansiiskaya, Pravdinskaya, and, particularly, Verkhneshapshinskaya fields. They are characterized by high formation pressures (K_{an} = 1.2–1.5) and temperatures close to 100°C. According to Neruchev et al. [5], oil reserves at the Kamynskaya field in the Salymskii district can be provisionally attributed to a system with the hindered reflux of hydrocarbon fluids, and, thus, it is reasonable to expect that fields can be formed there in situ.

Accumulations of hydrocarbon fluids in the northern part of the Surgut arch and its monocline (Vostochno-Yagunskaya, Zapadno-Tevlinskaya, Russkinskaya, and Sorymsko–Imenskaya fields) correspond to normal hydrostatic pressures (K_{an} < 1), and the formation temperatures in this area lie within the range of 75–90°C. Our data suggest that the oils of the northern part of the Surgut arch and its monocline correspond to systems with the free reflux of hydrocarbon fluids.

It should be noted that the terms *closed* and *open* systems are applied here only provisionally and largely reflect the modern state of these systems. The dynamics of the thermal transformations of organic matter (OM) significantly differs in closed and open systems. At hindered reflux and the development of anomalously high formation pressures (closed system), the transforma-

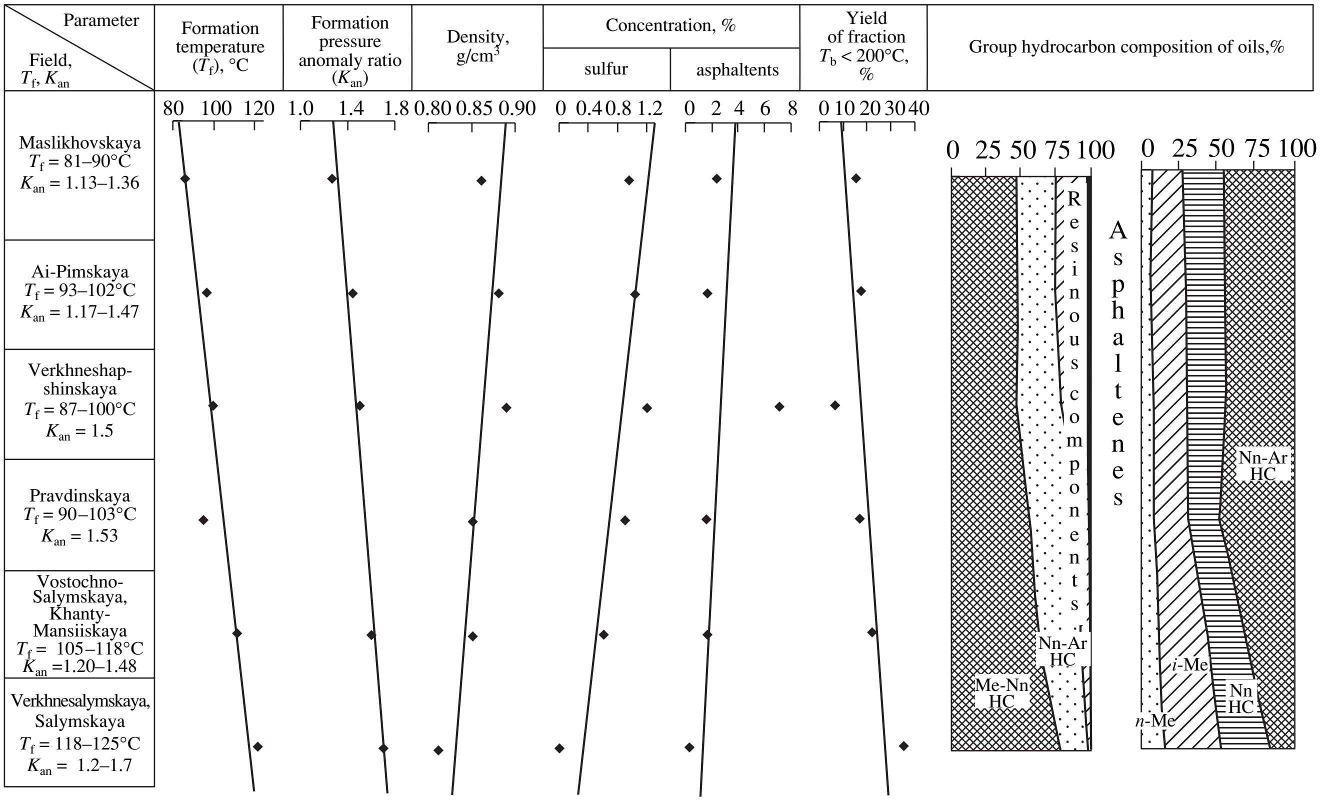

Fig. 1. Variations in the physicochemical parameters and group hydrocarbon composition of oils from the Bazhenovskaya Formation in a system with anomalously high formation pressure (AHFP) as functions of the formation pressure and temperature.

tions of OM are decelerated and reach a maximum of the main phase of oil generation (MPO) at greater depths and higher temperatures than in an open system with a normal hydrostatic pressure. At anomalously high formation pressures (AHFP), the process of OM transformations is apparently shifted toward the predominant generation of liquid oil hydrocarbons and wet gases. Conversely, these processes in a closed system are shifted toward the large-scale production of methane and the less intense generation of liquid products [5].

METHODS

The physicochemical analysis of oils from the Bazhenovskaya Formation was conducted at the Laboratory of Organic Geochemistry, FGUP SNIIGGiMS, in compliance with the scheme [6] for the analysis of oil. We examined 50 oil samples. The group hydrocarbon composition of the analyzed fluids was calculated based on mass spectrometric data [7]. The composition of the alkanes of normal structure (nC$_{10}$–nC$_{36}$) and acyclic isoprenoids (iC$_{14}$–iC$_{20}$) was analyzed by gas–liquid chromatography on an Khrom-500 M chromatograph with a capillary column 50 m long and an internal diameter of 0.25 mm [8]. The immobile phase was apiezon L. The cyclic isoprenoids of oils from the northern and western fields of the Surgut oil and gas district (OGD) were analyzed at IGNiG SO RAS. The cyclic isoprenoids of oils from the Salymskii district were studied with the use of data published elsewhere [9–11].

RESULTS AND DISCUSSION

The results obtained on the geochemistry of oils from the Bazhenovskaya Formation in the Salymskii district (Salymskaya, Verkhnesalymskaya, Vostochno-Salymskaya, Pravdinskaya, Khanty-Mansiiskaya, Verkhneshapshinskaya, Multanovskaya, and Malobalykskaya fields) demonstrate that the temperature was not the only factor that controlled the composition of the hydrocarbon fluids [12]. The state of hydrocarbons in the oil-bearing bed of the system is controlled by the *P–T* parameters, i.e., a certain combination of temperature and pressure. The variations in these parameters allowed us to trace the effect of formation pressure and temperature on the composition of the fluids and to distinguish the following three groups of oils:

(1) Oils in high-pressure and high-temperature regions (K_{an} = 1.2–1.7, >120°C, respectively).

(2) Oils of high-pressure (K_{an} = 1.2–1.5) and medium-temperature (100–120°C) regions.

(3) Oils of high-pressure (K_{an} = 1.2–1.5) and relatively low-temperature (<100°C) regions.

The broad variations in the *P–T* parameters in the deposits of the Bazhenovskaya Formation are reflected in the unusual composition of the oils. Figure 1 presents the results obtained on the physicochemical parameters of oils in systems with the hindered reflux of HC fluids. These data demonstrate that an increase in the formation temperature (from 81 to 125°C) and pressure ($K_{an} = 1.1–1.7$) is associated with a decrease in the density of the fluids from 0.90 to 0.83 g/cm^3. Simultaneously the concentrations of sulfur and asphaltenes also decrease (from 1.2 to 0.2% and from 4 to 1%, respectively), whereas the contents of low-boiling hydrocarbons ($T_b < 200°C$) increase from 10% (Verkhneshapshinskaya field, Well 1; Maslikhovkaya field, Well 21) to 29% (Salymskaya field, Wells 15 and 18).

The physicochemical characteristics of the oils affect the group compositions of hydrocarbons in these fluids (Fig. 1). An increase in the formation pressure and, particularly, temperature ($T_f > 100°C$) results in an increase in the concentration of the methane–naphthene fractions in the fluids from 40% (Verkhneshapshinskaya field, Well 1) to 80% (Salymskaya field, Wells 15 and 18), whereas the concentrations of naphthene–aromatic fractions simultaneously decrease from 34 to 15%.

The fluids of the Bazhenovskaya Formation are noted for high concentrations of naphthene–aromatic fractions (Fig. 1). In the oils whose formation temperature did not exceed 100°C and the formation pressure anomaly ratio ranges from 1.3 to 1.5, these fractions account for approximately 50%. An increase in the formation pressure ($K_{an} = 1.7$) and, particularly, temperature ($T_f = 125°C$) results in a decrease in their contents to 10–15%, whereas the concentrations of normal and branched alkanes simultaneously increase.

Examining the variations in the group hydrocarbon compositions of the fractions, we determined that the more rigid *P–T* regimes of the oil system are associated, as was mentioned above, with an increase in the contents of low-boiling fractions ($T_b < 200°C$) from 10% (Verkhneshapshinskaya field, Well 1) to 29% (Salymskaya field, Well 31). The amount of asphaltene resinous components (tars) decreases from 32 to 3–6% (Fig. 2).

The gasolines are characterized by an increase in the concentrations of aromatic components from 1 to 7% (Fig. 2). The concentrations of normal and branching alkanes decrease. A temperature increase to >100°C results in an increase in the concentrations of *n*-alkanes in the high-boiling hydrocarbons from 8 to 12%. The concentrations of naphthene–aromatic fractions decrease to ~20%. It should be mentioned that a temperature increase to >100°C in systems with hindered fluid reflux leads to an increase in the contents of saturated hydrocarbons, such as naphthenes and normal and branched alkanes. The concentration of unsaturated alkanes drastically decreases.

The changes in the proportions of *n*-alkanes in the stripped fractions are also reflected in the qualitative composition of the *n*-alkanes. For example, oils from the Maslikhovskaya, Ai-Pimskaya, and Verkhneshapshinskaya fields, whose formation temperatures are close to 100°C, are characterized by roughly equal concentrations of *n*-alkanes of the composition $nC_{12}–nC_{18}$ and $nC_{19}–nC_{36}$ (Table 1). As the temperature increases to >100°C, the concentrations of short-chain *n*-alkanes of the composition $nC_{12}–nC_{18}$ increase in the oils by a factor of 1.5.

It follows that a temperature increase to >100°C in systems with an anomalously high pressure ($K_{an} \geq 1$) results in an increase in the concentrations of *n*-alkanes due to an increase in the amounts of low-boiling compounds. In relatively low temperature systems ($T_f < 100°C$), the temperature effect is significantly “suppressed” by the very high formation pressures, and, thus, pressure plays in these systems a determining role. As the formation temperature increases to >100°C, the role of the temperature factor rapidly increases, and this results in an increase in the contents of low-molecular compounds, including normal alkanes. This also follows from the occurrence of a concentration maximum in the region of *n*-alkanes of the composition $nC_9–nC_{12}$ in the Salymskaya oil, which is characterized by the highest formation pressure ($K_{an} = 1.7$) and a high formation temperature ($T_f = 125°C$). It should be mentioned that the character of the relative distribution of *n*-alkanes ($nC_{10}–nC_{36}$) in the stripped oil fractions ($T_f > 200°C$) is the same. The molecular-mass distribution of the *n*-alkanes has a concentration maximum at *n*-alkanes of the composition $nC_{15}–nC_{17}$ (Fig. 3), which is consistent with the supposedly marine genesis of fluids in the Bazhenovskaya Formation [8, 10, 11].

The effect of the *P–T* parameters of oil systems is also discernible in the qualitative and, sometimes, quantitative composition of the isoprene compounds of aliphatic and cyclic structure.

The acyclic isoprenoids of the oils are alkanes of the composition $iC_{14}–iC_{20}$ (Table 1). The concentration maximum in the homologous series of these hydrocarbons falls onto phytane (iC_{20}). The values of the pristane/phytane (iC_{19}/iC_{20}) ratio vary from 0.77 to 0.89, averaging 0.8. The increase in the *n*-octadecane to phytane (nC_{18}/iC_{20}) ratio from 1.1 to 2.2 most probably resulted from the general tendency toward a decrease in the fraction of acyclic isoprenoids in the oils under the effect of high temperatures.

The cyclic isoprenoids of these oils are cheilanthanes, steranes, and hopanes. The composition of the cyclic isoprenanes is characterized by constant concentrations of steranes (~36%; Fig. 4). A temperature increase results in an almost twofold increase in the contents of triterpanes (cheilanthanes), while the concentrations of pentaterpanes (hopanes) decrease from

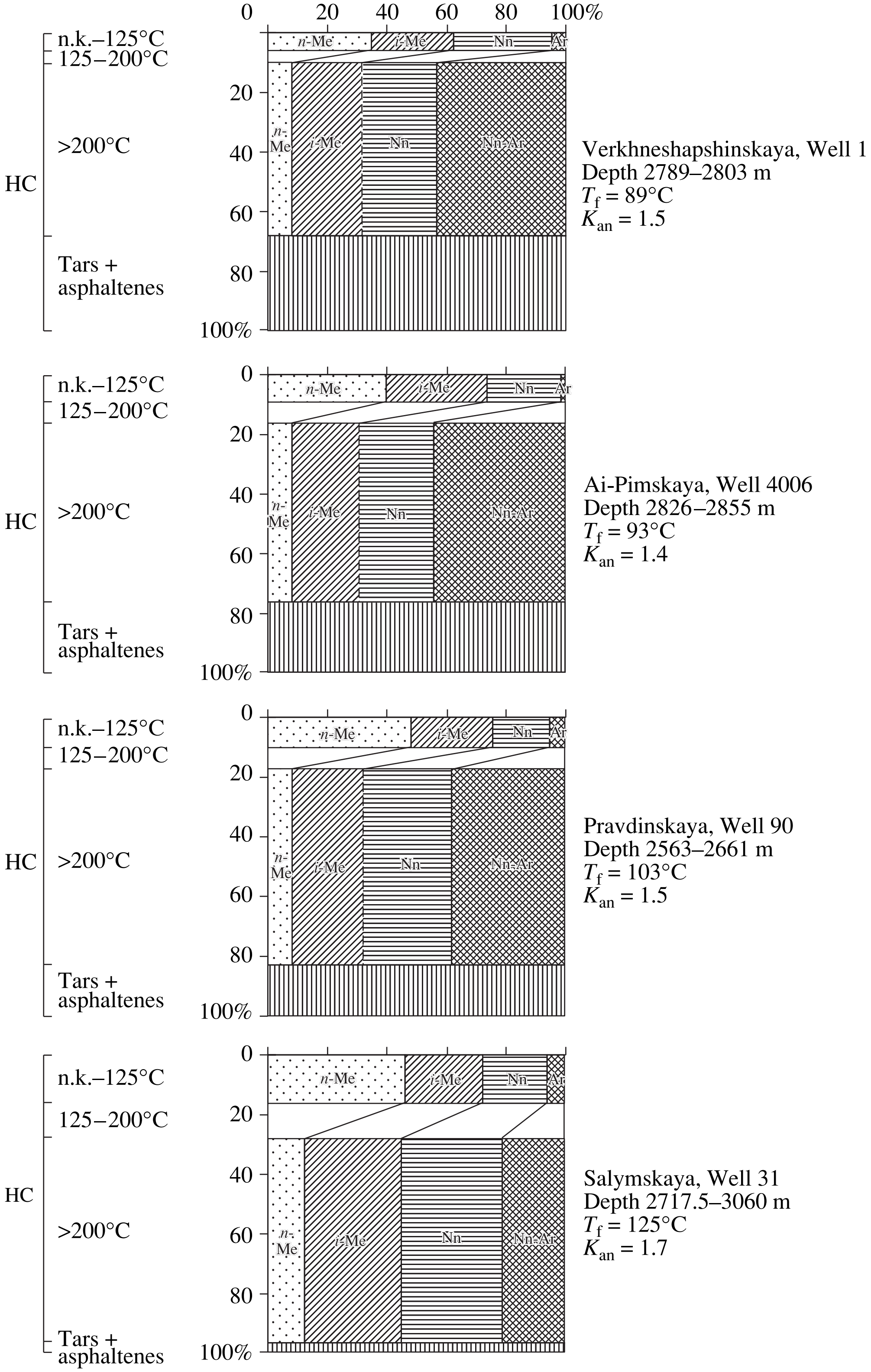

Fig. 2. Concentrations of hydrocarbon groups in the oils of the Bazhenovskaya Formation with the hindered reflux of hydrocarbon fluids.

Table 1. Composition of *n*-alkanes and isoprenoids in the oils of the Bazhenovskaya Formation with the hindered reflux of hydrocarbon fluids

Field, well	Depth, m	T_f, °C	K_{an}	*n*-Alkanes (%, per oil)			Isoprenoids (%, per oil)			$\frac{iC_{19}}{iC_{20}}$	$\frac{nC_{12}–nC_{18}}{iC_{14}–iC_{20}}$	$\frac{nC_{18}}{iC_{20}}$
				$nC_{12}–nC_{18}$	$nC_{19}–nC_{36}$	$nC_{15}–nC_{25}$	$iC_{14}–iC_{20}$	iC_{19}	iC_{20}			
Ai-Pimskaya, 3	2808–2856	–	–	2.82	1.70	2.88	0.90	0.16	0.19	0.86	3.15	1.67
Ai-Pimskaya, 4006	2826–2855	93	1.38	2.22	2.42	3.40	0.93	0.24	0.27	0.88	2.39	1.35
Maslikhovskaya, 21	2835–2867	90	1.32	2.78	2.25	3.60	0.77	0.16	0.21	0.77	3.61	1.87
Verkhneshapshinskaya, 1	2789–2803	89	1.50	1.67	2.58	2.69	0.95	–	–	0.82	–	1.14
Salymskaya, 101	2823–2880	125	1.70	5.39	3.48	4.14	–	–	–	0.89	–	2.17

53 to 45%. Thus, a temperature increase at a hindered reflux leads to the destruction of pentacyclic compounds. The proportion of tri- to pentaterpanes increases from 0.24 (Ai-Pimskaya field, Well 4006, $T_f = 93°C$) to 0.40 (Salymskaya field, Well 301, $T_f = 110°C$). According to Petrov [8, 10], this parameter reflects the degree of catagenetic transformations in a given oil-generating system.

Our research has demonstrated that regular steranes (which are tetracyclic compounds) are characterized by equal concentrations of cholestanes (C_{27}), methyl- (C_{28}), and ethyl- (C_{29}) cholestanes (Table 2, Fig. 5). The distribution of these hydrocarbons in the oils corresponds to $C_{27} : C_{28} : C_{29} = 33 : 32 : 35$. Thus, changes in the *P–T* parameters of closed oil-generating systems have virtually no effect on the composition of regular steranes. Because of this, the proportions of these

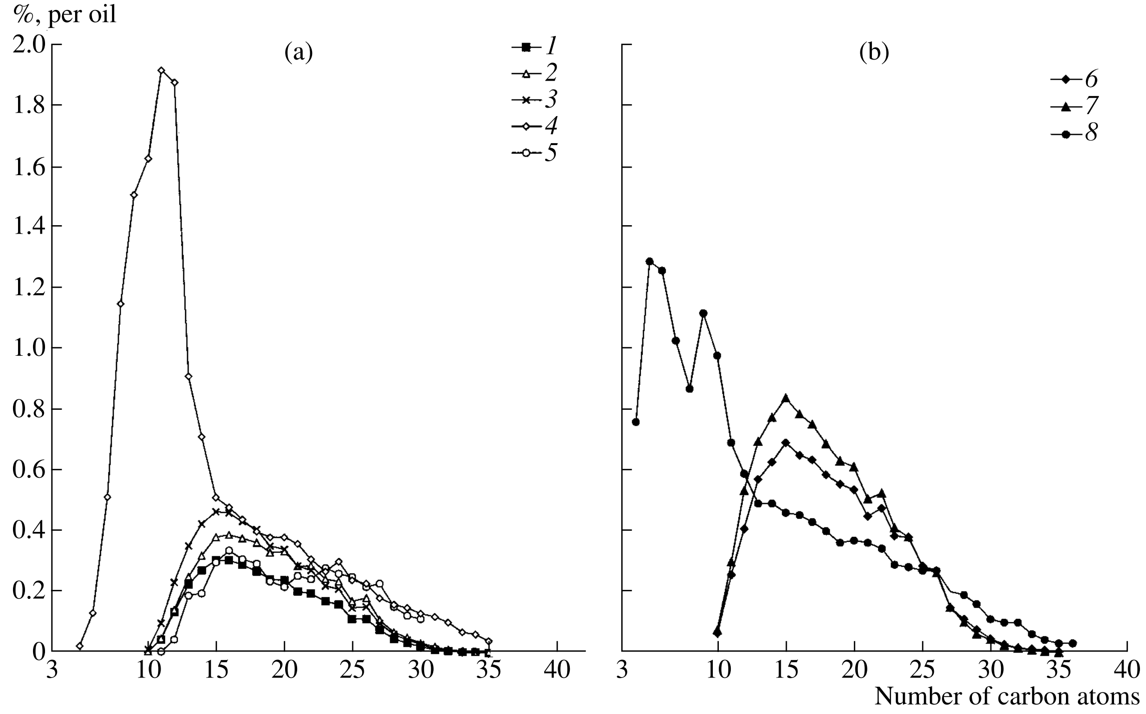

Fig. 3. Distribution of *n*-alkanes in oils from the Bazhenovskaya Formation for systems with (a) hindered and (b) free reflux of hydrocarbon fluids. (*1*) Ai-Pimskaya field, Well 3, depth 2808–2856 m; (*2*) Ai-Pimskaya field, Well 4006, depth 2826–2855 m; (*3*) Maslikhovskaya field, Well 21, depth 2835–2867 m; (*4*) Salymskaya field, Well 101, depth 2823–2880 m; (*5*) Verkhneshapshinskaya field, Well 1, depth 2789–2803 m; (*6*) Russkinskaya field, Well 214, depth 2780–2790 m; (*7*) Zapadno-Tevlinskaya field, Well 83, depth 2774–2804 m; (*8*) Sorymsko-Iminskaya field, Well 9, depth 2735–2848 m.

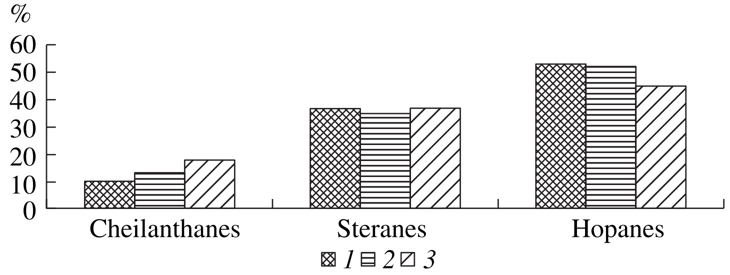

Fig. 4. Variations in the composition of cyclic isoprenoids in oils from systems with hindered reflux. (*1*) Ai-Pimskaya field, Well 4006, depth 2826–2855 m (T_f = 93°C); (*2*) Maslikhovskaya field, Well 21, depth 2835–2867 m (T_f = 90°C); (*3*) Salymskaya field, Well 301, depth 2970–3024 m (T_f = 105°C).

hydrocarbons are an important indicator that makes it possible to identify correlations in systems of oils and their source rocks.

In contrast to regular steranes, diasteranes are very sensitive to temperature variations (Table 2). An increase in the temperature to >100°C leads to the appearance of significant amounts of regrouped steranes. The contents of diasteranes in the Salymskaya oil, whose formation temperature is close to 125°C, are almost doubled relative to those in oils with lower formation temperatures (Ai-Pimskaya, Maslikhovskaya, Verkhneshapshinskaya, and Salymskaya (Wells 96 and 114) fields).

According to their distribution of hopanes, the oils can be classified into three groups (Fig. 5), which corresponds to the classification of oils from the Salymskii district according to their concentrations of hydrocarbon groups and individual hydrocarbons. For example, the proportions of hopanes ($C_{27} : C_{29} : C_{30} = 17 : 25 : 58$) in the oils of the Maslikhovskaya and Ai-Pimskaya fields are the same as in the oils of the Verkhneshapshinskaya field, whose formation pressure corresponds to $K_{an} = 1.5$ and the temperature is close to 100°C. The oil from the Salymskaya field (Wells 96 and 114), which is characterized by a high formation pressure ($K_{an} = 1.05–1.45$) and formation temperatures from 100 to 118°C, composes the second group of oils, which display the following proportions of hopanes: $C_{27} : C_{29} : C_{30} = 30 : 21 : 49$. The third group comprises oils from fields with very high formation temperatures (T_f > 120°C) and anomalously high pressures ($K_{an} = 1.2–1.7$). The proportions of hopanes in these oils are $C_{27} : C_{29} : C_{30} = 46 : 17 : 37$ (Table 2, Fig. 5).

A temperature increase results in an increase in the concentrations of trisnorhopanes (C_{27}) among pentacyclic isoprenoids due to a change in the concentrations of structurally regrouped trisnorhopane (T_s) (Table 2, Fig. 6).

Table 2. Composition of steranes and hopanes in the oils of the Bazhenovskaya Formation with the hindered reflux of hydrocarbon fluids

Field, well	Depth, m	Fluid type	T_f, °C	K_{an}	Steranes				Hopanes	
					distribution of regular steranes $C_{27} : C_{28} : C_{29}$	C_{29}			distribution of hopanes $C_{27} : C_{29} : C_{30} : C_{31}$	$\frac{T_s}{T_s + T_m}$
						$\frac{\text{dia-}}{\text{regular}}$	K_1	K_2		
Ai-Pimskaya, 4006	2826–2855	oil	93	1.38	35 : 29 : 36	0.26	0.47	4.34	12 : 18 : 37 : 33	0.40
Ai-Pimskaya, 4004	2848–2857 (0.3)	bitumoid	–	–	35 : 30 : 34	0.22	0.48	3.94	17 : 17 : 37 : 29	0.50
Verkhneshapshinskaya, 1	2789–2817	oil	89	1.50	30 : 35 : 35	0.43	0.56	5.60	10 : 17 : 38 : 35	0.50
Salymskaya, 96	2830–2896	oil	105	1.23	33 : 33 : 34	0.57	0.53	5.40	24 : 17 : 35 : 24	0.75
Salymskaya, 114	2868–2900	oil	120	1.10	34 : 28 : 38	0.43	0.50	4.50	20 : 15 : 38 : 27	0.77
Salymskaya, 28	2775–2820	oil	132	1.45	36 : 31 : 33	0.82	0.55	5.38	34 : 11 : 30 : 25	0.86
Salymskaya, 1	2824.9	bitumoid	125	1.27	38 : 31 : 31	1.15	0.56	5.25	37 : 14 : 28 : 21	0.81

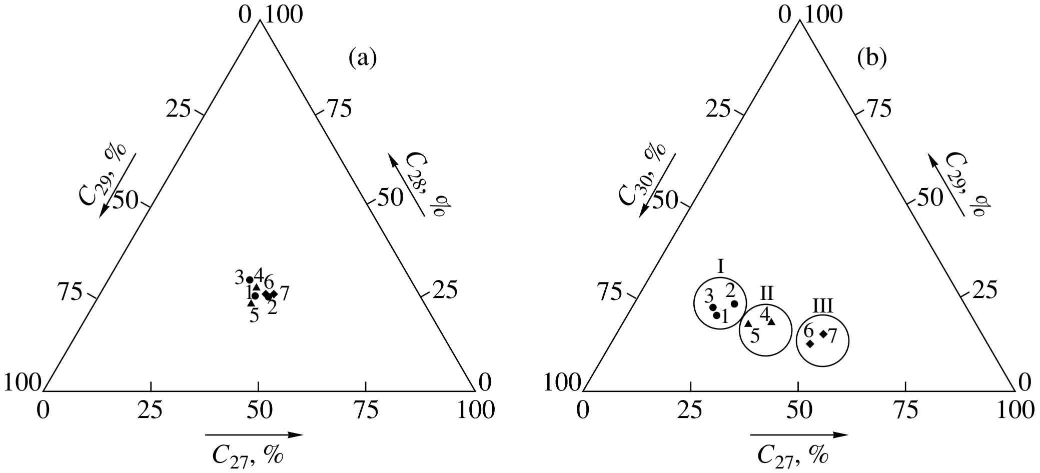

Fig. 5. Triangular plots for the composition of (a) regular steranes and (b) hopanes in (1–6) oils and (7) bitumoid from the Bazhenovskaya Formation for the system with the hindered reflux of hydrocarbon fluids. (1) Ai-Pimskaya field, Well 4006, depth 2826–2855 m; (2) Maslikhovskaya field, Well 21, depth 2835–2867 m; (3) Verkhneshapshinskaya field, Well 1, depth 2789–2803 m; (4) Salymskaya field, Well 96, depth 2830–2896 m; (5) Salymskaya field, Well 114, depth 2868–2900 m; (6) Salymskaya field, Well 28, depth 2775–2820 m; (7) Salymskaya field, Well 1, depth 2824.9 m.

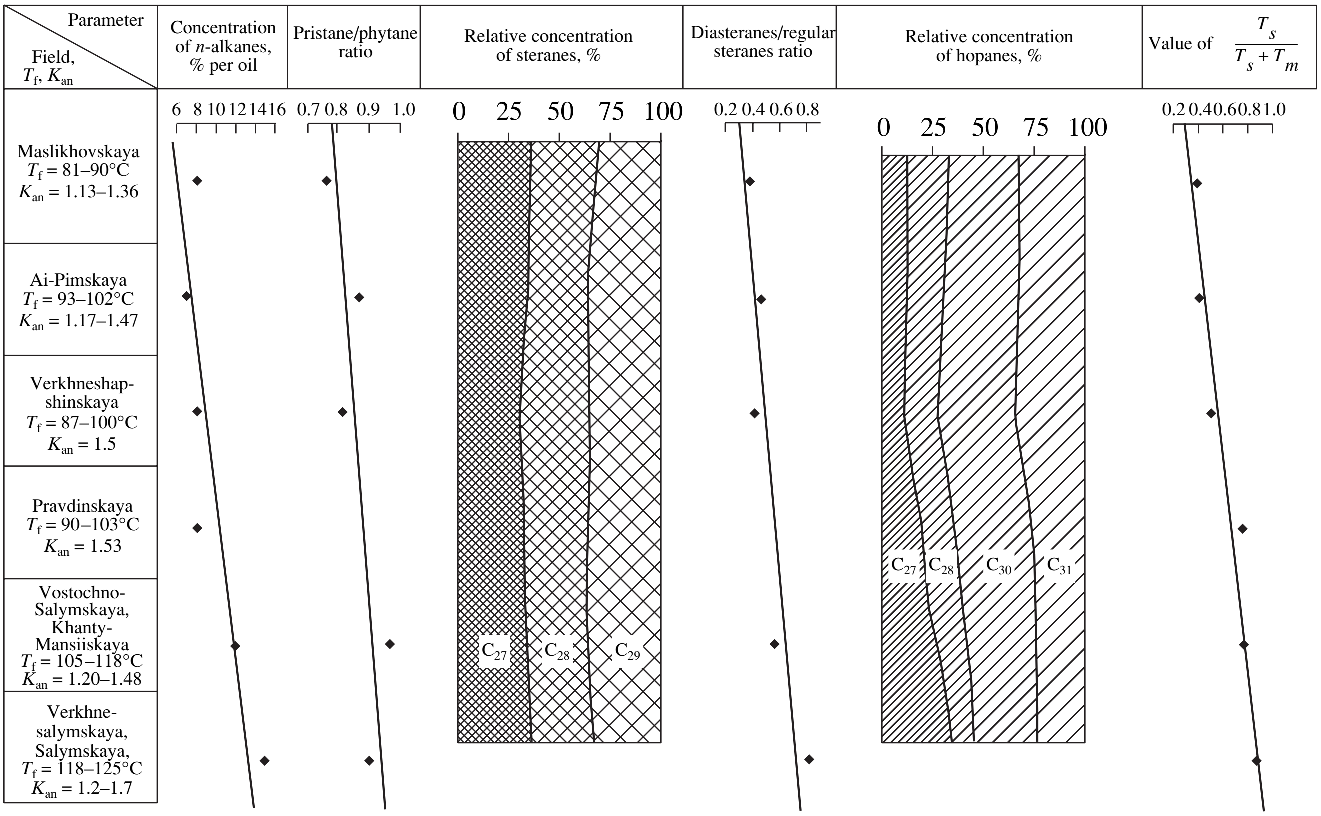

Fig. 6. Variations in the composition of relict hydrocarbons in oils from the Bazhenovskaya Formation in a system with anomalously high formation pressure (AHFP) as functions of the formation pressure and temperature.

The $T_s/(T_m + T_s)$ ratio becomes more than twice as high (increases from 0.4 to 0.9) with increasing temperature. It is worth mentioning that an increase in the contents of trisnorhopanes in the oils is analogous to the variations in the amounts of methane and naphthene hydrocarbons (Fig. 1).

Note that changes in the group hydrocarbon composition in systems with hindered HC fluid reflux are also

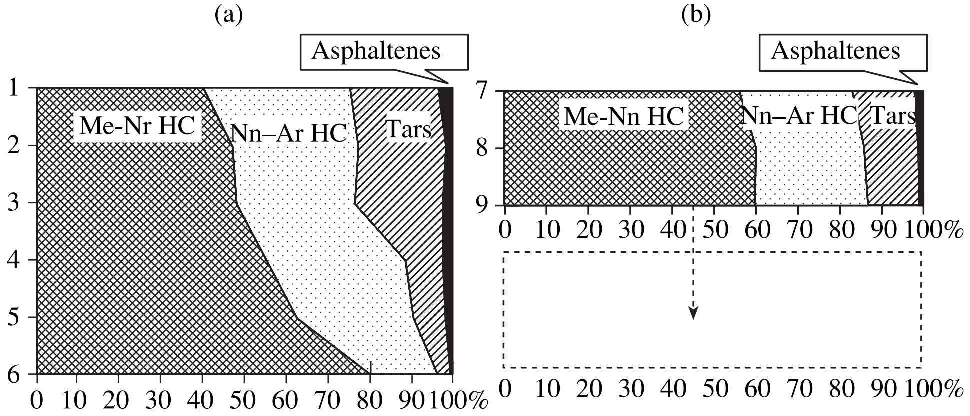

Fig. 7. Variations in the concentrations of hydrocarbon groups in the oils of the Bazhenovskaya Formation with (a) hindered and (b) free reflux of hydrocarbon fluids as functions of the formation temperature and pressure. Oils: (1) Verkhneshapshinskaya (K_{an} = 1.5, T_f = 87–110°C); (2) Maslikhovskaya (K_{an} = 1.13–1.36, T_f = 81–90°C); (3) Ai-Pimskaya (K_{an} = 1.17–1.47, T_f = 93–102°C); (4) Pravdinskaya (K_{an} = 1.53, T_f = 90–103°C); (5) Khanty-Mansiiskaya, Vostochno-Salymskaya (K_{an} = 1.2–1.48, T_f = 105–118°C); (6) Salymskaya, Verkhnesalymskaya (K_{an} = 1.2–1.7, T_f = 118–125°C); (7) Zapadno-Tevlinskaya ($K_{an} \leq 1$, T_f = 75–80°C); (8) Russkinskaya ($K_{an} \leq 1$, T_f = 90°C); (9) Vostochno-Yagunskaya ($K_{an} \leq 1$, T_f = 88°C).

reflected in the composition of the relict hydrocarbons (Fig. 6).

It was determined that a temperature increase (to >100°C) results in an increase in the concentrations of *n*-alkanes, a decrease in the contents of acyclic isoprenoids, and an increase in the amount of cheilanthanes, trisnorhopanes (mostly owing to an increase in the concentrations of trisnorneohopane T_s), and diasteranes.

The facts presented above testify to the catagenetic transformations of the oils, with these transformations occurring in oils at higher temperatures (T_f > 100°C) if the formation pressures increase.

If an oil system is characterized by a free discharge, the processes of oil generation proceed in a different manner, so that temperature is the major factor controlling the origin of the hydrocarbons. Information pertinent to this problem is still scarce. However, some tendencies in the variations in the composition of hydrocarbons in open systems were identified in oils from the Bazhenovskaya Formation in the northern limb of the Surgut arch and its monocline (Russkinskaya, Zapadno-Tevlinskaya, Vostochno–Yagunskaya, and Syromsko–Imenskaya fields).

The data obtained on these fluids indicate that the Bazhenovskaya oils from these fields are less dense (0.85–0.88 g/cm^3), are less sulfuric (0.6–1.2%) and resinous (3–7%), and have higher concentrations of gasoline fractions (18–32%). The group composition of the hydrocarbons is characterized by an increase in the concentrations of aliphatic structures (Fig. 7).

In contrast to the oils of the Kamynskaya field and Salymskii district, whose formation temperatures are no higher than 100°C, the oils of the Zapadno-Tevlinskaya and Russkinskaya fields have elevated contents of methanonaphthene HC fractions. The amounts of these hydrocarbons in the oils of open systems increase mostly due to an increase in the concentrations of *n*-alkanes (Fig. 7), whose contents in the oil fractions boiling at temperatures of >200°C amount to 7–9% (Table 3). It should be mentioned that these concentrations of alkanes of anomalous structure are typical of the oils of closed systems, which are characterized by high formation pressures (K_{an} = 1.7) and temperatures (T_f = 125°C). Our data suggest that the catagenetic transformations of oils start in open systems at lower formation temperatures (T_f = 75–90°C) than in the oils of closed systems. It should be mentioned also that the oils of closed systems with formation temperatures lower than 100°C contain approximately 5% *n*-alkanes, and the contents of individual *n*-alkanes in these oils do not exceed 0.4% of the oil. The oils of open systems generally bear more individual *n*-alkanes: up to 0.85% of the oil. In spite of these significant differences in the quantitative parameters, the qualitative composition of *n*-alkanes in open and closed systems remains practically identical. The molecular-mass distribution of *n*-alkanes (nC_{10}–nC_{36}) boiling at >200°C has a maximum at normal alkanes of the composition nC_{15}–nC_{17} (Fig. 3), which suggests that the hydrocarbon fluids of the oils in open and closed systems originated from the same source (from the Bazhenovskaya Formation).

The oils of the Bazhenovskaya Formation with the free reflux of hydrocarbon fluids contain much more acyclic isoprenoids, from 1.2 to 1.7% of the oils (Table 3). The pristane/phytane ratio in the Zapadno-Tevlinskaya and Russkinskaya oils approaches unity. An increase in the concentrations of pristane, a component migrating more readily, indicates that the oils of the open system are more strongly affected by migration processes, and, hence, these oils are characterized by a more equalized

Table 3. Composition of *n*-alkanes and isoprenoids in the oils of the Bazhenovskaya Formation with the free reflux of hydrocarbon fluids

Field, well	Depth, m	*n*-Alkanes, % per oil			Isoprenoids, % per oil			$\frac{iC_{19}}{iC_{20}}$	$\frac{nC_{12}–nC_{18}}{iC_{14}–iC_{20}}$	$\frac{nC_{18}}{iC_{20}}$
		$nC_{12}–nC_{18}$	$nC_{19}–nC_{36}$	$nC_{15}–nC_{25}$	$iC_{14}–iC_{20}$	iC_{19}	iC_{20}			
Sorymsko-Iminskaya, 9	2735–2848	3.31	3.56	4.01	1.18	0.19	0.27	0.70	2.80	1.48
Zapadno-Tevlinskaya, 83	2774–2804	5.06	4.01	6.40	1.70	0.40	0.36	1.10	2.98	1.89
Russkinskaya, 214	2780–2790	4.16	3.78	5.62	1.58	0.38	0.37	1.02	2.63	1.59

Table 4. Composition of steranes and hopanes in the oils of the Bazhenovskaya Formation with the free reflux of hydrocarbon fluids

Field, well	Depth, m	Steranes				Hopanes			
		distribution of steranes $C_{27} : C_{28} : C_{29}$	$\frac{\text{dia-}}{\text{regular}}$	C_{29}		distribution of hopanes $C_{27} : C_{29} : C_{30} : C_{31}$	ratios		
				K_1	K_2		$\frac{Ts}{Tm}$	$\frac{Ts}{Ts + Tm}$	$\frac{H_{29}}{H_{30}}$
Zapadno-Tevlinskaya, 83	2774–2804	35 : 31 : 34	0.47	0.5	4.18	13 : 17:40 : 30	1.69	0.63	0.42
Russkinskaya, 214	2780–2790	37 : 30 : 33	0.43	0.5	3.70	12 : 22 : 37 : 29	0.71	0.42	0.59

composition of the relict hydrocarbons. This is confirmed by the values of the nC_{12}–nC_{18}/iC_{14}–iC_{20} ratio. The oils of the open system have this ratio varying within a very narrow range: from 2.6 to 3.0. The oils of closed systems, in which fluid reflux is practically impossible, display this ratio varying from 2.4 to 3.6.

Cyclic isoprenoids in the oils of the Zapadno-Tevlinskaya and Russkinskaya fields comprise a wide spectrum of these hydrocarbons. The regular steranes of the composition C_{27}–C_{29} in these hydrocarbon fluids, as in the oils with a hindered reflux, have equal concentrations of each homologue (Table 4). The proportions of cholestanes (C_{27}), methyl- (C_{28}), and ethyl- (C_{29}) cholestanes correspond to $C_{27} : C_{28} : C_{29} = 36 : 30 : 34$. Hence, the distribution of regular steranes indicates that the oils have a single source: the deposits of the Bazhenovskaya Formation. The distribution of hopanes ($C_{27} : C_{29} : C_{30} : C_{31} = 12 : 19 : 39 : 30$) and the ratios of regrouped steranes to regular steranes (dia-/regrouped steranes = 0.4–0.6) in the fluids coincide with the analogous values for oils from systems with hindered HC fluid reflux, whose formation temperatures are close to 100°C (Tables 2, 4). These parameters point to the equal degrees of their transformations and confirm the earlier hypothesis that oil- and gas-generating processes in systems with free fluid reflux are initiated at lower formation temperatures. The values of the geochemical coefficients (K_1 = 0.51–0.52 and K_2 = 3.70–4.18) that characterize the catagenetic maturity of fluids in the northern part of the Surgut arch and its monocline indicate that these oils correspond to the "oil window," i.e., they are the oils of the main phase of oil production (Table 4).

The oils of the open system are characterized by extremely broadly varying concentrations of trisnorhopane (T_m) and its structurally regrouped homologue (T_s). The T_s/T_m ratio varies widely from 0.7 to 1.7 (Table 4), whereas the relative contents of trisnorhopanes ($T_s + T_m$) in the hopanes vary within a very narrow range of 12–13%. This broad scatter in the contents of trisnorhopane (T_m) and its structurally regrouped homologue (T_s) likely reflects migration processes, which play a determining role in open systems. As was demonstrated above, the catagenetic transformations of oils in closed systems lead to an increase in the contents of trisnorhopanes, mostly via a drastic increase in the concentrations of trisnorneohopane (T_s).

CONCLUSIONS

Our data on the composition of oils from the Bazhenovskaya Formation make it possible to trace the effects of anomalously high formation pressures at the hindered reflux of hydrocarbon fluids from the source rocks at various formation temperatures. The diversity of parameters characterizing the oils from the same oil-bearing bed demonstrates that an increase in formation pressures and temperatures results in a decrease in the densities of the oils and their concentrations of sulfur and asphaltenes, and an increase in the contents of gasoline fractions. A distinctive characteristic of the group hydrocarbon composition of the oils is the drastic decrease in the contents of asphaltenes and an increase in the concentrations of methane-naphthene fractions at high formation pressures and temperatures of >100°C. Analogous changes were identified in *n*-alkanes, diasteranes, and hopanes. In spite of such a variable composition of the oils, all of them are genetically related to sapropelic OM that reached the MK_1^1 and MK_1^2 catagenetic grades and are oils generated during the main phase of oil generation. The latter occurs for the oils of these systems at higher temperatures, because the anomalously high pressures suppress the processes of oil generation.

The oils of the Bazhenovskaya Formation with the free reflux of hydrocarbon fluids are characterized by elevated concentrations of alkanes of normal structure and acyclic isoprenoids, and their contents of pristane and phytane are equalized. The qualitative composition of steranes and hopanes in these oils coincides with that in oils from systems with hindered HC fluid reflux and formation temperatures of about 100°C. The extremely broadly varying proportions of structurally regrouped trisnorhopane (T_s) and trisnorhopane (T_m) and the increasing contents of acyclic isoprenoid, pristane, suggest that migration processes take place in these systems, with these processes playing an important role in the formation of oil reserves in open systems.

Our materials on the composition of oils from the Bazhenovskaya Formation in correlation with the *P–T* conditions yield interesting results and provide insight into oil-generating processes. These materials and results can also be utilized to improve the efficiency of geochemical techniques designed for predicting oil reserves and the quality of the oils.

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