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Prediction of the Phase State of Hydrocarbon Accumulations in the Mesozoic Deposits of Northwestern Siberia

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Abstract—The phase state of hydrocarbon accumulations was predicted using recent drilling data for three oil and gas complexes of the northern regions of the West Siberian petroliferous basin: Lower and Middle Jurassic, Upper Jurassic, and Berriasian–lower Valanginian (Achimov member); these results were compiled in simplified maps presented in the paper. In order to develop a plausible model and distinguish the zones of hydrocarbon accumulation of various phase states, we analyzed and systematized the existing concepts on the distribution of oil, oil–gas condensate, and gas condensate pools in the Mesozoic sequences of this region, types of organic matter in rocks, and stages of catagenetic alterations. Based on the data of the Tyumen SG-6 superdeep well, the oil-generating capacity of source deposits was assessed. Three zones differing in the phase state of hydrocarbons, oil, gas condensate–oil (transitional), and gas condensate, were distinguished in the map of the distribution of hydrocarbon accumulations in the Early–Middle Jurassic petroliferous complex of northwestern Siberia. Only two zones of hydrocarbon accumulations, oil and transitional, were detected in the Late Jurassic complex of the Nadym–Taz and Ust'-Yenisei regions. The same zones but within different boundaries were distinguished in the Achimov sequence. In contrast to the Jurassic beds, the zone of occurrence of oil accumulations in the Achimov member occupies a larger area and extends further north. In terms of density, the oils of the Achimov deposits were subdivided into three types: ultralight, light, and medium. The zones of their occurrence are shown in the map.

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INTRODUCTION

Western Siberia is the main oil- and gas-producing province of Russia. Year after year, the problem of maintaining high oil and gas recovery in this region has become more and more urgent. In this connection, oil geochemists face the problems of assessing perspectives and prediction of the phase state of hydrocarbon (HC) accumulations in deeper oil- and gas-bearing beds in the Mesozoic deposits of the northern regions of the West Siberian petroleum basin (PB).

Although the geology and geochemistry of the region have been extensively investigated, many problems are not yet solved and/or their solution requires additional efforts. This is related to the complexity of the geologic history of the region, wide range of oil and gas content, great depths of occurrence, strong differentiation of HC composition and the phase type of fluids, and considerable lithological variability of the deposits.

This study focuses on determining the geochemical characteristics of the spatial distribution of types of hydrocarbon accumulations in the Jurassic and Berriasian–early Valanginian (Achimov sequence) deposits of the Nadym–Pur and Pur–Taz petroliferous regions of western Siberia and prediction of the phase state of HC accumulations. It is based on our own data and the results of investigations by A.E. Kontorovich et al. (1975, 2001), I.V. Goncharov (1985, 1987), M.Ya. Rudkevich et al. (1985, 1988), N.N. Nemchenko et al. (2000), A.A. Nezhdanov et al. (2000), G.S. Fedorova et al. (2000), N.V. Lopatin et al. (1997, 1999), A.M. Brekhuntsov et al. (2000), V.A. Chakhmakhchev, S.A. Punanova, and T.L. Vinogradova (2003), T.L. Vinogradova and S.A. Punanova (2003, 2004), V.A. Skorobogatov et al. (1989, 2003), and others. Data from the Cadastre of the Mineral Resources of the Russian Federation as of January 1, 2003, were also used. This paper presents simplified maps showing the distribution of hydrocarbon fluid accumulations in the northern part of the West Siberian PB, which improve the existing concepts and provide additional details. The phase state and physicochemical conditions of HC fluids were predicted. The maps of three petroliferous complexes, Lower–Middle Jurassic, Upper Jurassic, and Berriasian–early Valanginian (Achimov sequence), show the zones of occurrence of hydrocarbon systems of various phase states and physicochemical properties.

PHASE ZONING OF ACCUMULATION TYPES AND GENERAL CHARACTERISTICS OF OILS AND CONDENSATES

The lower and upper zones of gas formation, the main zone of oil formation, and the zone of gas condensate generation were distinguished by several authors

[1, 2] in the generalized scheme of the vertical zoning of oil formation. Each genetic zone corresponds to certain phase types of accumulations and specific hydrocarbon compositions of their fluids, which are controlled by the degree of catagenetic transformation of rocks and OM and the facies varieties of OM.

Vertical zoning corresponding in general to the theoretical models was described in the section of Mesozoic deposits over the whole West Siberian PB and in its northern part [2–4]. Several zones with accumulations of a certain phase state were distinguished over the area of the basin and in its section.

The first zone is mainly gas-bearing. This zone comprises the main gas accumulations of the Aptian–Albian–Cenomanian sequences. They can be exemplified by giant gas pools in the northern and Arctic regions: Urengoi, Medvezh'e, Yamburg, Zapolyarnoe, Gubkinskoe, etc. The second zone is represented by gas condensate and oil. The Valanginian–early Aptian sequences host both gas condensate and oil–gas condensate pools. The third zone is dominated by oil. This zone includes the Valanginian–Hauterivian and Berriasian–Valanginian sequences in the middle reaches of the Ob River. Only a few gas pools were found there in the Valanginian–Hauterivian sequence. Recent drilling data (cadastre materials) allowed us to refine the position of the zones proposed by Nemchenko [2]: the oil zone of these deposits extends further north, into the Nadym–Pur and Pur–Taz regions, and occurs at greater depths, up to 3800 m; the oil fields are replaced northward by oil–gas condensate and gas condensate fields. The fourth zone is an oil–gas condensate one. It is confined to the Upper and Middle Jurassic. Compared with the third zone, it contains a smaller number of oil pools. The fifth zone is a gas condensate one. Gas condensate pools are confined to the deep levels of the Lower and Middle Jurassic.

Thus, the West Siberian PB shows a zoning in the distribution of accumulations of various phase states both over the area of the basin and in the section of petroliferous complexes. This zoning is updated and described in more detail by us as the new results of sampling become available.

The geochemical types and subtypes of HC accumulations in the northern part of the West Siberian PB are characterized in Table 1, which is based on the data of various researchers [5–8]. The table presents the types of oils and condensates occurring in the Mesozoic sedimentary cover and their correlation with the depth, paleotemperatures, and age of rocks. The classes of hydrocarbon fluids were distinguished by Rudkevich et al. [5, 6] on the basis of their physicochemical properties (Tables 2, 3); the geochemical type and subtype were assigned using the distribution of *n*-alkanes and isoprenoids in the 200–400°C fraction, pristane/phytane ratio (Pr/Ph), and the hydrocarbon composition of the gasoline fraction. The distinguishing of geochemical types was based on the cyclohexane/cyclopentane (K_1) and xylene/ethylbenzene (K_2) ratios in the gasoline fractions of these fluids, and the geochemical subtype was determined from the alkane/cyclane (K_3) and *n*-alkane/isoalkane (K_4) ratios. Table 1 shows changes in geochemical types and classes along the section of petroliferous complexes.

The Early–Middle Jurassic, Late Jurassic, and Berriasian–early Valanginian sequences contain hydrocarbon fluids of geochemical types IIIg and IIg. These oils are characterized by a medium, high, and very high degree of alteration, and medium (M) and low (L) densities. Their composition is low-sulfur (S_1), low-resin, low-paraffinic (P_1) or paraffinic (P_2), with medium and high contents of light fractions (b.p. 300°C). The condensates of these types are light (L) and medium-density (M), low-paraffinic (P_1) and paraffinic (P_2). These fluids have paraffin or naphthene–paraffin HC compositions. The condensates and most of the oils show a maximum in the distribution of *n*-alkanes at n-C_5–n-C_9.

The spatial distribution of various hydrocarbon accumulations in the section of the Mesozoic cover of the Urengoi petroleum region is exemplified by Fig. 1 [5, 6], which shows the type of formation, age of the source complex and productive beds, paleotemperatures, types of hydrocarbon reservoirs, and compositions of hydrocarbon fluids. As can be seen from Fig. 1, the degree of oil and condensate alteration increases regularly from top to bottom in the section. For instance, weakly altered naphthene (cyclane) oils of type O_n and condensates of types O_g and I_g were found in the sequences of the Albian–Cenomanian petroliferous complex. According to the chemical classification of Petrov [7], they belong to type B-1 (B-1t, B-1b, and B-1m). The gases of the Albian–Cenomanian are dry, low-condensate (less than 10 cm^3/m^3), low-nitrogen, and low-CO_2. HC pools are confined to the zone of low-temperature catagenesis at depths of 1000–1600 m.

Condensates of type IIg (subtype II_g^v, B-2ts) are predominant in the Aptian complex at depths of 1600–1800 m. Deeper levels, to a depth of 3200 m, contain condensates and oils from the rims of petroleum reservoirs belonging to type IIg (subtype II_g^b; B-2i, A-2). At depths of 3200–3600 m, oils and condensates of type IIg become most important, but type IIIg (A-1) also appears and dominates at depths of 3700–4200 m in the Early–Middle Jurassic complex. The condensates of type IIIg have a peculiar composition. They are characterized by high contents of cyclic compounds (arenes and six-membered cyclanes) and alkanes. As a result, the density of type IIIg M (P_2) condensates increases, and their physicochemical properties approach those of type IIIg LP_2 oils. The free gases of these deposits are semiwet and wet, medium- (51–100 cm^3/m^3) and high-condensate (>100 cm^3/m^3), low-nitrogen, and low-CO_2.

The physicochemical investigation of a number of representative fluid samples from the Achimov

Table 1. Types and subtypes of oils and condensates from the northern West Siberian PB according to Rudkevich et al. [5, 6] and Petrov et al. [7]

Depth of host rocks, km	Paleotemperature, °C	Age of host rocks	Type of oil and condensate			Subtype of oil and condensate			Chemical type
			degree of HC and OM catagenesis	index	K_1 and K_2 indicators	index	K_3 and K_4 indicators	group composition of b.p. 130°C fraction	
0.8–1.8	50–70	K_1a–K_2c	Low PK	O_o^*	No fraction up to 200°C	–	–	Mainly cyclane (fraction 200–450°C)	B-1
0.7–1.2	50–70	K_1al–K_2c	Low PK	O_g^{**}	No fraction up to 200°C	–	–	Mainly cyclane (fraction 200–450°C)	B-1
1.0–1.6	60–80	K_1al–K_2c (locally K_1h, K_1v^2)	PK	I_g^{**}	$0.2 < K_1 < 3.4$	–	$0.1 < K_3 < 0.5$	Mainly cyclane	B-1t
									B-1b
					$4.0 < K_2 < 12.0$		$0.01 < K_4 \leq 0.2$	Cyclane	B-1m
1.3–3.7	75–150	J-K_1a	Medium and high MK_{1-3}	II_g	$1.5 < K_1 \leq 3.5$	II_g^v	$0.2 < K_3 \leq 0.5$	Cyclane	B-2ts
							$0.01 < K_4 \leq 0.5$	Alkane–cyclane	B-2i
					$4.0 < K_2 \leq 100$	II_g^b	$0.5 < K_3 \leq 1.8$	Cyclane–alkane	B-2i
							$0.75 < K_4 \leq 1.6$	Alkane–cyclane	A-2
					(9–20)	$^{**}II_g^a$	$K_3 > 1.8$	Cyclane–alkane	A-2
							$0.9 < K_4 \leq 1.6$	Alkane	A-1
2.5–4.2	140–210	J-K_1br	Very high MK_{4-5}	III_g	$3.5 < K_1$	–	$-0.5 < K_3 \leq 1.5$	Cyclane–alkane	A-1
					$10.0 < K_2 \leq 100$		$0.6 < K_4 \leq 2.0$	Alkane–cyclane	A-1
					(11–20)				
			K_1 = Σcyclohexane/Σcyclopentane; K_2 = Σxylene/ethyl benzene			K_3 = Σalkane/Σcyclane; K_4 = Σn-alkane/Σisoalkane			

Notes: Dashes indicate that subtypes are not defined.
* Only oils.
** Only condensates. Dashes indicate that subtypes are not defined.

Table 2. Classes and subclasses of oil according to Rudkevich et al. [6]

Class			Subclass		
index	parameter d_4^{20}, g/cm^3	character	index	parameter S and P, %	character
VH	>0.92	Very heavy	S_2	$0.5 < S \leq 1.0$	Medium-sulfur
H	0.89–0.92	Heavy	S_1	$S \leq 0.5$	Low-sulfur
			S_1	$S \leq 0.5$	"
M	0.85–0.88	Medium	P_3	$P > 10$	Highly paraffinic
			P_2	$5 < P \leq 10$	Paraffinic
			P_1	$P \leq 5$	Low-paraffinic
L	≤0.84	Light	P_3	$P > 10$	Highly paraffinic
			P_2	$5 < P \leq 10$	Paraffinic
			P_1	$P \leq 5$	Low-paraffinic

Table 3. Classes and subclasses of condensates according to Rudkevich et al. [6]

Class			Subclass		
index	parameter d_4^{20}, g/cm^3	character	index	parameter P, %	character
H	>0.82	Heavy	–	Absent	–
M	0.79–0.82	Medium	P_2	5–10	Paraffinic
			P_1	≤5	Low-paraffinic
L	0.71–0.78	Light	–	Absent	–
vL	≤0.70	Very light	–	Absent	–

Note: Dashes represent the unspecified characteristics and indexes because of the absence of paraffins.

sequence of the Urengoi field [9] showed that the condensates from Achimov reservoirs have a heavy composition. The 360°C residue is up to 12.0–22.5%. The molecular mass ranges from 128 to 183. The density varies in the range 0.7852–0.8293 g/cm^3, which suggests that the condensates become oil-like. The content of sulfur is low, no higher than 0.042%, and that of solid paraffins is relatively high, 3.3–7.0%. The group hydrocarbon composition is dominated by methane hydrocarbons (40–43%), but relatively high contents of naphthene (37–39%) and aromatic (19–20%) hydrocarbons were also detected. The oils from the Achimov sequence show Pr/Ph ratios of 2.1–2.7. The indicators of catagenetic alteration suggest the generation of these fluids within the oil window. The condensates are similar in genetic index and maturity parameters to the oils from the same wells and reservoirs.

GEOCHEMICAL CHARACTERISTICS OF OM FROM THE MESOZOIC DEPOSITS AND THEIR CATAGENETIC ZONING

The established phase zoning in the distribution of the types of HC accumulations in western Siberia has a genetic basis and is controlled by the facies of initial OM and the degree of its catagenetic transformation.

The Early–Middle Jurassic sequences containing mainly humus-related OM (coal-bearing and sub-coal-bearing continental associations) are classified as gas-producing, which is responsible for the occurrence of large gas and gas condensate accumulations in these deposits. The OM of the Late Jurassic deposits belongs to the sapropel or mixed humus–sapropel type and generates mainly oil accumulations [10, 11].

The analysis of the available data [2, 10, 12–15] revealed a variety of opinions and some controversies

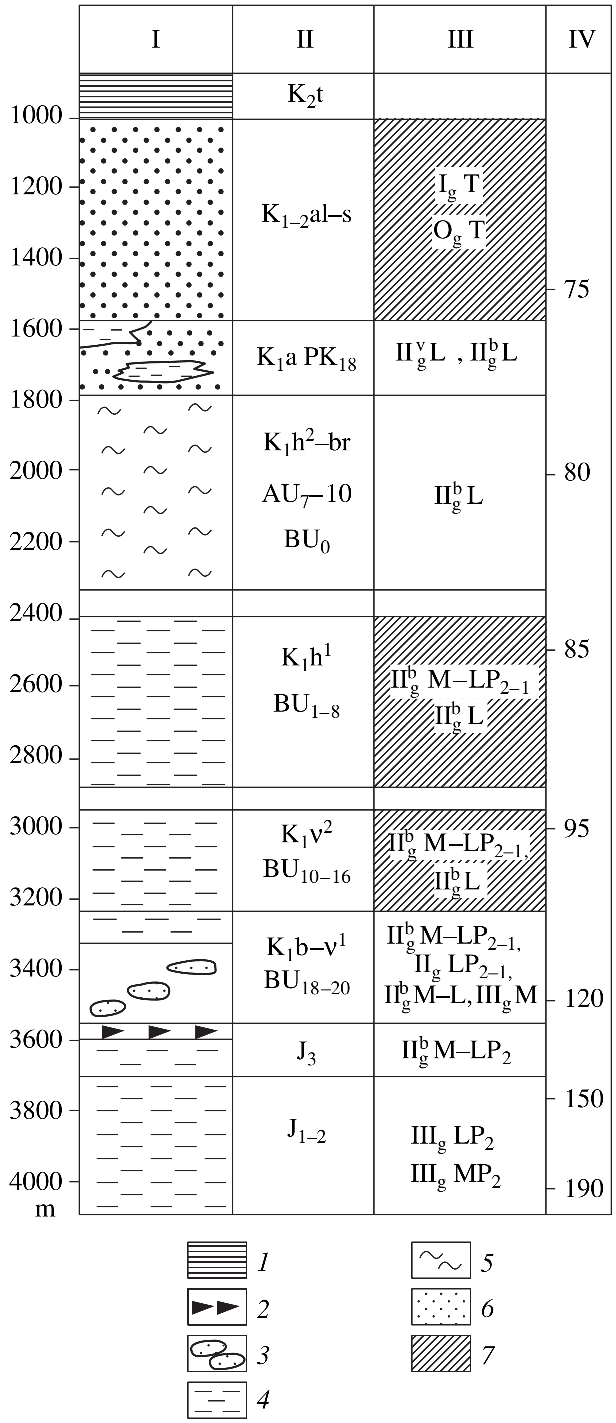

Fig. 1. Schematic distribution of the types of oil and condensate in the vertical section of the Urengoi region after Rudkevich et al. [6]. *I*, lithologic column; *II*, age of oil- and gas-bearing complexes and source beds; *III*, indexes of oils of condensates; *IV*, paleotemperatures. Formations: (*1*) marine, clay-dominated; (*2*) deep marine, bituminous clay; (*3*) sand–siltstone of submarine currents; (*4*) sand–clay, rhythmically layered, shallow marine; (*5*) sand–clay–silt, lenticular and layered, coastal marine and lagoon; (*6*) sand-dominated alluvium and deltaic; and (*7*) stratigraphic intervals of main productive complexes.

in the estimation of the stages of catagenetic transformation of OM in the Mesozoic deposits of the West Siberian PB, especially its northern regions. Let us consider the most recent inferences of Fomin et al. [14], which rely on a tremendous factual basis.

The degree of catagenetic transformation of OM in the basal sequences of the Jurassic varies considerably over the area and involves the whole range of catagenetic stages, from PK_3 to AK_3. The major areas of the northern West Siberian PB are represented by three stages of catagenesis: MK_2, MK_3, and AK_{1-3}, i.e., moderate and strong mesocatagenesis and apocatagenesis. The zone of moderate catagenesis (R_0 = 0.85–1.15%) forms a narrow band extending from the northwest to southeast in the Southern Yamal petroleum region; it was also traced in the southern part of the Nadym–Taz region and in the upper reaches of the Taz River. The zone of strong catagenesis (R_0 = 1.15–2.0%) is located in the middle part of the Nadym–Taz petroleum region and in the middle and southern parts of the Pur—Taz region and forms a narrow band in the Central Yamal region. The zone of apocatagenesis ($R_0 > 2\%$) is located in the northern part of the Nadym–Taz petroleum region, Gydan region, and the northeastern part of the Yamal region.

These three zones of catagenetic conversion in the basal sequences of the Jurassic correspond to certain types of HC accumulations differing in phase state. The zone of moderate catagenesis comprises oil accumulations, whereas gas condensate–oil systems are most common in the zone of strong catagenesis. The zone of apocatagenesis hosts gas condensate accumulations with a low condensate factor.

The organic matter of the Late Jurassic deposits is much less extensively altered. The degree of catagenesis ranges from late protocatagenesis to strong mesocatagenesis, i.e., from PK_3 to MK_3. Zones with variable catagenesis, from weak to strong (MK_1–MK_3), are widespread. The zone of weak mesocatagenesis (MK_1, R_0 = 0.5–0.85%) comprises the southwestern part of the Yamal Peninsula (Yamal region) and the southern part of the Nadym–Taz region, expanding from the periphery to the central parts of the basin. The zone of moderate mesocatagenesis (MK_2, R_0 = 0.85–1.15%) extends from the central part of the Yamal Peninsula to the southeast into the northern part of the Nadym–Taz region and forms in the east a narrow band in the eastern part of the Gydan petroliferous region. The zone of strong mesocatagenesis (MK_3, R_0 = 1.15–2.0%) was observed in the western part of the Gydan region and the northeastern part of the Yamal region.

Similar to the Early–Middle Jurassic petroleum complexes, the described types of catagenesis show a distinct correlation with the types of HC accumulations, which is manifested by the presence of oil accumulations in the zone of weak mesocatagenesis (southern part of the Nadym–Taz region) and gas condensate–

oil accumulations in the zone of moderate mesocatagenesis (northern parts of the Nadym–Taz and Pur–Taz regions and eastern parts of the Pur–Taz region).

Let us consider briefly the results of investigations on the oil-generation capacity of the Mesozoic deposits.

Up to now, the question of the interpretation of the Achimov clay sequences as source rocks has been disputable because of the scarcity of relevant data. Based on Rock-Eval data, Lopatin and Emets [15] argued that the Achimov sequences have low oil-generation capacity and there are no traces of large-scale oil migration in them. In their opinion, the high oil and gas content in the Achimov deposits is related to the Bazhenov Formation, where the processes of HC migration into the Achimov productive reservoirs were detected. These authors considered the Bazhenov Formation as having excellent oil-generating potential and being a rich source of light oil and wet gas. The sequences of the Tyumen Formation have a lower but also high gas-generating capacity [15].

Our predictive estimates for this region [16] are based on the geological and geochemical data obtained for the Tyumen ultradeep well (SG-6) and deep wells drilled in the Urengoi, Geologicheskaya, and Samburg prospects. Based on the correlation of vitrinite reflectance and paleotemperature with the depth of rock occurrence, it was shown that the lower boundary of the main phase of oil generation occurs at depths from 4250 m in the Urengoi and Tyumen prospects to 4750 m in the Samburg and Geologicheskaya prospects. The dead line marking the attenuation of the processes of wet gas and gas condensate generation is confined to depths of 4750–5450 m. In the SG-6 well, this depth is about 5000 m, where the Kotukhtinskaya Formation of the Lower Jurassic was penetrated.

The geochemical estimation of the oil-generating potential of the Mesozoic sequences is illustrated by the diagram of their oil potential as a function of the stage of OM catagenesis determined from vitrinite reflectance (Fig. 2). The diagram is based on the analytical data by N.V. Lopatin, T.P. Emets, V.A. Chakhmakhchev, and M.S. Zonn. According to this diagram, the maximum petroleum potential (PP) and hydrogen index (HI) are characteristic of the deposits of the Bazhenov and Vasyugan formations, located in the main zone of oil generation. This is explained by both the sapropel type of the initial OM and its moderate catagenetic alteration (MK_1–MK_3). If hydrocarbon reservoirs and other favorable geologic conditions are available, the sequences of the Bazhenov and Vasyugan formations can be estimated as promising to search for oil accumulations. Lower PP and HI values are characteristic of the Tyumen Formation, which is characterized by the final stage of oil formation. The inherently low generation capacity of plant–humus OM in these rocks is not favorable for the discovery of economically significant oil accumulations in this formation. Finally, the oil potential of kerogen from the Early Jurassic mudstones of the Kotukhtinskaya Formation is almost completely exhausted. With respect to the thermal maturity of OM, these sequences can generate gas condensate and gas. The lowest parts of the Kotukhtinskaya Formation and the underlying sequences, including the Yagel'naya and Beregovaya formations of the Lower Jurassic as well as all the series of the Triassic, are estimated as unfavorable for the search for oil and gas accumulations. The oil and gas generating properties of rocks in this interval (5000–7500 m) are completely lost, which is illustrated by Fig. 2.

OIL AND GAS CONTENT AND PREDICTION OF THE PHASE STATE OF HYDROCARBON SYSTEMS IN THE JURASSIC AND ACHIMOV SEQUENCES

The geochemical criteria of predictive estimates [16] include the facies and genetic type of organic matter, degree of its thermal maturity, stage of catagenesis of source rocks and their oil-generating potential, and the physicochemical properties and hydrocarbon composition of fluids. These criteria were used as a basis for the construction of schematic maps of the composition of oils and condensates in the Early–Middle Jurassic, Late Jurassic, and Achimov sequences of the northern West Siberian PB and for the prediction of the location of zones with different phase states of HC.

Three zones of HC phase state are shown in the map of the distribution of the types of hydrocarbon accumulations in the Early–Middle Jurassic petroleum complex (Fig. 3): oil (O), gas condensate–oil (transitional) (GCO), and gas condensate (GC).

The oil zone occupies almost the whole Nadym–Taz region. The boundary of the oil zone passes north of the Lenzit field, along the Urengoi megaswell, and north of the Beregovoe and Kynskoe fields. The oil zone is subdivided into three subzones. The most submerged part of the Nadym–Taz region, where the first subzone was distinguished, contains fluids of geochemical type IIIg LP_2S_1 in the Urengoi field and IIIg LP_3S_1 in the Beregovoe field. This subzone is rimmed by oils of type IIg^b $LP_{1-2}S_1$. The southwestern corner of the region and a small band in its southern part are characterized by the occurrence of type IIg^b MP_1S_1 oils.

The transitional zone, where GCO and, occasionally, GC reservoirs occur, extends as a wide band through the South Yamal petroleum region and the northern part of the Nadym–Taz region. Its hydrocarbon accumulations are usually represented by GC reservoirs with oil rims. The condensate factor varies within the range 135–241 g/m^3 in the western part of the zone and increases up to 274–537 g/m^3 in the eastern part. The gas factor of the oil rim varies from 15 to 355 m^3/t.

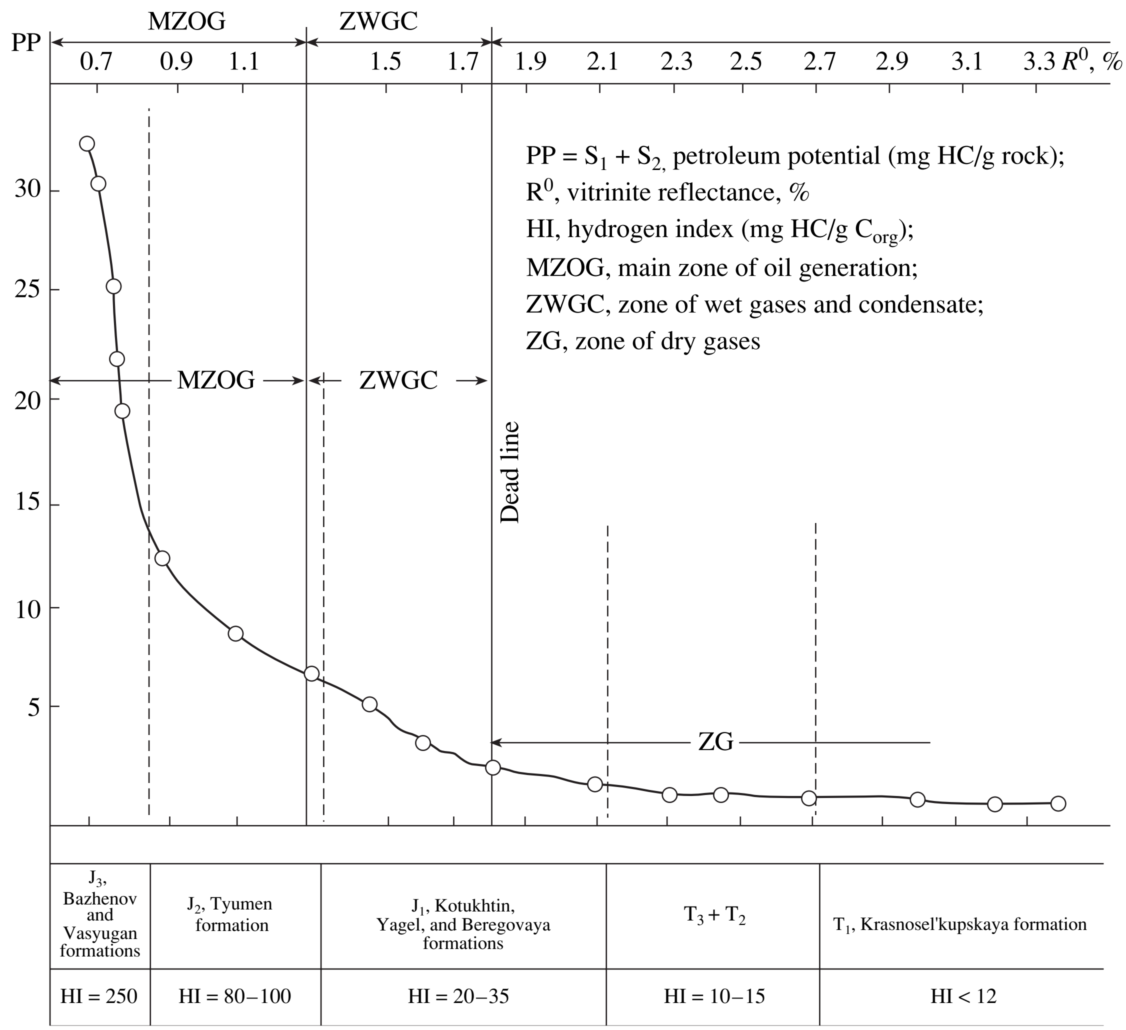

Fig. 2. Oil potential of the OM of rocks as a function of vitrinite reflectance in the section of the SG-6 superdeep well.

Condensate of type IIIg MP_2 occurs in the central, most submerged parts of the zone (Taz field). The periphery of the zone contains condensates of type IIg^b $L–MP_{1–2}$. The oil rim is represented by type IIg MP_2S_1 oils.

The boundary between the GCO and GC zones of the Yamal region passes north of the Bovanenkovskoe field through the Yamburg and Taz fields and the northern part of the Pur–Taz region.

The gas condensate zone is located in the Yamal–Gydan and Ust'-Yenisei petroleum regions and occupies the northeastern part of the Yamal Peninsula, Middle Messoyakh arch, extending toward the Ust'-Portovskii megaswell. This zone comprises mainly GC accumulations with small values of the condensate factor, 70–156 g/m^3.

The condensate of this zone is represented mainly by type IIIg; types IIIgL and IIIgLM are predicted for the western and eastern parts of the zone, respectively.

Oil and gas companies plan extensive exploration operations in the Early–Middle Jurassic sequences in promising areas of the Yamal–Gydan and Ust'-Yenisei regions, primarily for condensate and gas. In this area, the presence of methane-based GC accumulations of geochemical types IIIg L and IIIg L–M is predicted in the former and latter regions, respectively.

On the map of the distribution of the types of HC accumulations (Fig. 4) for the Late Jurassic petroleum complex, HC accumulations are absent in the western part of the region because of the claying of reservoirs. In other areas (Nadym–Taz and Ust'-Yenisei regions), oil and transitional zones were distinguished.

The oil zone is located in the southern part of the Nadym–Taz region. In the central and eastern parts of the Nadym–Taz and Ust'-Yenisei regions, the transitional zone with GCO and O reservoirs is located, where accumulations of two types, GCO and O, may occur within a single field. The oil zone is dominated by geochemical type IIg^b LP_1S_1, which includes light oils

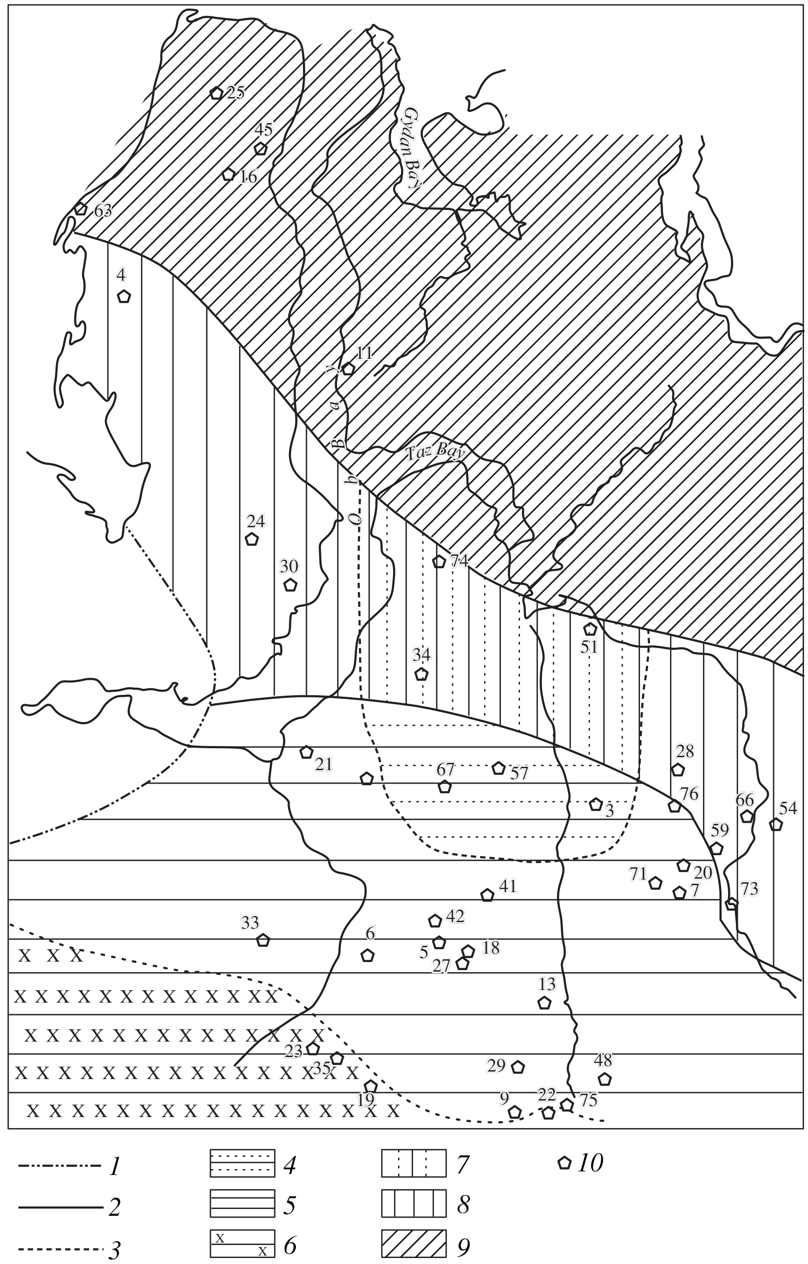

Fig. 3. Schematic map showing the predicted phase states and physicochemical properties of hydrocarbon systems in the Early–Middle Jurassic deposits of the northern West Siberian PB. Boundaries: (*1*) West Siberian PB; (*2*) zones of various phase states of HC systems; and (*3*) subzones of fluid types. Zones of the phase state of HC systems and fluid types: oil, (*4*) IIIg, (*5*) $IIg^bLP_1S_1$, and (*6*) $IIg^b MP_1S_1$; gas condensate–oil, (*7*) IIIg MP_2 and (*8*) IIg LMP_{1-2}; gas condensate, (*9*) IIIg. (*10*) Oil and condensate fields. The fields are indicated by numbers: 1, Akaitem, 2, Apokopur; 3, Beregovoe; 4, Bovanenkovskoe; 5, Verkhnepurpeiskoe; 6. Verkhnekharlovskoe; 7, Verkhnechasel'skoe; 8, Eastern Izvestinskoe; 9, Vyngapur; 10, Vyngayakh; 11, Geofizicheskoe; 12, Gubkinskoe; 13, Ety-Pur; 14, Western Byngapur; 15, Western Novogodnee; 16, Western Tambei; 17, Western Kharampur; 18, Izvestinskoe; 19, Krainee; 20, Kynskoe; 21, Lenzitskoe; 22, Limbayakh; 23, Malo-Pyakutinskoe; 24, Malo-Yamal'skoe; 25, Malyginskoe; 26, Mangazeiskoe; 27, Metel'noe; 28, Naumovskoe; 29, Novogodnee; 30, Novoportovskoe; 31, Novopureiskoe; 32, Novochasel'skoe; 33, Pal'nikovskoe; 34, Pestsovoe; 35, Pyakutinskoe; 36, Ravninnoe; 37, Romanovskoe; 38, Russko-Rechenskoe; 39, Ruch'evskoe; 40, Northern Vyngapur; 41, Northern Gubkinskoe; 42, Northern Komsomol'skoe; 43, Northern Iokhtur; 44, Northern Stakhanovskoe; 45, Northern Tambei; 46, Srednekharampurskoe; 47, Sporyshevskoe; 48, Stakhanovskoe; 49, Sutorminskoe; 50, Tagrinskoe; 51, Taz; 52, Tapskoe; 53, Tekto-Kharampur; 54, Termokarstovoe; 55, Tol'kinskoe; 56, Terel'skoe; 57, Urengoi; 58, Ust'-Chasel'skoe; 59, Fakhirovskoe; 60, Festival'noe; 61, Khanchei; 62, Kharampur; 63, Kharasavei; 64, Kholmistoe; 65, Chatyl'kinskoe; 66, Chernichnoe; 67, Yubileinoe; 68, Southern Tarasovskoe; 69, Southern Tarkosalinskoe; 70, Southern Udmurtskoe; 71, Southern Khadyr'yakh; 72, Southern Yarainer; 73, Yutyrmal'skoe; 74, Yamburg; 75, Yarainer; and 76, Yarovoe.

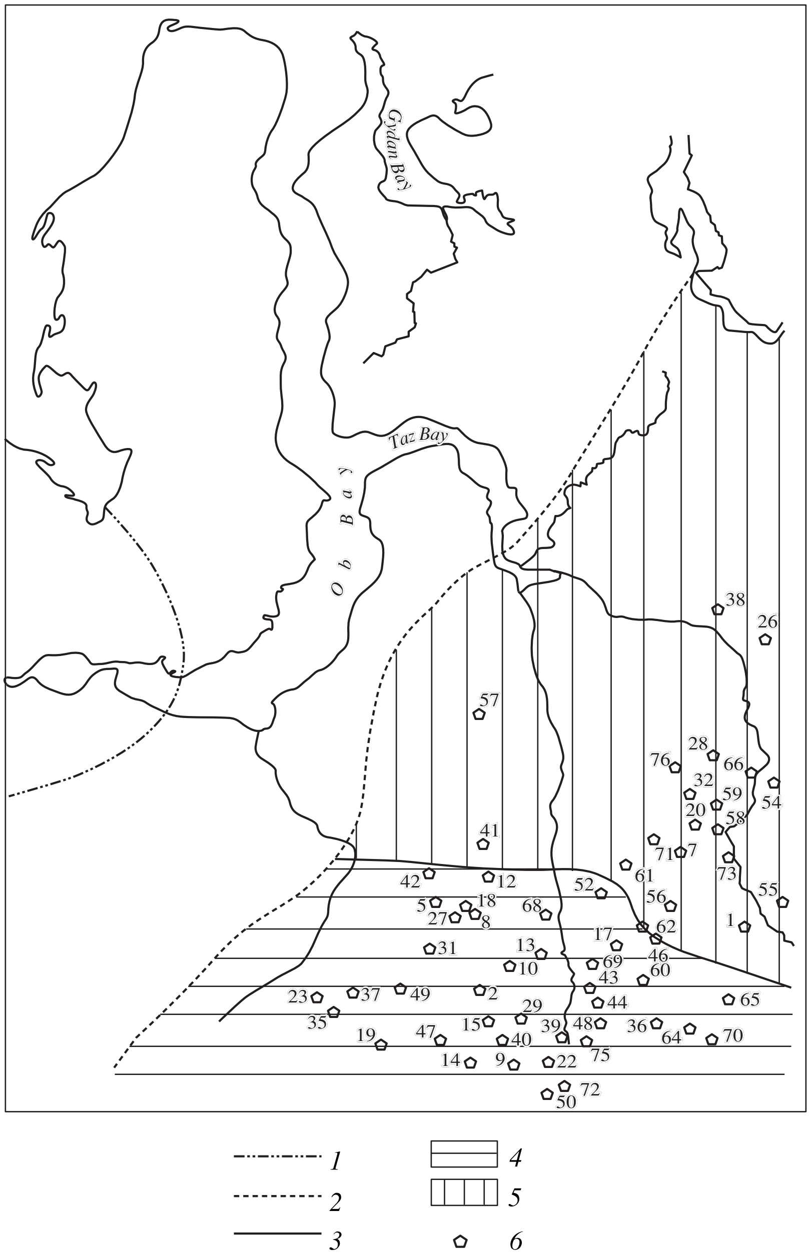

Fig. 4. Schematic map showing the predicted phase states and physicochemical properties of hydrocarbon systems in the Late Jurassic deposits of the northern part of the West Siberian PB. Boundaries: (*1*) West Siberian PB, (*2*) clay development in permeable rocks, and (*3*) zones of various phase states of HC systems. Zones of the phase state of HC systems: (*4*) oil; (*5*) gas condensate–oil; (*6*) oil and condensate fields. The names of fields are the same as in Fig. 3.

with low paraffin and sulfur contents. The abundance of resin–asphaltene components is up to 5%. Less common are type IIg^b $L–MP_{1–2}S_1$ oils of medium density with low and medium paraffin contents, low sulfur content, and up to 12% resin–asphaltene components.

The condensates and oils of transitional zone reservoirs are also assigned to type IIg^b. The dominating type of condensate is IIg^b $LP_{1–2}$; i.e., the condensates are light, low-paraffinic, and paraffinic. Minor amounts of type IIg^b $L–MP_1$ condensate occur in the Kharampur field. The main type of oil rim is represented by light oils with low paraffin and sulfur contents (IIg^b LP_1S_1).

The condensate factor of the GCO accumulations varies between 180 and 333 g/m^3. With respect to this parameter, GC accumulations are represented by the Akaitem (57 g/m^3) and Tol'kinskoe (139 g/m^3) fields. Very high condensate factors were obtained for the GCO accumulations of the Late Jurassic sequences of the Kharampur field (1007–1177 g/m^3).

The Achimov deposits are confined to the lower part of the Early Cretaceous sequences (Berriasian–lower Valanginian) and occur at depths of 2500–4000 m practically over the whole area of western Siberia. These deposits are not yet adequately studied. The potential resources of these sequences are estimated to be at least 5 billion tons of oil, 4.8×10^{12} m^3 of gas, and 1 billion tons of condensate [17].

The Achimov sequences are composed of massive fine-grained sandstones with a clay–carbonate cement and clay interbeds of varying thickness (up to 10–15 m). The coefficient of open porosity of the sandstones varies within the range 13–23%, and their permeability is from 0.25 to a few millidarcy. The effective thickness of individual beds in some wells is up to 45–50 m [18]. Characteristic features of the Achimov sequences [19] are the lithological variability, wedge-shaped structure, alternation of clay and sand layers, variable thickness, and nonuniform distribution. There are four zones of maximum thickness of the Achimov sequence [18], which cross the West Siberian platform from the south and southwest to the north and northeast. The distribution of zones is not controlled by the modern structural patterns, and they are separated by areas of partial or complete claying in the section.

Many researchers considered the Achimov deposits as an independent petroliferous system belonging to the Neocomian productive megacomplex. Nezhdanov et al. [18] established regional criteria for the location of Achimov reservoirs, which are controlled by stratigraphic, paleobathymetric, and morphologic features. According to these authors, the most promising targets are Achimov depocenters, zones of elevated thickness of sand–siltstone rocks related to the alluvial–deltaic sources supplying clastic material to the shelf.

These researchers showed that the oil field is superimposed on both the depocenter zones and areas with ordinary thicknesses of Achimov reservoirs. In the former case, economically significant pools are formed. They are confined to the northern part of the province, where the Achimov complex is the main oil- and gas-bearing structure. In the latter case, minor HC accumulations develop in the Achimov sequences and their development is not sufficiently profitable. In this connection, the prediction and mapping of these zones is considered one of the most important tasks during the investigation of oil and gas content of these deposits.

Figure 5 presents a map based on all available information, including the data on the catagenetic transformation of OM in rocks. It shows the boundaries of zones where fluids of various phase states and physicochemical properties occur.

A zone of development of GCO pools is outlined in the central part of the region at depths from 2743 to 4059 m. The depth of occurrence increases from south to north and northeast. This zone hosts a number of large fields, including the Urengoi, Eastern Urengoi, Samburg, Esetinskoe, Northern Pur, Yamsovei, and Evo-Yakhinskoe fields, as well as the smaller V'yuzhnoe, Sterkhovoe, and other fields. Both free gas and gas caps occur in these fields. The condensate factor ranges from 220 to 430 g/m^3, and the condensate density is 0.63–0.78 g/cm^3. The deeper pools from the Achimov deposits of the Samburg, Northern Samburg, and Neponyatnoe fields (depths from 3710 to 4059 m) can be classified as transitional from condensate to ultralight and light oils. The multilayer pools of these fields (from Ach1 to Ach4) show a very complex and diverse composition of condensate and are characterized by a rather high gas factor of up to 397 m^3/t (dissolved gas). This parameter is up to 1048 m^3/t in the pool of layer Ach1/2 in the Neponyatnoe field. The density of these fluids varies from 0.797 to 0.840 g/cm^3.

Two zones of condensate accumulations, Kharampur and Vyngapur fields, were found to the east and south of the above region (practically at the boundary of the Yamal–Nenets and Khanty–Mansi autonomous districts). The Achimov deposits rise in the same direction toward the Kharampur and Vyngapur arches. These beds occur at the shallowest depth there, 2433 m in the Vyngapur prospect and 2800 m in the Kharampur prospect. Since there is no detailed information on the properties of these fluids, these zones were distinguished only tentatively.

The main oil fields are located south of the zone of GCO pools. However, the presence of pure oil accumulations to the north in layers Ach3 and Ach4 of the Yamburg prospect, to the west in the Eastern Medvezhii and Southern Khulym fields (in layers Ach1 and Ach3–4), and to the east in the Yumantyl, Western Tarkosalinskoe, and other fields allowed us to outline the Urengoi–Samburg zone of condensate accumulations from the south, east, and west and extend the zone of development of oil accumulations in the Achimov sequences not only to the south but also to the east and west. In this respect, the zones of GCO accumulations in the Jurassic and Achimov deposits are significantly different. The depth of occurrence of oil accumulations ranges from 2662 m in the Gubkinskoe field to 3786 m in the Yamburg field.

Three zones were distinguished on the basis of oil density: ultralight oils with densities equal to or less than 0.82 g/cm^3, light oils with densities of 0.82–0.85 g/cm^3, and medium oils with densities of 0.85–0.87 g/cm^3. The zone of medium-density oils (Pyakutinskoe, Krainee, Northern Soimlor, Northern Pyamaliyakh, and other fields) is located in the southern part of the region near the boundary between the Yamal–Nenets and Khanty–Mansi autonomous districts. The zone of light oil forms a very wide band and includes the Yamburg, Northern Medvezh'e, Novogodnee, Apokopur, Vyngayakh, and other fields. The zone of ultralight oils forms a narrow band around the zone of condensate and oil–gas condensate accumulations. It comprises the Komsomol'skoe, Vrkhnekharlovskoe, Gubkinskoe, Southern Tarkosalinskoe, Ety-Pur, and other fields.

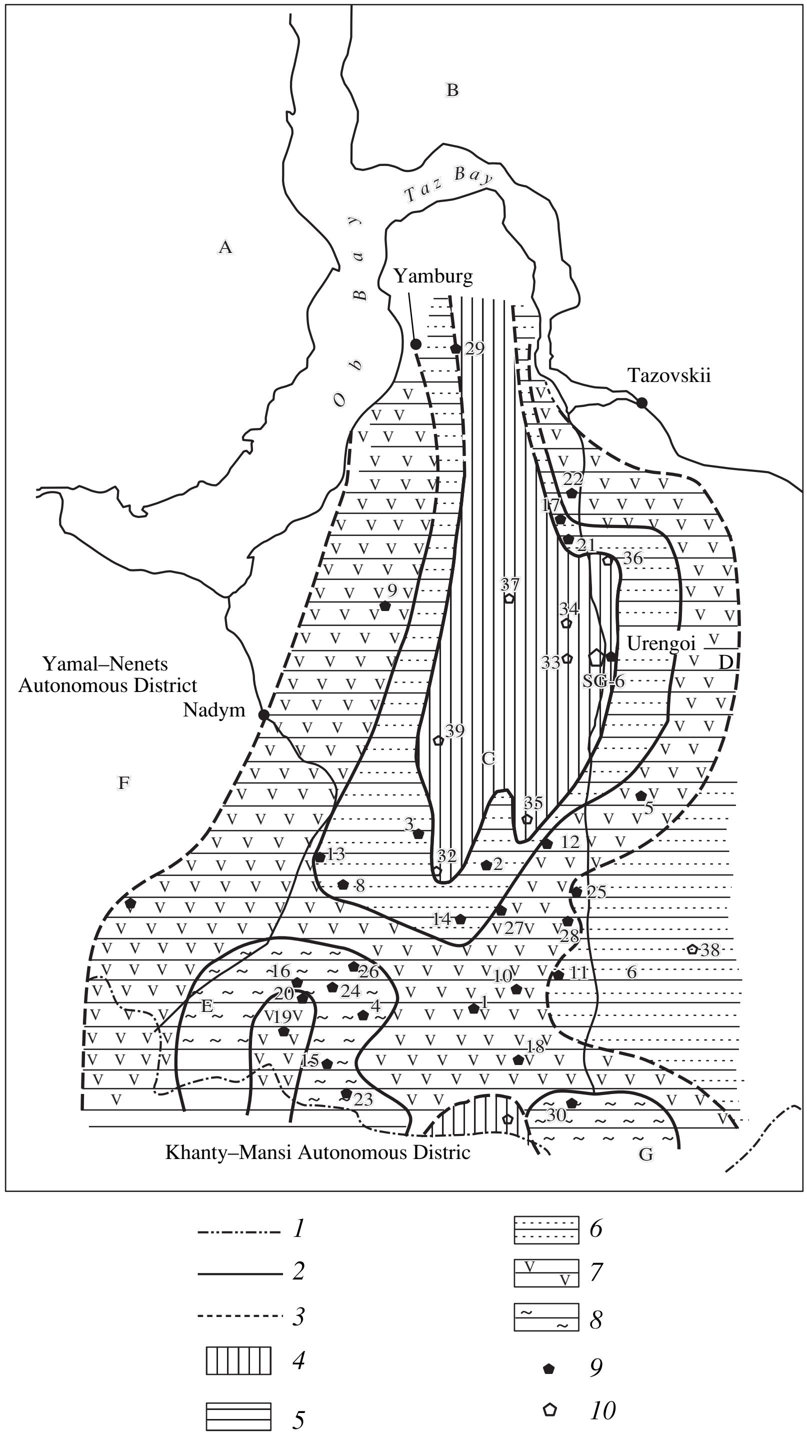

Fig. 5. Schematic map showing the predicted phase states and physicochemical properties of hydrocarbon systems in the Achimov deposits of the northern part of the West Siberian PB. Oil and gas-bearing regions: A, Yamal; B, Gydan; C, Nadym; D, Pur–Taz; E, Sredneobskaya; F, Frolovskaya; and G, Vasyugansk. Boundaries: (*1*) administrative boundaries of autonomous district; zones of the phase state of HC systems and fluid types: (*2*) proved and (*3*) inferred. Zones of occurrence of (*4*) gas condensate and (*5*) oil accumulations. Zones of occurrence of oils of different densities (g/cm^3): (*6*) ultralight, UL, density <0.82; (*7*) light, L, density 0.82–0.85; and (*8*) medium, M, density 0.85–0.87. Fields: (*9*) oil and (*10*) gas condensate. Fields are indicated by numbers on the map: 1, Apokopur; 2, Gubkinskoe; 3, Northern Komsomol'skoe; 4, Sutorminskoe; 5, Yumantyl'skoe; 6, Southern Tarkosalinskoe; 7, Southern Khulym; 8, Verkhnekharlovskoe; 9, Eastern Medvezh'e; 10, Vyngayakh; 11, Ety-Pur; 12, Western Tarkosalinskoe; 13, Karasevskoe; 14, Komsomol'skoe; 15, Krainee; 16, Malo-Pyakutinskoe; 17, Neponyatnoe; 18, Novogodnee; 19, Pyakutinskoe; 20; Romanovskoe; 21, Samburg; 22, Northern Samburg; 23, Northern Soimlor; 24, Northern Pyamaliyakh; 25, Tarkosei; 26, Umsei + Southern Purpei; 27, Central Purpei; 28, Southern Tarasovskoe; 29, Yamburg; 30, Yarainer; 31, Vyngapur; 32, V'yuzhnoe; 33, Evo-Yakhinskoe; 34, Esetinskoe; 35, Sterkhovoe; 36, Northern Pur; 37, Urengoi; 38, Kharampur; and 39, Yamsovei.

Almost all the oils are strongly altered, low-paraffinic (up to 5%, P_1), and low-sulfur (up to 0.5%, S_1) and show a moderate content of asphalt–resin components (up to 12.8%).

CONCLUSIONS

The results of the analysis and systematization of geological and geochemical data on the distribution of oil and gas in the northern regions of western Siberia can be summarized as follows.

(1) Geological and geochemical characteristics were provided for HC accumulations, oil, gas condensate–oil, gas condensate, and oil–gas condensate, for the Early–Middle Jurassic, Late Jurassic, and Berriasian–early Valanginian petroliferous complexes of the Nadym–Pur and Pur–Taz regions of the West Siberian PB.

(2) The hydrocarbon fluids of the petroleum complexes were classified into geochemical types and subtypes on the basis of their physicochemical properties, bulk hydrocarbon composition, and hydrocarbon composition of their gasoline fractions.

(3) Phase states and physicochemical properties were predicted for the hydrocarbon systems of the northwestern Siberian complexes. Schematic maps showing the distribution of oil, gas condensate–oil, and gas condensate accumulations were compiled; the boundaries of the predicted zones of occurrence of HC accumulations differing in phase composition and physicochemical properties were drawn. Three zones of the phase state of HC were distinguished in the Early–Middle Jurassic petroliferous complex: oil, gas condensate–oil (transitional), and gas condensate ones. Only two zones of hydrocarbon accumulations, oil and transitional, were found in the Late Jurassic complex of the Nadym–Taz and Ust'-Yenisei regions. Compared with the Jurassic sequences, the zone of oil accumulations in the Achimov member occupies a greater area and extends further north.

(4) The sedimentary sequences occurring at depths of no more than 4750 m are the most promising to search for economically significant hydrocarbon pools. Taking into account the lithologic and facies characteristics of the Middle and Early Jurassic deposits of the northern part of the province and the prevailing plant–humus type of the initial OM, a zone dominated by destructive processes is expected at depths greater than 4500–4750 m. Nonetheless, gas and condensate pools can be found there under favorable geologic conditions.

The differentiated geochemical classification of hydrocarbon fluids obtained using recent data on the age of petroliferous complexes and structural and tectonic units of the West Siberian PB provides a basis for a more efficient assessment of the oil and gas potential of the area and the quality of the resources. Moreover, it provides a means to improve the techniques of separate prognosis, i.e., determination of the type of fluids, which is important for the development of methods for the exploration and exploitation of pools.

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