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Typification of Oils in the Timan–Pechora Province According to the Composition of Hydrocarbon Biomarkers (Steranes and Terpanes)

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Abstract—Distinctive compositional features of cyclic saturated hydrocarbon biomarkers have been established in oils from the main petroliferous lithostratigraphic complexes of various structural zones in the Timan–Pechora petroliferous province (TPPP). Four geochemical families (types) of oils in TPPP are recognized based on the variations in the geochemical parameters of steranes and terpanes including sterane ratios C_{27}/C_{29} and C_{28}/C_{29}, K^1 mat and K^2 mat, diasterane/regular sterane, pregnane (C_{21-22})/ sterane ($C_{21-22} + C_{27-29}$), as well as terpane Ts/Tm parameters, adiantane C_{29}/hopane C_{30}, neoadiantane/adiantane, tryciclic terpane/pentacyclic terpane, hopane/sum of C_{29} steranes, etc. The distribution of various types of oil in the sedimentary sequence of TPPP makes it possible to infer source rocks for each of the four selected types.

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An attempt to typify oils from the Timan–Pechora petroliferous province (TPPP) according to the composition of cyclic saturated HC biomarkers (steranes and terpanes) was undertaken more than ten years ago, already during the initial stage of HC study in this territory, at the laboratory of petroleum geochemistry at the Institute of the Geology and Exploitation of Fossil Fuels [1]. At that time, the distribution of the parameters that characterize sterane and terpane HC was determined in 43 samples from the rocks of the Ordovician, Silurian, Devonian, Carboniferous, Permian, and Triassic systems throughout TPPP; the territory was provisionally divided into the northeastern, central, and western parts. Thereby, none of these areas were tied up to the structural zones and petroliferous complexes.

Nevertheless, these pioneering investigations revealed some important features in the distribution of sterane and terpane parameters for the oils hosted in rocks of different ages. In particular, a low concentration of adiantane C_{29} and tricyclic terpanes C_{19}–C_{30} was established for oils hosted in the Ordovician, Silurian, and Devonian rocks, at elevated contents of these HC biomarkers in oils from the Carboniferous, Permian, and Triassic rocks. As a result, it was concluded that the Ordovician–Devonian and Carboniferous–Triassic oils are related to self-dependent sources, i.e., two geochemical families (types) of oils have been recognized.

Afterwards, the geochemical study of steranes and terpanes in oils from the northern TPPP (Varandei–Adz'va Structural Zone, Khoreiver Basin, Kolva Arch, and the southern Pechora Sea) was carried out by Requejo *et al.* [2]. Having studied 36 samples of oils, the American geochemists selected four geochemical types of oils. The first type comprised only oil from the Permian and Triassic rocks of the Khyl'chuyu field in the northern Kolva Arch; this oil is characterized by elevated contents of diasteranes, pregnanes, and tricyclic terpanes, as well as by high terpane Ts/Tm ratios and adiantane/hopane values.

The Permian-Traissic oils from the Sorokin Arch and Varandei–Adz'va Structural Zone differ from the oil of the first type in having higher pregnane contents at low concentrations of diasteranes and not a high terpane parameter Ts/Tm. The third type in the classification proposed by Requejo *et al.* [2] includes mainly oil from the Upper Devonian carbonate formation in the Khoreiver Basin. The oil of this type is characterized by relatively low concentrations of pregnanes, high concentrations of tricyclic terpanes, and an extremely low Ts/Tm value.

Finally, the fourth type comprises oils from the Lower Devonian and lower Frasnian rocks in some fields of the Khoreiver Basin and the Sorokin Arch and differs from other oils of these structural zones by higher concentrations of diasterenes, lower concentrations of pregnanes, and high Ts/Tm and tetracyclic terpane/pentacyclic terpane values, along with a low adiantane/hopane ratio. Requejo *et al.* [2] suggested that all oils of groups II–IV were born in the Paleozoic source rocks of carbonate and clayey–carbonate lithologies, as follows from the low concentrations of diasteranes, relatively low C_{28}/C_{29} sterane ratio, high adiantane/hopane value, and the elevated concentrations of tetracyclic C_{24} terpanes [3–5].

During the study of HC biomarkers in oils from TPPP, which was subsequently carried out by the Institute of the Geology and Exploitation of Fossil Fuels [6, 7], much attention was focused on low-molecular steranes C_{21}–C_{22} (pregnanes) and tetracyclic terpanes $C_{19–30}$ (heulantanes). The pregnane and heulantane concentrations in oils from the northern TPPP systematically increase from the oils hosted in the Ordovician–Silurian sequence to the oils of the Permian–Triassic complex. The decreasing concentration of relatively low-molecular pregnanes and heulantanes from top to bottom of the TPPP's sedimentary cover was not related to a possible catagenetic thermodestruction of the higher-molecular steranes and terpanes of oil. The elevated contents of these HCs in the oil from the upper petrolioferous complexes probably resulted both from the secondary biodegradation of higher-molecular steranes and terpanes (the effect of residual accumulation) and, largely, from the effect of primary microbiological processes that occurred in the oils themselves and in the parental dispersed organic matter (DOM) during the initial stage of oil formation. In this regard, it was proposed to use pregnanes and heulantanes as characteristic indices inherent to oils from sedimentary rocks of certain ages.

The cyclic saturated HC-markers also were recently studied in other academic and non-academic institutions in Russia (All-Russia Research Institute of Geology and Petroleum, Institute of Geology, Komi Scientific Center, RAS) and abroad (Exxon Production Research Company in the United States; University of South Carolina, the United States; in Norway, and elsewhere). In particular, 54 oil samples collected by geochemists of the Arkhangelskgeologiya Territorial Geological Survey mainly from the Khoreiver Basin and partly from the Sorokin Arch were analyzed in Houston [8, 9]. Only three genetic families of oils (A, B, and C) were established in the northern TPPP from this complex geochemical study. Oils belonging to family A are characterized by lower adiantane concentration relative to hopane, low hopane/sterane C_{29} ratio, and elevated concentrations of tetracyclic hopane C_{24} in comparison with concentration of tricyclic terpane C_{26}. These are relatively low-maturity oils generated in rocks of marine origin with DOM of algal–sapropel type (chemical type II). The Silurian–Lower Devonian and Lower Permian oils from the southern Sorokin Arch (Osovei, Khosolta, and other fields) and the oil from the Devonian carbonate complex in the Khoreiver Basin, largely adjacent to the Varandei–Adz'va Structural Zone, were classed with this type. According to Abrams *et al.* [8], the domanik unit of the middle Frasnian Substage of the Upper Devonian were the source rocks of this oil.

The majority of oils in the Khoreiver Basin mainly occurring in the Upper Devonian carbonate rocks in the zone of reef facies are regarded as oils of type B. They are characterized by higher sterane C_{27}/C_{29} ratio than in oils of type A, low concentration of heulantanes, high homohopane C_{35}/C_{32} ratio, very high hopane/sterane C_{29} ratio (as high as 35), the prevalence of tetra-C_{24} over tri-C_{26}, approximately equal concentrations of adiantane C_{29} and hopane C_{30}, and the presence of hexacyclic hopanoid C_{32}–C_{35} alkanes. As was suggested by Abrams *et al.* [8], the domanik facies (domanikoids) of the upper Frasnian and Famennian sediments within inter-reef depressions in the central Khoreiver Basin and probably the lagoonal facies of the upper Frasnian Ukhta Formation served as sources of B-type oils.

The third family of C from the Abrams *et al.* collection includes only two oil samples from the Serpukhov Stage of the Lower Carboniferous at the Sed'yaga field in the Sorokin Arch and from the middle Frasnian rocks of the Upper Devonian at the Southern Syurkharata field in the Khoreiver Basin. These oils are rather close to oils of type A in the composition of the HC-biomarkers. However, the pronounced h-alkanes in the range of C_{13}–C_{17} commonly inherent to the Ordovician oils indicates an Ordovician rather than domanik age of the sources for oils of group C [8]. According to the classification proposed by Requeijo *et al.* [2], these oils are ascibed to type IV.

Cyclic HC markers of oils from the Varandei–Adz'va Structural Zone were also studied by Bushnev [10], who suggested an upward vertical migration of oil, for example, a flow of oil from the Ordovician rocks into the Tournaisian beds at the Labogan and Naul fields in the Varandei–Adz'va Zone.

Thus, a rather great body of information has been gained on the composition and distribution of steranes and terpanes in the oils of TPPP, particularly, in its northern portion. The study of these HC biomarkers in the oils of this province initiated by the Institute of the Geology and Exploitation of Fossil Fuels more than ten years ago is continued until now. New data have been obtained on the HC biomarkers of oils from the Varandei–Adz'va Zone, the Khoreiver Basin and its extension in the southern and southeastern Pechora Sea; additional samples have been analyzed from the oils in the Kolva and Shapkino–Yur'yakh arches, Malaya Zemplya–Kolguev Monocline, and from the southern TPPP (Izhma–Pechora Basin, Michayu–Pashnino Arch, Timan, etc.). More than 100 oil samples have been studied for steranes and terpanes in total.

The processing and interpretation of this data set with regard for the results obtained at other institutions allowed us to propose our own version of the geochemical classification (typification) of oils according to steranes and terpanes for the entire TPPP. Following Requejo *et al.* [2], we also recognize four geochemical families (Tables 1–7; Figs. 1–3).

Oils of type I occur in the northern TPPP, where they are hosted in the Triassic, Permian, and Carboniferous rocks of the Varandei–Adz'va Structural Zone (Table 1, fields and areas: Varandei, North Sorkino, Toravei, South Toravei, and Sed'yaga), the southeastern Pechora

Table 1. Steranes and terpanes in oils from the Varandei-Adz'va Structural Zone (average values)

Age	Field	Depth, m	Steranes						Triterpanes					Geochemical type of oil
			$\frac{C_{27}}{C_{29}}$	$\frac{C_{28}}{C_{29}}$	$\frac{\text{Dia.}}{\text{reg.}}$	K^1 mat	K^2 mat	$\frac{C_{21}-C_{22}}{C_{21-22}+C_{27-29}}$ %	$\frac{Ts}{Tm}$	$\frac{C_{29}}{C_{30}}$	$\frac{\text{Neo-}C_{29}}{C_{29}}$	$\frac{\text{Tri-}}{\text{penta-}}$	$\frac{\text{Hopane}}{\text{sterane } C_{29} \text{ sum}}$	
T_{1-2}	North Sorokin	1052–1251	0.55	0.5	0.3	0.55	5.3	36.0	0.6	1.25	0.45	0.7	2.5	I
	Varandei	1352	0.6	0.5	0.3	0.55	5.4	49.3	0.6	1.2	n.a.	0.7	2.7	
T_{1-2}–P_2	South Toravei	976–1377	0.65	0.5	0.25	0.55	5.2	46.0	0.7	1.3	n.a.	1.0	2.2	
P_2	Sed'yaga	1022	0.7	0.45	0.3	0.5	4.7	31.6	0.5	1.0	n.a.	0.5	2.8	
P_1	Varandei	1673	0.6	0.4	0.3	0.5	4.8	31.5	0.4	1.3	n.a.	0.5	2.5	
	Toravei	1625	0.65	0.4	0.15	0.5	4.7	31.8	0.4	1.3	0.25	0.6	4.8	
	Sed'yaga	1019	0.6	0.5	0.15	0.5	4.6	14.0	0.7	0.9	0.4	0.2	4.5	
C_1 t	Naul	2311	0.7	0.6	0.6	0.5	4.5	10.3	1.25	0.6	0.9	0.1	5.9	III
	Labogan	2350	0.7	0.7	0.3	0.5	4.7	8.7	1.1	0.6	0.9	0.1	3.8	
D_3 f^2–fm	South Toravei	2484	0.8	0.4	0.2	0.55	4.1	9.7	0.5	0.7	0.3	0.1	5.5	II
	Medyn	3200	0.6	0.6	0.2	0.5	3.6	8.6	0.7	0.85	0.5	0.1	3.7	
	Toboi	2700	0.8	0.4	0.2	0.5	4.3	6.9	0.4	0.8	n.a.	0.15	4.3	
D_3 f^1	West Lekkeiyaga	2670	0.6	0.7	0.2	0.5	4.6	8.4	1.0	0.75	n.a.	0.1	3.6	III
	Sed'yaga	2902	0.6	0.6	0.3	0.5	4.6	9.7	1.4	0.6	0.9	0.1	3.4	
D_1	Naul	4092	0.6	0.6	0.45	0.5	5.0	12.6	1.5	0.6	1.0	0.2	3.4	
	Yareiyaga	3200	0.45	0.5	0.3	0.45	4.5	3.0	1.0	0.6	0.6	0	1.0	
	Osovei	3508	0.6	0.4	0.25	0.5	4.3	11.4	0.4	0.7	n.a.	0.2	7.2	II
	North Saremboi	3170	0.4	0.6	0.2	0.6	3.6	3.8	1.4	0.8	0.8	0.1	4.4	III
	Toboi	4050	0.6	0.75	0.5	0.5	5.3	11.0	1.4	0.45	1.0	0.2	4.4	
	Myadsei	3920	0.4	0.5	0.4	0.5	5.5	8.9	3.0	0.5	n.a.	0.15	3.7	
S_2	Varandei	4322	0.7	0.65	0.5	0.55	5.8	11.6	1.75	0.5	1.0	0.2	5.3	
	Osovei	3645	0.6	0.4	0.3	0.5	4.4	10.7	0.45	0.7	n.a.	0.2	2.6	II
	Khosolta	3966	0.6	0.5	0.3	0.5	5.1	9.5	0.7	0.8	n.a.	0.1	3.1	
	West Lekkeiyaga	3600	0.4	0.5	0.3	0.5	4.0	6.3	2.2	0.85	1.0	0.02	4.2	III
O-S	Khosolta	4085	0.7	0.5	0.25	0.5	4.5	10.7	0.8	0.7	n.a.	0.15	4.0	II

Table 2. Steranes and terpanes in oils from the southeastern Pechora Sea

Age	Field	Depth, m	Steranes						Terpanes					Geochemical type of oil
			$\frac{C_{27}}{C_{29}}$	$\frac{C_{28}}{C_{29}}$	$\frac{\text{Dia.}}{\text{reg.}}$	K^1 mat	K^2 mat	$\frac{C_{21}-C_{22}}{C_{21-22}+C_{27-29}}$ %	$\frac{Ts}{Tm}$	$\frac{C_{29}}{C_{30}}$	$\frac{\text{Neo-}C_{29}}{C_{29}}$	$\frac{\text{Tri-}}{\text{penta-}}$	$\frac{\text{Hopane}}{\text{sterane } C_{29} \text{ sum}}$	
P_2	North Gulyaevo	2212–2245	0.6	0.4	0.15	0.55	5.4	26.0	0.5	1.2	0.3	0.5	3.4	
P_1	Pakhancha	2223–2273	0.7	0.4	0.3	0.55	4.5	20.0	0.55	1.4	0.3	0.6	1.4	I
	Prirazlomnoe	2409–2460	0.6	0.4	0.2	0.5	4.5	31.2	0.4	1.3	n.a.	0.5	4.2	
	South Dolgaya	2718–2725	1.2	0.8	0.5	0.5	4.5	57.0	1.1	1.1	0.6	4.6	0.5	IV
P_1–C_2	Medyn-More-2	1326–1380	0.6	0.4	0.2	0.5	4.0	19.0	0.6	1.0	n.a.	0.2	2.0	I
C_2m–C_1 srp	Medyn-More-1	1185–1300	0.6	0.6	0.2	0.5	4.4	26.7	0.7	0.8	0.4	0.35	5.5	
C_1	South Dolgaya	3165–3327	0.6	0.5	0.4	0.5	5.2	44.5	2.5	1.5	0.9	2.0	0.4	IV
C_1 srp	Medyn-More-2	1443–1465	0.6	0.5	0.2	0.5	5.6	28.0	0.5	1.1	0.6	0.3	2.0	
C_1 t	Medyn-More-1	1352–1450	0.7	0.5	0.2	0.5	4.2	29.7	0.6	1.1	0.5	0.3	5.0	I
	Medyn-More-2	1563–1595	0.6	0.5	0.3	0.6	4.3	21.0	0.9	1.1	0.6	0.4	1.6	
D_3 f^2–fm	Medyn-More-1	2364–2394	0.55	0.6	0.3	0.5	4.6	8.9	1.3	0.7	0.9	0.1	5.8	III
D_1	Medyn-More-2	3080–3097	0.8	0.7	0.35	0.5	4.0	17.0	1.9	0.7	0.85	0.2	1.3	
S_1	Pakhancha	4268–4334	1.05	0.7	0.67	0.55	4.2	21.0	1.4	0.8	0.6	0.5	1.4	IV

Table 3. Steranes and terpanes in oils from the Khoreiver Basin

Age	Field	Depth, m	Regular steranes		Steranes C_{29}			$\frac{C_{21}-C_{22}}{C_{21-22}+C_{27-29}}$ %	Terpanes					Geochemical type of oil
			$\frac{C_{27}}{C_{29}}$	$\frac{C_{28}}{C_{29}}$	$\frac{Dia.}{reg.}$	K^1 mat	K^2 mat		$\frac{Ts}{Tm}$	$\frac{C_{29}}{C_{30}}$	$\frac{Neo\text{-}C_{29}}{C_{29}}$	$\frac{Tri\text{-}}{penta\text{-}}$	$\frac{Hopane}{sterane\ C_{29}\ sum}$	
P_1	Tyulisei (Titov)	2250–2254	0.6	0.4	0.2	0.5	4.6	19.6	0.5	1.1	0.3	0.5	3.1	I
	Bagan	2131–2163	0.6	0.3	0.2	0.5	4.7	10.3	0.6	0.7	0.5	0.15	4.0	II
D_3 fm–f^2	Varknav	3608–3699	0.7	0.35	0.2	0.5	5.0	13.8	0.3	0.8	n.a.	0.3	5.0	
	North Khosedayus	2939–2943	0.6	0.5	0.2	0.5	4.1	9.2	0.75	0.8	n.a.	0.1	3.3	
	North Khosedayus	2978–2980	0.6	0.5	0.15	0.5	4.8	24.7	0.5	1.2	n.a.	0.5	3.2	I
	Ardala	3265–3303	0.5	0.4	0.3	0.5	5.0	19.3	0.95	0.7	0.6	0.35	3.1	
	Urernyrd	3188–3193	0.4	0.4	0.1	0.5	4.6	11.1	0.4	0.9	n.a.	0.04	18.5	II
D_3 f^1 p	Visovoe	3129–3153	0.6	0.35	0.2	0.5	4.7	10.1	0.4	0.6	n.a.	0.2	3.3	
D_1	Varknav	4052–4077	0.6	0.6	0.3	0.6	6.5	11.8	1.1	0.6	1.0	0.2	5.3	III
	Olen'ya	3930–4030	0.7	0.6	0.3	0.5	5.2	12.4	1.3	0.6	1.0	0.2	3.6	
	Olen'ya	4034–4037	0.6	0.6	0.4	0.6	6.4	9.9	1.4	0.6	1.0	0.2	6.4	
	West Yareiyaga	3772–3796	0.7	0.4	0.35	0.5	4.9	11.8	1.4	0.55	0.6	0.4	2.5	
	West Yareiyaga	3221–3253	0.6	0.5	0.2	0.5	4.5	12.1	0.9	0.6	0.5	0.4	1.8	
D_1–S_2	Varknav	4098–4109	0.6	0.6	0.4	0.6	5.6	11.5	0.85	0.6	1.0	0.1	5.3	
S_2	Bagan	3263–3311	0.55	0.4	0.25	0.5	5.0	10.9	0.9	0.7	n.a.	0.4	1.7	
	Middle Makarikha	3088–3120	0.55	0.3	0.2	0.5	4.5	7.9	0.1	0.75	n.a.	0.1	2.1	II
S_1	Middle Makarikha	3122–3127	0.55	0.3	0.2	0.5	4.5	5.9	0.1	0.7	n.a.	0.1	2.4	
	East Vozei	3555–3582	0.5	0.4	0.25	0.5	4.4	9.8	1.2	0.6	0.5	0.3	2.0	III
O	Middle Makarikha	4168–4285	0.5	0.3	0.2	0.5	4.9	4.8	0.4	0.6	n.a.	0.05	2.8	II

Table 4. Steranes and terpanes in oils from the Kolva Arch

Age	Field	Depth, m	Steranes						Terpanes					Geochemical type of oil
			$\frac{C_{27}}{C_{29}}$	$\frac{C_{28}}{C_{29}}$	K^1 mat	K^2 mat	$\frac{\text{Dia.}}{\text{reg.}}$	$\frac{C_{21}-C_{22}}{C_{21-22}+C_{27-29}}$ %	$\frac{Ts}{Tm}$	$\frac{C_{29}}{C_{30}}$	$\frac{\text{Neo-}C_{29}}{C_{29}}$	$\frac{\text{Tri-}}{\text{penta-}}$	$\frac{\text{Hopane}}{\text{sterane } C_{29} \text{ sum}}$	
T_1	Yareiyu	1484–1488	0.7	0.6	0.5	4.7	0.5	28.4	1.6	0.8	0.5	1.6	1.2	IV
P_2	Khyl'chuyu	1700–1710	0.75	0.5	0.5	4.6	0.5	34.0	1.6	0.7	0.5	1.4	1.5	
	Khyl'chuyu	1787–1809	0.7	0.5	0.5	4.9	0.4	37.8	1.7	0.8	0.3	2.4	1.9	
	Vozei	1488–1512	0.5	0.4	0.5	4.4	0.25	13.0	0.9	0.6	0.55	0.25	4.0	II
P_1	Khyl'chuyu	1932–1937	0.6	0.55	0.6	4.8	0.3	35.2	1.1	1.0	0.45	1.3	1.5	IV
	South Chyl'chuyu	2255–2262	0.65	0.5	0.5	4.9	0.5	36.6	1.3	1.0	0.2	1.4	1.6	
	East Sarutayu	1900–2010	0.8	0.5	0.4	3.8	0.4	28.0	1.0	1.0	0.01	1.3	0.6	
	Vozei	1508–1530	0.5	0.4	0.5	4.5	0.2	10.2	0.9	0.6	0.5	0.2	9.2	II
C_3	Vozei	1568–1592	0.5	0.4	0.5	4.6	0.3	12.9	1.1	0.7	0.3	0.3	5.0	III
C_2	Vozei	1629–1640	0.5	0.4	0.5	4.5	0.2	13.0	0.7	0.7	0.2	0.3	2.5	II
$D_3 f^2$–fm	Vozei	1658–1691	0.5	0.5	0.5	4.3	0.2	8.0	0.9	0.7	0.1	0.2	3.3	
$D_3 f^1$	East Sarutayu	4526–4562	0.6	0.5	0.6	4.8	0.5	12.0	0.7	0.8	1.5	0.6	0.8	II + III
D_2 gv	East Sarutayu	4561–4601	0.8	0.8	0.5	4.3	0.4	10.0	0.9	0.8	0.6	0.3	1.2	II
	Inzyrei	4206–4249	0.4	0.65	0.4	4.8	0.55	12.2	4.2	0.55	1.0	0.7	1.5	III
	Khar'yaga	4000	0.6	0.5	0.4	4.0	0.3	16.2	0.75	0.7	0.6	0.3	3.1	II
	Vozei	3442–3454	0.4	0.4	0.6	4.6	0.6	11.9	1.5	0.3	1.0	0.2	7.0	III
	Usina	3080–3144	0.6	0.45	0.5	4.5	0.2	5.5	1.05	0.6	0.7	0.15	2.3	
S_1	Upper Vozei	3403–3476	0.4	0.5	0.5	4.6	0.3	9.2	1.7	0.8	0.7	0.4	2.6	

Table 5. Steranes and terpanes in oils from the Shapkino-Yur'yakh Arch and Malaya Zemlya-Kolguev Monocline

Age	Field	Depth, m	Steranes						Terpanes					Geochemical type of oil
			$\frac{C_{27}}{C_{29}}$	$\frac{C_{28}}{C_{29}}$	$\frac{\text{Dia.}}{\text{reg.}}$	K^1 mat	K^2 mat	$\frac{C_{21}-C_{22}}{C_{21-22}+C_{27-29}}$ %	$\frac{Ts}{Tm}$	$\frac{C_{29}}{C_{30}}$	$\frac{\text{Neo-}C_{29}}{C_{29}}$	$\frac{\text{Tri-}}{\text{penta-}}$	$\frac{\text{Hopane}}{\text{sterane } C_{29} \text{ sum}}$	
T_1	Tarka	1716–1727	0.7	0.6	0.8	0.5	5.9	16.8	3.0	0.5	0.5	1.2	2.7	IV
	Peschano-ozerskoe	1690–1698	0.8	1.0	n.a.	n.a.	5.9	27.8	Background value					
P_1 as-skm	South Shapkino	1394–1406	0.65	0.6	0.3	0.5	4.9	23.0	1.5	0.5	0.8	1.3	2.6	
C_3–C_2	South Shapkino	2040–2045	0.7	0.6	0.5	0.5	5.9	23.9	1.9	0.6	0.7	1.5	1.3	
	Upper Kharitsei	2539–2547	0.5	0.5	0.4	0.5	4.6	10.3	1.4	0.6	0.9	0.1	4.0	III
D_3 f^2	Upper Grubeshor	3622–3670	0.7	0.4	0.6	0.55	5.8	19.3	2.3	0.4	1.0	0.45	2.9	

Sea (Table 2, North Gulyaevo, Prirazlomnoe, Pakhancha, and Medyn-More fields), and in the Permian and Frasnian–Famennian sedimentary rocks at some fields of the Khoreiver Basin (Table 3, Tyulisei and North Khosedayu fields).

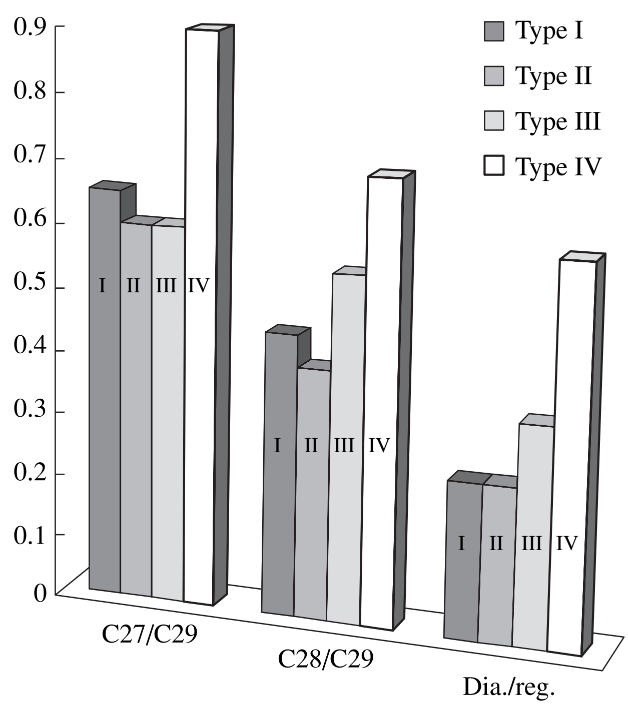

Fig. 1. Sterane parameters of oils of various types from the Timan–Pechora petroliferous province.

They are distinguished by the following set of parameters:

—Extremely high concentrations of low-molecular (C_{21-22}) steranes–pregnanes amounting to 20% of total steranes, on average.

—The prevalence of norhopane C_{29} (adiantane) over hopane C_{30} ($C_{29}/C_{30} > 1$).

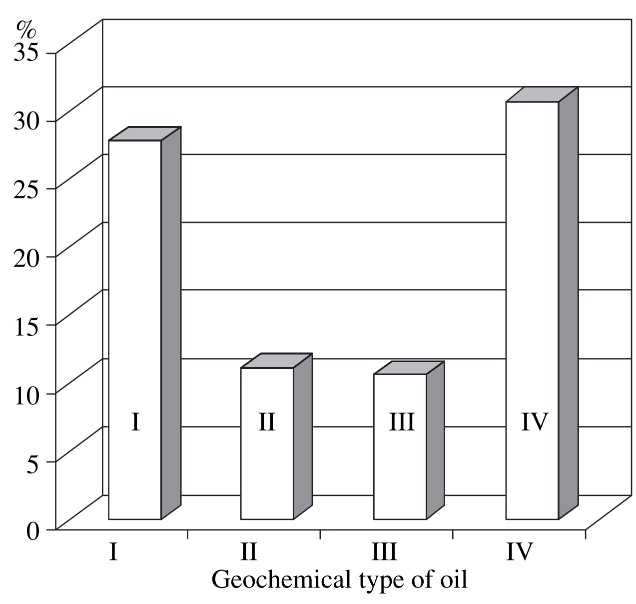

Fig. 2. Pregnane (C_{21-22})/sterane (C_{21-29}), % in oils belonging to various types in the Timan–Pechora petroliferous province.

—A relatively high concentration of tricyclic terpanes $C_{19–30}$ (tri-/penta- ratio is 0.4–0.6).

—A low average Ts/Tm terpane C_{27} ratio (0.5–0.6).

—A low (<0.6) neoadiantane C_{29}/adiantane C_{29} ratio.

It should be noted that elevated contents of pregnanes $C_{21–22}$ in oils from the upper petroliferous complexes of Upper Permian and Triassic age in the northern TPPP (Varandei–Adz'va Structural Zone) are commonly detected in the biodegraded oils, for example, in the Triassic oils in the Varandei, North Sorokin, and South Toravei areas and in the Upper Permian oils at the Sed'yaga and Southern Toravei fields, although they are also known from the Lower Permian unbiodegraded oils, e.g., in oils from the Varandei area, Toravei and Sed'yaga fields. Furthermore, many pregnanes are contained in a number of Permian–Triassic nonbiodegraded oils from other structural zones in the northern TPPP, in particular, in the Triassic oils at the Tarka, Peschano-Ozersky, and Yareiyu fields; in the Upper Permian oils at the North Gulyaevo and Khylchuyu fields; and in the Lower Permian oils at the Prirazlomnoe, Pakhancha, South Dolgaya, and South Khylchuyu fields. At the same time, some biodegraded oils reveal low concentration of pregnanes, e.g., in the Famennian oil at the Urernyrd field in the Khoreiver Basin and in the Upper Permian oil at the North Vel'yus field in the Izhma–Pechora Basin. Therefore, high pregnane content may be regarded, first of all, as a primary distinctive feature of oils belonging to type I. This also applies to heulantanes. The low Ts/Tm and neoadiantane/adiantane ratios indicate that oils of type I are not highly mature.

Judging from their low diasterane/regular sterane ratio, oils of this group were born in marine carbonate or cherty carbonate source sequences similar to the domanik sequence.

Oils of type I in our classification correspond to oils of type II in the classification of Requeijo *et al.* [2] and oils of class B in geochemical typification proposed by Adams *et al.* [8].

Oils of type II in our classification are widespread not only in the northern TPPP within the Varandei–Adz'va Structural Zone (Table 1, South Toravei, Toboi, Osovei, and Khosolta fields), the Khoreiver Basin (Table 3, Bagan, Varktnav, North Khosedayu, Ardala, Urernyrd, Visovoe, and Middle Makarikha fields), and in the Kolva Arch (Table 4, Vozei and Khar'yaga fields), but also in the south of the province, in the Izhma–Pechora Basin and in the Timan (Table 6, Northern Vel'yu, Isakovo, Pashnino, Upper Omra, Lower Omra, Dzh'er, Nibel, Yarega, West Tebuk, Turchaninovo, and Beregovoe fields), where they are traceable in a wide stratigraphic range from the Ordovician to Upper Permian. The following parameters are typical of oils belonging to this family:

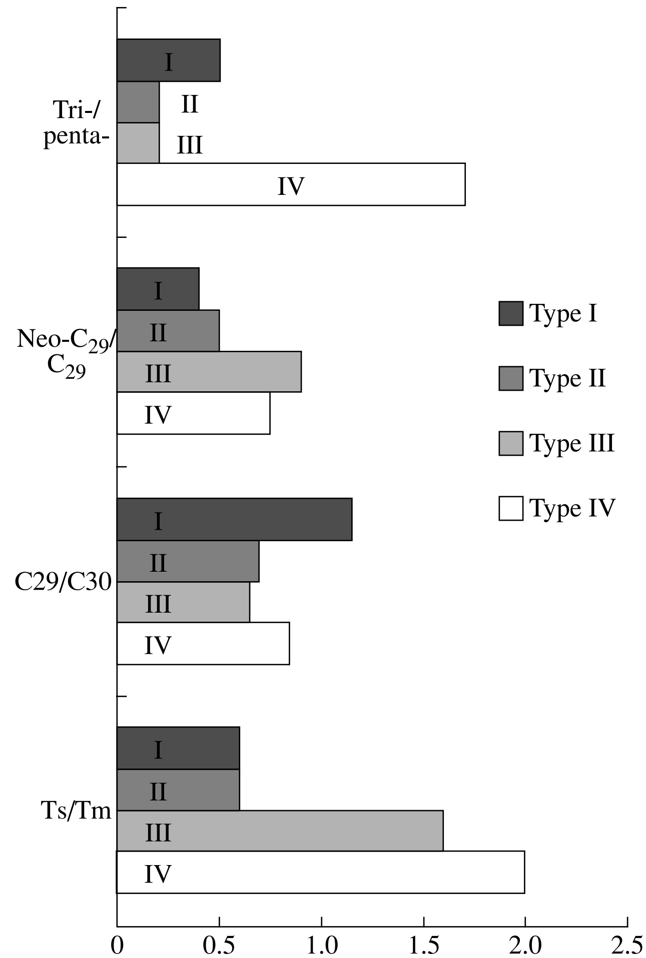

Fig. 3. Terpane parameters of oils belonging to various types in the Timan–Pechora petroliferous province.

—A low pregnane concentration (less than 15% of total steranes).

—The prevalence of hopane over adiantane and, thus, a lower adiantane/hopane ratio (0.6–0.8) than in oils of type I.

—An extremely low percentage of heulantanes (tri-/penta- = 0.1–0.4).

—The parameters of maturity: Ts/Tm (0.5–0.7) and neo-C_{29}/C_{29} (0.4–0.6) are as low as in oils of type I.

The reasons for the low maturity of oils in old and deep-seated Ordovician and Silurian rocks at some fields of the Varandei–Adz'va Structural Zone, e.g., Osovei and Khosolta, and in the southern Khoreiver Basin (Middle Makarikha field) are uncertain.

According to the indices of their HC biomarkers, oils of type II correspond to group III according to Requijo *et al.* [2] and group A according to Abrams *et al.* [8].

Type III of oils in our classification is in general close to oils of group II in the composition of HC biomarkers and is distinguished from the latter only in hav-

Table 6. Steranes and terpanes in oils from the southern Timan-Pechora province (Izhma-Pechora Basin, Ukhta and Michayu-Pashnino arches)

Age	Field	Depth, m	Steranes						Terpanes					Geochemical type of oil
			$\frac{C_{27}}{C_{29}}$	$\frac{C_{28}}{C_{29}}$	$\frac{\text{Dia.}}{\text{reg.}}$	K^1 mat	K^2 mat	$\frac{C_{21}-C_{22}}{C_{21-22}+C_{27-29}}$ %	$\frac{Ts}{Tm}$	$\frac{C_{29}}{C_{30}}$	$\frac{\text{Neo-}C_{29}}{C_{29}}$	$\frac{\text{Tri-}}{\text{penta-}}$	$\frac{\text{Hopane}}{\text{sterane } C_{29} \text{ sum}}$	
P_2	North Vel'yu	552–558	0.6	0.5	0.2	0.55	4.1	14.0	0.5	0.65	0.4	0.4	3.1	II
P_1	Isakovo	1207–1247	0.6	0.4	0.2	0.5	4.1	11.4	0.4	0.7	0.3	0.3	1.5	
	Pashnino	965–990	0.6	0.4	0.2	0.5	4.6	12.6	0.4	0.8	0.3	0.3	3.7	
$D_3\ f^1$	Upper Omra	942–947	0.6	0.4	0.3	0.5	4.4	14.7	0.6	0.75	0.1	0.5	2.1	
	Dzh'er	1531–1534	0.95	0.3	0.3	0.5	4.7	13.5	0.5	0.6	0.6	0.3	2.2	
D_2 gv	Yarega	215–226	0.6	0.3	0.2	0.5	4.4	14.5	0.6	0.7	0.3	0.4	3.3	
	Nibel-95	911–920	0.6	0.4	0.3	0.5	5.1	13.9	0.6	0.7	n.a.	0.4	1.7	
	Nibel-115	920–923	0.6	0.3	0.3	0.5	4.4	13.0	0.5	0.7	0.4	0.4	2.5	
	Lower Omra	999–1007	0.6	0.4	0.3	0.6	5.5	17.4	0.9	0.8	0.5	0.6	2.0	
	Upper Omra	938–942	0.6	0.35	0.3	0.5	4.7	12.8	0.5	0.8	0.4	0.4	2.5	
	West Tebuk	1940–1953	0.5	0.3	0.2	0.5	5.2	13.3	0.6	0.75	0.5	0.4	2.2	
	Turchaninovo	1983–1988	0.6	0.3	0.3	0.5	5.6	14.8	0.9	0.7	0.4	0.4	2.0	
	Beregovoe	2772–2782	0.6	0.4	0.4	0.6	5.6	16.0	0.75	0.7	0.35	0.5	2.4	
	Pashnino	2664–2668	0.6	0.4	0.4	0.6	5.7	12.4	0.8	0.7	0.5	0.4	3.4	

Table 7. Geochemical types of oil in the Timan-Pechora petroliferous province by HC-markers (average values)

Geochemical	Structural zone	Age of host rocks	Steranes						Triterpanes					Inferred oil sources
			$\frac{C_{27}}{C_{29}}$	$\frac{C_{28}}{C_{29}}$	K^1 mat	K^2 mat	$\frac{\text{Dia.}}{\text{reg.}}$	$\frac{C_{21}-C_{22}}{C_{21-22}+C_{27-29}}$ %	$\frac{Ts}{Tm}$	$\frac{C_{29}}{C_{30}}$	$\frac{\text{Neo-}C_{29}}{C_{29}}$	$\frac{\text{Tri-}}{\text{penta-}}$	$\frac{\text{Hopane}}{\text{sterane } C_{29} \text{ sum}}$	
I	Varandei-Adz'va Zone	P_1–T_2	0.6	0.45	0.55	5.3	0.3	33.7	0.5	1.1	0.3	0.6	2.5	D_3 f^2 domanik
	Pechora Sea	C_1 srp–P_2	0.7	0.45	0.55	4.6	0.2	27.0	0.65	1.1	0.5	0.4	3.1	
	Khoreiver Basin	D_3 fm–f^2–P_1	0.6	0.45	0.5	4.8	0.2	22.0	0.5	1.2	0.3	0.5	3.1	
II	Varandei-Adz'va Zone	S_2–D_3 fm–f^2	0.7	0.45	0.5	4.3	0.25	10.0	0.5	0.7	0.4	0.15	4.3	S–D_1
	Khoreiver Basin	D_3 f^1–P_1	0.6	0.4	0.5	4.6	0.2	11.0	0.6	0.8	0.6	0.2	6.8	D_3 fm–f^2 + O–D_1
	Khoreiver Basin	O–D_1	0.55	0.4	0.5	4.7	0.2	10.0	0.6	0.6	0.6	0.2	2.5	O–D_1
	Kolva Arch	D_2–P_2	0.5	0.4	0.5	4.4	0.25	13.2	0.8	0.7	0.4	0.3	3.9	S–D_1
	Izhma–Pechora Basin	D_2 gv–P_2	0.6	0.3	0.5	4.9	0.3	13.5	0.7	0.7	0.4	0.4	2.5	D_3 f^2 domanik, D_2 gv
III	Varandei-Adz'va Zone	S_2–D_3 f^1	0.6	0.55	0.5	4.7	0.35	9.0	1.55	0.6	0.9	0.1	3.9	S–D_1
	Pechora Sea	D_3 fm–f^2, D_1	0.7	0.65	0.5	4.3	0.3	12.9	1.6	0.7	0.9	0.15	4.8	
	Khoreiver Basin	S–D_1	0.65	0.5	0.5	5.3	0.3	10.5	1.1	0.6	0.9	0.3	3.6	
	Kolva Arch	S–C_3	0.5	0.5	0.5	4.7	0.4	10.0	2.2	0.55	0.8	0.3	2.8	
	Malaya Zemlya-Kolguev Monocline	C_{2-3}	0.5	0.5	0.5	4.6	0.4	8.5	1.4	0.6	0.9	0.1	4.0	
IV	Malaya Zemlya-Kolguev Monocline	T_1	0.75	0.8	0.5	5.9	0.8	20.4	3.0	0.5	0.8	1.2	2.7	*P–T* in the Pechora and Barents seas
	Pechora Sea	C–P_1	0.9	0.7	0.5	4.8	0.4	50.7	1.8	1.3	0.8	3.3	0.5	
	Pechora Sea	S_1	1.05	0.7	0.55	4.2	0.7	21.0	1.4	0.8	0.6	0.5	1.4	S_1
	Kolva Arch	P_1–T_1	0.65	0.5	0.5	4.6	0.45	35.0	1.5	0.8	0.7	1.6	1.4	*P–T* in the Pechora and Barents seas
	Shapkino-Yur'yakh Arch	C_2–P_1	0.7	0.6	0.5	5.4	0.4	23.5	1.7	0.55	0.75	1.4	2.0	
	Shapkino-Yur'yakh Arch	D_3 fm–f^2	0.7	0.4	0.55	5.8	0.6	19.3	2.3	0.4	1.0	0.45	2.9	D_3 f^2 domanik, S–D_1

ing higher terpane parameters of maturity. Hence, the average Ts/Tm ratio is >1, and the neoadiantane/adiantane ratio is also relatively high (largely, >0.5). Group III comprises many of oils from various structural zones in the northern TPPP, including oils from the Varandei–Adz'va Structural Zone (Table 1), the southeastern Pechora Sea (Table 2), Khoreiver Basin (Table 3), Kolva Arch (Table 4), and Malaya Zemlya–Kolguev Monocline (Table 5). In the Kolva Arch, such oils are traceable in a wide stratigraphic range from the Silurian to the Upper Permian, and only here, e.g., at the Vozei field do some oils have somewhat lowered parameters of maturity (Ts/Tm = 0.9; neo-C_{29}/C_{29} = 0.1–0.5) and approach the values characteristic of oils classed with type II. In other structural zones of the northern TPPP, oils of group III are mainly hosted in the Silurian and Devonian rocks.

According to the geochemical indices of the HC biomarkers, oils of group III are correlated with family IV in Requeijo *et al.* classification [2] and with group C, after Abrams *et al.* [8].

Type IV of oils from TPPP has some parameters analogous to the geochemical features of types I and III, however, this type can hardly be a mixture of oils belonging to the above groups, because type IV is distinguished by anomalously high heulantane contents, which are 1.2–4.5 times higher than the concentrations of pentacyclic terpanes. Oils from Permian and Triassic sedimentary rocks in the northwestern TPPP, on Kolguev Island, in the northern Shapkino–Yur'yakh and Kolva arches (Tables 4 and 5) are especially enriched in heulantanes. Only the Silurian oil at the Pakhancha field and the Middle Frasnian oil at the Upper Grubeshor field have a tricyclic/pentacyclic terpane ratio of less than unity.

In addition, oils of the fourth geochemical type are characterized by the following features:

—An elevated diasterane/regular sterane ratio (0.3–0.8), particularly in the Lower Triassic beds at the fields on Kolguev Island and in the Silurian oil at the Pakhancha field in the southeastern Pechora Sea.

—The concentration of pregnanes C_{21-22} (19–57%) is as high as in oils of type I.

—A high (1.1–3.0) Ts/Tm ratio along with a relatively high neoadiantane/adiantane ratio (0.6–1.0).

It is worth noting that the high pregnane and heulantane contents in oils of type IV in the northern TPPP are inherent to light, catagenetically-transformed oils devoid of any traces of biodegradation effects. This feature is most likely primary.

Oils of type IV in our classification correspond to group I after Requejo *et al.* [2].

Thus, according to our data, which are generally highly consistent with the results obtained by Requejo *et al.* [2], Abrams *et al.* [8], Kosenkova and Timoshenko [9], Matveeva and Gordadze [7], four distinct geochemical types (families) of oils are recognized in TPPP. The distribution of these oil types through petroliferous lithostratigraphic complexes in the main structural zones of TPPP makes it possible to approximately determine the oldest age of the sedimentary rocks that host the oil of each type and, thus, to establish the age of the oil sources, i.e., to outline a position of the main source sequences in the lithostratigraphic section (Table 7).

For example, the middle Frasnian–Famennian carbonate sequence of the Khoreiver Basin, including the highly bituminous rocks of the domanik unit strongly enriched in DOM, as well as the Upper Frasnian–Famennian domanik-like rocks in inter-reef and other paleodepressions of the Frasnian–Famennian marine basin, are the oldest rocks that host oils of the first geochemical type. Precisely these sequences are suggested to be a source for many oils in the Khoreiver Basin and the Varandei–Adz'va Structural Zone [8, 9]. These rocks probably served as the major source of oils that belong to type I in our classification. These oils occur not only in the Upper Devonian carbonate sequence of the Khoreiver Basin but also in the Carboniferous and Permian rocks in the southeastern Pechora Sea and in the Permian and Triassic rocks of the Varandei–Adz'va Structural Zone (Tables 1–3).

The source rocks of the domanik unit and the Frasnian and Famennian domanikoids might also serve as a source of oils pertaining to type II and hosted in the middle Frasnian and Lower-Permian beds in the central-Khoreiver Basin (Table 3, Varktnav, Bagan, Ardala, Urernyrd, and North Khosedayu fields) and even probably of some oils that belong to type III in the southeastern Pechora Sea (Medyn-More field). However, the Lower Devonian and Silurian rocks were the main sources of oil that belongs to type II and especially to type III in the Varandei–Adz'va Structural Zone and the Khoreiver Basin. These rocks also were the major suppliers of oil at the fields of the Kolva Arch.

According to Bushnev [10] and Kosenkova and Timoshenko [9], the domanik source rocks could have supplied OM even to some pools hosted in the Lower Devonian and Silurian, e.g., at the Khosolta and Osovei fields in the southern Sorokin Arch of the Varandei–Adz'va Structural Zone, although from the geological standpoint, OM migration from overlying into underlying rocks is low probable.

Oils of geochemical type II in the southern TPPP, within the Izhma–Pechora Basin and Timan, were apparently born in the domanik or/and the Givetian source rocks.

The stratigraphic range of oil belonging to type III and derived from the Silurian and Lower Devonian sequences is the widest in the Kolva Arch, where these oils are traceable from the Lower Silurian to the Upper Permian.

Oils of type IV likely had three different sources. The Permian–Triassic oils from Kolguev Island and the northern Shapkino–Yur'yakh arches are genetically related to the first source, while oils from the Middle-Frasnian rocks in the southern Shapkino–Yur'yakh Arch belong to the second one, and the Silurian oil in the southeastern Pechora Sea originated from the third source. The first source, strongly enriched in heulantanes, was probably situated in the north, being localized in the Permian–Triassic sediments of the Pechora and Barents seas. The domanik beds in the southern Shapkino–Yur'yakh Arch could be the second source, and the Silurian rocks in the Pechora Sea were the third source.

The identification of the geochemical types of oils makes it possible to trace the flows of specific HC liquids from the lower units into the upper ones at many fields of TPPP. For example, the flows of oil (III type) from the Lower Devonian rocks into the Tournaisian units at the Naul and Labogan fields may be suggested in the Sorokin Arch of the Varandei–Adz'va Structural Zone (Table 1); from the Lower Devonian into the Frasnian and even Middle-Carboniferous rocks (Medyn-More fields) in the Talota Arch; from the Lower Devonian into the Famennian and Lower-Permian rocks in the Kolva Arch (Bagan, Ardala, Varktnav, and North Khosedayus fields); and from the Silurian into the Famennian, Middle-Carboniferous, and Lower-Permian rocks in the Kolva Arch (Vozei and other fields).

Thus, the study of cyclic saturated HC biomarkers (steranes and terpanes) in oils of TPPP has shown a wide diversity of geochemical parameters, concentration ratios of particular steranes and terpanes, in oils from petroliferous complexes having various ages and localized in different structural zones of the province. Four geochemical families (types) of oils are recognized on the basis of this variation. The localization of oil types in sedimentary rocks of various ages, within main structural zones of TPPP, allowed us to establish inferred sources of oil belonging to each of the types and to estimate the vertical migration of oil through the geological section at specific fields.

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