Influences of Neo-Pleistocene permafrost on thermal history of petromaternal Lower Jurassic Togur suite (Tomsk region)

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Abstract. Based on paleotemperature modeling, evaluation of Neo-Pleistocene permafrost rock thickness impact on geothermal regime of the petromaternal Togur deposits has been performed within the territory of oil fields of the Tomsk region (the southeast of Western Siberia). It has been stated that paleopermafrost with the thickness of about 300 m must be considered for appropriate reconstruction of geothermal history of petromaternal rocks in the south-east areas of West Siberia. This condition is relevant to a consistent consideration of thermal history of maternal deposits in course of assessment of resources by a volumetric-genetic method.

1. Introduction

The previous researches have studied the impact of secular trend in the temperature on the surface of the Earth, as well as, the influence of neopleystotsen permafrost on the thermal history and oil-generation potential of Bazhenov deposits in the south-east of West Siberia [1]. The article presents the assessment of significant influence of secular temperature trend and paleopermafrost on implementation extent of oil-generation potential of Bazhenov suite forming deposits of hydrocarbons in the lower Jurassic and upper Jurassic oil-and-gas bearing complexes in the south-east of West Siberia. The purpose of the present study is to estimate the influence of Neo-Pleistocene permafrost thickness on geothermal regime of the Togur deposits forming deposits of hydrocarbons of the lower Jurassic and pre-Jurassic oil-and-gas bearing complexes in the south-east of West Siberia.

2. Research methods

Based on data from sedimentary cross-section of deep well 1 in the North Festival field, modeling of paleogeothermal conditions in Togur deposits was performed (fig. 1). Generative potential of the Togur deposits within this territory is caused by the high content of dispersed organic matter of gumic-sapropelic type and rather high content of organic C (to 10%) [2]. In the North Festival field hydrocarbon deposits are mainly associated with medium-Lower Jurassic reservoirs (table 1).

The evaluation of Neo-Pleistocene permafrost rock thickness impact on the geothermal regime and degree of oil-generation potential implementation of Togur deposits is performed on the basis of the results of four optional paleotemperature reconstructions variability analysis. Reconstruction 1 considers both secular trend in the temperature on the Earth surface [3], and Neo-Pleistocene permafrost sequence of about 300 m in thickness [4]. Reconstruction 2 involves secular trend in the Earth surface temperature analysis without considering permafrost rock sequence. Reconstruction 3 gives analysis regardless of secular trend of surface temperature and permafrost rock sequence. Reconstruction 4 refers to secular trend of surface temperature and Neo-Pleistocene permafrost which is assumed to be up to 1000 m thick [5].

In *Reconstruction 1* (table 2) permafrost sequence is considered to be of 300 m thick. Formalized calculation of permafrost thickness is provided beginning from 240 thousand years ago when an “immediate”(according to the standards of geological time, for the period of 1,5+ 3,0 thousand years) replacement of “normal” sedimentary deposits by permafrost sequence with particular thermophysical parameters – thermal conductivity, temperature conductivity occurred [6]. This sequence of permafrost rocks has overlaid sedimentary mantle for 179 thousand years. Hereafter, “immediately” (1,5+3,0 thousand years) permafrost sequence is substituted for “normal” sedimentary deposits and since that time “normal” sedimentary mantle has been retained up to the present moment for over the recent 52 thousand years.

Reconstruction 4 deals with permafrost thickness of 1000 m, other procedure being the same as in Reconstruction 1.

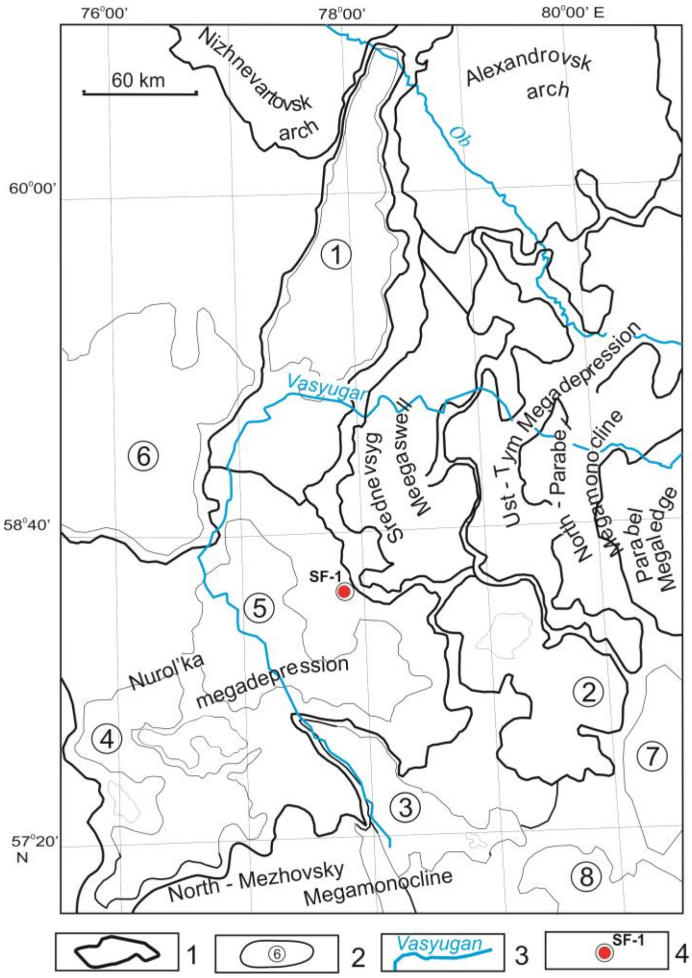

Figure 1. Tectonic scheme of the study area (on basis [7]): 1) – structures of the I order 2) – structures of the II order: 1 – Koltogorsky mesodeflection, 2 – Pudinskoe mesoraising, 3 – Lavrovsky mesoledge, 4 – Southern Nyurol`ka megadepression, 5 – Tsentralnonyurolsk mesohollow, 6 – Novovasyugansk mesoshaft, 7 – Goreloyarsk mesoraising, 8 – Kalgachsky mesoledge; 3) – rivers; 4) – the studied well: SF-1– North Festival 1

Simulation of the thermal history of the Togur suite deposits has been carried out on the basis of paleotectonic and paleotemperature reconstructions. In the present research paleotemperature modeling has been applied [8]

Table 1. Characteristic of the well North Festival 1 section (northeast board of the Nyurolsky megahollow)

Characteristics	Value
Face, m	3270
Deposits on a face (suite)	Paleozoic (PZ)
Base of Lower Jurassic deposits, m	3234
Top of togur suite, m	3165
Power of togur suite, m	30
Top of Bazhenov suite, m	2705
Power of Bazhenov suite, m	23
Power of paleogenov deposits, m	704
Power of neogenov deposits, m	-
Power of quarternary deposits, m	35
Results of tests (suite; layer; fluid type; output)	Bazhenov-vasyugan (Yu$_1$); chilly. (an oil smell in a core) Tyumen; IO$_{13-15}$; oil; 2,57 m^3/d. Tyumen; IO$_{13-14}$; oil; 0,28 m^3/d. Urmansk; IO$_{16}$; oil; 0,13 m^3/d.. Urmansk+Paleozoic; IO$_{16}$+PZ; oil, gas; 1,54 m^3/d.890 m^3/d. Paleozoic; PZ; gas; 410 m^3/d.
Measured rock temperatures (suite; measurement depth; rock temperature)	Tyumen; 3130 m; 118 ^{o}C. Tyumen; 3145 m; 123 ^{o}C.
«Measured temperatures " according to vitrinite reflectance (suite; selection depth; temperature)	Urmansk; 3232 m; 124 ^{o}C.

Table 2. Description of sedimentation history and thermophysical properties of the sedimentary sequence tapped with the North Festival well (Neo-Pleistocene permafrost thickness is 300 m).

Suite, sequence (stratigraphy)	Thickness, m	Age, Ma ago	Accumulation period, Ma	Density, g/cm^3	Thermal Conductivity, W/m K	Temperature Conductivity, m^2/s	Temperature Conductivity, m^2/s
Quaternary *Q*	-	0,052-0,00	0,052	-	-	-	-
Quaternary *Q*	300	0,055-0,052	0,003	2,10	1,3	7e-007	1,22e-006
Quaternary *Q*	-300	0,0565-0,055	0,0015	2,10	2,09	1,05e-006	1,22e-006
Quaternary *Q*	-	0,2355-0,0565	0,179	-	-	-	-
Quaternary *Q*	300	0,2385-0,2355	0,003	2,10	2,09	1,05e-006	1,22e-006
Quaternary *Q*	-300	0,24-0,2385	0,0015	2,10	1,3	7e-007	1,22e-006
Quaternary *Q*	35	1,64-0,24	1,4	2,02	1,27	6,5e-007	1,1e-006
Pliocene N_2	–	1,64–4,71	3,07	–	–	–	–
Miocene N_1	–	4,71–24,0	19,29	–	–	–	–
Nekrasovskaya *nk* Pg_3	154	24,0–32,3	8,3	2,09	1,35	7e-007	1,2e-006
Cheganskaya *hgPg* $_{3-2}$	70	32,3-41,7	9,4	2,09	1,35	7e-007	1,2e-006
Lyulinvorskaya *ll* Pg_2	240	41,7-54,8	13,1	2,09	1,35	7e-007	1,2e-006
Talitskaya *tl* Pg_1	70	54,8-61,7	6,9	2,09	1,35	7e-007	1,2e-006
Gankinskaya P_{1-K2gn}	170	61,7-73,2	11,5	2,11	1,37	7e-007	1,25e-006
Slavgorodskaya *sl* K_2	130	73,2-86,5	13,3	2,11	1,37	7e-007	1,25e-006
Ipatovskaya *ip* K_2	-	86,5-89,8	3,3	-	-	-	-
Kuznetsovskaya *kz* K_2	15	89,8-91,6	1,8	2,18	1,43	8e-007	1,25e-006
Pokurskaya *pk* K_{1-2}	800	91,6–114,1	22,5	2,26	1,49	8e-007	1,25e-006
Alymskay a_2 K_1	24	114,1-116,3	2,2	2,39	1,6	8e-007	1,25e-006
Alymskay a_1 K_1	17	116,3-120,2	3,9	2,39	1,6	8e-007	1,25e-006
Kiyalinskay *kls* K_1	613	120,2–132,4	12,2	2,39	1,6	8e-007	1,25e-006
Tarskay *tr* K_1	54	132,4–136,1	3,7	2,44	1,62	8e-007	1,25e-006
Kulomzinskay *lm*K_1	313	136,1–145,8	9,7	2,44	1,64	8e-007	1,25e-006
Bazhenov *bg* J_3	23	145,8–151,2	5,4	2,42	1,62	8e-007	1,3e-006
Georgiev *gr* J_3	5	151,2–156,6	5,4	2,42	1,62	8e-007	1,3e-006
Vasyugan *vs*J_{3-2}	70	156,6–162,9	6,3	2,42	1,6	8e-007	1,3e-006
Tyumen *tm* J_{1-2}	362	162,9–200,8	37,9	2,46	1,64	8e-007	1,3e-006
Togur *tg* J_1	**30**	**200,8-203,9**	**3,1**	**2,46**	**1,64**	**8e-007**	**1,3e-006**

Urmanskoye *ur* J_1	39	203,9-208,0	4,1	2,46	1,64	8e-007	1,3e-006

Note. Grey shading indicates geological time intervals of "immediate" formation and degradation of NeoPleistocene permafrost sequence. Dark shading indicates time interval of permafrost sequence existence.

3. Results and discussion

A number of observations can be deduced from the analysis of computational values of mantle basement heat flow density (table 3). In *Reconstructions 1, 3 and 4* heat flow increases by 1,1–1,6–4,7 mW/m^2 relatively to computational value of heat flow in *Reconstruction 2* which is – 55.7 mW/m^2. In *Reconstructions 1 and 4* the increase of computational density of heat flow is due to the increase of heat diffusion throughout daylight surface caused by abnormally high thermal conductivity and temperature conductivity of the permafrost sequence present in the model. In this case more heat is dissipated through the daylight surface; therefore, higher value of computational density of mantle basement heat flow is required.

Provided that the secular trend of surface temperature (*Reconstruction 3*) is not taken into consideration, there is also an increase in computational heat flow – 57,3 mW/m^2, which is due to absence of heat solar source in the paleotemperature reconstruction model of this type.

The comparison of calculated and measured geotemperatures in the borehole is presented in table 4. Since the measured temperatures (including those defined against vitrinite reflectance) and calculated geotemperatures can have uncertainty of ±2ºC, results of *Reconstructions 3 and 4* are unacceptable. In these reconstructions true error exceeds optimal [9] rate more than four times, while the difference from vitrinite reflectance («maximum paleotermometer») data is 7–13ºC. Thus, neglect of paleoclimate (*Reconstruction 3*) does not allow producing a precise physic-mathematical model of geothermal regime of Togur source rock. In the same way the hypothetical assumption about Neo-Pleistocene permafrost being 1000 m thick in the latitudes of 57-61 ºis not confirmed by paleotemperature modeling.

Table 3. Calculated geotemperatures of the Togur suite in North Festival well 1 cross-section.

Time, million years ago	Secular trend of surface temperature («local),ºC	Togur suite basement depth, m	Suite geotemperatures, ºC			
			Reconstruction 1	Reconstruction 2	Reconstruction 3	Reconstruction 4
0	0	3183	119	120	125	115
0.001	+1	3182	119	120	125	115
0.003	+2	3182	119	120	125	115
0.005	+3	3182	119	120	125	115
0.018	+1	3182	119	120	125	115
0.03	–2	3182	119	120	125	115
0.05	–1	3181	119	120	125	115
0.052	–1	3181	119	120	125	115
0.055	–1	3181	119	120	125	115
0.0565	–2	3181	119	120	125	115
0.07	–4	3181	119	119	125	115
0.09	–1	3180	119	119	125	115
0.11	–4	3180	119	119	125	115
0.13	–1	3179	119	119	125	115
0.15	–4	3179	119	120	125	115
0.19	–9	3178	119	120	125	115
0.21	–6	3177	119	121	125	115
0.222	–7	3177	119	120	125	115
0.225	–8	3177	119	121	125	115
0.235	–10	3177	119	121	125	115
0.2355	–9	3177	119	121	125	115
0.2385	–2	3177	119	121	125	115
0.24	0	3177	119	122	125	115
1.4	+1	3158	124	122	124	131
1.64	+1	3158	124	122	124	131
3.1	+2	3147	126	124	124	133

3.2	+2	3147	126	124	124	133
3.8	+12	3147	126	124	124	133
4.7	+3	3147	130	128	124	138
5.2	–3	3146	126	124	124	133
5.7	+7	3146	126	124	124	134
6.3	+10	3146	132	129	124	139
7	+4	3146	127	124	124	134
20	+15	3146	138	135	124	145
24	+16	3141	138	136	124	146
31,5	+17	3011	133	131	117	140
32,3	+16	2993	132	130	117	139
34	+15	2977	130	128	116	137
37,6	+14	2955	128	126	115	135
41,7	+12	2925	125	123	114	131
42	+11	2913	123	121	113	130
46	+8	2838	117	115	110	124
54,8	+19	2687	120	118	103	126
58	+24	2647	124	122	101	130
61,7	+22	2616	121	119	100	127
73	+15	2441	107	105	92	113
73,2	+16	2441	107	105	92	113
86,5	+22	2314	107	105	87	113
89,8	+22	2311	107	105	86	113
90	+23	2307	107	105	86	113
91,6	+22	2299	107	105	86	112
114,1	+21	1491	74	73	54	77
118	+19	1463	71	70	53	74
120,2	+19	1453	71	70	52	73
132,4	+19	850	49	48	30	50
136,1	+19	783	46	46	28	48
145,8	+19	493	36	36	17	37
Computational basement heat flow, mW/m^2			56.8	55.7	57.3	60.3

Note. Shaded areas indicate temperatures of major oil generation zone (OGZ) [10], dark-colour shading indicates absolute OGZ paleotemperature maxima. Threshold OGZ geotemperature is 95 °C.

Table 4. Comparison of measured and calculated geotemperatures (North Festival well 1).

Depth, m	Measured (observed) temperature, °C	Measurement method	Reconstruction 1, °C		Reconstruction 2, °C		Reconstruction 3, °C		Reconstruction 4, °C	
			Calculated temperatures	Discrepancy	Calculated temperatures	Discrepancy	Calculated temperatures	Discrepancy	Calculated tempe-ratures	Discrepancy
3130	118	Sheeted	117	–1	119	+1	124	+6	114	–4
3145	123	Sheeted	118	–5	119	–4	124	+1	114	–8
3232	124	On OSV	130	+6	128	+4	117	–7	137	+13
Mean squared error («true error»), ºC			±4		±3		±5		±9	

In case of the paleoclimate accounting (*reconstructions 1 and 2*) the true error of inverse modelling is close to optimal and is equal. Thus, comparison of the measured and assumed geotemperatures, allows concluding that according to the criteria of the true error results of *reconstructions 1 and 2* are acceptable and equal.

Existence of intensive Togur petroleum paleocharge in results of *reconstructions 1* (table 3) well explains exposed oil accumulation in the Lower Jurassic deposits with the North Festival 1 well (table 1). Moreover, in *reconstructions 1* during the longest period 34-6 million years ago (table 3) catagenetic conditions of gas generation deep zone (geotemperatures reach 138^{0}C) took place; the given fact conforms with gas bearing of Lower Jurassic and Paleozoic oil-and-gas bearing complexes (table 1).

4. Conclusion

By the example of Mesozoic-Cainozoic section of the south-east of West Siberia it has been stated that the neglect of secular trend of temperature and Neo Pleistocene permafrost thickness do not make it possible to reconstruct thermal history of Togur source rocks appropriately.

To estimate hydrocarbon resources in south-east areas of West Siberia using volumetric-genetic method [10] it is advisable to apply "local" secular trend of surface temperature [3] and deal with permafrost thickness of 300 m, that provides more consistent consideration of the main oil generation phase history and prevent from underestimating.

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