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.

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].

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 mesoleoge, 4 – Southern Nyorol’ka megadepression, 5 – Tsentralnyurolsk mesohollow, 6 – Novovasyugansk mesoshift, 7 – Goreloyarsh mesoraising, 8 – Kalgachsky mesoleoge; 3) – rivers; 4) – the studied well: SF-1 – North Festival 1
### Table 1. Characteristic of the well North Festival 1 section (northeast board of the Nyuroisky 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 quaternary deposits, m                       | 35     |
| Bazhenov-vasyugan (Yu); chilly. (an oil smell in a core) |        |
| Tyumen; IO31; oil; 2.57 m/d.                          |        |
| Tyumen; IO31; oil; 0.28 m/d.                          |        |
| Urmansk; IO31; oil; 0.13 m/d.                          |        |
| Measured rock temperatures (suite; measurement depth; rock temperature) |
| Tyumen: 3130 m; 118 °C.                               |        |
| Tyumen: 3145 m; 123 °C.                               |        |
| Urmansk; 3232 m; 124 °C.                              |        |

#### Results of tests (suite; layer; fluid type; output)

- Power of togur suite, m
  - 3165
- Power of Bazhenov suite, m
  - 2705
- Power of paleogenov deposits, m
  - 704
- Power of neogenov deposits, m
  - 35
- Bazhenov-vasyugan (Yu); chilly. (an oil smell in a core)
  - Tyumen; IO31; oil; 2.57 m/d.
  - Tyumen; IO31; oil; 0.28 m/d.
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- Measured rock temperatures (suite; measurement depth; rock temperature)
  - Tyumen: 3130 m; 118 °C.
  - Tyumen: 3145 m; 123 °C.
  - Urmansk; 3232 m; 124 °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/cm³ | Thermal Conductivity, W/m K | Temperature Conductivity, m²/s | Temperature Conductivity, m²/s |
|--------------------------------|--------------|-------------|-------------------------|----------------|-----------------------------|--------------------------------|--------------------------------|
| Quaternary Q                   | -            | 0.052-0.000 | -                       | -              | -                           | -                              | -                              |
| Quaternary Q                   | 300          | 0.055-0.052 | 0.003                   | 2.10           | 1.3                         | 7e-007                         | 1.22e-006                      |
| Quaternary Q                   | -300         | 0.0055-0.055| 0.0015                  | 2.10           | 2.09                        | 1.05e-006                      | 1.22e-006                      |
| Quaternary Q                   | -            | 0.2555-0.0565| 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 N2                    | -            | 1.64-4.71  | 3.07                    | -              | -                           | -                              | -                              |
| Miocene N1                     | -            | 4.71-24.0  | 19.29                   | -              | -                           | -                              | -                              |
| Nekrasovskaya nk P6           | 154          | 24.0-32.3  | 8.3                     | 2.09           | 1.35                        | 7e-007                         | 1.22e-006                      |
| Cheganskaya hQg P7            | 70           | 32.3-41.7  | 9.4                     | 2.09           | 1.35                        | 7e-007                         | 1.22e-006                      |
| Lyulinovskaya Il P6           | 240          | 41.7-54.8  | 13.1                    | 2.09           | 1.35                        | 7e-007                         | 1.22e-006                      |
| Talitskaya Il P6             | 70           | 54.8-61.7  | 6.9                     | 2.09           | 1.35                        | 7e-007                         | 1.22e-006                      |
| Gankinskaya P6,7             | 170          | 61.7-73.2  | 11.5                    | 2.11           | 1.37                        | 7e-007                         | 1.22e-006                      |
| Slagorodskaya d K5          | 130          | 73.2-86.5  | 13.3                    | 2.11           | 1.37                        | 7e-007                         | 1.22e-006                      |
| Ipatovskaya ip K5          | -            | 86.5-89.8  | 3.3                     | -              | -                           | -                              | -                              |
| Kuznetsovskaya ks K7         | 15           | 89.8-91.6  | 1.8                     | 2.18           | 1.43                        | 8e-007                         | 1.25e-006                      |
| Pokurskaya pk K6,7         | 800          | 91.6-114.1 | 22.5                    | 2.26           | 1.49                        | 8e-007                         | 1.25e-006                      |
| Alymskay a1 K1             | 24           | 114.1-116.3| 2.2                     | 2.39           | 1.6                         | 8e-007                         | 1.25e-006                      |
| Alymskay a1 K1             | 17           | 116.3-120.2| 3.9                     | 2.39           | 1.6                         | 8e-007                         | 1.25e-006                      |
| Kiyalinskay klK5           | 613          | 120.2-132.4| 12.2                    | 2.39           | 1.6                         | 8e-007                         | 1.25e-006                      |
| Taras ktr K1               | 54           | 132.4-136.1| 3.7                     | 2.44           | 1.62                        | 8e-007                         | 1.25e-006                      |
| Kulomzinskaya lnK5         | 313          | 136.1-145.8| 9.7                     | 2.44           | 1.64                        | 8e-007                         | 1.25e-006                      |
| Bazhenov hQg J3            | 23           | 145.8-151.2| 5.4                     | 2.42           | 1.62                        | 8e-007                         | 1.3e-006                       |
| Georgiev gr J3             | 5            | 151.2-156.6| 5.4                     | 2.42           | 1.62                        | 8e-007                         | 1.3e-006                       |
| Vasyugan vsJ3,7           | 70           | 156.6-162.9| 6.3                     | 2.42           | 1.6                         | 8e-007                         | 1.3e-006                       |
| Tyumen tm J1,2            | 362          | 162.9-200.8| 37.9                    | 2.46           | 1.64                        | 8e-007                         | 1.3e-006                       |
| **Togur** J1              | 30           | 200.8-203.9| 3.1                     | 2.46           | 1.64                        | 8e-007                         | 1.3e-006                       |

3
IOP Conf. Series: Earth and Environmental Science 43 (2016) 012009  doi:10.1088/1755-1315/43/1/012009

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/m² relatively to computational value of heat flow in Reconstruction 2 which is −55.7 mW/m². 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/m², 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 ±2°C, 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 paleotemperature) data is 7–13°C. 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 °is 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«), °C | Togur suite basement depth, m | Suite geotemperatures, °C |
|------------------------|-----------------------------------------------|-------------------------------|------------------------|
|                        |                                               |                               | 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                  | 4                                             | 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               | 120             | 125             | 115             |
| 0.09                   | −1                                            | 3180                          | 119               | 120             | 125             | 115             |
| 0.11                   | −4                                            | 3179                          | 119               | 120             | 125             | 115             |
| 0.13                   | −1                                            | 3178                          | 119               | 120             | 125             | 115             |
| 0.15                   | −4                                            | 3179                          | 119               | 120             | 125             | 115             |
| 0.19                   | −9                                            | 3178                          | 119               | 120             | 125             | 115             |
| 0.21                   | −6                                            | 3177                          | 119               | 120             | 125             | 115             |
| 0.222                  | −7                                            | 3177                          | 119               | 120             | 125             | 115             |
| 0.225                  | −8                                            | 3177                          | 119               | 120             | 125             | 115             |
| 0.235                  | −10                                           | 3177                          | 119               | 120             | 125             | 115             |
| 0.2355                 | −9                                            | 3177                          | 119               | 120             | 125             | 115             |
| 0.2385                 | −2                                            | 3177                          | 119               | 120             | 125             | 115             |
| 0.24                   | 0                                             | 3177                          | 119               | 120             | 125             | 115             |
| 1.4                    | 4                                             | 3158                          | 124               | 122             | 124             | 131             |
| 1.64                   | 4                                             | 3158                          | 124               | 122             | 124             | 131             |
| 3.1                    | 2                                             | 3147                          | 126               | 124             | 124             | 133             |

Note. Grey shading indicates geological time intervals of “immediate” formation and degradation of Neo-Pleistocene permafrost sequence. Dark shading indicates time interval of permafrost sequence existence.
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°C) took place; the given fact conforms with gas bearing of Lower Jurassic and Paleozoic oil-and-gas bearing complexes (table 1).

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

| Depth, m | Measured (observed) temperature, °C | Measure ment method | Reconstruction 1, °C | Reconstruction 2, °C | Reconstruction 3, °C | Reconstruction 4, °C |
|----------|------------------------------------|---------------------|----------------------|----------------------|----------------------|----------------------|
|          |                                    |                     | Calculated temperatures | Discrepancy | Calculated temperatures | Discrepancy | Calculated temperatures | Discrepancy | Calculated temperatures | 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 Shopping                        | On OSV              | 113                   | +6       | 128                   | +4        | 117                   | –7         | 137                   | +13        |

Mean squared error («true error»), °C: ±4 ±3 ±5 ±9

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.

Computational basement heat flow, mW/m²: 56.8 55.7 57.3 60.3
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.

The present research is conducted with financial support from the Russian Foundation of Basic Research as a part of the scientific project № 16-35-00080 mol_a

References
[1] Iskorkina A, Isaev V, Terre D 2015 *IOP Conf. Series: Earth and Environmental Science*. Assessment of Mesozoic-Kainozoic climate impact on oil-source rock potential (West Siberia). Vol. 27 pp. 012023.
[2] Isaev V I, Fomin A N 2006 *Russian Geology and Geophysics*. Loki of generation of bazhenov- and togur-type oils in the southern Nyurol’ka megadepression. Vol. 47 (6) pp. 734-745.
[3] Isaev V I, Iskorkina A A 2014 *Journal of Geophysics*. Mezozojsko-kajnozojskij khod temperatur na poverkhnosti Zemli i geotermicheskij rezhim Yurskich neftematerinskikh otlozhenij (Uyzhnaya paleoklimatichesky zona Zapadnoj Sibiri. Vol. 36 (5) pp. 64–80.
[4] Efimenko S V, Badina M V, Efimenko V N 2013 *TGASU bulletin*. K obosnovaniyu territorialnogo rasprostraneniya granici 1–II dorojno_klimaticheskih zon v Zapadno-Sibirskom regione. Vol. 4 pp. 295–303.
[5] Pavlov A V, Gravis G F 2000 *Nature*. Vechnaya merzlota i sovremennoi klimat. Vol. 4 pp. 10-18.
[6] Ivanov N S, Gavrilev R I 1965 *Nauka*. Teplofizicheskie svoistva merzlih gornih porod. Pp. 74.
[7] Kontorovich V A, Belyaev S Yu, Kontorovich A E, Krasavchikov V O, Kontorovich A A, Suprunenko O I 2001 *Geology and Geophysics*. Tektonicheskoe stroenie i istoriya razvitiya Zapadno-Sibirskoi geosineklizi v mezozoe i kainozoe. Vol. 42 pp. 1832–1845.
[8] Gulenok R Yu, Isaev V I, Kosygın V Yu, Lobova G A, Starostenko V I 2011 *Russian Journal of Pacific Geology*. Estimation of the Oil-and-Gas Potential of Sedimentary Depression in the Far East and West Siberia Based on Gravimetry and Geothermy Data. Vol. 5 (4) pp. 273–287.
[9] Isaev V I 2013 *Russian Journal of Pacific Geology*. Interpretation of High-Accuracy Gravity Exploration Data by Mathematical Programming. Vol. 7 (2) pp. 92–106.
[10] Kontorovich A E, Burshtein L M, Malishev N A, Safronov P I, Guskov S A, Ershov S V, Kazanenkov V.A. Kim N.S. Kontorovich V.A. Kostireva E.A. Melenevskii V.N. Livshic V.R. Polyakov A A, Skvorcov M B 2013 *Geology and Geophysics*. Istoriko-geologicheskoe modelirovanie processov naftidogeneza v mezozoisko-kainozoiskom osadochn. Vol. 54 (8) pp. 1179–1226.