# Assessment of Mesozoic-Kainozoic climate impact on oil-source rock potential (West Siberia)

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**Abstract.** Based on paleotemperature modeling, the evaluation of the effect of Neo-Pleistocene permafrost rock thickness on geothermal regime of the Bazhenov deposits has been performed. It has been stated that permafrost about 300 m in thickness must be considered for appropriate reconstruction of geothermal history of source rocks in the south-east areas of West Siberia. This condition is relevant to a consistent consideration of oil-generation phase history and can prevent underestimation (to 25%) of hydrocarbon-in-place resources.

## 1. Introduction

Potential permafrost rock formation in the Late Quaternary in the area of 61ºN latitude, West Siberia (Shirotnoye Priobye) has been presented in research [1]. In hydrointegrator modeling performed for a calculation period of 245 kya, A.A. Sharbatyan applied surface temperature time series as an upper-boundary condition for the stated problem (table 1). Time series for surface temperatures has been defined by time series chart of solar radiation (proposed by M. Milankovich) taking into account geographical peculiarities of the area.

**Table 1**. Permafrost rock thickness variation over time [1].

| Time, kya (thousands of years ago) | Permafrost base depth, m | Surface temperature time series, °C |
|---|---|---|
| 245 | 0 | 0 |
| 235 | -350 | -10.0 |
| 210 | -450 | -5.5 |
| 190 | -550 | -8.5 |
| 165 | -450 | -4.5 |
| 145 | -400 | -3.5 |
| 130 | -350 | -1.0 |
| 110 | -300 | -3.9 |
| 95 | -300 | -0.7 |
| 70 | -250 | -4.0 |
| 50 | -250 | -1.0 |
| 30 | -200 | -4.3 |
| 5 | 0 | +2.5 |

According to recent data [2] permafrost was not only in the central and southern parts of West Siberia, but Quaternary ice cover embraced northern and northeastern parts of Kazakhstan; ice sheet can be traced in Central Kazakhstan as well.

The previous researches [3] have addressed the impact of paleoclimate (surface temperature time series) on the thermal history and oil-generation potential of Bazhenov deposits in the south-east of West Siberia (South-Siberian paleoclimate zone [4]). The studies focused on West Siberia are of particular interest provided that paleotemperature reconstruction model considers not only surface temperature time series but permafrost sequence as a peculiar lithostratigraphic unit. The purpose of the present study is to estimate the influence of Neo-Pleistocene permafrost thickness in geothermal regime of Bazhenov deposits in the south-east of West Siberia.

## 2. Research methods

Based on data from sedimentary cross-section of deep well №183 in Luginetskoye field (Tomsk Oblast), modeling of paleogeothermal conditions in Bazhenov deposits was performed. Hydrocarbon deposits are mainly associated with Upper-Jurassic reservoirs ($J_1$ horizon). The major source of hydrocarbons in $J_1$ traps ($J_3$vs) are potential oil source rocks of the Bazhenov suite ($J_3$bg).

Simulation of the thermal history of the Bazhenov suite deposits has been carried out on the basis of paleotectonic and paleotemperature reconstructions. In the present research paleotemperature modeling has been applied [5, 6]

The evaluation of Neo-Pleistocene permafrost rock thickness effect on the geothermal regime and degree of oil-generation potential of Bazhenov deposits is performed on the basis of result variability analysis of four optional paleotemperature reconstructions. Reconstruction 1 considers both surface temperature time series and Neo-Pleistocene permafrost sequence about 300 m in thickness. Reconstruction 2 involves surface temperature time series analysis without considering permafrost rock sequence. Reconstruction 3 gives analysis regardless of surface temperature time series and permafrost rock sequence. Reconstruction 4 refers to surface temperature time series and Neo-Pleistocene permafrost which is assumed to be up to 1000 m thick.

In Reconstruction 1 (table 2) permafrost sequence is considered to be of 300 m thick (table 1). Formalized calculation of permafrost thickness is provided beginning with 240 kya when “immediate” (by standards of geological time, over 1.5+ 3.0 ky period) replacement of “normal” sedimentary deposits by permafrost sequence with particular thermophysical parameters – thermal conductivity, temperature conductivity occurred. This sequence of permafrost rocks has overlaid sedimentary mantle for 179 ky. Hereafter, “immediately” (1.5+3.0 ky) permafrost sequence is substituted by “normal” sedimentary deposits and since that time “normal” sedimentary mantle has been retained over the recent 52 ky.

Reconstruction 4 deals with permafrost thickness of 1000 m, other procedures being the same as in Reconstruction 1. Formalized consideration of permafrost thickness has been performed in the same way as in the previous reconstruction beginning with 240 kya. Replacement of “normal” sedimentary deposits by permafrost sequence has been completed in terms of geological time over 5.0 + 3.0 ky. Later, this sequence of permafrost rocks has overlaid sedimentary mantle for 206 ky. Hereafter, permafrost is substituted by “normal” sedimentary deposits and since that time the present day section has been retained for 21 ky.

**Table 2.** Parametric description of sedimentation history and thermophysical properties of the sedimentary sequence tapped from well Luginetskaya №183 (NeoPleistocene 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 | Heat release, W/m$^3$ |
|---|---|---|---|---|---|---|---|
| Quaternary *Q* | - | 0.052–0 | 0.052 | 2.10 | 1.3 | 7e-007 | 1.22e-006 |
| 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 | 2.10 | 2.09 | 1.05e-006 | 1.22e-006 |
| 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* | 25 | 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* $Pg_3$ | 84 | 24.0–32.2 | 8.3 | 2.09 | 1.35 | 7e-007 | 1.2e-006 |
| Cheganskaya+Lyulinvorskaya+Talitskaya *hg ll tl* $Pg_{3\text{-}1}$ | 173 | 32.2-61.7 | 29.4 | 2.09 | 1.35 | 7e-007 | 1.2e-006 |
| Slavgorodskaya+ Ipatovskaya+Kuznetsovskaya *sl ip kz* $K_2$ | 364 | 73.2-91.6 | 29.9 | 2.15 | 1.4 | 7e-007 | 1.25e-006 |
| Pokurskaya *pk* $K_{1\text{-}2}$ | 803 | 91.6–114.1 | 22.5 | 2.26 | 1.49 | 8e-007 | 1.25e-006 |
| Alymskay $a_{1,2}K_{1\text{-}2}$ | - | 114.1-120.2 | 6.1 | - | - | - | - |
| Kiyalinskay *kls* $K_1$ | 550 | 120.2–132.4 | 12.2 | 2.39 | 1.6 | 8e-007 | 1.25e-006 |
| Tarskay *tr* $K_1$ | 74 | 132.4–136.1 | 3.7 | 2.44 | 1.62 | 8e-007 | 1.25e-006 |
| Kulomzinskay $lmK_1$ | 237 | 136.1–145.8 | 9.7 | 2.44 | 1.64 | 8e-007 | 1.25e-006 |
| **Bazhenov** $\boldsymbol{bgJ_3}$ | **16** | **145.8–151.21** | **5.4** | **2.42** | **1.62** | **8e-007** | **1.3e-006** |
| Georgiev *gr* $J_3$ | - | 151.2–156.6 | 5.4 | - | - | - | - |
| Vasyugan $vsJ_{3\text{-}2}$ | 55 | 156.6–168.3 | 11.7 | 2.42 | 1.6 | 8e-007 | 1.3e-006 |
| Tyumen *tm* $J_2$ | 115 | 168.3–172.0 | 3.7 | 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 existing permafrost sequence.

## 3. Results and discussion

A number of observations can be deduced from the analysis of computational values of mantle basement heat flow density *q* (table 3). In Reconstructions 1, 3 and 4 heat flow increases by 1.4–2.6–7.1 mW/m$^2$ (by 3–5–14%) relative to computational value of heat flow in Reconstruction 2 which is 52.2 mW/m$^2$. In Reconstructions 1and 4 the increase of computational density of heat flow *q* is due to increase of heat diffusion throughout daylight surface caused by 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 which, in its turn, increases calculated geotemperatures of source deposits and, consequently, volumes of generated hydrocarbon resources.

Provided that surface temperature time series (Reconstruction 3) is not taken into consideration, there is also an increase in computational heat flow – 54.8 mW/ m$^2$ which is due to the absence of solar source heat 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 cannot be regarded as admissible. In these reconstructions true error exceeds optimal rate by more than four times, while the difference between adjusted and vitrinite reflectance («maximum paleotermometer») data is 11–12ºC. Thus, exclusion of paleoclimate (Reconstruction 3) does not allow producing a precise physico-mathematical model of geothermal regime of Bazhenov 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 Bazhenov suite in Luginetskaya well №183 cross-section (South-East of West Siberia, Tomsk Oblast).

| Time, million years ago | Surface temperature time series («local [3]),ºC | Bazhenov suite basement depth, m | Suite geotemperatures, ºC | | | |
|---|---|---|---|---|---|---|
| | | | Reconstruction 1 | Reconstruction 2 | Reconstruction 3 | Reconstruction 4 |
| 0 | 0 | 2321 | 80 | 81 | 87 | 75 |
| 0.001 | +1 | 2321 | 80 | 81 | 87 | 75 |
| 0.003 | +2 | 2321 | 80 | 81 | 87 | 75 |
| 0.005 | +3 | 2321 | 80 | 81 | 87 | 75 |
| 0.018 | +1 | 2320 | 80 | 81 | 88 | 77 |
| 0.03 | –2 | 2321 | 79 | 81 | 88 | 78 |
| 0.05 | –1 | 2320 | 79 | 81 | 88 | 78 |
| 0.052 | –1 | 2320 | 79 | 81 | 88 | 78 |
| 0.055 | –1 | 2321 | 79 | 81 | 88 | 78 |
| 0.0565 | –2 | 2320 | 79 | 81 | 88 | 78 |
| 0.07 | –4 | 2319 | 79 | 80 | 88 | 78 |
| 0.09 | –1 | 2319 | 79 | 80 | 87 | 78 |
| 0.11 | –4 | 2319 | 79 | 80 | 87 | 78 |
| 0.13 | –1 | 2319 | 79 | 80 | 87 | 78 |
| 0.15 | –4 | 2318 | 80 | 80 | 87 | 78 |
| 0.19 | –9 | 2318 | 83 | 81 | 87 | 79 |
| 0.21 | –6 | 2317 | 84 | 82 | 87 | 82 |
| 0.222 | –7 | 2317 | 85 | 82 | 87 | 82 |
| 0.225 | –8 | 2317 | 86 | 82 | 87 | 86 |
| 0.235 | –10 | 2317 | 86 | 82 | 87 | 91 |
| 0.2355 | –9 | 2317 | 86 | 82 | 87 | 94 |
| 0.2385 | –2 | 2317 | 86 | 83 | 87 | 94 |
| 0.24 | 0 | 2317 | 86 | 83 | 87 | 95 |
| 1.4 | +1 | 2299 | 86 | 83 | 86 | 94 |
| 1.64 | +1 | 2296 | 86 | 83 | 86 | 95 |
| 3.1 | +2 | 2295 | 88 | 85 | 86 | 96 |
| 3.2 | +2 | 2295 | 89 | 89 | 86 | 97 |
| 3.8 | +12 | 2295 | 95 | 93 | 86 | 104 |
| 4.7 | +3 | 2295 | 88 | 85 | 86 | 96 |
| 5.2 | –3 | 2294 | 89 | 86 | 86 | 97 |
| 5.7 | +7 | 2294 | 92 | 89 | 86 | 101 |
| 6.3 | +10 | 2294 | 94 | 90 | 86 | 102 |
| 7 | +4 | 2294 | 89 | 86 | 86 | 97 |
| 20 | +15 | 2294 | 100 | 97 | 86 | 108 |
| 24 | +16 | 2294 | 101 | 98 | 86 | 110 |
| 31.5 | +17 | 2218 | 98 | 95 | 83 | 107 |
| 32.3 | +16 | 2210 | 97 | 94 | 82 | 105 |
| 34 | +15 | 2200 | 96 | 93 | 82 | 103 |
| 37.6 | +14 | 2178 | 94 | 91 | 80 | 101 |
| 41.7 | +12 | 2154 | 90 | 87 | 80 | 98 |
| 42 | +11 | 2158 | 89 | 87 | 80 | 97 |
| 46 | +8 | 2129 | 86 | 83 | 79 | 93 |
| 54.8 | +19 | 2077 | 95 | 92 | 77 | 102 |
| 58 | +24 | 2058 | 99 | 96 | 76 | 106 |
| 61.7 | +22 | 2037 | 95 | 92 | 74 | 102 |
| 73 | +15 | 1899 | 83 | 81 | 69 | 90 |
| 73.2 | +16 | 1897 | 83 | 81 | 68 | 90 |
| 86.5 | +22 | 1735 | 83 | 81 | 62 | 90 |
| 89.8 | +22 | 1694 | 82 | 80 | 61 | 88 |
| 90 | +23 | 1692 | 82 | 81 | 61 | 88 |
| 91.6 | +22 | 1673 | 79 | 77 | 58 | 85 |
| 114.1 | +21 | 870 | 50 | 49 | 29 | 53 |
| 118 | +19 | 869 | 48 | 47 | 29 | 51 |
| 120.2 | +19 | 869 | 47 | 47 | 29 | 51 |
| 132.4 | +19 | 319 | 29 | 29 | 11 | 30 |
| 136.1 | +19 | 245 | 14 | 27 | 8 | 18 |
| Computational basement heat flow, mW/m$^2$ | | | 53.6 | 52.2 | 54.8 | 59.3 |

*Note.* Shaded areas indicate temperatures of major oil generation zone (OGZ) [7], dark-colour shading indicates absolute OGZ paleotemperature maximum, grey shading – relative OGZ paleotemperature maximum. Threshold OGZ geotemperature is 85 ºC.

**Table 4.** Comparison of measured and calculated geotemperatures (Luginetskaya well №183).

| Depth, m | Measured («observed») temperatures, °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 temperatures | Discrepancy |
| 2200 | 77 | In-place | 76 | –1 | 78 | +1 | 83 | +6 | 70 | –7 |
| 2350 | 84 | In-place | 81 | –3 | 82 | –2 | 89 | +5 | 76 | –8 |
| 2345 | 98 | VRV | 101 | +3 | 99 | +1 | 87 | –11 | 110 | +12 |
| Mean squared error («true error»), °C | | | ±2 | | ±1 | | ±8 | | ±9 | |

*Note.* Reconstruction 1 considers surface temperature time series, and Neo-Pleistocene permafrost sequence of 300 m thick. Reconstruction 2 deals with surface temperature time series without considering permafrost rock sequence. Reconstruction 3 gives analysis of surface temperature time series and permafrost rock sequence. Reconstruction 4 considers surface temperature time series and permafrost sequence of 1000 m thick.

Calculation of generated Bazhenov oil density R [8] (table 5) yields maximum value for appropriate Reconstruction 1 (68 cu.). This type considers presence of NeoPleistocene permafrost sequence which is 300m thick apart from surface temperature time series.

**Table 5.** Estimation of resource density of generated Bazhenov oils (*R*) for reconstructions considering surface temperature time series and permafrost thickness (Luginetskaya well №183).

| Scenario of paleo temperature modeling | Calculated resources (*R*), cu. | Number of calculated time intervals (*n*) | Period of paleo kitchen zone activity, m years ago | Duration of kitchen zone activity, million years | Peak temperatures of paleo kitchen zone, °C |
|---|---|---|---|---|---|
| Reconstruction 1 | 68 | 24 | 61.7–0.222 | 61.5 | 101 |
| Reconstruction 2 | 55 | 19 | 61.7–54.8<br>42–3.1 | 45.8 | 98 |
| Reconstruction 3 | 27 | 29 | 24–0 | 24.0 | 87 |
| Reconstruction 4 | 109 | 23 | 91.6–0.21 | 91.4 | 110 |

*Note.* Shaded areas indicate reconstruction types which are appropriate and consistent regarding optimal agreement of calculated geotemperatures with both measured in-place (formation) temperatures and geotemperatures determined based on vitrinite reflectance values.

## 4. Conclusion

By the example of Mesozoic-Kainozoic section of the south-east of West Siberia (in the latitude of Tomsk Oblast) it has been stated that neglect of surface temperature time series and NeoPleistocene permafrost thickness hinders appropriate reconstruction of thermal history of Bazhenov source rocks.
To estimate hydrocarbon resources in south-east areas of West Siberia using volumetric-genetic method [9] it is advisable to apply “local” surface temperature time series [3] and deal with permafrost thickness of 300 m. The latter will allow a more consistent consideration of the history of main oil generation phase and prevent underestimation (to 25 %) of hydrocarbon-in-place resources.

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