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THERMAL CONDUCTIVITY OF SEDIMENTARY ROCKS IN THE LENO-VILUY OIL-AND-GAS BEARING PROVINCE

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The results of studying the thermal conductivity of sedimentary rocks in the West-Central part of the Leno-Viluy oil-and-gas bearing province have been obtained and analyzed. The data have been obtained from laboratory studies of 283 samples from 12 deep boreholes bored in different parts of the structure. Thermal conductivity of the rocks has been analyzed under conditions of their natural bedding, with complete water saturation assessed. Effective thermal conductivity has been estimated for certain geological suites.

Thermal conductivity, rock density, effective thermal conductivity, sedimentary rocks, sandstone, siltstone, argillite

INTRODUCTION

Due to high concentration of hydrocarbon resources and their economic value, the Leno-Viluy oil-and-gas bearing province is one of the most significant geological regions of Russia. Currently, comprehensive geological survey has been restarted by *Gazprom* and *Rosgeologiya* companies at different features and fields, which accounts for the practical value of this study.

When territories and deposits of natural resources are developed, the thermo-physical characteristics of the sedimentary rocks are required for geologists to describe their geothermal fields and to make calculations relating to thermal interaction between the engineering facilities and the sedimentary rocks. No targeted thermo-physical studies of the rocks in the upper part of the drilled section (to 1,500 m) composing the Leno-Viluy oil-and-gas bearing province have been conducted before. Single data are known describing the thermo-physical properties of certain samples of mountain rocks [*Gavrilyev, 2013*], which is clearly insufficient for extensive characterization of this region. Under conditions of solid permafrost, typical of the territory in question, the importance of thermo-physical studies increases. Based on the laboratory works conducted, the values of thermal conductivity of frozen rocks were obtained, which would make it possible to carry out more precise calculations of the Earth's temperature field and to use the data obtained in solving applied problems and in making theoretical predictions.

THE NATURAL CONDITIONS OF THE TERRITORY

The Leno-Viluy oil-and-gas bearing province (OGBP) is situated in the south-eastern part of the Siberian Platform, tectonically belonging to the Viluy Syneclise and not including the eastern part of the province, the Verkhoyansk orogenic region. In the south, the Leno-Viluy OGBP borders on the Aldan anteclise; in the north, it borders on the Anabar-Olenek anteclise, and administratively it refers to the Suntarsky, Kobyaysky, Nurbinsky and Viluysky districts of the Sakha Republic (Yakutia).

Geologically, the region is represented by pre-Cambrian, Paleozoic and Mesozoic sediments, overlaid by a solid sedimentary cover of Cainozoic formations. Lower Paleozoic carbonate rocks are represented by salinated limestones, gypsified clays, argillites, siltstones, chalky clays, sandstones, sands, calk sinters, tuffites and rock salt beds up to 80 m thick. The sediments of the Upper Triassic – Lower Jurassic Ages are very common and are represented by rhythmic alternation of sands, sandstones, siltstones, argillites and clays. Their thickness within the province grows from 100 m in the west to 900 m in the eastern part. The sandy-clayey coal-bearing sediments of the Upper Jurassic and of the Lower Cretaceous are bedded nearly horizontally: in the marginal parts, the syneclise has the depth from 3 to 100 m, and in the central part it is at the depths of 500–1000 m. They are represented by rhythmic alternation of sands, sandstones, siltstones, argillites and clays. Primarily sandy sediments of the Late Cretaceous form single basin-like depressions in the central part of the provinces. In the deepest parts, their thickness reaches 1000 m, whereas within the Upper Viluy Rise (Anteclise) it decreases to 160 m [*Geology of the USSR, 1970*].

The Cainozoic sandy and clayey sediments forming a solid cover of varying depth superpose the sediments of the Paleozoic and Mesozoic ages. Their greatest depth (reaching 1,000 m) is characteristic of depressions in the lower reaches of the Viluy River. Alluvial and lacustrine-alluvial sediments are widespread. The Pleistocene sediments within the Viluy Syneclise are common, and their depth varies from several meters to several dozens of meters [*Tectonics..., 2001*].

According to hydrogeological studies, the static levels of the ground waters of the existing aquifers vary from 40 to 100 m. In this regard, at the depth exceeding 100 m, the sedimentary rocks are in the condition of complete water saturation over the entire territory under study, including the permafrost zone.

THE METHODOLOGY OF DETERMINING THE THERMAL CONDUCTIVITY OF SEDIMENTARY ROCKS

The thermo-physical studies were conducted using samples from the departmental core library of *Yakutskgeologiya* mining and geological survey company. The cores were obtained from deep test and key holes, the drilling of which started in the 1950s in the territory in question. The lithological description and laboratory studies were conducted in the laboratory of the geothermal studies of permafrost of the Melnikov Permafrost Institute, SB RAS. Altogether, 283 core samples from 12 boreholes located at 10 survey features were selected and analyzed (Fig. 1). The core samples selected from different bedding depths (from the first dozens of meters to 3500 m) characterize the main types and structural complexes of the rock section. In terms of the geological age, the cores were obtained from the Cretaceous, Jurassic, Triassic, Permian and Cambrian rock strata.

The thermal conductivity of the sedimentary rocks was determined in the dry-air and thawed states using an instrument for thermal conductivity scanning – TCS.

The principle of the thermal conductivity scanning method is based on heating of the samples of sedimentary rocks under study by optical radiation concentrated in a small spot moving along the sample surface at a constant rate (Fig. 2). An optical source was used for heating the samples. The samples' initial temperatures and heating values were recorded with infrared radiation receivers, the field of vision of each of which was moving along the same surface at the same rate as the heating spot. Two standard samples with known thermal conductivity values (reference specimens) were included into the testing series. The thermal conductivity of the rock samples was determined by comparing the temperatures of their heating with the heating temperatures of the reference specimens.

Measurements were made on the cylindrical surface of the cores (when the samples were scanned along the core axis) or on the flat surface of the core samples. In some cases, the thermal conductivity measurements on the cylindrical surface of a core and on its edges were combined.

The thermal conductivity profile was recorded when the samples were exposed to radiation and when they were scanned with temperature gauges. That enabled us to determine both the mean values of thermal

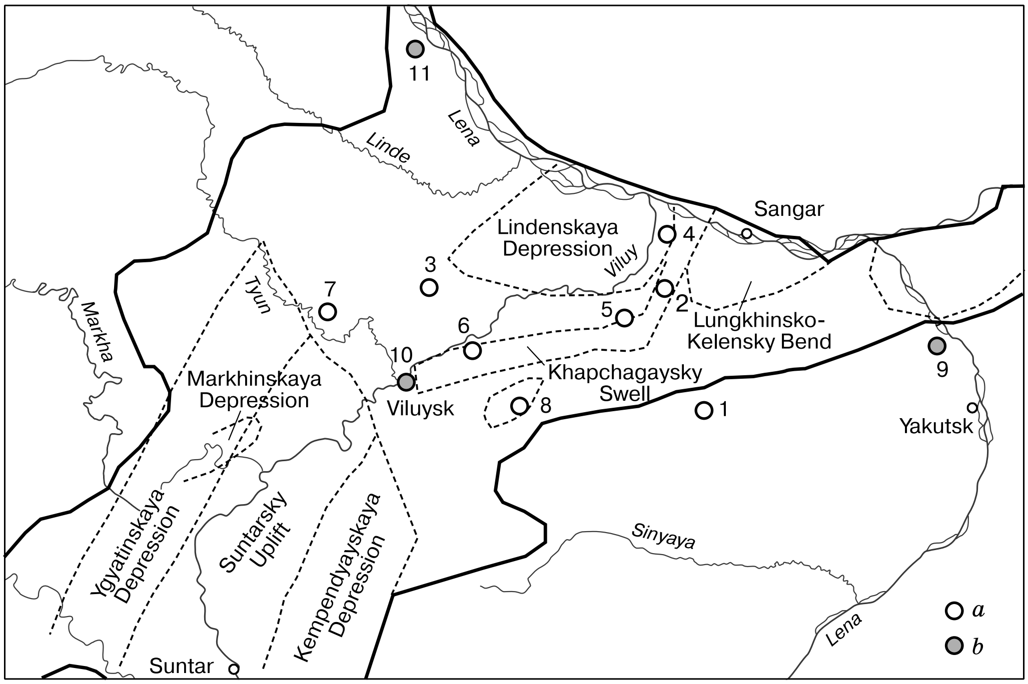

Fig. 1. A map of boreholes from which the core samples were obtained for thermo-physical studies.

Boreholes: *a* – test boreholes; *b* – key boreholes. 1 – Andreevskaya (borehole 2); 2 – Badaranskaya (borehole 1-r); 3 – Balagachinskaya (borehole 2); 4 – Nizhneviluyskaya (borehole 1-r); 5 – Nedzhelinskaya (borehole 16); 6 – Sredneviluyskaya (borehole 19); 7 – Srednetyungskaya (borehole 231); 8 – Khailakhskaya (borehole 1, 2); 9 – Namskaya (key borehole); 10 – Viluyskaya (key borehole); 11 – Bakhynaiskaya (key borehole).

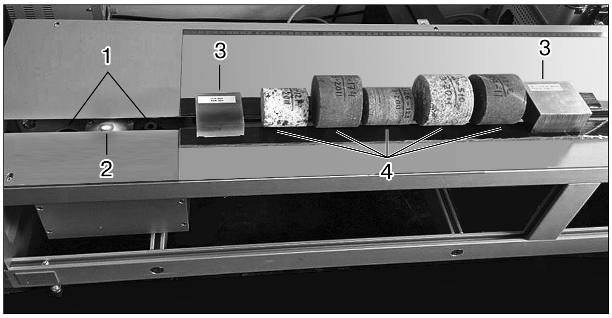

Fig. 2. An optical scanning setup.

1 – infrared temperature gauges; 2 – an optical heater; 3 – thermal conductivity and temperature conductivity reference samples; 4 – rock samples under study.

conductivity for the entire sample and its local values in certain parts of the sample. This characteristic allows good differentiation of the rocks having close thermal conductivity values but different structural and textural properties. The advantage of the TCS method lies in the high rate and precision of the measurements and the possibility of making them on samples of arbitrary shapes and sizes. The technical characteristics of the TCS method are the following: the thermal conductivity measurement range varying from 0.2 to 50 W/(m·K), the measurement error 3 % (with the confidence coefficient 0.95) [*Popov et al., 1983*].

Thermal conductivity of the rocks in a water-saturated state was calculated on the basis of hydrogeological data of the regions [*Hydrogeology of the USSR, 1970; Grubov and Slavin, 1971; Antsiferov, 1989*] and of the studies of the relation between the thermal conductivity of dry and water-saturated sediments of the West-Siberian Plate [*Duchkov et al., 1987, 2013*].

Effective (averaged) thermal conductivity of rocks was calculated by the formula of *R.I. Gavrilyev* [*1988*]:

$$\lambda_{\text{eff}} = \frac{I}{\sum_{i=1}^{n} \left(h_i / \lambda_i \right)},$$

where λ_i – the thermal conductivity coefficient of the i-th separate bed (a rock unit) considering their complete water saturation, W/(m·K); h_i – the height (depth) of the i-th separate bed, m; I – the integrated height of the layers of the stratigraphic complex (rock formation, horizon), m.

Thermal conductivity of frozen rocks was calculated by the formula proposed by R.I. Gavrilyev for sedimentary rocks [*Gavrilyev, 1998*].

RESULTS AND DISCUSSION

The lithological description of the samples investigated and analysis of their thermal conductivity revealed heterogeneity of the properties of similar rocks of different geological ages. They were divided into three groups: 1) Cretaceous rocks (K); 2) Jurassic rocks (J); 3) Triassic, Permian, and Cambrian rocks (T + P + Є) (Table 1).

The Cretaceous sedimentary rocks are represented by thick sandstones, with interbeds of siltstones and argillites. Here the sandstones are loose, fine- and medium-grained; in most cases, they are of sulfate or feldspar composition, more rarely of clayey or quartz-feldspar composition. The thermal conductivity of Cretaceous sandstones in the dry air state λ_{ad} varies from 0.84 to 4.05 W/(m·K), on average being 1.54 W/(m·K). The thermal conductivity of siltstones λ_{ad} varies from 0.62 to 1.89 W/(m·K), with its mean value being 1.17 W/(m·K) and their mean density being 2048 kg/m^3; that of argillites varies from 1.09 to 1.52 W/(m·K), with its mean value being 1.22 W/(m·K). The thermal conductivity of sands λ_{ad} has the lowest values to vary from 0.60 to 0.92 W/(m·K), on average being 0.73 W/(m·K). Their density varies from 1799 to 1970 kg/m^3.

The sediments of the second group of rocks (of the Jurassic Age) are represented by alternation of sandstones, argillites and siltstones, with interlayers of coals and clays. In the south-eastern part of the province (Fig. 1, Namskaya borehole) interlayers of limestones and dolomites can be seen in the core section. Similarly to siltstones and argillites, the sandstones of this group have greater mean values of thermal conductivity in the dry-air state than the rocks of the Cretaceous age, respectively, 1.67, 1.63 and 1.60 W/(m·K). Both the thermal conductivity and density of the sedimentary rocks of this stratum are higher than those of the stratum of Cretaceous sediments (Table 1).

In total, the value of thermal conductivity of the rocks of this group varies from 0.95 W/(m·K) in coals to 4.29 W/(m·K) in sandstones. The mean values of the thermal conductivity of limestones are 1.83 W/(m·K), those of dolomites are 1.78 W/(m·K), and those of local clays are 1.25 W/(m·K).

The sediments of the third group (of the combined Triassic, Permian, and Cambrian ages) are represented by sandstones, limestones, and dolomites with interlayers of clayey rocks. Dolerites and conglomerates are rare. Sandstones are mainly of the sericite or quartz-feldspar composition, more rarely of the clayey composition; they are fine-grained and solid. Their thermal conductivity λ_{ad} is higher than that of sandstones of the Jurassic Age and varies from 1.47 to 2.35 W/(m·K), on average being 1.91 W/(m·K). The thermal conductivity of limestones λ_{ad} varies from 1.39 to 2.61 W/(m·K), with the mean value being 2.03 W/(m·K). Similarly to sandstones, argillites and dolomites have higher, compared to the second-group rocks, values of thermal conductivity and density, the mean values are 1.79,

Table 1. **Thermal conductivity coefficient (λ_{ad}) in dry-air state and skeletal density (ρ_{sk}) of the main types of rocks of the Leno-Viluy Oil and Gas Bearing Province**

Rock	Geological index					
	K		J		T + P + Є	
	λ_{ad}, W/(m·K)	ρ_{sk}, kg/m^3	λ_{ad}, W/(m·K)	ρ_{sk}, kg/m^3	λ_{ad}, W/(m·K)	ρ_{sk}, kg/m^3
Sand	0.60 – 0.92 0.73 (12)	1779 – 1970 1888 (12)	–	–	–	–
Sandstone	0.84 – 4.05 1.54 (84)	1065 – 2833 2204 (84)	1.21 – 4.29 1.67 (83)	1950 – 3080 2345 (83)	1.47 – 2.35 1.91 (28)	2203 – 2740 2441 (28)
Siltstone	0.62 – 1.89 1.17 (19)	1883 – 2193 2048 (19)	1.01 – 2.10 1.63 (7)	1000 – 2510 2186 (7)	–	–
Argillite	1.09 – 1.52 1.22 (7)	1799 – 2371 2126.7 (7)	1.24 – 2.13 1.60 (27)	1000 – 2707 2368 (27)	1.40 – 2.13 1.79 (6)	2383 – 3073 2595 (6)
Clay	–	–	1.24 – 1.26 1.25 (2)	2000 – 2192 2096 (2)	–	–
Coal	–	–	0.95 – 1.53 1.24 (2)	1000 – 2336 1668 (2)	–	–
Limestone	–	–	1.48 – 2.35 1.83 (4)	2316 – 2604 2498 (4)	1.39 – 2.61 2.03 (6)	2436 – 2668 2563 (6)
Dolomite	–	–	1.58 – 2.04 1.78 (3)	2430 – 2484 2453 (3)	1.74 – 2.16 1.97 (3)	2273 – 2667 2476 (3)
Conglomerates	–	–	–	–	1.63 – 1.64 1.64 (2)	2408 – 2468 2438 (2)
Dolerites	–	–	–	–	1.09 – 1.57 1.34 (3)	2475 – 2917 2631 (3)

Note. The nominator indicates extreme values, the denominator contains mean values; the brackets contain the number of samples averaged. K – Cretaceous rocks; J – Jurassic rocks; T + P + Є – Triassic, Permian, and Cambrian rocks.

1.97 W/(m·K) and 2595, 2476 kg/m^3, respectively. Dolerites and conglomerates have the mean thermal conductivity 1.34 and 1.64 W/(m·K), with their density 2631 and 2438 kg/m^3, respectively.

Based on the laboratory data, a diagram of changes in the averaged values of thermal conductivity of mountain rocks related to their geological age was built (Fig. 3). A vivid trend of the increase in the thermal conductivity values rocks depending on their age and the bedding depth is noted (Fig. 3). This is related to changes in the material composition of the rocks and to their density. Among sandstones of different ages, carbonate sandstones demonstrate the highest mean value of thermal conductivity 1.66 W/(m·K), while feldspar sandstones have the lowest mean value 1.18 W/(m·K). In clayey rocks, the averaged values of thermal conductivity vary from 1.16 W/(m·K) in siltstones to 1.63 W/(m·K) in argillites.

Based on the correlation analysis made, we obtained regression equations describing dependence of the thermal conductivity coefficient (λ) on the skeletal density (ρ_{sk}) for clayey rocks and sandstones of different compositions (Fig. 4):

$\lambda = 0.0014\ \rho_{sk} - 1.7722$ ($R^2 = 0.71$) for siltstones and argillites;

$\lambda = 0.0018\ \rho_{sk} - 2.7047$ ($R^2 = 0.75$) for clayey sandstones;

$\lambda = 0.0015\ \rho_{sk} - 2.0262$ ($R^2 = 0.71$) for carbonate sandstones;

$\lambda = 0.0026\ \rho_{sk} - 4.4765$ ($R^2 = 0.77$) for feldspar sandstones.

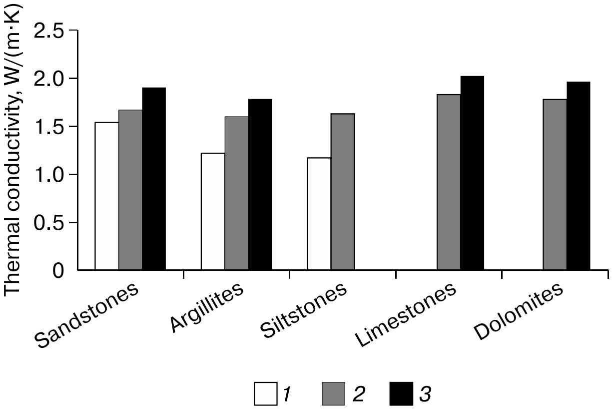

Fig. 3. Diagrams of changes in the averaged thermal conductivity values relating to their age.

Rocks: *1* – Cretaceous (K); *2* – Jurassic (J); *3* – Triassic, Permian, and Cambrian (T + P + Є).

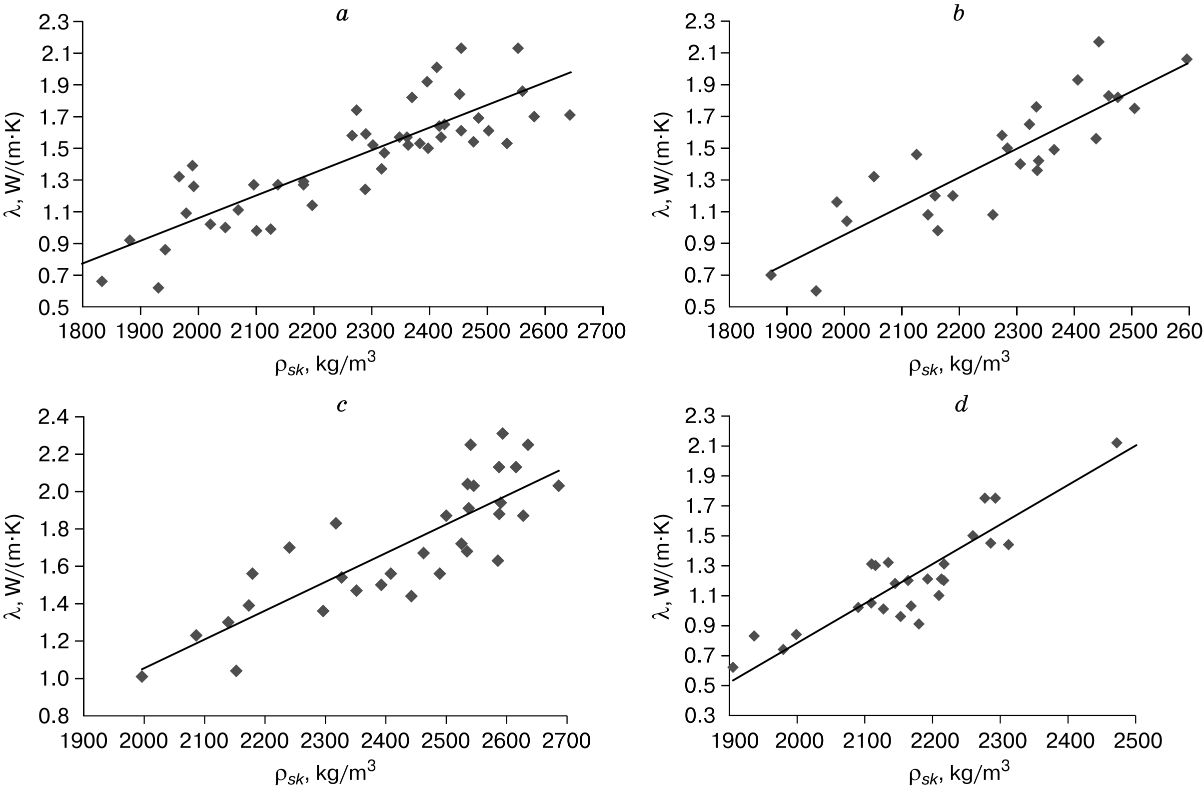

Fig. 4. Dependence of the thermal conductivity coefficient (λ) on skeletal density (ρ_{sk}):

a – clayey (siltstones and argillites) rocks; *b* – clayey sandstones; *c* – carbonate sandstones; *d* – feldspar sandstones.

The laboratory studies of the thermo-physical characteristics of the sedimentary rocks were conducted for the dry-air state of the samples. Under natural bedding conditions, the sub-permafrost rocks are in a water-saturated state. The experimental studies of thermal conductivity of the sedimentary rocks from different regions versus the open porosity coefficient in dry-air (λ_{ad}) and water-saturated (λ_m) states were conducted by many researchers. They proposed different empirical formulae for expressing this relation [*Gairbekov, 1975; Rzhevsky and Novik, 1978; Duchkov et al., 1987, 2013*].

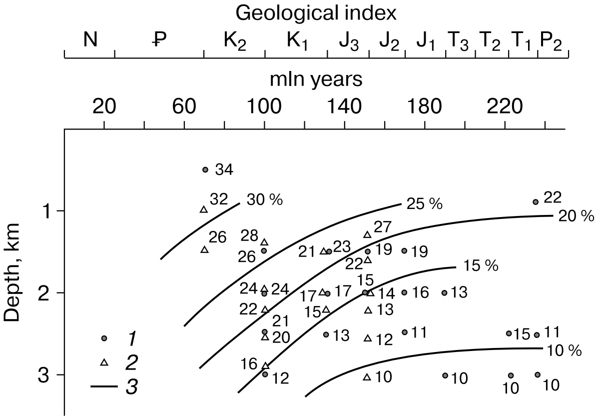

Fig. 5. The open porosity coefficient of sandstones of different ages.

1 – The rocks of the Leno-Viluy OGBP; *2* – The rocks of the West-Siberian Plate; *3* – The lines of the averaged values of open porosity by depths, %.

The material composition and the formation conditions of the sedimentary rocks of the Leno-Viluy OGBP are closest to those of the rocks of the West-Siberian Plate. The relation between the values of the thermal conductivity coefficient of dry-air (λ_{ad}) and water-saturated (λ_m) Cretaceous and Jurassic sediments for thawed rocks of the clay and sandstone compositions was determined by A.D. Duchkov and L.S. Sokolova [*Duchkov et al., 1987*]. Their correlation is

$$\lambda_m = 0.54 + 0.9\,\lambda_{ad}, \qquad (1)$$

where λ_m – thermal conductivity of rocks if completely water-saturated; λ_{ad} – thermal conductivity of the rocks in the dry-air state.

Later it was found during the experimental laboratory studies [*Duchkov et al., 2013*] that the values of λ_m were 20–30 % higher than the values of λ_{ad}. Besides the material composition, the rocks of the structures in question are close for the values of their open porosity. According to *B.A. Sokolov et al.* [*1986*], the porosity coefficient (K_p) changes depending on the bedding depth of sandstones of different ages in different regions of the West-Siberian Plate. The attenuation gradients K_p depending on the bedding depth of the sediments in the structures in question in the range of depths 500–3000 m vary within 5–10 % by 1000 m (Fig. 5) [*Sokolov et al., 1986*]. In this regard, the choice of the relation (1) of thermal conductivity coefficients λ_{ad} and λ_m was correct, in the authors' opinion. Using the relation (1), we determined the thermal conductivity values of the mountain rocks considering their water saturated state for thawed and frozen rocks (Table 2).

Thus, the mean values of thermal conductivity of dry-air and water-saturated sedimentary rocks are (W/(m·K)): for sandstones of the first group (K) λ_{ad} = 1.54, λ_m = 1.93, for sandstones of the second

Table 2. **The thermal conductivity coefficient of the main rocks of the Leno-Viluy oil-and-gas-bearing province in thawed λ_m (t) and frozen λ_m (f) states considering their moisture content**

No.	Rock	Geological index	Bulk density, g/cm^3	Thermal conductivity coefficient, W/(m·K)	
				λ_m(t)	λ_m(f)*
1	Sand	K	1.78 – 1.97 1.9 (12)	1.08 – 1.37 1.2 (12)	2.57
2	Sandstone	K	1.1 – 2.8 2.2 (84)	1.30 – 4.19 1.93 (84)	2.67
		J	1.95 – 3.08 2.34 (83)	1.63 – 4.40 2.04 (83)	–
		T + P + Є	2.20 – 2.74 2.44 (28)	1.86 – 2.66 2.26 (28)	–
3	Siltstone	K	1.83 – 2.19 2.04 (19)	1.10 – 2.24 1.59 (19)	2.23
		J	1.00 – 2.51 2.19 (7)	1.45 – 2.43 2.01 (7)	–
4	Argillite	K	1.80 – 2.37 2.13 (7)	1.52 – 1.91 1.64 (7)	2.03
		J	1.00 – 2.71 2.37 (27)	1.66 – 2.46 1.98 (27)	–
		T + P + Є	2.38 – 3.07 2.6 (6)	1.80 – 2.46 2.15 (6)	–
5	Limestone	J	2.32 – 2.60 2.5 (4)	1.87 – 2.66 2.19 (4)	–
		T + P + Є	2.40 – 2.67 2.56 (6)	1.79 – 2.89 2.37 (6)	–
6	Dolomite	J	2.43 – 2.48 2.45 (3)	1.96 – 2.38 2.14 (3)	–
		T + P + Є	2.27 – 2.67 2.48 (3)	2.10 – 2.48 2.31 (3)	–
7	Clay	J	2.00 – 2.19 2.1 (2)	1.66 – 1.67 1.67 (2)	–
8	Coal	J	1.0 – 2.3 1.67 (2)	1.40 – 1.92 1.67 (2)	–
9	Conglomerite	T + P + Є	2.41 – 2.47 2.44 (2)	2.01 – 2.02 2.02 (2)	–
10	Dolerite	T + P + Є	2.48 – 2.92 2.63 (3)	1.52 – 1.95 1.75 (3)	–

Note. The nominator contains min and max values, the denominator contains mean values; in brackets – the number of samples for averaging. K – Cretaceous rocks; J – Jurassic rocks; T + P + Є – Triassic, Permian, and Cambrian rocks.

* Mean values.

group (J) $\lambda_{ad} = 1.67$, $\lambda_m = 2.04$, for sandstones of the third group (T + P + Є) $\lambda_{ad} = 1.91$, $\lambda_m = 2.26$; for argillites of the first group (K) $\lambda_{ad} = 1.22$, $\lambda_m = 1.64$, for argillites of the second group (J) $\lambda_{ad} = 1.60$, $\lambda_m = 1.98$, for argillites of the third group (T + P + Є) $\lambda_{ad} = 1.79$, $\lambda_m = 2.15$ (Table 2). Generally, the mean values of λ_m of the sedimentary rocks of the structure in question are higher than the values of λ_{ad} by 15–25 %.

Using the obtained thermal conductivity values of the mountain rocks considering their complete water saturation and geological structure, we calculated the values of effective thermal conductivity [*Gavrilyev, 1998, 2013*] of stratigraphic subdivisions by three key boreholes – Namskaya, Viluyskaya and Bakhynayskaya boreholes (Fig. 1, Table 3). The obtained values of effective thermal conductivity vary in formations from 1.27 to 2.16 W/(m·K) depending on the age of the rocks and their material composition.

For the Timirdyakh formation, composed by the rocks of the Upper Cretaceous and represented by sands with interbeds of clays and by small sandstone units, the values of λ_{eff} vary within 1.27–1.55 W/(m·K). For the Lower Cretaceous Namskaya, Eksenyakhskaya, Sangarskaya and Batylykhskaya formations, composed by large units of sands with interbeds of siltstones, argillites and clays, the values of λ_{eff} vary from 1.31 to 1.88 W/(m·K). For the rocks of the Upper Jurassic age, composed of the Chechumskaya, Verkhnevolzhskaya, Sytaginskaya and Dzhaskoyskaya formations, composed of frequent alternations of sandstones, siltstones, argillites, and coals,

Table 3. **Effective conductivity coefficient (λ_{eff}) of the stratigraphic subdivisions of the rocks of the Leno-Viluy Oil- and-Gas-Bearing Province**

Key borehole	System	Interval, thickness, m	λ_{eff}, W/(m·K)	Division	Interval, thickness, m	λ_{eff}, W/(m·K)	Formation, rock horizon	Thickness, m	λ_{eff}, W/(m·K)
Namskaya	Cretaceous	130–1900, 1770	1.34	Upper	130–540, 272	1.27	Timirdyakhskaya formation	272	1.27
				Lower	540–1900, 1360	1.36	Namskaya formation	513	1.31
							Eksenyakhskaya formation	185	1.38
							Sangarskaya formation	580	1.37
	Jurassic	1900–3000, 1100	2.03	Upper	1900–2450, 670	1.95	Chechumskaya formation	670	1.95
				Middle–Lower	2450–3000, 650	2.02	Baylykhskaya formation	650	2.02
Viluyskaya	Cretaceous	26–1654, 1628	1.39	Upper	26–514, 488	1.34	Timirdyakhskaya formation	488	1.34
				Lower	514–1654, 1140	1.41	Horizon III	367	1.27
							Horizon II	491	1.52
							Horizon I	282	1.44
	Jurassic	1654–2940, 1286	1.82	Upper	1654–2695, 1041	1.77	Horizon III	339	1.45
							Horizon II	173	1.89
							Horizon I	531	2.03
				Middle	2697–2940, 243	2.02	Horizon II	131	2.02
							Horizon I	112	2.03
Bakhynayskaya	Cretaceous	20–1428, 1408	1.70	Upper	20–376, 356	1.55	Timirdyakhskaya formation	356	1.55
				Lower	376–1458, 1082	1.81	Namskaya formation	224	1.79
							Eksenyakhskaya formation	280	1.88
							Batylykhskaya formation	578	1.79
	Jurassic	1458–2730, 1272	2.00	Upper	1458–1970, 512	1.99	Verkhnevolzhskaya formation	90	1.93
							Sytaginskaya formation	60	2.02
							Dzhaskoyskaya formation	362	2.00
				Middle	1970–2290, 320	2.03	Khorongskaya formation	160	2.03
							Verkhnekystatymskaya formation	74	2.06
							Nizhnekystatymskaya formation	86	2.02
				Lower	2290–2730, 440	2.00	Upper Leyas	110	1.99
							Middle Leyas	330	2.01
	Triassic	2730–2825, 95	2.16	Lower	2730–2825, 95	2.16	Kelterskaya formation	95	2.16

the values of λ_{eff} vary within 1.77–1.99 W/(m·K). For the rocks of the Upper Jurassic age, composed of the Bailykskaya, Khorongskaya, Verkhnekystatymskaya, and Nizhnekystatymskaya formations, composed of heterogeneously alternating large units of sandstones, argillites and siltstones, the values of λ_{eff} vary within 2.00–2.03 W/(m·K). For the Kelterskaya formation of the Lower Triassic age, composed by large units of argillites with subordinated interbeds of sandstones and siltstones, the values of λ_{eff} are equal to 2.16 W/(m·K).

It was established in the previous geothermal studies [*Semenov and Zheleznyak, 2013, 2016*] that the territory in question refers to the region of unstable permafrost with significant heterogeneity of the thermal field and the permafrost thickness varying from 45 to 820 m. In this regard, the rocks of the Lower- and Upper Cretaceous ages of the Leno-Viluy OGBP are partly in a frozen state. To evaluate the thermal conductivity of the rocks in a frozen state λ_f considering the open porosity coefficient and given complete water saturation, we used the theoretical calculation method proposed by *R.I. Gavrilyev* [*1998*] for sedimentary rocks. According to the data obtained, the mean thermal conductivity values (λ_f) for frozen sands, sandstones, siltstones, and argillites are 2.57, 2.67, 2.23 and 2.03 W/(m·K), respectively (Table 2), which exceeds the thermal conductivity values of the samples in the dry-air state for sands by a factor of 3.5, for sandstones and argillites, by a factor of 1.7, and for siltstones, by a factor of 1.9 times.

CONCLUSIONS

The thermal conductivity of mountain rocks characterizing the main lithological varieties of the Leno-Viluy OGBP has been investigated. The thermal conductivity of mountain rocks has been established to vary in a broad range – from 0.6 W/(m·K) in sands to 4.29 W/(m·K) in sandstones, whereas the density of the rocks varies from 1000 kg/m^3 in clays to 3080 kg/m^3 in sandstones. This is caused by the variety in the material composition of the rocks and sediments constituting the province under study.

Based on the data obtained, three groups of the mountain rocks have been identified: Cretaceous, Jurassic groups and a combined group of the Triassic, Permian, and Cambrian ages, with a clearly visible trend for the growth of thermal conductivity values dependent on the increase of the geological age of the rocks.

Using hydrogeological data and theoretical findings, we have obtained the thermal conductivity values of the rocks given their complete water saturation, characteristic for natural conditions of their bedding in the mass of the geological cross-section under study (up to 3500 m of the material composition). For Cretaceous rocks, which are partly in a frozen state, thermal conductivity coefficients, the values of which essentially exceed the thermal conductivity coefficients in the dry-air state of the rocks, have been calculated. The original data of the laboratory studies of the samples are provided, to enable their further interpretation.

Correlation analysis has been made, and relations between thermal conductivity and rock density for different types and material compositions of the rocks have been obtained.

It is to be noted that alternation of different types of rocks in the cross section and their heterogeneity, characteristic of the geological structure of the province under study, in many ways determines the wide range of the values of effective thermal conductivity of gedogical strata in different parts of the province, which is to be taken into account in the further studies of the Earth's temperature field.

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