ORIGINAL RESEARCH ARTICLE

DOI: https://doi.org/10.18599/grs.2019.3.136-140

The reconstruction of the paleotemperature of the Earth's surface on Yuzhny Island (Novaya Zemlya archipelago) according to geothermal data

D.S. Nikitin[1], V.R. Akhmedzianov[1], D.Yu. Demezhko[2], M.D. Khutorskoi[1]*
[1]Geological Institute of the Russian Academy of Sciences, Moscow, Russian Federation
[2]Institute of Geophysics of the Ural Branch of the Russian Academy of Sciences, Ekaterinburg, Russian Federation

---

Abstract. According to the complex geothermal investigation results (thermal conductivity, rocks thermal heterogeneity measurements as well geothermal gradient and heat flow calculation) on Yuzhny Island of Novaya Zemlya archipelago (Pavlovskoe lead-zinc field), the paleotemperature on the surface in the historical past are modeled. The results of the climatic history reconstruction in this region are discussed. An earlier heat flow estimate on on Yuzhny Island of Novaya Zemlya archipelago (46 mW/m^2) could be underestimated if we assume the glacier absence during the "Pleistocene/Holocene warming". In this case, the calculated heat flow will be 55 mW/m^2. If during the "small glacial period" the glacier existence lasted for 20 thousand years, then the first heat flow estimate is more likely.

Keywords: paleotemperature, Earth's surface, reconstruction, Novaya Zemlya, geothermy, heat flow

Recommended citation: Nikitin D.S, Akhmedzianov V.R., Demezhko D.Yu., Khutorskoi M.D. (2019). The reconstruction of the paleotemperature of the Earth's surface on Yuzhny Island (Novaya Zemlya archipelago) according to geothermal data. *Georesursy = Georesources*, 21(3), pp. 136-140. DOI: https://doi.org/10.18599/grs.2019.3.136-140

Introduction

In recent years, along with the development of oil and gas fields on the shelf of the Barents Sea near the Novaya Zemlya archipelago, the Pavlovsky lead-zinc silver-containing field is being developed on Yuzhny Island (for the needs of the state corporation Rosatom) (Fig. 1). The Pavlovsky field is fifth in Russia in terms of zinc and lead reserves. It was discovered in 2001. The mineral and raw material base of the field will make it possible to organize one of the largest processing enterprises in Russia.

At present, according to the State Commission of Mineral Reserves, the balance reserves in Novaya Zemlya amount to more than 47 million tons of ore: of which 2.48 million tons of zinc, 549 thousand tons of lead and 11.9 million tons of silver. It is also planned to organize the associated production of uranium concentrate (up to 10 tons per year) and rare-earth metals concentrate (up to 450 tons per year).

It is expected that the construction of a mining and processing plant on the island of South Archipelago Novaya Zemlya will begin in 2020. The approximate release date of the mining and processing plant to industrial volumes is 2023 (http://www.rosatom.ru/journalist/news/dobycha-rudy-na-novoy-zemle-nachnetsya-v-2023-godu).

In 2014, the first large-scale hydrogeological work began on the Pavlovsky field within the Bezymyansky ore cluster within the framework of the RUSBURMASH project. Nine hydrogeological wells were drilled (below the level of permafrost rocks, equal to ≈ 250 m), on which thermometric and pilot filtration works were carried out (Shadrin et al., 2015).

Thermometric well surveys

For thermometric studies, the KSKA-10 downhole tool was used. Initially, temperatures were measured immediately after drilling. Thermal logging was carried out during the descent of the downhole thermometer at a speed of not more than 100 m/h. Thermal logging readings were monitored while climbing after the main logging. The error in temperature measurements by an electrothermometer was determined by comparing its measurements with the readings of a mercury thermometer. The absolute value of the discrepancies in the comparison did not exceed ± 0.5°C.

For all wells below the interval of depths of 40-70 m, negative temperatures were obtained. The SG-1 well was an exception, but repeated thermometry carried out after three days also showed frozen rocks at a depth of more

---

*Corresponding author: Dmitry S. Nikitin
E-mail: ndsnomination@mail.ru

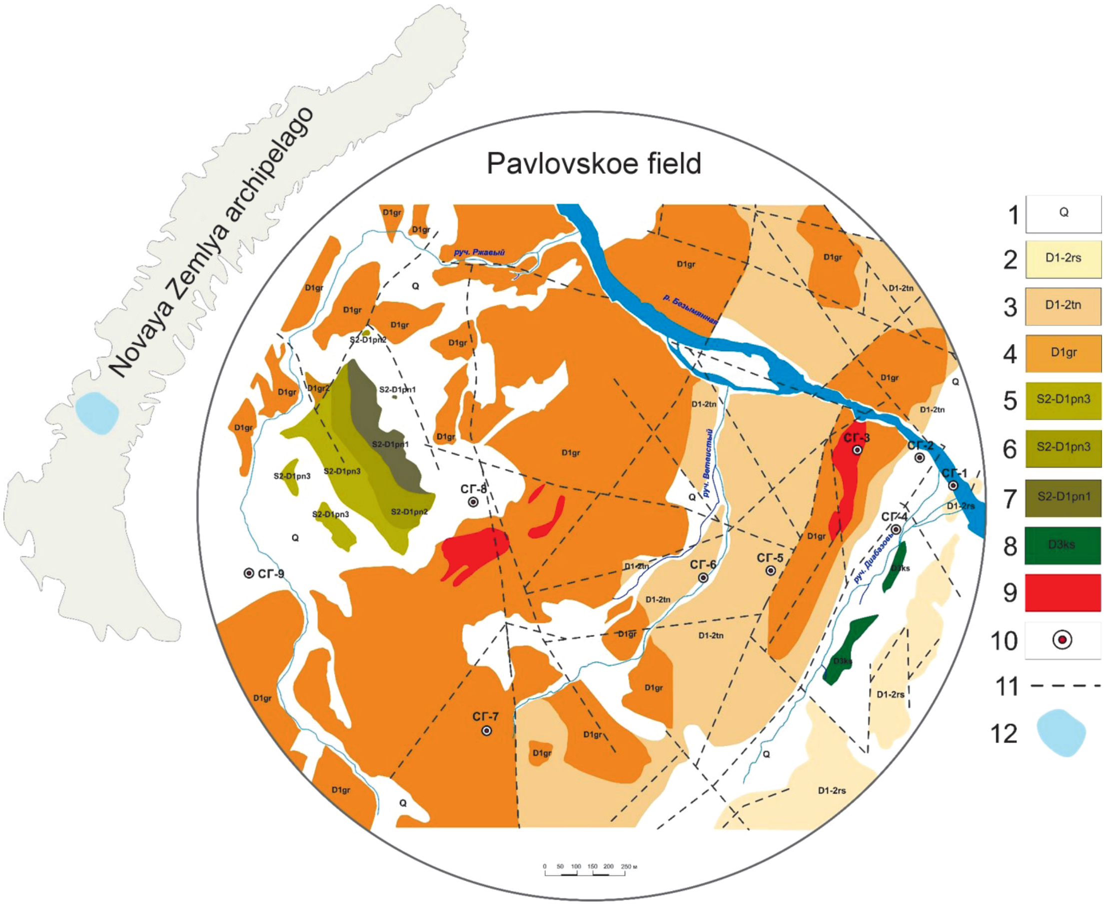

Fig. 1. The location scheme of the Pavlovskoe field within the Bezymyansky ore cluster. 1 – Undivided Quaternary sediments (Q); 2 – Reys Formation (D1-2rs), basalts, tuffs; 3 – Taininskaya suite (D1-2tn). Mudstones, clayey limestones, siltstones; 4 – Undivided Gribovskaya formation (D1gr). Clay and dolomitic limestones, sedimentary breccias; 5 – Pankovskaya suite (S2-D1pn3), upper bench, phyllite schists, quartz sandstones; 6 – Pankovskaya suite (S2-D1pn2), middle bench, quartz sandstones, siltstones; 7 – Pankovskaya suite (S2-D1pn1), lower bench, quartz sandstones; 8 – Dolerite Dykes (D3ks); 9 – Ore outcrop; 10 – Wellhead; 11 – Faults; 12– Bezymyansky ore polymetallic cluster.

than 30 m. As the experience of repeated measurements in the SG-1 well showed, the temperature in it decreases over time, until the well completely freezes. This is due to the fact that due to the exothermic effect during well drilling and constant circulation of the drilling fluid, the temperature in the near-well zone increased to positive temperatures. After drilling is completed, the temperature gradually returns to the natural temperature background.

Naturally, the measurement of negative temperatures below -2ºC – -3ºC in the well is impossible even with the injection of brine, as the wellbore freezes. Therefore, thermal logging, carried out immediately after drilling, fixes elevated temperatures and gives only general ideas about the temperature field and its change with depth. In this regard, three wells (SG-4, SG-6, SG-9) were specially equipped with 250-meter sealed dry columns for long engineering-geocryological observations. Temperature measurements were carried out using a portable controller digital sensor PKTs-1/100, designed to read the measurement results from digital temperature sensors, and multi-zone digital temperature sensors MCDT 0922 (thermistor chain).

Temperature observations on thermistor chains in the SG-4, SG-6, SG-9 wells lasted from 7 to 21 days. During this time, two or three measurements were made for different dates. As a result, temperatures close to the natural background were measured. Having processed the results of observations on thermistor chains, it was possible to obtain a generalized scheme of permafrost conditions of the Pavlovsky field (Fig. 2). At depths below 150 m, a clear geothermal gradient can be traced, which can be estimated with sufficient accuracy as 20 mK/m. The obtained gradient value can be extended to other wells in the study area, when simulating the heat flow.

In 2018, using core samples from two hydrogeological wells SG-5 (depth 493.1 m) and SG-3 (depth 175.0 m), the authors of the article studied the main thermophysical properties of 165 core samples (Nikitin, Khutorskoi, 2018). The data obtained made it possible for the first time to characterize the heat flow density of the Novaya Zemlya Archipelago and calculate its deep value in the conditions of structural-thermophysical inhomogeneities.

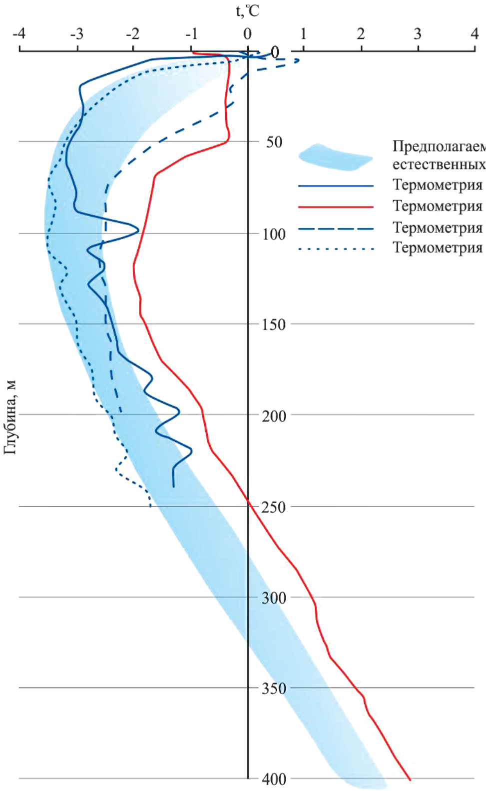

Fig. 2. Well thermograms of Pavlovskoe field

Modeling the temperature of the geological past

In this work, we studied the restoration of surface paleotemperature in the area of the SG-5 well. For paleoclimatic analysis, the interval 70-415 m was selected, the initial thermogram was thinned out (digitization after 5 m). Based on the data on the distribution of thermal conductivity of rocks, models of the stationary temperature distribution are constructed:

$$T_{i\ стац} = T_n - \sum_{n-1}^{i} \frac{q}{\lambda_i}\Delta h;\quad z_i = i\Delta h;\quad T_n = T(z = z_{\max});$$

here q is the heat flow at a depth of $z_{\max}$, Δh is the sampling interval, λ_i is the thermal conductivity of the rocks in the interval $i\,\Delta h - (i+1)\,\Delta h$.

A stationary model is necessary for constructing a “reference” geothermal gradient in an inhomogeneous medium (Fig. 3). The heat flow value is taken equal to 46 ± 4 mW/m^2 (Nikitin, Khutorskoi, 2018). The intersection of stationary curves with the earth’s surface determines the value of T_0 – the surface temperature before the start of reconstructed changes. Temperature anomalies caused by changes in the Earth’s surface temperature in the past were calculated as $T_{ian} = T_i - T_{istats}$. The technique for reconstructing the ground surface temperature history (GSTH) is described in detail in (Demezhko, Shchapov, 2001; Demezhko, 2001).

In the reconstructions obtained (Fig. 4), we can recognize the known climatic episodes of the last millennium: the medieval warm period, the small ice age and modern warming. But all these episodes are shifted in later times. So, medieval warm period is usually dated 10-14 centuries, MLP – 16-19 centuries. The reason is probably due to the lack of measured parameters. The timeline of reconstructions is determined by the value of the coefficient of thermal diffusivity (a). We used the value a = 1·10^{-6} m^2/s. If the thermal diffusivity is actually two times lower, then all episodes will have twice as long ago.

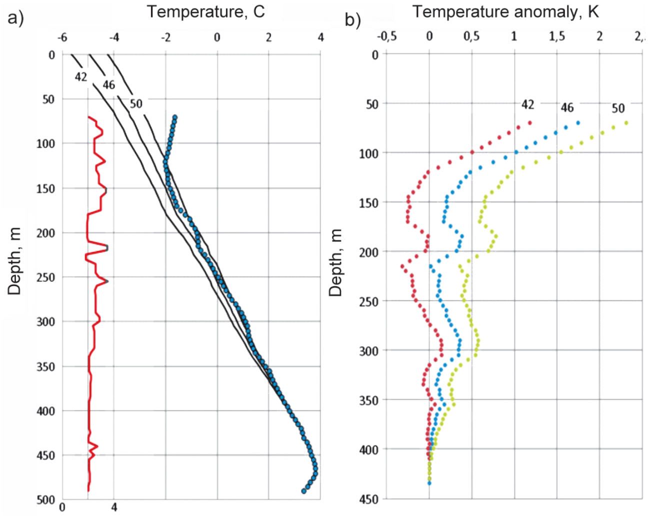

Fig. 3. (a) Distribution of the measured temperature (blue circles), thermal conductivity (red curve) and stationary temperature (black curves) at various values of the heat flow from a depth of z_{max} =415 m (curve code). (b) Temperature anomalies for three values of the heat flow from a depth of z_{max} = 415 m (curve code).

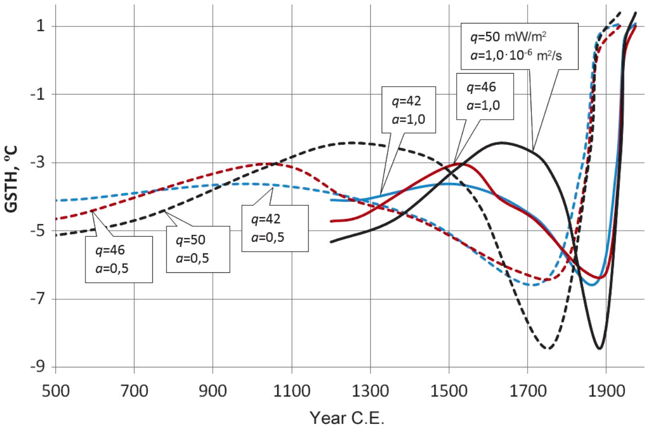

Fig. 4. Reconstruction of changes in the temperature of the Earth’s surface relative to T_0 at various values of the heat flow from the base of the studied interval. Smoothed surface temperatures in the “real” temperature scale at a = 1·10^{-6} m^2/s (solid line) and a = 0,5·10^{-6} m^2/s (dotted line).

Initially, we estimated the heat flow density of 46 ± 4 mW/m^2 (Nikitin, Khutorskoi, 2018). Perhaps it is somewhat understated for two reasons. Firstly, due to insufficient well-alignment, the temperature gradient can be underestimated. Perhaps the temperature logging of the wells had to be carried out an additional 2-3 months after drilling. Secondly, this estimate was made for an interval of 150-450 m. There is still an underestimating effect of the Pleistocene/Holocene warming about

10 thousand years ago (Fig. 5). In part, it is offset by the influence of cooling of the small ice age. This can be calculated on the model, given the temperature amplitudes of these climatic events. The only estimate of the Pleistocene/Holocene warming amplitude is given in (Fuchs et al., 2015).

For the south-west of Novaya Zemlya, it is approximately equal to 16 K. The small ice age was manifested by a decrease in temperature of about 3 K and a subsequent increase of 7 K (according to the reconstruction according to SG-5). The distribution of the anomalous temperature gradient corresponding to this model is shown in Fig. 5. The correction is 4.9 mK/m. If our estimate of the heat flow (46 mW/m^2) was made based on the average gradient in the range of 150-450 m equal to 18 mK/m, then the corrected estimate will be $q_{corr} = 46\ (18 + 4.9)/18 = 58.5$ mW/m^2. However, this assessment was made under the assumption that there is no glacier in this part of Novaya Zemlya (or its insignificant thickness and insignificant lifetime – that is, under the assumption that the hypothesis of "minimal spread" of Eurasian glaciation is valid (Demezhko et al., 2007)). In support of this hypothesis, we can turn to geothermal reconstructions for wells on the Kola Peninsula (Siegert et al., 2001) and in Karelia (Glaznev et al., 2004; Demezhko et al., 2013), which indicate very low Earth surface temperatures in the maximum of the last glaciation – -18.0 and -14.5 °C, respectively.

But if we nevertheless assume that a powerful (up to 3-4 km, as in Canada) glacier existed here for a long period (> 20 thousand years), then, by analogy with the Lawrence Shield, we can expect a difference of modern and late Pleistocene temperatures of only 8 K (or 4 K in relation to the mid-Holocene). Then the cooling of the small ice age almost completely compensates for the influence of the Pleistocene/Holocene warming in the range of 150-450 m (Fig. 6), and our estimate of 46 mW/m^2 will be close to real.

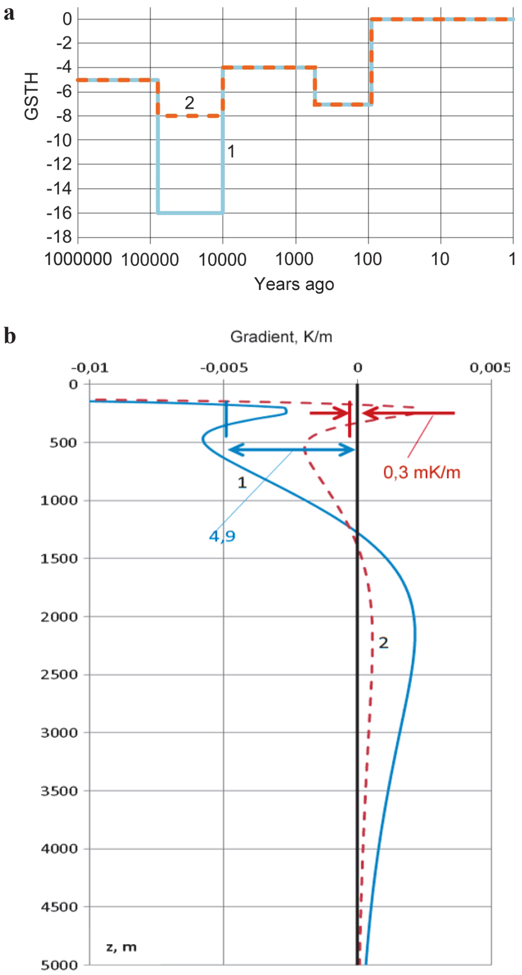

Fig. 5. (a) Two models of temperature history for the southwestern part of Novaya Zemlya in the absence of glaciation (1) and in the presence of powerful glaciation (2); (b) The distribution of the anomalous gradient corresponding to these models. Horizontal lines indicate the average values of the anomalous gradient in the range of 150-450 m.

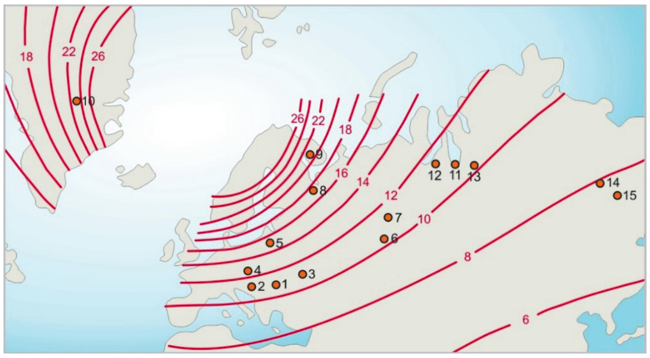

Fig. 6. The model of the spatial distribution of Pleistocene/Holocene warming amplitudes ~10 thous. years ago (Demezhko et al., 2007)

Financing

The work was supported by state budget theme 0135-2019-0040, Program of the Presidium of the Russian Academy of Sciences No. P49, and state budget theme 0394-2019-0002.

References

Demezhko D.Yu., Gornostaeva A.A., Antipin A.N. (2019). Late Weichselian thermal state at the base of the Scandinavian Ice Sheet. *Climate of the Past Discussions*, 1-23, https://doi.org/10.5194/cp-2019-49.

Demezhko D.Yu. (2001). Geotermicheskii metod rekonstruktsii paleoklimata (na primere Urala) [The geothermal method of reconstructing the paleoclimate (on the example of the Urals)]. Ekaterinburg: Ural Branch of the Russian Academy of Sciences, 144 p. (In Russ.)

Demezhko D.Yu., Shchapov V.A. (2001). 80,000 years ground surface temperature history inferred from the temperature-depth log measured in the superdeep hole SG-4 (the Urals, Russia), *Global and Planetary Change*, 29(1-2), pp. 219-230. https://doi.org/10.1016/S0921-8181(01)00091-1

Demezhko D.Yu., Gornostaeva A.A., Tarkhanov G.V., Esipko O.A. (2013). 30,000 years of ground surface temperature and heat flux changes in Karelia reconstructed from borehole temperature data. *Bulletin of Geography. Physical Geography Series*, 6, pp. 7-25, https://doi.org/10.2478/bgeo-2013-0001

Demezhko D.Yu., Gornostaeva A.A., Tarkhanov G.V., Esipko. O.A. (2013). Reconstruction of the temperature history of the Earth's surface over the past 30,000 years according to thermometry data of the Onega parametric well. *Geofizicheskie issledovaniya = Geophysical exploration*, 14(2), pp. 38-48. (In Russ.)

Demezhko D.Yu., Ryvkin D.G., Outkin V.I., Duchkov A.D. and Balobaev V.T. (2007). Spatial distribution of Pleistocene/Holocene warming amplitudes in Northern Eurasia inferred from geothermal data. *Climate of the Past*, 3, 559-568, http://www.clim-past.net/3/559/2007/cp-3-559-2007.html

Fuchs S., Balling N., Förster A. (2015). Calculation of thermal conductivity, thermal diffusivity and specific heat capacity of sedimentary rocks using petrophysical well logs. *Geophysical Journal International,* 203(3), pp. 1977-2000. https://doi.org/10.1093/gji/ggv403

Glaznev V.N., Kukkonen I.T., Raevskii A.B. Ekinen Ya. (2004). New data on heat flow in the central part of the Kola Peninsula. *Doklady Akademii nauk,* 396(1), pp. 102-104. (In Russ.)

Khutorskoi M.D., Akhmedzyanov V.R., Ermakov A.V. et al. (2013). Geotermiya arkticheskikh morei [Geothermy of the Arctic seas]. Moscow: GEOS, 238 p. (In Russ.)

Nikitin D.S., Khutorskoi M.D. (2018). The first measurements of heat flow on the Novaya Zemlya archipelago. *Doklady Akademii nauk*, 478(6), pp. 692-696. (In Russ.)

Shadrin M.A. et al. (2015). Pre-feasibility study report on the development of the Pavlovsky deposit of silver-containing lead-zinc ores (Novaya Zemlya archipelago). Geology and assessment of the mineral resource base of the Pavlovskoye deposit with risk assessment. Moscow: Funds of CJSC Project Laboratory. (In Russ.)

Siegert M.J., Dowdeswell J.A., Hald M., Svendsen J.-I. (2001). Modelling the Eurasian ice sheet through a full (Weichselian) glacial cycle. *Global and Planet. Change*, 31, pp. 367-385. https://doi.org/10.1016/S0921-8181(01)00130-8

About the Authors

Dmitry S. Nikitin – Researcher, Laboratory of Heat and Mass Transfer, Geological Institute of the Russian Academy of Sciences

7, Pyzhevsky lane, Moscow, 119017, Russian Federation

Vitaly R. Akhmedzyanov – PhD (Geology and Mineralogy), Senior Researcher, Laboratory of Heat and Mass Transfer

Geological Institute of the Russian Academy of Sciences

7, Pyzhevsky lane, Moscow, 119017, Russian Federation

Dmitry Yu. Demezhko – DSc (Geology and Mineralogy), Leading Researcher

Institute of Geophysics of the Ural Branch of the Russian Academy of Sciences

91, Pervomaysky st., Ekaterinburg, 620049, Russian Federation

Mikhail D. Khutorskoi – DSc (Geology and Mineralogy), Professor, Head of the Heat and Mass Transfer Laboratory

Geological Institute of the Russian Academy of Sciences

7, Pyzhevsky lane, Moscow, 119017, Russian Federation

Manuscript received 14 March 2019;
Accepted 26 July 2019; Published 1 September 2019