GEODYNAMICS & TECTONOPHYSICS
Published by the Institute of the Earth's Crust, Siberian Branch, Russian Academy of Sciences
RECENT GEODYNAMICS

2026 VOLUME 17 ISSUE 2 ARTICLE 0889 ISSN 2078-502X

DOI: 10.5800/GT-2026-17-2-0889

GEOLOGY, GEOPHYSICS AND HYDROCHEMISTRY OF THE DACHNOYE HYDROTHERMAL DEPOSIT (ITURUP ISLAND)

O.V. Veselov, A.I. Kazakov ✉, R.V. Zharkov

Institute of Marine Geology and Geophysics, Far Eastern Branch of the Russian Academy of Sciences, 1B Nauki St, Yuzhno-Sakhalinsk 693022, Russia

ABSTRACT. This article provides a geological, geophysical and geochemical description of the Dachnoye hydrothermal deposit (the central part of the Iturup Island, Kuril Islands), located in a zone of the modern tectonomagmatic activity. The results reported in the article describe the detailed thermal and geochemical studies within the deposit. This work presents the sublatitudinal geological and geothermal section of the deposit based on drilling and logging data. A statistical analysis of shallow-depth temperature survey of the deposit in an area of 6 km^2 (over 1300 measurement points) allowed us to determine the sites where thermal mineral waters reach the surface and to characterize the tectonic features of the deposit area. Regarding the chemical composition of the waters, this area has a promising potential for balneological development.

KEYWORDS: Iturup Island; Dachnoye hydrothermal deposit; thermal survey; statistical analysis; hydrochemistry

FUNDING: The study was supported by the RFBR on the state assignment of the IMGG FEB RAS (project No. 13-05-00544A, "Modern fumarole and hydrothermal activity of volcanoes in the Southern Kuril Islands").

EDN: XTQOQJ

RESEARCH ARTICLE

Received: December 25, 2025
Revised: February 2, 2026
Accepted: February 13, 2026

Correspondence: Artem I. Kazakov, legn@inbox.ru

FOR CITATION: Veselov O.V., Kazakov A.I., Zharkov R.V., 2026. Geology, Geophysics and Hydrochemistry of the Dachnoye Hydrothermal Deposit (Iturup Island). Geodynamics & Tectonophysics 17 (2), 0889. doi:10.5800/GT-2026-17-2-0889

1. INTRODUCTION

The Iturup Island is rich in hydrothermal deposits with unique properties. One of them is the Dachnoye carbon dioxide siliceous hydrothermal deposit. This deposit lies in the central part of the island 3 km west of the coastline of Kasatka Gulf in the valley of the Nadezhda Creek, the right tributary of the Vysokotravnaya River, approximately 38 km southwest of the city of Kurilsk (Fig. 1). The studies of thermal water outlets along the northeastern side of the Nadezhda Creek valley began in the 1950s. The reports of L.E. Mikhailov, V.V. Ivanov, O.K. Kalishevich, V.E. Bevz (Rusgeolfund, Central Storage Facility) describe the chemical composition of three thermal springs from the deposit. These data is referred to in the monograph, Hydrotherms of the Kuril Islands [Markhinin, Stratula, 1977]. According to V.V. Ivanov, the Dachnoye hydrothermal deposit springs are medium-mineralized, carbonatic, hydrobicarbonate-chloride, magnesic and neutral waters, similar to Essentuki-4. High temperature and high metaflintic acid content of the thermal spring waters grant them additional healing properties. Due to promising balneological characteristics of the thermal water sources, under assignment of the Ministry of Geology of the RSFSR, the systematic geological, geophysical and hydrogeological studies of the Dachnoye hydrothermal deposit have been performed since the late 1970s.

The Iturup Island is part of the present-day tectonic and magmatic activity zone. In its center lies the Osennyaya Neogene volcanotectonic structure, limited by arcuate faults clearly defined from the fragments of the concentric riverine network pattern. The formation of the structure dates back to the late Pliocene Pleistocene. It consists primarily of volcanoclastic facies with numerous subvolcanic bodies and dykes of various compositions. The fault network is clearly mapped out from sharp terrain changes and straight-line river valley segments. The faults are accompanied by crush zones (tectonic breccias), mylonitization zones, and slickensides. Often there are contiguous fault dislocations. The fault planes are steeply dipping. Shear displacements do not exceed 1 km. Many disjunctives are still tectonically active. Moreover, the modern seismic dislocations exhibit mainly the left-lateral oblique-slip displacement. The Dachnoye hydrothermal deposit in the central part of the Osennyaya structure lies within the intermountain artesian basin filled with well-drained Quaternary sediments of insignificant thickness. The upper aquifers discharge water into erosional incisions in river and creek valleys. The sediments consist of modern effusives and the Late Quaternary and Middle Quaternary pyroclastics. According to the adopted stratification scheme of sedimentary deposits of the Iturup Island (Fig. 1), the Quaternary sedimentary-volcanogenic sequence is underlain by the Late

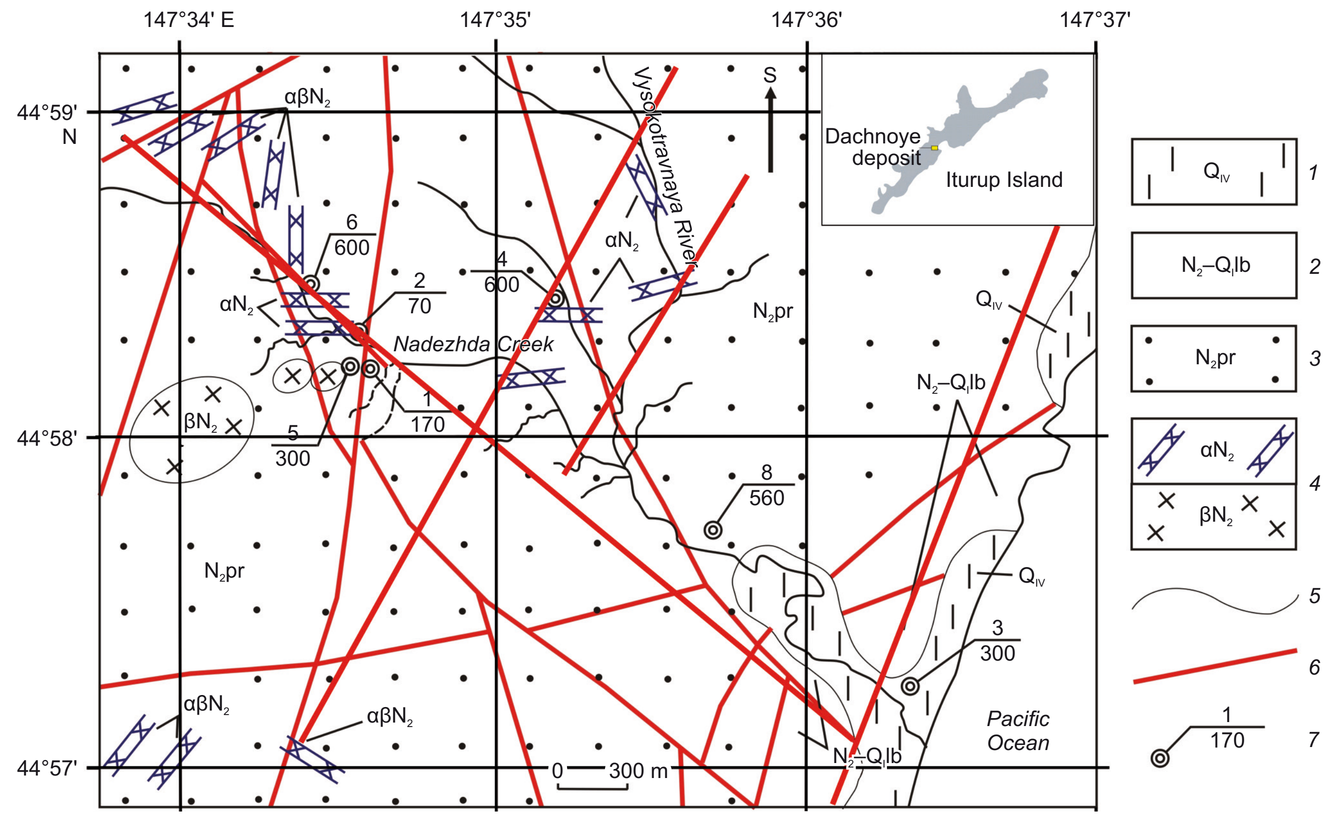

Fig. 1. Location of the Dachnoye hydrothermal deposit, Iturup Island (Kurils).
1 – recent beds; *2* – Upper Pliocene – Pleistocene (Lebedinsky formation); *3* – Middle-Upper Pliocene (Parusny formation); *4* – Upper Pliocene subintrusions and dykes of andesites (α), basalts (β), andesite-basalts (αβ); *5* – borders of heterochronous subdivisions; *6* – tectonic dislocations; *7* – hydrogeological wells: the numerator is the number of well, the denominator is the depth of the well (m). Inset: Iturup Island and Dachnoye deposit.

Pliocene and early Pleistocene Lebedinsky formation (N_2–Q_1lb). The formation is composed of effusive and subvolcanic deposits which are not widely distributed within the Dachnoye hydrothermal deposit. Adjacent to the Lebedinsky formation, lies the Pliocene Parusny formation (N_2pr). It is composed of andesite tuffs, tuffites, basaltic andesites, andesites, sandstone interlayers, and siltstones. The Dachnoye deposit exhibits strong activity of disjunctive fault systems acting as channels for discharging deep mineral waters that form surface thermal anomalies.

In 1979, structural wells 1-D and 2-D no deeper than 170 m were drilled through thermal water outlets in the middle Nadezhda Creek bed. The water brought to the land surface by wells was below 30 °C. Waters were gushing out of the wells under high pressure. In 1980, the Sakhalin Geophysical Expedition conducted vertical electrical sounding (VES) and ground magnetic survey of the Dachnoye hydrothermal deposit in an area of 10 km^2. The results were presented as maps of the initial and altered magnetic fields and as geoelectric cross-sections.

Magnetic survey allowed mapping of intrusive bodies and fault zones. Intense positive anomalies up to 2000 gammas coincide with intrusive bodies, in particular, with the subvolcanic stock in the Nadezhda Creek valley. However, a number of other anomalies were not correlated with intrusive bodies. A positive anomaly on the western coast of Kasatka Gulf was interpreted as evidence of effusive sedimentary strata. However, drilling 3-D well in this area revealed the presence of sedimentary-terrigenous deposits. Based on the VES data, magnetologists concluded that at a thermal water mineralization of 4–5 g/l, the deep zone with an apparent resistivity of 10–15 Ohm·m should be characterized by a temperature above 100 °C. Thus, four sites have been identified as promising for high-temperature thermal waters. One of them is located in the middle reaches of the Nadezhda Creek, where wells 1-D and 2-D were drilled. Water with a temperature of at least 100 °C was expected to be found at depths of up to 425 m. However, the well-logging data from wells drilled subsequently at this and other sites showed that the temperature did not exceed 56 °C at a depth of 600 m. The actual data showed an apparent disagreement with the predicted water salinity ratios and the VES-based temperature distribution. The low efficiency of the VES method is explained by the use of tabular relationships of water salinity and rock conductivity for platform structures.

The team of the Sakhalin hydrogeological expedition under the leadership of Yu.S. Chaban performed a thermal survey in August – September 1984 using the equipment developed by O.V. Veselov (Institute of Marine Geology and Geophysics FEB AS USSR). A shallow borehole thermal survey to evaluate thermal energies and hydromineral resources of the Dachnoye hydrothermal deposit was carried out in an area of 6 km^2.

The thermal survey data were used to identify the sites for drilling two exploratory wells confined to maximum surface temperatures in the middle reaches of the Nadezhda Creek. In the second half of 1984, drilling was carried out in this area (wells 5-D and 6-D) and adjacent territories (wells 3-D, 8-D, 4-D) to determine the geological structure and temperature regime within the Osenny Isthmus (Fig. 1). The maximum temperature in the first group was measured in well 6-D at a depth of 596 m and amounted to 55.6 °C. The maximum temperature in the second group, measured in well 4-D at a depth of 589 m, was 50.4 °C. Thermograms of all wells are presented in Fig. 2. Significant differences between the wells of the two groups concern only the upper depth intervals. Thermograms of wells 3-D, 8-D are slightly concave-shaped, with a gradual increase in the geothermal gradient. The temperature distribution in the wells of the first group indicates upward movement of groundwater and is characterized by a slight temperature gradient in the depth interval penetrated by drilling. Core analysis of wells 1-D, 5-D, and 6-D revealed a significant number of fractured zones and intense fracturing of the rocks. Wells 5-D and 6-D, penetrated to a depth of 300 m, have exposed 29 and 19 fracture zones, respectively. The thickness of the fracture zones ranges

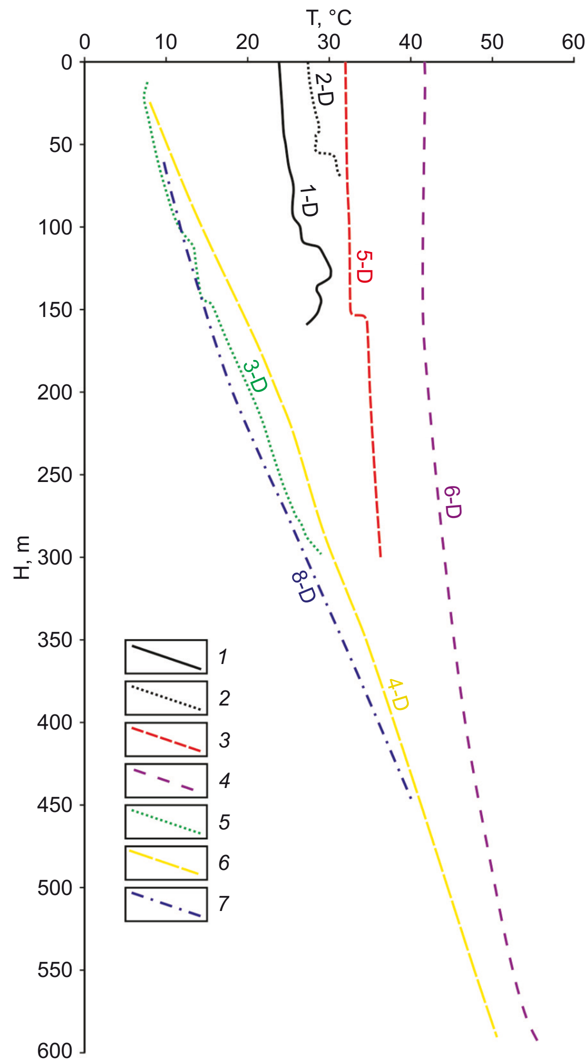

Fig. 2. Thermograms of wells at the Dachnoye deposit. *1* – well 1-D; *2* – well 2-D; *3* – well 5-D; *4* – well 6-D; *5* – well 3-D; *6* – well 4-D; *7* – well 8-D.

from a few tenths of a meter to 4.4 m. Fracture networks form open circulation systems. The fracture orientation is predominantly vertical (5–15° to the core axis). Thermal water upwelling created a low-gradient zone in the upper depth interval of wells 1-D, 5-D, and 6-D. Thus, well 5-D shows the average geothermal gradient of 1.8 °C/100 m in the 0–300 m depth interval. The average geothermal gradient of 4.7 °C/100 m in the 0–200 m depth interval was observed in the wells beyond the carbonate mineral water discharge area. The temperature distribution in the upper depth interval across the deposit site is determined by the structural framework of the area. Maximum values are observed in the central part of the arched uplift, characterized by the maximum degree of fracture opening and the upward flow of thermal waters.

Heat stored in the deposit site is most likely provided by magma chamber located at a significant depth. Its activity has lead to the formation of an intrusive body on the right side of the Nadezhda Creek and of numerous dikes. These dikes are primarily located along a northwest-trending fault zone. For access to thermal waters with temperatures exceeding 70 °C, it is suggested to drill at least a 850 m deep well in a volcanotectonic uplift segment with maximum values of fracture system.

Drilling locations should be selected based on the analysis of shallow temperature survey results. This article provides descriptions on the geological structure, shallow temperature survey results, their interpretation, and hydrochemistry for the Dachnoe deposit.

2. METHODS

The practice of using shallow temperature survey in parallel with other surface geophysical exploration methods such as electrical prospecting, shallow seismic, gravimetric and other surveys allows obtaining certain geological data without exploratory drilling. The successful application of this method resulted in discovery of deep structures, oil and gas fields, certain types of ores such as sulfides, tectonic faults, geothermal structures, etc. [Chekalyuk et al., 1974; Cheremensky, 1972; Khrebtov, 1965; Lyalko et al., 1979; Parovyshny et al., 2008; Vakin et al., 1986; and others]. Research showed that deep temperature anomalies remain active until they reach the Earth's surface where they can be identified by the near-surface temperature survey. Moreover, the near-surface temperature distribution reflects the shape of hydrocarbon deposits and deep tectonic faults as well as features of geological structures. Heat removal by fluids during formation of geothermal zones creates well-defined positive surface temperature anomalies with highly contrasting linear areas marking active faults. These theoretical principles supported with practical results served as a basis for conducting shallow-depth temperature survey of the Dachnoye hydrothermal deposit.

The analysis of various methods of temperature measurements at different depths showed that the optimal installation depth for temperature sensors is 1.5 m. This depth is not exposed to daily temperature changes regardless of soil composition, thus facilitating installation of the sensor at an assigned depth [Chekalyuk et al., 1974]. On the other hand, seasonal temperature fluctuations penetrate greater depths and, therefore, the optimum installation period is the time of the year when 1.5 m deep temperature attains its maximum value and remains relatively constant for two to three weeks in monsoon regions. According to the data from the weather station in Kurilsk (Iturup Island) located at an altitude of 25 m above the sea level, the temperature at a depth of 1.6 m reaches its maximum value in the first half of September and remains unchanged until the second half of October. The temperature during this period fluctuates within ±0.2 °C [Handbook..., 1970, 1981]. In this methodologically optimal period, the temperature measurements were made at the Dachnoye hydrothermal deposit in 1.5 m deep boreholes (Fig. 3).

The thermal survey covered the middle and lower parts of the Nadezhda Creek valley, the Nadezhda Creek and the Vysokotravnaya River interfluve area, and the right bank of the Vysokotravnaya River within the Osenny Isthmus (Fig. 3, a).

Observations were made using thermometers with MMT-1-type thermistor temperature sensors, whose thermal resistance ratio is $\alpha T=-4$ Ohm/°C, calibrated to an accuracy of ±0.05 °C. The thermistors were placed in titanium tubes 180 cm long and 8 mm in diameter. DC MO-62 was used as a measuring instrument. Nineteen reconnaissance profiles 375 to 3100 m long were acquired within the area including three sites with 45 detailed measurement profiles, each approximately 125 m long and spaced 25 to 50 m apart. The temperature measurement points were gridded with a triangulation theodolite and followed by determination of geographic coordinates of the points along which the observation grid was mapped at a scale of 1:10000. The distance between the boreholes on the profiles is 25 m. Thus, the detailed site measurements were made mainly within a 25×25 m grid which allows drawing the plan view of temperature field of the sites at a depth of 1.5 m. The total length of all profiles is 32650 m. The measurements were made in 1318 points overall. Absolute frequency spectrum was plotted based on the temperature data sampled during the survey (Fig. 4). The temperatures obtained at 1033 points were ranging from 7.5 to 9.5 °C; the temperatures obtained at 690 points out of 1033 were ranging from 8 to 9 °C. 40 points showed high temperatures in the range of 12 to 25 °C. If the latter are excluded from the analysis, then the temperatures range from 7.5 to 9.5 °C as recorded at 81 % of points and their values represent a normal distribution. The mean temperature therein is 8.5 °C, which should be considered as a reference point typical at a depth of 1.5 m for low mountains of the Osenny Isthmus during the measurement period.

Before moving to the analysis of the mass temperature measurement results for the Dachnoye hydrothermal deposit, emphasis should be placed on single temperature jumps on the profiles beyond the thermal zones. However, the use of a dense grid of temperature measurement points could permit mathematical interpretation of the smoothed temperature rebound curve. Most of the jumps are caused by near-surface features (primarily landforms) as the south-facing sunny slopes are much warmer than the slopes facing north. At the same time, in the central part of the Iturup Island, this contrast decreases due to precipitation and winds, thus providing smoothed mean values of the temperatures on differently oriented slopes. Depending on the terrain inclinations, the difference between monthly temperatures does not exceed 0.5 to 1.0 °C. This observation is confirmed by statistical processing of the thermal data. In this regard, the following quotation can be cited [Chekalyuk et al., 1974, p. 63]: "Sufficiently

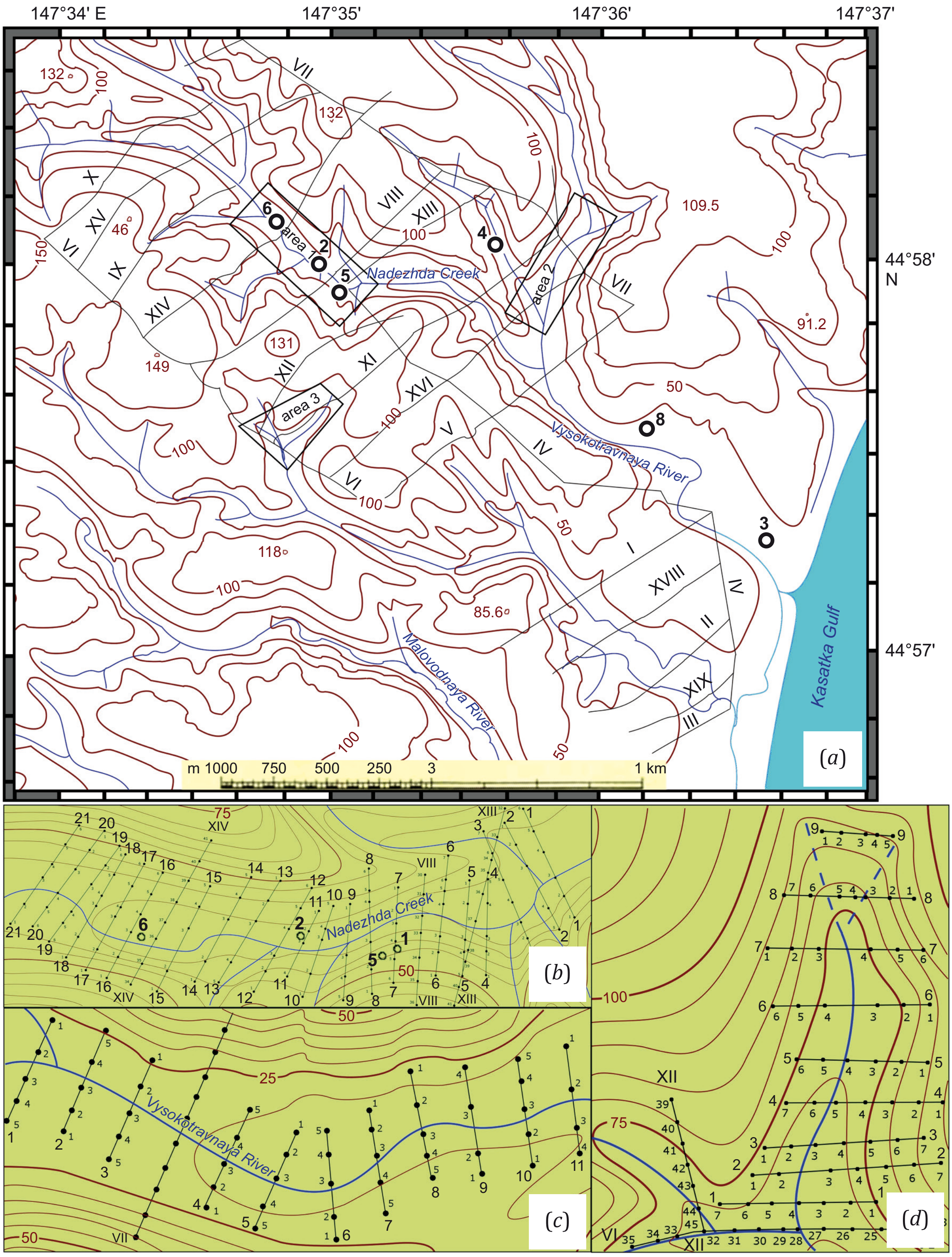

Fig. 3. Shallow temperature survey in the Dachnoye hydrothermal deposit area.
Roman numerals mark the exploration measurement profiles. Large Arabic numerals mark the detailed profiles, small Arabic numerals mark the pickets, and circles mark the wells. Letters mark the measurement sites: (*a*) – study area, (*b*) – site 1, (*c*) – site 2, (*d*) – site 3.

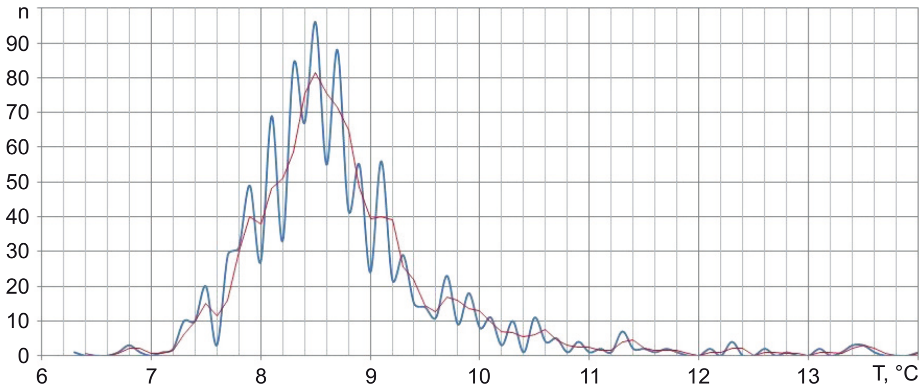

Fig. 4. Absolute frequency spectrum sampled during the thermal survey.
Horizontal coordinates are temperatures (°C), vertical coordinates are absolute frequencies of the temperatures according to the measurement results. Blue line marks the initial spectrum, red line depicts the post-linear filtration.

dense grid of temperature measurement points allows direct mathematical interpolation and smoothing of sawtooth-shaped temperature curves using the rule for averaging the thermophysical properties of the Earth's surface without any interpretation".

3. RESULTS

The areal measurements have been made at three thermometric-anomaly detection-related sites (see Fig. 3, a) of the Dachnoye hydrothermal deposit. The first site lies in the middle reaches of the Nadezhda Creek, the right tributary of the Vysokotravnaya River. The second site lies within the Vysokotravnaya River valley 675 m above the Nadezhda Creek confluence. The third site lies 300 m southwest of the Dachnoye deposit, 1300 m away from the Nadezhda Creek mouth. Detailed measurements to identify the nature of contrasting temperature changes have been made along the system of profiles spaced approximately 25 m apart. At the first site there are 22 profiles 125 m long on average (see Fig. 3, b). Each profile has 6 pickets spaced approximately 25 m apart. Measurements are made at 125 points. The site exhibits two elliptic high-temperature (25 °C and higher) zones located along the Nadezhda Creek banks and oriented approximately along the azimuth of 300–310°. At the second site, 66 measurements were taken on 13 profiles that are 100 m long on average (see Fig. 3, c). The site includes a reltively high (to 13°C) temperature zone along the azimuth of 40–45°. At the third, northeast-elongated site, 77 temperature measurements were made on 11 profiles that are on average 150 m long (see Fig. 3, d). The site includes two slightly elevated (to 11.8°C) temperature zones. The northern zone is oriented along the azimuth of 70°. The second zone lies at the intersection of two narrow high-temperature bands, with one of which oriented along the azimuth of 40–45°, and the other – along the azimuth of 310°. The identified linear thermal anomalies mark deep thermal-water outcrops along the fault zones. The orientation of abnormal temperature zones indicates the segments of the northwest- and northeast-directed regional faults. In this case, the northeast-directed faults correspond to the main strike of the Great Kuril Range axis. The northwest-directed faults are disjunctives that divide the island into blocks.

The analysis of temperature distribution across the thermal survey area at the first stage of data processing allows us to draw the following conclusions. The springs with temperatures ranging from 8 to 20 °C form the largest discharge zones linearly elongated in plan. These zones with thermal spring outlets are traceable over large distances. Some sites have closely spaced linear zones comprising a discharge area. The chemical composition of the waters of these springs is characterized as sodium chloride-hydrocarbonate. Site 1 in the middle reaches of the Nadezhda Creek is the most promising area for further exploration.

The temperature conditions of the thermal water deposit are provided by endogenous heat sources. The system of tectonic fractures above the thermal source determines the circulation of water in the Neogene and Quaternary strata of the deposit. The system consists of many fractures converging and intersecting with each other. High-temperature hydrothermal discharge in the northwest-striking zones may be indicative of their more intense current tectonic activity in modern times.

Based on the results of geological study and thermal survey, the exploration wells were drilled in the late 1980 year at the sites of thermal anomaly zones and beyond their contours to determine the geological structure of the Dachnoye deposit and adjacent areas as well as to bring thermal waters to the surface. The strata uncovered by wells demonstrated the distribution of tectonically crushed rocks throughout the entire drilling depth (to 600 m), especially at the temperature anomaly sites. The vertical distribution of temperatures indicates the presence of ascending medium-temperature waters within site 1 where wells 5 and 6 were drilled in addition to previously made wells 1 and 2. These wells brought carbon dioxide mineral waters of chloride-hydrocarbonate and magnesium-sodium composition to the surface in self-discharge mode with well-head temperatures ranging from 28 to 44 °C and flow rate to 50 l/s. The maximum measured temperature for well 6 at a depth of 596 m was 55.6 °C. Such wells as 3 and 8, drilled southeast of thermal anomaly site 1, on the sides of the volcanotectonic uplift, contain alkaline, chloride, and slightly salted waters.

A geological-geothermal profile running from well 3 to well 6 (Fig. 5) shows the temperature distribution pattern both beyond and within thermal site 1. The results of analysis of the section penetrated by wells 1, 2, 5 and 6 show that the site zone is characterized by heavy fracturing and fragmentation of volcanoclastic deposits to depths of more than 300 m, which resulted in high permeability, convective removal of high-temperature mineral waters, and strong heating of the strata within the depth range of 0–400 m.

Prospecting and exploration of the Dachnoye deposit were ended in the 1990s. In subsequent years, the scientists from IMGG FEB RAS conducted hydrochemical and temperature measurements in the deposit wells.

4. DISCUSSION

In 2013–2017, encouraged by the growing trend of government interest in thermomineral resources of the Kuril Islands, the scientists from the IMGG FEB RAS carried out the assessment of the present-day physicochemical parameters of thermomineral waters in the Kunashir and Iturup islands to ensure that these waters can be used in balneology.

4.1. Hydrochemical investigations

These studies employed another hydrochemical exploration of the thermal springs of the Dachnoye deposit [Zharkov, 2014]. The exploration involved thermal water sampling, pH determinations, and temperature measurements in wells 1 and 5. The pH value was measured with Hanna Hi 9025 pH meter. The complete chemical analysis of water from wells 1 and 5 was performed based on standard methods at the laboratory of OJSC Primgeologiya. The analysis of oxygen and hydrogen isotope in water sample using the Finnigan MAT 252 mass spectrometer was performed at the Far East Geological Institute of the FEB RAS (analyst T.A. Velivetskaya). The basic analyses of spontaneous and dissolved gases using the Crystallux 4000 gas chromatograph were made at the Gas Geochemistry Laboratory of the V.I. Il'ichev Pacific Oceanological Institute of the FEB RAS (analysts E.V. Korovitskaya and O.F. Vereshchagina).

The thermal water resources of the Dachnoye deposit are 14.900 cubic meters per day; with numerous thermal springs and wells having relatively low flow rates. Wells 1 and 5, tested in 2013–2014, have similar physicochemical characteristics. The average temperature of the water discharged from well 5 is 33 °C (31.7 °C in September 2021), and the flow rate is approximately 40–50 l/s. According to its chemical composition, this thermal water belongs to subneutral (pH 6.5) chloride-hydrocarbonate sodium type with a high content of metasilicic acid and a mineralization of 4.9 g/dm^3. The water gas composition in the well is dominated by carbon dioxide (93 %), while the nitrogen content reaches 6 %. The chemical composition of water from well 1, located 15 m east of well 5, is almost identical to that of water from well 5. The discharge water

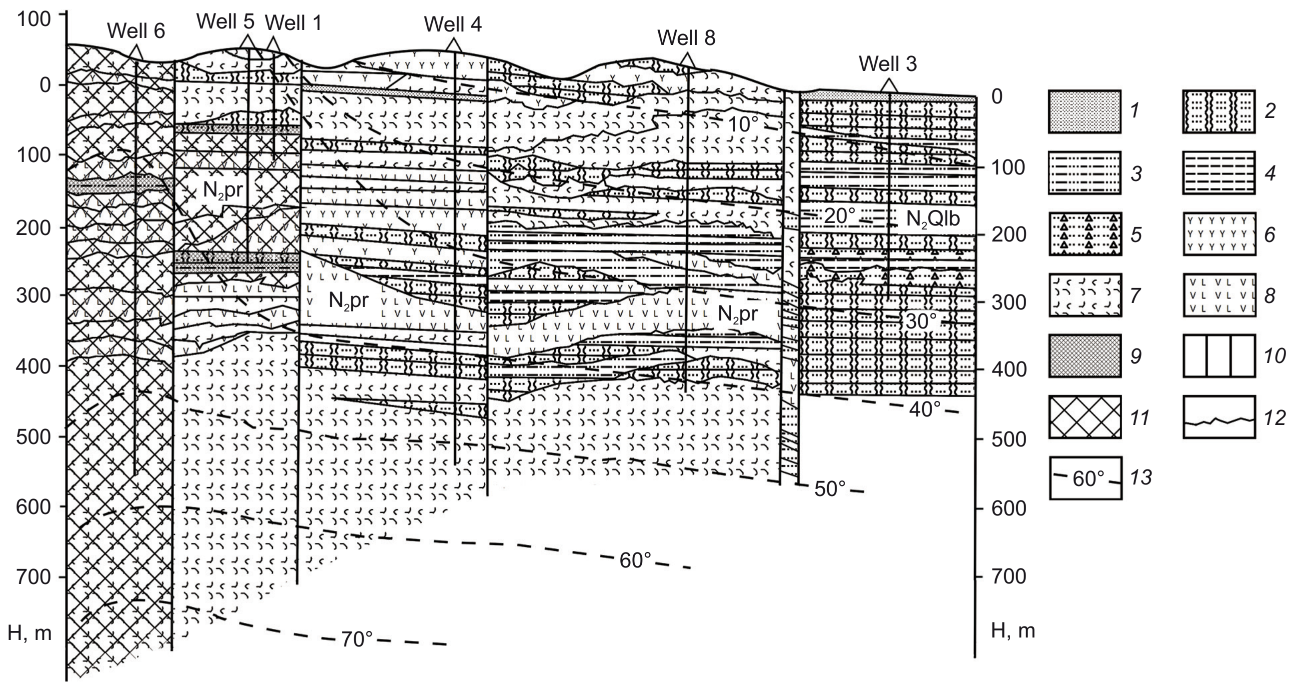

Fig. 5. The geological and temperature cross-sections along the sublatitudinal profile running across wells 3, 8, 4, 5, 1 and 6.
The geological section is drawn from the geological survey and drilling data. The horizontal scale is 1:25000; the vertical scale is 1:10000. *1* – volcanomictic sandstones; *2* – pumice-containing areas; *3* – volcanomictic aleurolites; *4* – clays; *5* – volcanic breccia of variable composition; *6* – agglomeratic tuffites; *7* – basic and intermediate tuffs; *8* – andesitic-basaltic lavas; *9* – mylonitization zones; *10* – disjunctive dislocations; *11* – fractured zones; *12* – unconformity boundaries; *13* – isotherms (°C).

temperature is 23 to 28 °C, and the flow rate is 3 l/min. The well water is neutral (pH 7.0), chloride-hydrocarbonate sodium with a mineralization of 4.9 g/dm^3. In terms of isotopic hydrogen and oxygen content (δD of –58.8 to –63.2 ‰, δ^{18}O of –7.5 to –8.7 ‰), the thermal waters of the wells are similar to meteoric waters of the Southern Kurils Islands (δD=–68.8 ‰, δ^{18}O=–9.7 ‰), which indicates that hydrothermal waters are fed predominantly by waters of atmospheric origin [Zharkov, 2014, 2015].

4.2. Statistical analysis of the thermal survey data

For a more precise definition of the thermal characteristics of the Dachnoye deposit, the previous data regarding the thermal survey performed therein [Veselov, Kazakov, 2016] was reprocessed using statistical analysis methods [Davis, 1990]. The thermal survey data was digitized. All measurement results indicating profiles and pickets were recorded into a three-dimensional array of geographic coordinates and temperatures at a depth of 1.5 m. The sampling boundaries were determined for all three parameters, and the geographic coordinates were converted into relative ones. An initial analysis of the thermal survey data was performed using a quadrant grid with a step of 25 m for each site. The isotherms were generated using the grid method which implies estimating the measured value as a weighted average at the nearest points. The calculations were made using the quadrant search method necessary for performing four-sided initial measurements with at least one point taken from each quadrant. Equality between the regular grid step and the original, non-regular grid step provided that the mean number of temperature measurement points at the quadrant grid nodes was 5 to 7. After evaluation of the analyzed factor for the quadrant grid nodes, the equal values of the factor were transferred to a regular grid on condition of a linear variation of the factor along the edges of the quadrant network. For comparison, kriging was used as a method for generating isotherms [Baikov et al., 2012]. The generated results are corresponding to the results of statistical data processing described above. This made it possible to draw isoline maps showing temperature distribution over the entire survey area and to contour the temperature anomaly zones (Fig. 6). The map of site 1 shows that the wells drilled therein (1, 2, 5 and 6) are on the periphery of the highest temperature anomalies. The improved accuracy of high temperature locations in site 1 coincides with the the maximum temperatures measured in wells 5-D and 6-D. The results of the temperature distribution analysis in the detailed survey sites demonstrate that sites 2 and 3 are not priority study areas due to their low (no more than 12 °C) temperatures, whereas site 1, like several decades ago, is the most promising for thermal mineral water extraction when resuming drilling operations. The temperature field of site 1 breaks up into several elongated elliptic anomalies whose chain marks the fault zone striking northwest. It is obvious that thermal waters within the fault zone rise to the surface in several tectonically separated streams.

The research substantiated the use of a computer technology for the shallow temperature survey data processing and interpreting based on intra- and interprofile correlation. This technology allows for delineating high temperature zones in conditions of non-stationarity in initial data.

The use of correlational statistics for characterizing thermal survey provided more accurate and detailed information on the distribution features of temperature anomalies. This made it possible to estimate the depths of thermal water formation, the location of active fault zones, and

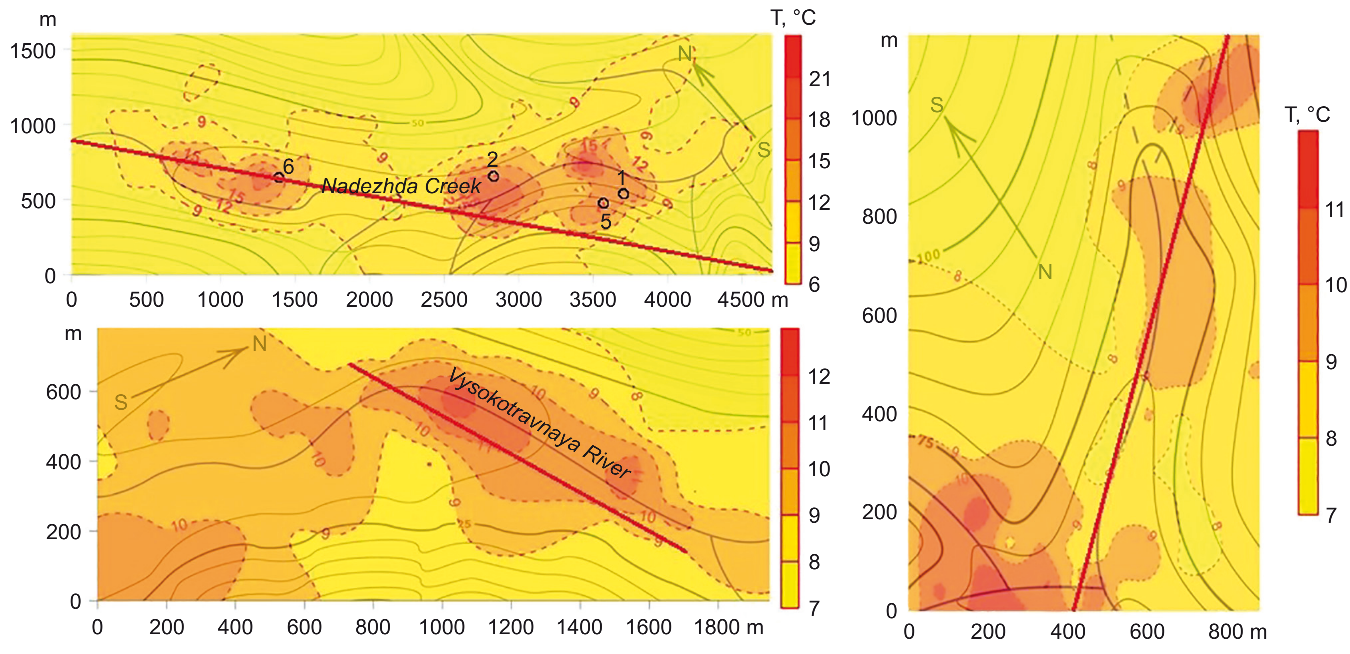

Fig. 6. Temperature charts produced for the detailed sites. The solid lines mark the relief isolines. The dashed lines mark the isotherms (°C). The circles mark the wells.

to determine the most promising areas for extraction of thermal mineral waters.

5. CONCLUSION

A shallow temperature survey in the modern tectonomagmatic activity zone has proven to be an effective way of identifying the sites for drilling thermal water wells.

The survey data processing using statistical analysis methods allows for more accurate identification of thermal anomaly boundaries and makes it possible to recommend the promising sites for drilling high flow-rate wells when resuming prospecting operations at the Dachnoye deposit. The described method of shallow-depth temperature survey and survey data processing applies to mapping of thermal fields in the modern tectonomagmatic activity zones of the Kuril Islands.

The Dachnoye hydrothermal deposit, studied using geological, geothermal and hydrochemical methods, is one of the most promising balneological sites of the Iturup Island. This is the only place in the Southern Kuril Islands with the identified natural outlets of neutral thermal mineral waters with the carbon dioxide content not exceeding 90 %.

6. CONTRIBUTION OF THE AUTHORS

All authors made an equivalent contribution to this article, read and approved the final manuscript.

7. DISCLOSURE

The authors declare that they have no conflicts of interest relevant to this manuscript.

8. REFERENCES

Baikov V.A., Bakirov N.K., Jakovlev A.A., 2012. Mathematical Geology. Vol. 1. Introduction to Geostatistics. IKI, Izhevsk, 228 p. (in Russian) [Байков В.А., Бакиров Н.К., Яковлев А.А., Математическая геология. Т. 1: Введение в геостатистику. Ижевск: ИКИ, 2012. 228 с.].

Chekalyuk E.B., Fedortsov I.M., Osadchiy V.G., 1974. Field Geothermal Investigation. Naukova Dumka, Kiev, 104 p. (in Russian) [Чекалюк Э.Б., Федорцов И.М., Осадчий В.Г. Полевая геотермическая съемка. Киев: Наукова думка, 1974. 104 с.].

Cheremensky G.A., 1972. Geothermy. Nedra, Leningrad, 272 p. (in Russian) [Череменский Г.А. Геотермия. Л.: Недра, 1972. 272 с.].

Davis J.S., 1990. Statistical Data Analysis in Geology. Book 2. Nedra, Moscow, 429 p. (in Russian) [Дэвис Дж.С. Статистический анализ данных в геологии. М.: Недра, 1990. Кн. 2. 429 с.].

Handbook on the Climate of the USSR, 1970. Sakhalin Region. Air and Soil Temperatures. Vol. 34. Part III. Gidrometeoizdat, Leningrad, USSR, 200 p. (in Russian) [Справочник по климату СССР. Сахалинская область. Температуры воздуха и почвы. Л.: Гидрометеоиздат, 1970. Вып. 34. Ч. III. 200 с.].

Handbook on the Climate of the USSR, 1981. Addition: Air and Soil Temperature, Air Humidity, Precipitation, Snow Cover, Wind, Cloudiness. Vol. 34. Gidrometeoizdat, Leningrad, 29 p. (in Russian) [Справочник по климату СССР. Дополнение: Температура воздуха и почвы, влажность воздуха, атмосферные осадки, снежный покров, ветер, облачность. Южно-Сахалинск, 1981. Вып. 34. 29 с.].

Khrebtov A.I., 1965. Geothermal Conditions and Thermal Waters of the Central Ciscaucasia. Nauka, Moscow, 110 p. (in Russian) [Хребтов А.И. Геотермические условия и термальные воды Центрального Предкавказья. М.: Наука, 1965. 110 с.].

Lyalko V.I., Mitnik M.M., Vulfson L.D., Shportyuk Z.M., 1979. Geothermal Prospecting for Minerals. Naukova Dumka, Kiev, 145 p. (in Russian) [Лялько В.И., Митник М.М., Вульфсон Л.Д., Шпортюк З.М. Геотермические поиски полезных ископаемых. Киев: Наукова думка, 1979. 145 с.].

Markhinin E.K., Stratula D.S., 1977. Geotherms of the Kuril Islands. Nauka, Moscow, 212 p. (in Russian) [Мархинин Е.К., Стратула Д.С. Геотермы Курильских островов. М.: Наука, 1977. 212 с.].

Parovyshny V.A., Veselov O.V., Senachin V.N., Kirienko V.S., 2008. Time Variations in the Geophysical Fields Above a Gas Field on Sakhalin Island. Russian Journal of Pacific Geology 2 (4), 283–293. https://doi.org/10.1134/S1819714008040015.

Vakin E.A., Lyalin G.N., Rozhkov A.M., 1986. Soil-Gas and Thermometric Survey. In: Geothermal and Geochemical Studies of High-Temperature Hydroterms. Nauka, Moscow, p. 78–108 (in Russian) [Вакин Е.А., Лялин Г.А., Рожков А.М. Почвенно-газовая и термометрическая съемка // Геотермические и геохимические исследования высокотемпературных гидротерм. М.: Наука, 1986. С. 78–108].

Veselov O.V., Kazakov A.I., 2016. Thermal Field Modeling in the Zones of Up-to-Date Tectonic and Magmatic Activity According to the Results of Shallow Temperature Survey. Problems of Subsoil Management 3, 40–47 (in Russian) [Веселов О.В., Казаков А.И. Моделирование термального поля в зонах современной тектоно-магматической активности по результатам малоглубинной термосъемки // Проблемы недропользования. 2016. № 3. С. 40–47]. https://doi.org/10.18454/2313-1586.2016.03.040.

Zharkov R.V., 2014. Thermal Springs of the South Kuril Islands. Dal'nauka, Vladivostok, 378 p. (in Russian) [Жарков Р.В. Термальные источники Южных Курильских островов. Владивосток: Дальнаука, 2014. 378 с.].

Zharkov R.V., 2015. Dachnoye Deposit of Thermomineral Water (Iturup Island, Kuril Islands). In: Geodynamic Processes and Natural Disasters. Neftegorsk Experience. Proceedings of the All-Russian Scientific Conference with International Participation: Collection of Materials (Yuzhno-Sakhalinsk, May 26–30, 2015). Vol. 2. Dalnauka, Vladivostok, p. 221–224 (in Russian) [Жарков Р.В. Дачное месторождение термоминеральных вод (о. Итуруп, Курильские острова) // Геодинамические процессы и природные катастрофы. Опыт Нефтегорска: Материалы Всероссийской научной конференции с международным участием (Южно-Сахалинск, 26–30 мая 2015 г.). Владивосток: Дальнаука, 2015. Т. 2. С. 221–224].