

## SURFACE AND GROUND WATER IN PERMAFROST REGION

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SUPRAPERMAFROST SUBAERIAL TALIKS, CENTRAL YAKUTIA,  
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The study presents the results of drilling, geophysical survey and ground temperature monitoring in the area of suprapermafrost subaerial water-bearing talik that is associated with sandy deposits in the sparsely vegetated gentle slope of the Levaya Shestakovka River terrace covered by pine forest. The talik is 180–200 m wide and more than 500 m long, has a complicated contour and consists of several water-conducting channels. The configuration of unfrozen zones assessed with a ground penetrating radar and electrical resistivity tomography is similar, thus confirming the efficiency of the applied geophysical methods. The mean value of the ground temperature and its amplitude for one year in the talik area are much higher than outside of the talik. The depth of the zero annual amplitude does not exceed 6 m due to the constant yearly temperature of the water-saturated deposits equal to 0 °C.

*Water-bearing talik, permafrost, soil temperature, electrical resistivity tomography, ground penetrating radar*

## INTRODUCTION

Central Yakutia is located in the continuous permafrost zone, with permafrost several hundred meters thick. As previously believed, the harsh climatic conditions preclude development of subaerial (radiation and thermal, according to *N.N. Romanovsky [1983]*) taliks. Yet, subaerial suprapermafrost and intrapermafrost water-bearing taliks are known to exist in Central Yakutia on medium-level terraces of the Lena and Viluy Rivers and on the ancient depositional denudational plains. As a rule, they are associated with dry sparsely vegetated sandy deposits covered by pine forests [*Katasonova and Tolstov, 1963; Boitsov and Shepelev, 1976; Boitsov, 1985, 2011; Shepelev et al., 2002; Anisimova, 2003*]. The distribution, origin, and evolution of the revealed subaerial water-bearing taliks in Central Yakutia have not been definitely ascertained. The hydrogeological, geothermal, and hydrochemical regimes of the ground waters are not sufficiently investigated. The studies of subaerial taliks are becoming especially relevant for evaluating the evolution of the hydrogeological permafrost conditions in the region in a changing climate.

Comprehensive long-term studies of a suprapermafrost talik were first organized in Central Yaku-

tia at the Chabyda station of the Permafrost Institute, Siberian branch of the Academy of Sciences of the USSR, in the area of Lake Malaya Chabyda in the basin of the Levaya Shestakovka River. From 1977 to 1991, hydrogeological permafrost studies were conducted, including the monitoring of the level, temperature, hydrochemical characteristics, landscape and other parameters [*Boitsov, 1985, 2002; Skryabin et al., 1998; Varlamov et al., 2002*]. The area near the monitoring station was covered by pine and larch forests. The subaerial water-bearing talik of the ground filtration class was opened by drilling the ground at the depth ranging from 2.5 to 7.0 m in the area of the pine forest having traces of fire. The static reserves of the ground waters contained in the Chabyda talik with the area of 58,000 m<sup>2</sup> and thickness of 4 m in the critical water flow period was evaluated to be 15,000 m<sup>3</sup> [*Boitsov, 1985*]. A.V. Boitsov determined the depth of the underground runoff to be equal to 35–40 mm [*Shepelev et al., 2002*].

In 2016, we discovered a similar talik in another place of the basin of the Shestakovka River – 5 km from the Chabyda monitoring station (Fig. 1).

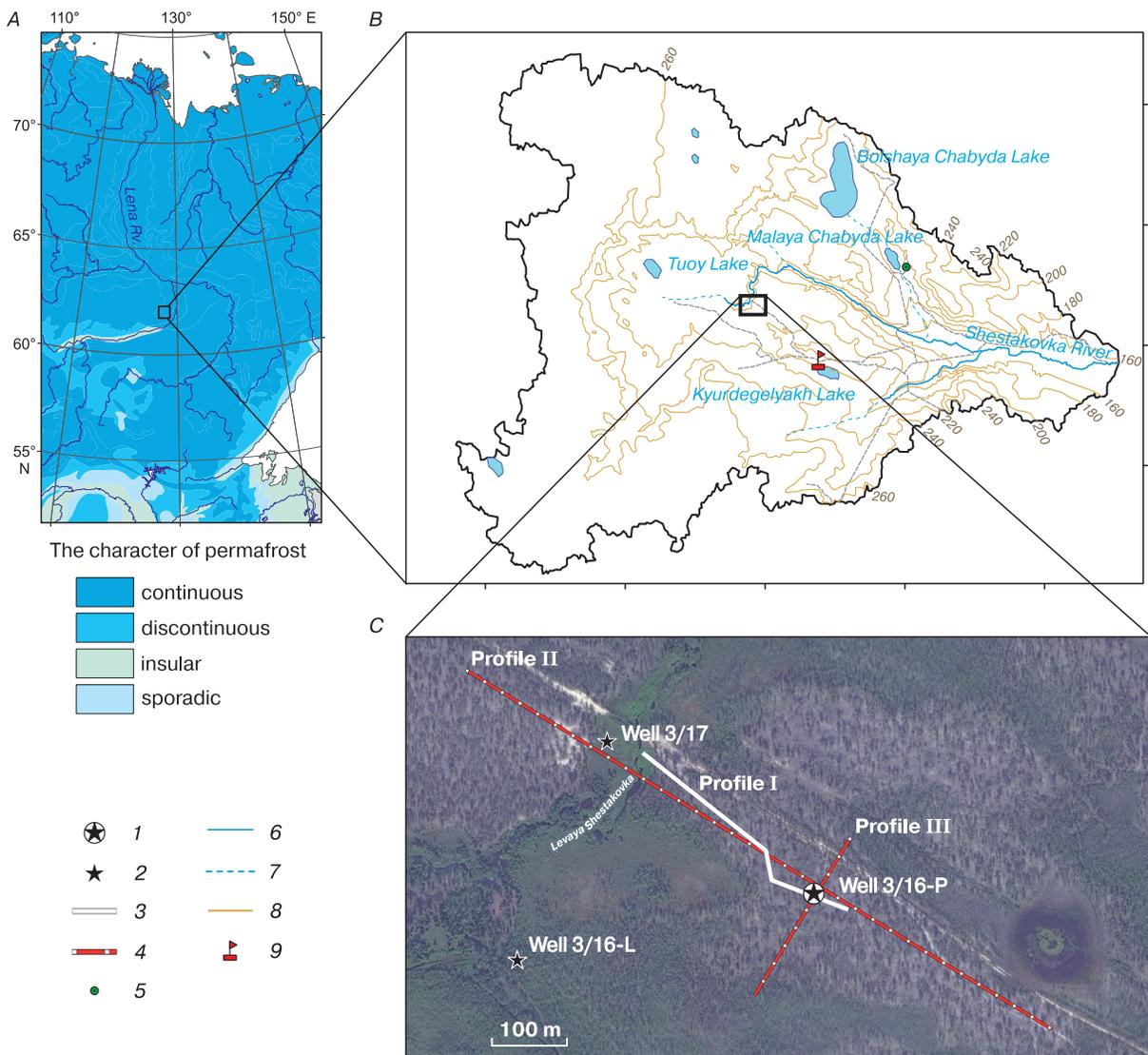
The goal of the study was to reveal the structure and the temperature regime of the suprapermafrost water-bearing talik revealed on the alluvial terrace of the Levaya Shestakovka River and to evaluate the possibilities of a ground penetrating radar and electrical resistivity tomography for studying suprapermafrost talik zones.

### THE OBJECT UNDER STUDY

The basin of the Shestakovka River is located 20 km south-west of Yakutsk on a erosion-denudational slope of an height records of 190–210 m a.s.l. (Fig. 1). The climate of the region under study is sharply continental with severe long winters and

short hot summers. The mean annual air temperature recorded at the nearest meteorological station in Yakutsk for the period of 1950–2015 is  $-9.2\text{ }^{\circ}\text{C}$ , that of January is  $-42.6\text{ }^{\circ}\text{C}$ , and that of July is  $+18.7\text{ }^{\circ}\text{C}$ , the mean annual precipitation is 245 mm, with 158 mm falling in the warm period.

In the valleys, depressions and flattened areas, larch and birch forests grow (according to our own landscape descriptions) in the basin of the Shestakovka River. Pine forests mostly occupy slopes and watersheds. Bogs and swampy territories are commonly found along creeks and near lakes. The top part of the geological cross section is composed of loose sandy deposits with rare interbeds of clay



**Fig. 1. Location and configuration of the object under study.**

A – location of the object under study on the permafrost map of Eastern Siberia; B – catchment of the Shestakovka River; C – the object under study in the upper reaches of the Levaya Shestakovka River; 1 – hydrogeological and thermometric wells; 2 – thermometric well; 3 – ground penetrating radar profile; 4 – electrical resistivity tomography profiles; 5 – Chabyda station; 6 – permanent; 7 – temporary stream; 8 – contour lines; 9 – meteorological station.

[Boitsov, 1985]. Sands on slopes and watersheds are represented by fine and medium-grained varieties. Their water content in the aeration zone does not exceed 2–8 % (hereinafter only volumetric water content is indicated). The sandy deposits have a quartz and feldspar composition, the skeletal density is over 1.70 g/cm<sup>3</sup> and porosity of 33–35 % [Boitsov, 2002]. On the bottoms of the valleys of creeks and intermontane valleys, moist (15–25 %) sands are overlaid by an organogenic layer [Skryabin *et al.*, 1998].

The thickness of permafrost reaches 400–500 m and is characterized by a variable thermal regime. At the depth of 100 m, the temperature of the deposits varies from –0.6 to –1.0 °C [Boitsov, 1985]. Depending on the landscape, the temperature of the deposits at the foot of the layer of zero annual amplitudes varies from positive (close to 0 °C) values to –2...–3 °C and lower [Varlamov *et al.*, 2012]. The thickness of the active layer varies from 4 m in pine forests on gentle slopes and watersheds to 0.5 m in bogs.

A.V. Boitsov [2002] discovered that a steady condition of suprapermafrost subaerial water-bearing taliks is possible when three factors are combined: 1) barren or sparsely vegetated earth surface; 2) sandy deposits; 3) rather smooth topography. Suprapermafrost subaerial water-bearing taliks have a complicated structure in the plan view and often have a dendritic drainage pattern.

Long-term observations of the deposit temperatures have been conducted at the Chabyda monitoring station since 1977, and regime-related hydrogeological monitoring in the talik area has been carried out since 1981. In 2016, hydrogeological permafrost investigations started in the key area on the right bank of the Levaya Shestakovka River 5 km from the Chabyda monitoring station.

The field works in the upper reaches of the Levaya Shestakovka River included visual observation of the territory, geophysical studies, drilling and installation of equipment for thermometric and hydrogeological wells, as well as regime monitoring over the ground temperature and the level of the talik waters.

The study area in question was selected based on the preliminary reconnaissance of the territory in April 2016. On the slope of a terrace of the Levaya Shestakovka River, icing was discovered 90 m long and up to 70 cm thick. The process of icing formation suggested the presence of an area of ground water discharge, which could originate from a water-bearing talik.

## METHODS OF INVESTIGATION

### Drilling

After reconnaissance under landscape conditions similar to the Chabyda talik, two wells were drilled. Well 3/16-P 10 m deep was located in a pine forest 300 m away from the edge of the terrace of the Levaya

Shestakovka River. Well 3/16-L was drilled 3 m deep in a larch forest 125 m upstream the riverbed. The distance between the wells was 410 m. The absolute height of the wells' heads was about 210 m above sea level. The wells were drilled using a column drill installed on a self-propelled drilling machine URB-2A2. Both wells were cased and equipped with thermistors. Well 3/16-P was coupled with a hydrogeological well, in which a filter was installed at the depth of the water-bearing talik.

In April 2017, Well 3/17 was drilled 20 m deep on the high left-bank floodplain of the Levaya Shestakovka River 30 m from the riverbed (the absolute height of the river mouth was about 200 m a.s.l.). The well was equipped with thermistors.

The grain-size distribution of the deposits from Wells 3/16-P and 3/16-L was determined in the field conditions, and that from Well 3/17 was determined using the areometric method (a hydrometer test) and a sieve under laboratory conditions. All the wells were drilled with a drill sample extracted, to determine the water content of the deposits with a thermostat-balance method.

### Thermometric monitoring

To study the temperature regime of the deposits, thermistors were used with Onset HOBO U12 logger (Wells 3/16-P, 3/16-L) and Maxim Integrated DL18B20 logger (Well 3/17). The accuracy of temperature measurements with Onset thermistors was  $\pm 0.25$  °C in the temperature range of 0–50 °C and  $\pm 0.5$  °C at –20 °C. P.Ya. Konstantinov *et al.* [2011] showed that the thermistor error did not normally exceed  $\pm 0.1$  °C. The temperature sensors were installed at the depths of 0.5, 1, 3 and 6 m in Well 3/16-P and 0.5, 1, 2 and 3 m in Well 3/16-L, with the records done every 3 hours. Well 3/17 was equipped with a thermistor chain having 26 calibrated temperature sensors located at the depths up to 5 m spaced at intervals of 0.5 m, and at the depth from 5 to 20 m – spaced at intervals of 1 m. The accuracy of temperature measurement with thermistors DL18B20 was  $\pm 0.5$  °C within the temperature range of –10...+85 °C. One temperature measurement was carried out on April 27, 2017, three weeks after drilling.

The temperature and water content of the air, the amount of liquid precipitation, the wind velocity and atmospheric pressure were registered every hour with the automated HOBO Microstation installed 2.5 km from the wells (Fig. 1). The accuracy of temperature measurement was  $\pm 0.2$  °C in the temperature range of 0–50 °C,  $\pm 0.5$  °C at –20 °C and  $\pm 1.1$  °C at –40 °C.

### Geophysical methods

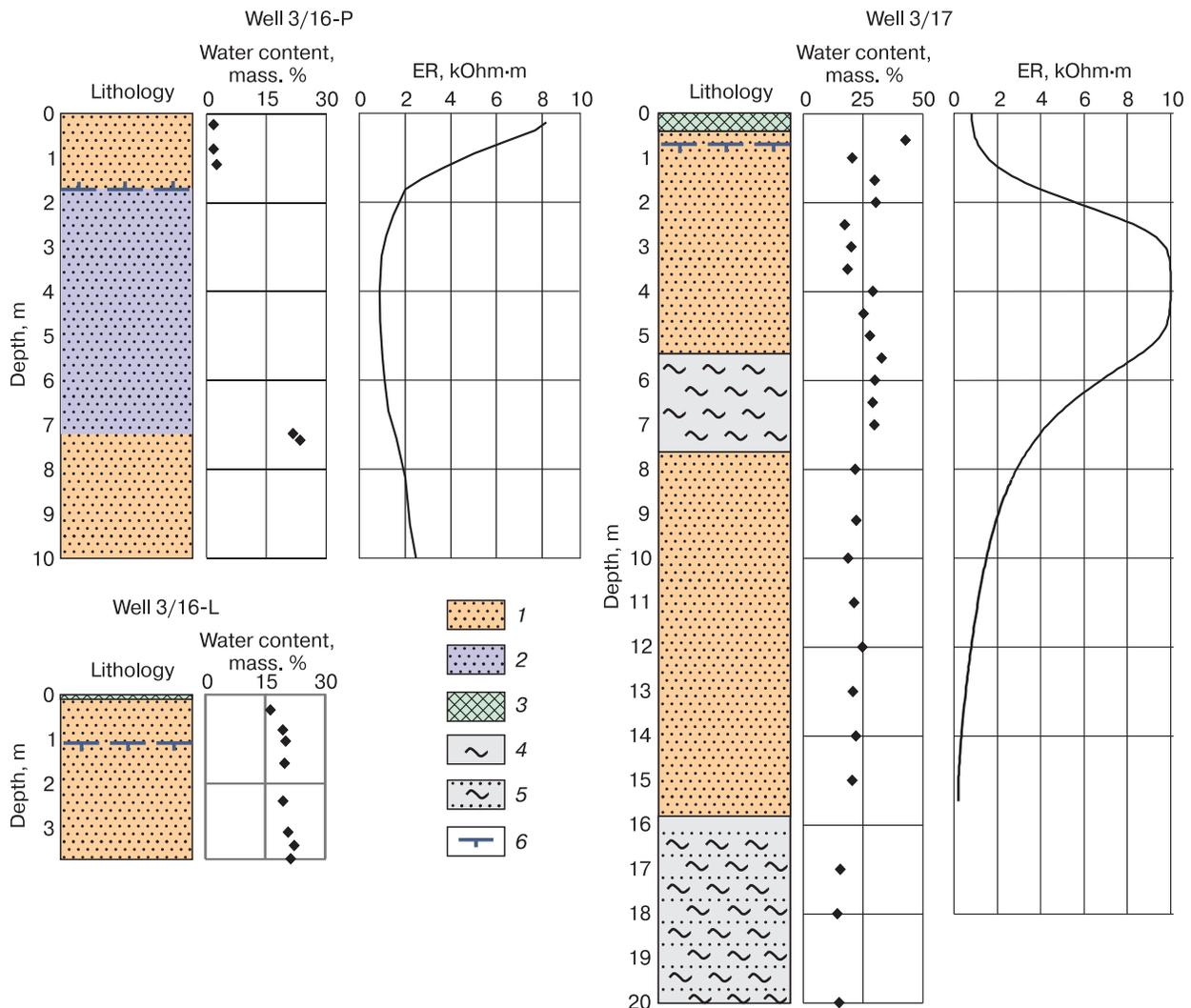
The geophysical works were conducted in the area under study in the upper reaches of the Levaya

Shestakovka River using a ground penetrating radar and electrical resistivity tomography. Availability of hydrogeological wells allowed us to specify the value of electrical resistivity of the medium in question to ensure more precise processing of the geophysical materials. Geophysical integration using the above methods proved to provide good results in geophysical permafrost studies in the permafrost regions [Olenchenko and Shein, 2012; Olenchenko et al., 2017; You et al., 2017].

The radar works were performed with the OKO-2 ground penetrating radar (OOO LogiS, Russia), with an aerial module AB-250 (the central frequency 250 MHz) attached. The radar survey was conducted in the northwest-southeast profile, covering the distance of about 300 m (Fig. 1, profile I) in April, in the period of maximum freezing of the ground. The following scanning parameters were applied to the study of the area in question: scanning 200 ns; dielectric

permeability 6; and continuous data recording. Measurements were made in close contact with the surface of the medium under study. To process and interpret the field data, the GeoScan32 software (OOO LogiS, Russia) was used.

To determine electrical resistivity (ER) of the deposits, we used a multi-channel multi-electrode station *Skala-64* manufactured by *KB Electrometry*, Novosibirsk. The station has 64 electrodes and 16 measurement channels. The obtained data were processed with the *ZonRes2D* software [Shevnin and Bovachev, 2013]. The measurements were made for Profiles II и III (Fig. 1). Profile II was passed on August 18, 2016, across the Levaya Shestakovka River in the NW–SE direction and was 955 m long, spaced at the interval of 5 m. Profile III 255 m long was covered, spaced at the interval of 1 m, on July 8, 2016 in parallel with the Shestakovka River 300 m from the bank in the NE–SW direction (Fig. 1). To



**Fig. 2. Cross sections of Wells 3/16-P, 3/16-L, 3/17.**

1 – fine and medium-grained frozen sand; 2 – fine and medium-grained thawed water-saturated sand; 3 – organic horizon; 4 – frozen silty sandy loam; 5 – interbedding of frozen sandy loam, loam, and sand; 6 – the lower boundary of AL/SFL.

make measurements, we used protocols made for a dipole doublet and for a 4-electrode Schlumberger array. In accordance with the Construction Regulations SP-11-105-97-VI [2004] (Exhibit G), the value of electrical resistivity dividing thawed and frozen sands is within 1000–2500 Ohm·m. Dry thawed sands are characterized by similar electric resistivity values. Water-saturated thawed sands are characterized by similar electric resistivity values. Given water salinity 0.1–0.3 g/dm<sup>3</sup>, water-saturated thawed sands have resistivity 100 Ohm·m and lower. When comparing the drilling and electrical resistivity data, we assumed water-saturated thawed sands to have electrical resistivity 2000 Ohm·m and less (Fig. 2). The relatively high values of ER are related to reduced salinity of the talik's ground waters (0.02–0.04 g/dm<sup>3</sup>) and a high-resistance screening horizon from the surface of the dry sands. Deposits with ER exceeding 2000 Ohm·m were considered to be frozen. Deposits with ER equal to about 2000 Ohm·m in the upper part of the cross section were interpreted as thawed and dry sands at the time of conducting the works.

## STUDY RESULTS

### The results of drilling

The lithological columns, the water content in three drilled wells and the ER values for two of them are shown in Fig. 2. Drilling of Well 3/16-P revealed sparse soil cover, which is a bed of pine needles and a growth of bearberry (*Arctostaphylos uva-ursi*). Across the entire cross section, yellow-gray medium sands were revealed with signs of ferrugination and with rare inclusions of organic matter. At the depths from the ground surface to 1.7 m and from 7.2 to 10 m, the sands were frozen. A water-saturated talik was found at the depth from 1.7 to 7.2 m. The total ice content of the sands from the seasonally frozen layer varied from 2 to 4 %. The total water capacity of the sandy deposits in the talik exceeded 30 %. The ice content of the underlying frozen deposits was equal to 33–35 %. In the area of drilling Well 3/16-L, the soil cover dense (thickness 5–10 cm) and was represented by mosses, lichens, and small shrubs. Throughout the depth of 3.7 m, the well revealed frozen sandy deposits of medium composition with organic remains. The ice content of the deposits varied from 26 to 36 %.

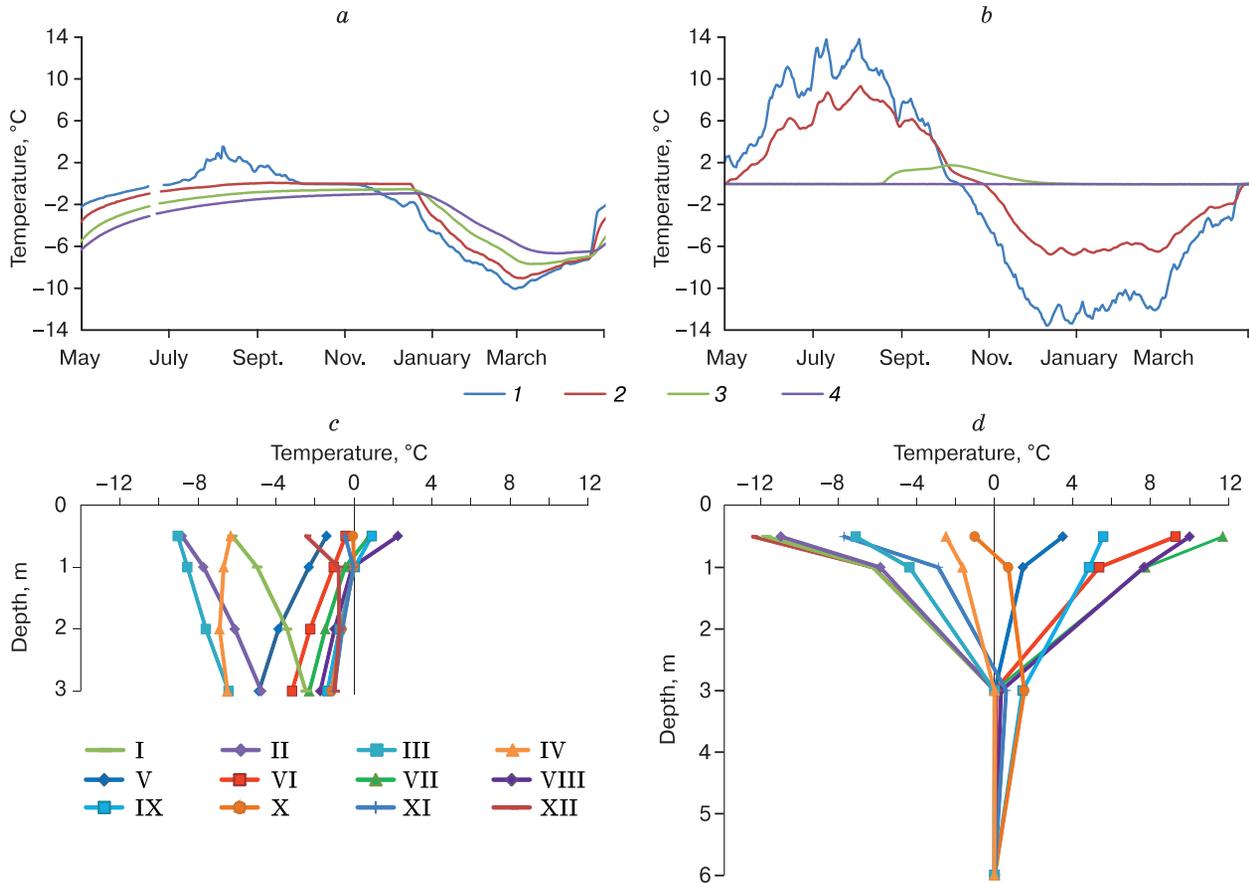
Well 3/17 revealed peat from the soil surface to the depth of 0.4 m, fine and medium-grained sands in the range of depths 0.4–5.4 m, fine sandy silt at the depths of 5.4–7.6 m, fine sand in the range of depths 7.6–15.8 m and interbedded sandy loam, loam and sand at the depths of 15.8–20 m. The deposits were frozen across the entire cross section. Their ice content varied from 14 to 35 %. The maximum ice content of 42 % is associated with the vegetated deposits in the upper part of the cross section.

### The temperature regime of the deposits

The data of the annual cycle of thermometric monitoring performed in the area of pine forest in Well 3/16-P in the period from 01.05.2016 to 30.04.2017 supported the existence of a talik at the depths of 3–6 m. The mean temperature of the deposits in the monitoring period was negative only at the depth of 0.5 m (–1.1 °C), and at the depths of 1, 3 and 6 m, it was 0, 0.3 and 0 °C respectively. The thickness of the seasonally frozen layer according to the drilling was 1.7 m (Fig. 3).

Transition of the mean daily air temperature beyond 0 °C towards positive values was recorded on April 17, after which snow melted fast. Thawing of the deposits from above started in late April. The maximum mean daily ground temperature at the depths of 0.5 and 1 m was 14.0 and 9.4 °C on July 10 and on August 3, respectively (Fig. 3). Before August 18, the ground temperature at the depth of 3 m was 0 °C. Further on, before October 6, the temperature of the deposits grew to 1.8 °C at this depth. Transition of the mean daily air temperature beyond 0 °C towards negative values was recorded on September 25. The seasonally frozen layer began to be formed on the first days of October. The minimum temperature of the deposits at the depths of 0.5 and 1 m was –13.5 and –6.7 °C on December 11 and 29, respectively. The temperature of the deposits at the depths of 3 and 6 m was around 0 °C throughout the entire cold season. The deposit temperature variation in the aeration zone at the depth of 0.5 m exceeded 27 °C, and that at the depth of 1 m was about 16 °C. In the upper part of the water-bearing horizon (the depth of 3 m from the daylight surface), the amplitude of the temperature variation was 1.8 °C throughout the year, with the mean value of 0.3 °C, whereas its lower part (6 m) had constant temperature close to 0 °C.

In the area of the larch forest, the monitoring data obtained from Well 3/16-L showed the mean annual temperature of the deposits across the entire cross section to be negative and varied from –2.6 to –3.0 °C at the depths from 0.5 to 3.0 m. The thawing rate of the deposits there was much lower. The 0 °C isotherm reached the depth of 0.5 m on July 4. The maximum temperature at that depth equal to 4.0 °C was recorded on August 7. 1 m deep from the earth surface, the deposit temperature exceeded 0 °C on August 26, to reach the maximum value of 0.1 °C on September 9–10. Minimum temperature values of the deposits at the depths of 0.5 and 1.0 m were observed on February 26 and March 5, 2017 and were –10.1 and –9.1 °C, respectively. The temperature of the deposits at the depths of 2 and 3 m remained negative throughout the entire monitoring period, reaching the maximum values of –0.6 and –1.0 °C and the minimum values of –7.7 and –6.7 °C, respectively (Fig. 3). The amplitude of the temperature variation



**Fig. 3. The time course of the deposits' temperature at different depths (a, b) and the temperature curves for May 2016 – April 2017 (c, d).**

a, c – Well 3/16-L; b, d – Well 3/16-P. Depths: 1 – 0.5 m, 2 – 1.0 m, 3 – 2.0 m, 4 – 3.0 m (Well 3/16-L) and 6.0 m (Well 3/16-P); I–XII – month number.

throughout the year accordingly decreased from 14 °C at the depth of 0.5 m to 5.8 °C at the depth of 3 m. The depth of the seasonal frozen layer was a little over 1 m.

Given the same weather background and the similar granulometric composition of the deposits, the mean temperature of the deposits in the monitoring year was higher in the pine forest than in the larch forest. The difference rose from 1.5 °C at the depth of 0.5 m to 3.3 °C at the depth of 3 m. The maximum temperatures of the deposits at the depth of 0.5 m in the larch forest were 10 °C lower than those in the pine forest. At the depth of 1 m, the difference was more than 9 °C. Greater annual variability of the deposits' temperatures is characteristic of the aeration zone of the pine forest than of the upper layer of the deposits in the larch forest. The difference of the amplitudes of the annual variations in the deposits' temperatures between the forest and larch forests at the depth of 0.5 m was 13.4 °C and 7.0 °C at the depth of 1 m. According to *S.P. Varlamov et al.* [2017], who worked at the Chabyda station of the Melnikov Per-

mafrost Institute SB RAS, the deposits' temperature in the layer of the annual temperature fluctuations (10–20 m) in the pine forest in the absence of a talik was higher than in the larch forest by 0.2–2.3 °C. The water-saturated deposits with the constant temperature of around 0 °C throughout a year resulted in small (less than 6 m) thickness of the layer of annual temperature fluctuations in the area of suprapermafrost subaerial taliks.

The character of the relation between daily temperatures of the deposits and the air temperature in two landscapes in questions varies considerably. Table 1 contains maximum correlation coefficients (CC) of the deposits' temperatures at different depths with the air temperature, for which a time shift was recorded. The deposits' temperature at the depth of 0.5 m in the pine forest had the maximum CC (equal to 0.96) with the air temperature recorded 5 days before. The deposits' temperature in the larch forest is characterized by the maximum CC (equal to 0.95) with the air temperature recorded 53 days before. The deposits' temperature at the depth of 1 m in the

Table 1. Maximum correlation coefficients (CC) of the deposits' temperature in the larch and pine forests with the air temperature (with time shift)

Depth, m (larch/pine forest)	Maximum CC		Time shift, days	
	Larch forest	Pine forest	Larch forest	Pine forest
0.5	0.95	0.96	53	5
1.0	0.92	0.94	67	16
2.0/3.0	0.95	0.67	92	86
3.0/6.0	0.97	–	102	–

pine forest had the maximum CC (equal to 0.94) with the air temperature recorded 16 days before, and in the larch forest, the maximum CC was equal to 0.92, with the air temperature recorded 67 days before. The deposits' temperature at low depths in the pine forest was characterized by a lower CC with the air temperature, while in the larch forest, the value of CC remained high up at the depth of 3 m and higher. The temperature of water-saturated deposits at the base of the talik in the pine forest at the depth of 6 m was close to zero throughout the year and had no relation to the air temperature. The deposits' temperature in the aeration zone of the water-bearing talik had direct close connection with the air temperature, whereas in the frozen deposits under the larch forest, it took nearly two months for the air temperature fluctuations to penetrate the ground to the depth of 0.5 m and about three months for them to reach the depth of 2 m. The main causes of different breakdown of the deposits' temperatures in the pine and larch forests are the contrasting water regime of the deposits and the presence of a thick vegetation cover in the larch forest.

In the valley of the Levaya Shestakovka River, in the area of Well 3/17 in late April, the deposits' temperature dropped from  $-4.7^{\circ}\text{C}$  at the depth of 0.5 m to  $-11.8^{\circ}\text{C}$  at the depth of 3.5 m and then rose to  $-3.3^{\circ}\text{C}$  at the depth of 20 m. The temperature of  $+0.5^{\circ}\text{C}$  was recorded on the ground surface.

#### The level and the chemical composition of ground waters

The processes of freezing and thawing affected the hydrodynamic regime of the talik's ground waters. The behavior of the water level in Well 3/16-P and of precipitation in the warm season of 2016 is shown in Fig. 4. The ground water level approached the Earth's surface most closely (1 m) in April. The height of the permafrost at the time was 0.7 m. The Earth's surface near Well 3/16-P was approximately 5 m higher than the edge of the terrace of the Shestakovka River, where icing was discovered. According to the monitoring data of 2016, the level of the talik waters was higher than the terrace edge. According to the visual observations of 2017–2018, icing began to be formed, to grow fast in December. At that time,

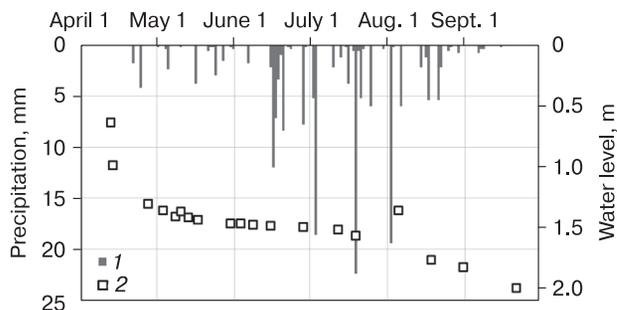


Fig. 4. Behavior of precipitation (1) and of the water level in Well 3/16-P (2) in the warm season of 2016.

the ground water reached the Earth's surface, saturated the snow cover and got frozen. By the beginning of February, formation of icing completed. In the warm period of 2016, the level of the ground water in the process of thawing of the seasonally frozen layer got reduced and got established at the depth of 2 m at the end of September. Water salinity in the talik throughout the year of 2016 varied from 24 to  $36\text{ mg/dm}^3$ . This variation is mainly related to the change in the concentrations of calcium and magnesium bicarbonates, which depend on the presence of the carbonic acid. The maximum values of salinization were recorded in June and in July, when intense thawing of the seasonally frozen layer took place, but a layer of the deposits frozen during winter remained under the talik.

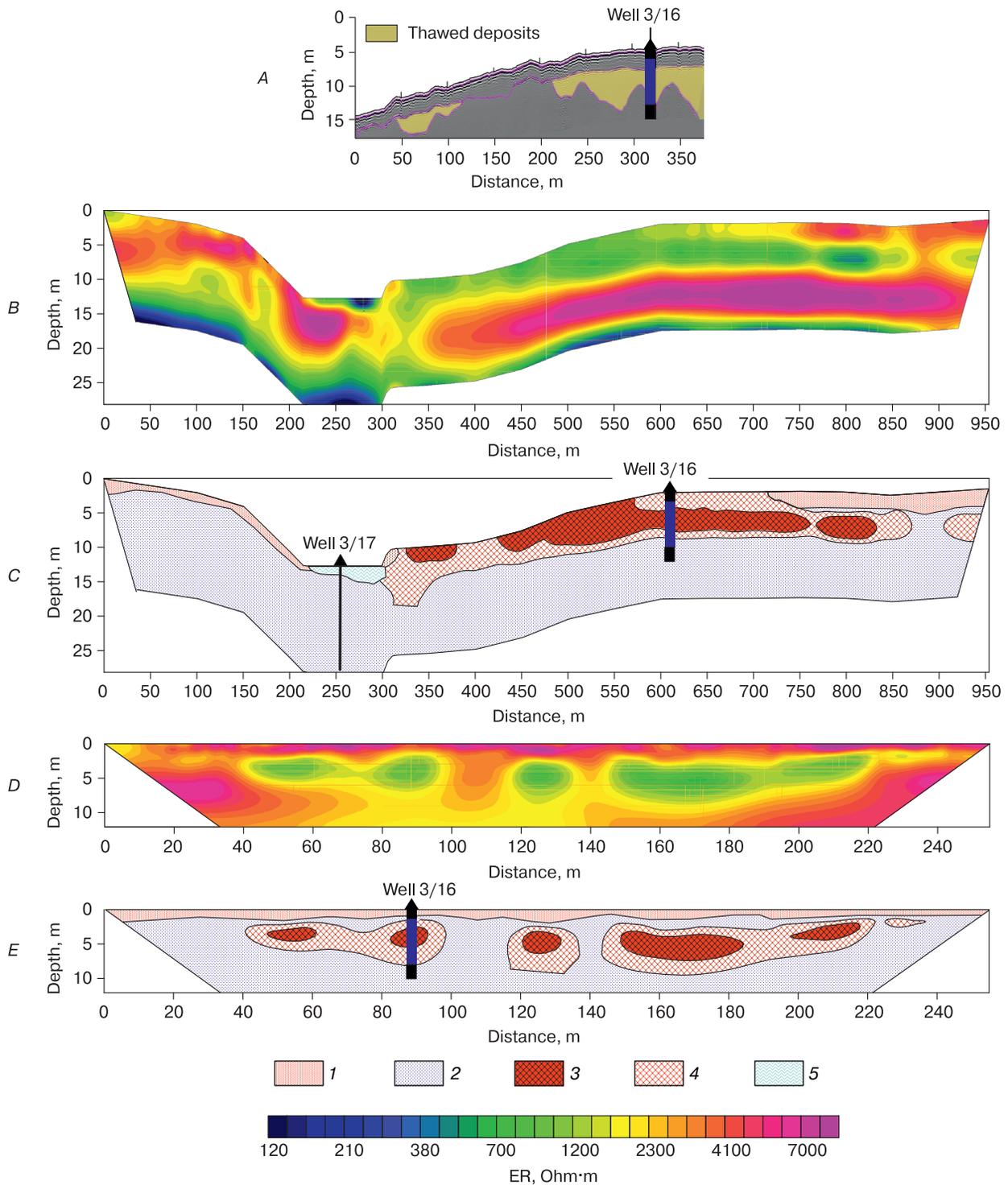
#### Geophysical studies

The radar studies showed that in April 2016 there were at least two presumably separated thawed zones (Fig. 5, A). One of them was found near the terrace edge of the Shestakovka River and was 50 m long. The second talik zone was discovered near the top of the upland 160 m from the terrace edge and was about 170 m long. The table of the revealed taliks was even enough, and the depth of its bedding coincided with the thickness of the seasonal thawing (freezing) layer, which was equal to 2–4 m. The taliks' thickness from 8 m in the upland reduced to 3 m in the direction of the valley of the Levaya Shestakovka River.

In accordance with the geoelectric resistivity section for Profile II (Fig. 5, B, C), the upper layer of the dry sandy deposits about 2 m thick corresponds to the active layer and to the seasonally frozen layer. The electric resistivity of the deposits of this thickness and lower is 2000–10 000 Ohm·m. Frozen sandy deposits underly the active layer of the permafrost on the left bank of the Levaya Shestakovka River. We attribute the regions of reduced resistivity at the depth of 10 m to a change in the lithological composition of the frozen deposits. On the right bank of the river, from the edge of the terrace to the end of

the profile, a talik is identified with ER less than 2000 Ohm·m, about 650 m long. The talik's thickness varies from 3 to 7 m. By the time of the geophysical

studies, the seasonally frozen layer above the talik had completely thawed. In the upper part of the gentle right slope, 400–630 m from the terrace edge, the



**Fig. 5.** The radar section for Profile I (A), electrical resistivity (B) and geophysical permafrost (C) sections for Profile II, electrical resistivity (D) and geophysical permafrost (E) sections for Profile III.

Profiles I and II passed close to each other and are superimposed on the horizontal axis. 1 – AL/SFL (ER 2000–9000 Ohm·m); 2 – frozen deposits (ER 2500–10 000 Ohm·m); 3 – thawed deposits (ER <1000 Ohm·m); 4 – thawed deposits (1000 Ohm·m < ER < 2000 Ohm·m); 5 – AL under the river bed (ER 50–100 Ohm·m).

seasonally frozen layer was characterized by the low water content and the electric resistivity values of 2000–10 000 Ohm·m, respectively. The talik is underlain by frozen deposits with ER varying from 2000 to 10 000 Ohm·m. The regions identified in the section having electric resistivity of less than 1000 Ohm·m presumably correspond to the zones of intense water filtration and ferrugination of the sands. Under the bed of the Levaya Shestakovka River, in which the water depth was about 1 m at the time of conducting electric tomographic studies, the thickness of the layer of seasonal melting was 2.5 m.

The electrical resistivity section for Profile III (Fig. 5, *D, E*) revealed a talik in the range of depths 2–10 m. The talik was separated into several fragments of water-saturated deposits, oriented in the NW–SE direction down the slope, with maximum thickness values equal to 5.8–6.5 m. Previously, A.V. Boitsov, who worked at the Chabyda station of the Melnikov Permafrost Institute SB RAS, revealed the presence of such thawed water-conducting channels, in which filtration of supra-permafrost waters takes place [Shepelev *et al.*, 2002].

The configuration of the thawed zone obtained by different geophysical methods from closely located profiles was similar and agreed with the information on the characteristics of the geological section obtained by drilling Well 3/16-P. The measurements from all the sections showed the talik thickness near the well to be about 7 m. Certain differences are explained by different resolution values of the electrical resistance tomography with differently spaced electrodes and also by carrying out the works in different seasons of the year. Good agreement of the data confirms the perspective of using geophysical methods for searching for taliks.

Suprapermafrost taliks are associated with the gentle sparsely vegetated slope covered with sparse pine forest. The width of the zone of the thawed water channels is 180–200 m, its length along the slope is about 500 m. In the winter period, deposits seem to be partly frozen, so that the movement of the pore water proceeds in separate zones, which can be seen from the results of ground-penetrating radar studies in Profile I (Fig. 5, *A*).

#### The origin of taliks

Following contouring of the thawed zones by geophysical works, it was revealed that the suprapermafrost water of the subaerial talik on the right bank of the Levaya Shestakovka River are connected with the river channel in the summer period. In winter, as deposits get frozen from the Earth's surface, suprapermafrost ground water is exposed to permafrost pressure. In December and January, icing is formed on the slope of the river terrace, which becomes completely melted by the end of May.

The results of the electrical resistivity tomography carried out on both banks of the river showed the

presence of a talik on the slope of the north-western exposure and its absence of the slope of the south-eastern exposure. This indicates the influence of secondary importance of the slope aspect on formation of suprapermafrost subaerial taliks under conditions of Central Yakutia.

There are several hypotheses of talik formation in the continuous permafrost zone of Central Yakutia. According to one of them, summer precipitation penetrating into sandy ground brought additional heat to form a talik. According to another hypothesis, repeated excess of the summer water content over the winter one results in the increase of the heat conductivity of the deposits and in their more intense warming in the summer period, compared to their cooling in winter [Boitsov and Lebedeva, 1989; Shender *et al.*, 1996]. The processes of condensation of the water vapor in sandy deposits may serve as a source of additional heat [Shepelev, 1980]. In 2013–2014, L.A. Gagarin [2015] discovered a residual thaw layer in the sandy deposits of the right bank of the Lena River, which became formed during several consecutive moist and snow-abundant years, suggesting the possibly dominant role of meteorological and climatic factors in the formation of thawed zones. A.V. Boitsov [2015] notes the current freezing of the Chabyda talik, caused by revival of the vegetation destroyed by the fire in the early 1960s.

The data obtained during the study do not allow us to make a definite conclusion regarding the origin of the talik in question. Regime monitoring of the deposits' temperature and of the level of the ground water is required, which would encompass the modern period of the air temperature rise, in order to ascertain the possible causes of formation and evolution of taliks in Central Yakutia.

#### CONCLUSIONS

The landscapes of the larch and pine forests in the basin of the Shestakovka River in Central Yakutia are characterized by contrasting hydrogeological permafrost conditions. The mean temperature of the deposits over the year of measurements was found to be higher in the pine forest than in the larch forest by 1.5 °C at the depth of 0.5 m and by 3.3 °C at the depth of 3 m. In the area of a sparse pine forest, a suprapermafrost ground-filtrating water-bearing talik of a radiative-thermal type was discovered. The temperature of the water-saturated deposits at the talik base proved to be close to zero throughout the year. The temperature of the deposits in the aeration zone has close connection with the air temperature. It takes the frozen deposits in the larch forest two months for the air temperature fluctuations to penetrate the ground to the depth of 0.5 m and three months, to the depth of 2 m. The geophysical studies revealed that the talik was separated into several thawed water-bearing channels, oriented along the gentle slope of

the terrace of the Levaya Shestakovka River. The width of the talik zone was 180–200 m, its length was over 500 m. The configuration of the thawed zone obtained by the electrical resistivity tomography and a ground-penetrating radar from closely located profiles in different seasons of the year was similar and agreed with the information obtained by drilling. This confirms the perspective of using geophysical methods of research for searching for taliks. To understand the mechanisms of talik formation in Central Yakutia, prolonged regime monitoring over the deposits' temperature and the level of ground water under conditions of modern air temperature rise is required, as well as further studies of the geometry of thawed zones and of its temporal variability.

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