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3-D structure of the discharging zone of the Daginsky hydrothermal system (Sakhalin Island) according to the ground penetrating radar method and well logs

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Abstract. The paper presents the results of a comprehensive analysis of GPR data and geophysical well survey data (gamma-ray logging and self-polarization potentials) to study the 3-D spatial structure of the Daginsky hydrothermal system discharging zone (Sakhalin Island) and its hydrogeological situation. According to the GPR method, the paleo-valleys were identified, the morphology of which indicates the presence of runoff hollows, the accumulation of sandy-aleurite-clay sediments covered with peat formations. It can be concluded that the caprock in this area consists of a pack of water layers and permeable zones. Based on the data of geophysical studies in wells, three zones can be distinguished, each of which is characterized by the corresponding values of gamma activity and changes in the potentials of its own polarization. All this helps in identifying permeable thermally conductive zones. The data obtained are of practical importance.

1. Introduction

The object of research is the Daginskaya hydrothermal system, which is located in the Nogliksky district of the Sakhalin region on the eastern coast of the northern part of the Sakhalin Island . The subject of research is the discharge zone of the Daginsky hydrothermal system. The purpose of the study is the spatial structure of the discharge zone and its hydrogeological setting. The objectives of the research include:

1. A detailed study of the structure of the upper stratum of the Daginsky hydrothermal system using such a modern geophysical method, such as GPR. A modern GPR survey within the Daginsky field has been carried out for the first time, the information content of the results of GPR measurements is high, as it allows us to judge layered structures, geological heterogeneities, albeit at shallow depths.

2. Processing of geophysical well survey data (gamma-ray logging and self-polarization potentials).

The Daginsky thermal springs are used for balneological purposes, landscaping and construction of a tourist-recreational complex are planned, additional wells are planned to be drilled, therefore the results obtained are of practical importance.

2. Research methods

The GPR method was performed using the OKO–150 georadar (center frequency 150 MHz, sounding depth 12 m, resolution 0.35 m). It is completed 9 profiles. On the territory of Daginsky hydrothermal system, where the surface is uneven, the presence of forest cover, does not allow for measurements on even main and orthogonal profiles. Therefore, measurements were carried out on profiles unrelated to each other, starting from the features of the terrain.

Available logging data (gamma-ray logging, self-polarization potentials) for five wells were used as data from geophysical studies of wells [3]. All logs were available only on paper. Digitization was performed using a modern computer program. For convenience, the data were exported to the XLS format, which allowed for further calculations and processing. Gamma-logging is based on measuring the natural gamma activity of rocks, and helps in detailed geological interpretation. Advantage: gamma-activity is determined only by the radioactivity of rocks and does not depend on other factors (temperature and mineralization, humidity, etc.). The method of self-polarization potentials is one of the most common methods of electrical logging. According to the level of geological tasks and ease of execution, it is an essential part of geophysical surveys in wells. The method is reduced to the measurement of constant natural potentials arising from formations with different electrochemical activity. The method helps in identifying areas of inflow and outflow of fluid.

Thus, the GPR data help to study in detail the surface of the hydrothermal system unloading zone, identify fracture zones and faults, gamma-logging data – a detailed internal geological structure in the area of the wells, and data on the self-polarization potential method – can help determine the inflow and outflow of fluid. Together, these methods will help in understanding the spatial structure of the discharge zone of the Daginsky hydrothermal system.

3. Research results and discussion

According to the chemical composition, the thermomineral waters of the Daginsky hydrothermal system are sodium chloride. The temperature of the springs and wells on the spout is 25–55 °C, pH 7–8, mineralization from 1.2 to 9 g/l. The temperature and mineralization of the springs depend on the degree of dilution by cold groundwater and surface water (the northern group is sea water; the central and southern groups are marsh water) [1, 2].

The discharging of thermal waters in the Daginsky hydrothermal system is observed at the sites where the zone of rupture disruption has been opened by erosional incisions. The first discharge center (South section: springs 17–19 in Figure 1) 40–80 m wide is located in the southwestern part of the study area. Springs of thermal waters come out in a small valley of a stream, mainly in its bed composed of fine-grained sand. The second group exit of ascending springs (Central section: springs 7–16 in Figure 1) extends from southwest to northeast in the form of a strip 60–150 m wide. Springs are located in a marshy lowland that is densely covered with reed. Outputs are concentrated in the funnels of various sizes in dense clay soil, unloading is carried out in the swamp. Springs of the northeastern part (North section: springs 2–6 in Figure 1) Are discharged within the littoral zone of the Nyisky Bay covered with clayey silt and the tide is filled with sea waters. Springs fill funnel-shaped boilers with a diameter of up to 3 m and a depth of more than 1 m. Small mud griffins can also be found here. Quaternary and Pliocene sediments are widespread. The predominant type is a pore collector. Peatlands, sands, rarely gravels among poorly permeable clay rocks are water-bearing. Only at depths greater than 1000 m are lithified sediments with fissure and fissure-vein type of reservoir - sandstones, siltstones, mudstones, opened by exploratory drilling.

The morphology of buried paleo-valley established by GPR studies (noted at a depth of about 6 m) indicates the presence of runoff depressions, accumulation of sandy-aleurite-clay sediments everywhere covered by peat formations up to 2 m thick closer to the coast [2]. It stands out throughout the dense clay soil up to 2 m, which obviously creates a layer of rocks with low permeability. It overlaps permeable rocks represented by sands of different composition. This layer can serve as a barrier to the circulation of convective coolant flows, as well as a heat insulator, contributing to an increase in temperature in the hydrothermal system. In the central area managed to fix the crushing zone. It is possible, it is included in a series of thermally-induced faults, intersecting with several flat permeable zones, and is included in the system of faults of meridional and sublatitudinal stretch characteristic of this territory and constituting a mosaic of tectonic blocks. It can be concluded that the caprock in this area consists of a pack of water layers and permeable zones.

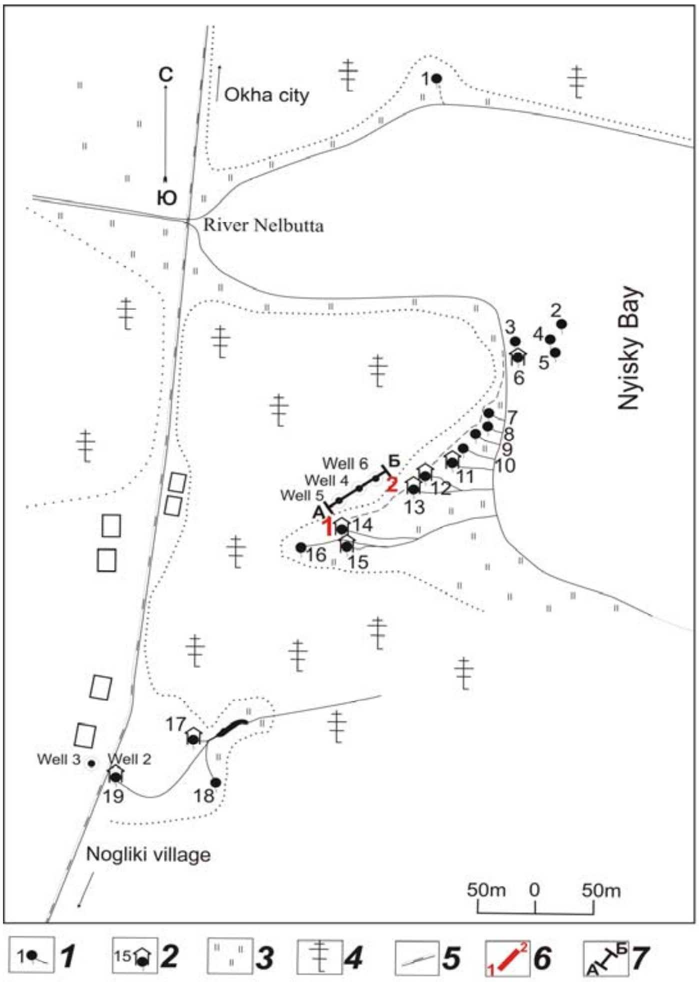


Figure 1. Diagram of Daginsky thermal springs. 1 – springs of thermal waters and their number on the diagram; 2 – a thermal spring with an under construction installation and its number; 3 – wetlands with sedge thickets; 4 – larch forest; 5 – mound of the former railway; 6 – GPR profile (numbers indicate the beginning and end of the profile); 7 – hydrogeological section.

The results of GPR surveys are in good agreement with the real supporting hydrogeological sections of the territory, which confirms the success of the application of this non-destructive testing method to obtain reliable data on the hydrogeological setting of the study area (Figure 2). This work seems to be useful, since it can to some extent be a reference for other areas with a similar geological structure. The obtained GPR data allow to clarify the most suitable areas for the future non-capital construction of a recreational and tourist complex based on Daginsky thermal springs. According to the authors, such construction is possible on the territory west of the Central group of springs and north of the Southern group of springs, in areas where the lowest peat thickness and paleo-valley surfaces (with relatively stable soils) are located closer to the day surface [2].

Based on the analysis of gamma-ray logging for wells 2, 3, 4, 5 and 6, three zones can be distinguished. The first zone is the presence of the highest values of gamma-activity of rocks in the area of wells 5 and 4 from 5.00 to 17.00 mkR/h (Figure 3). The second zone is located near wells 5 and 4 and well 6 is located (Figure 3). This indicates the leaching of radioactive components in rocks. The third zone is in the area of wells 3 and 2, the values of gamma activity from 4.00 to 13.00 mkR/h (Figure 4). There is a good match between the lithological layers in wells 3 and 2. It is worth noting that an error was found in the available data on the lithological section of well 2. The thickness of layer 15 was incorrectly calculated. The thickness of layer 15 was indicated at 18.4 m, in fact it was 18.6. This is an important addition, because when calculating the arithmetic mean value of gamma-activity of rocks, where the thickness of the layer is taken into account, it matters.

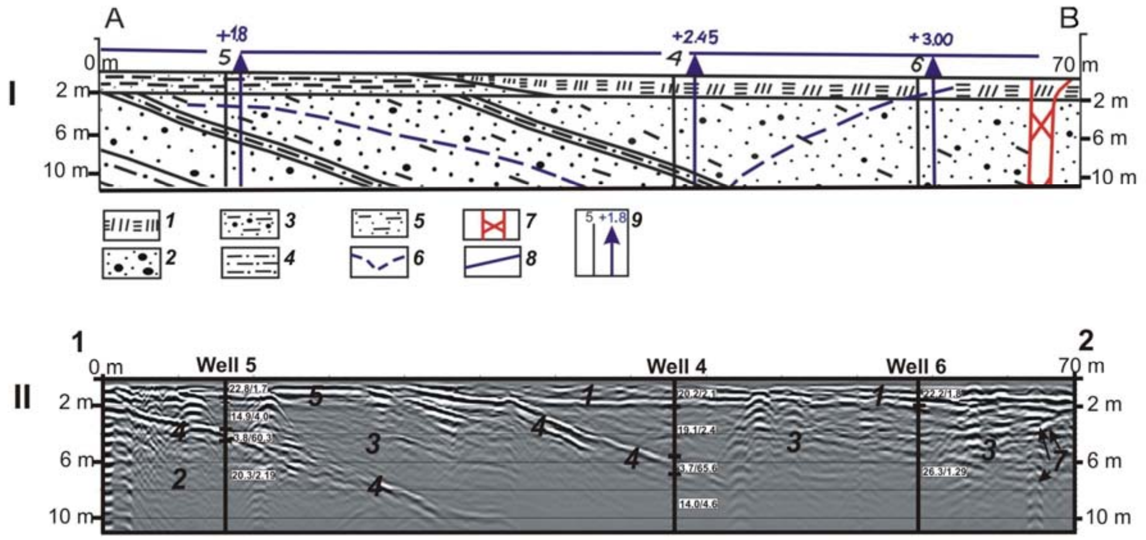


Figure 2. Comparison of the hydrogeological section A–B (I) with the GPR (II) profile 1–2 [2]. Above - hydrogeological section A–B in wells 5, 4, 6 (the numbers above the arrow indicate the steady pressure level from the surface: +18, +2.45 and 3.00 m, respectively). 1 - peat; 2 - sand with gravel and pebbles; 3 - clayey sand with gravel and pebbles; 4 - silt; 5 - clayey, aleuritic, aleurite-clay sands; 6 - depression curve during pilot pumping (it has an asymmetrical appearance due to the presence of a feed fault zone, from which the pressure spreads to the southeast at 100 m, to the northwest (at the rise of the layers) at 300–350 m) 7 - crushing zone; 8 - piezometric level. Below - GPR profile 1–2. Numbers 1, 2, 3, 4, 5, 7 correspond to the symbols for the hydrogeological section A–B for wells.

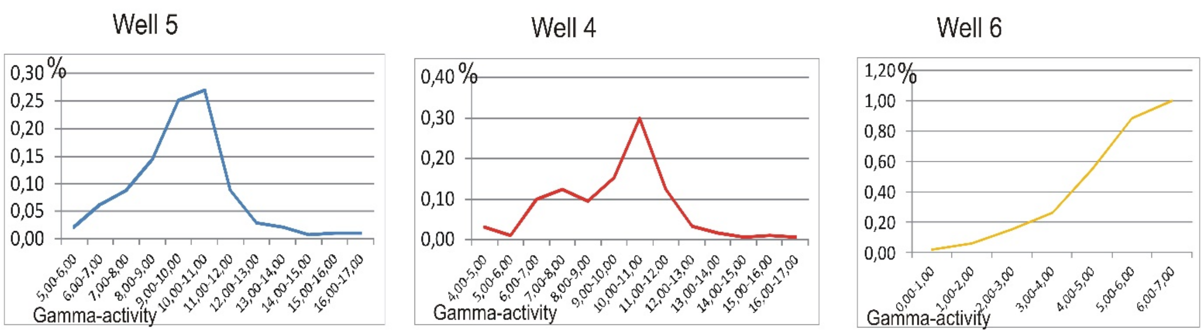


Figure 3. Graphs of the distribution of gamma-activity on the profile of 5-4-6.

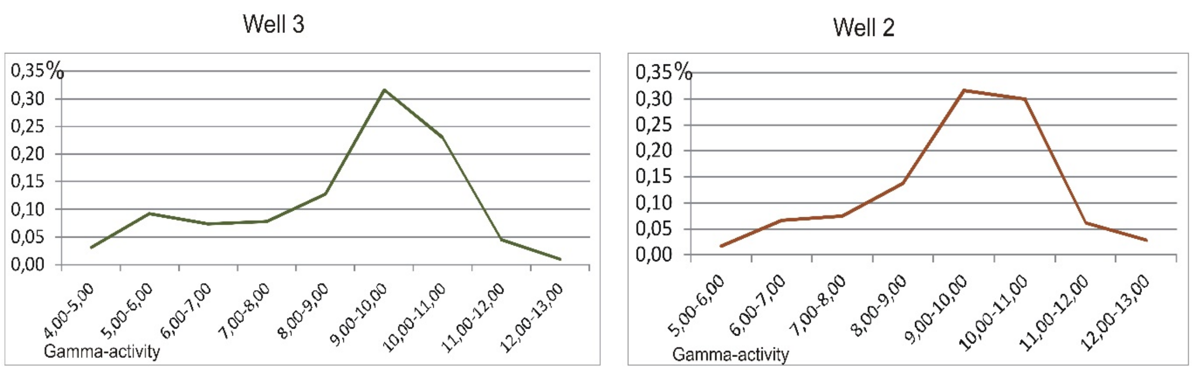
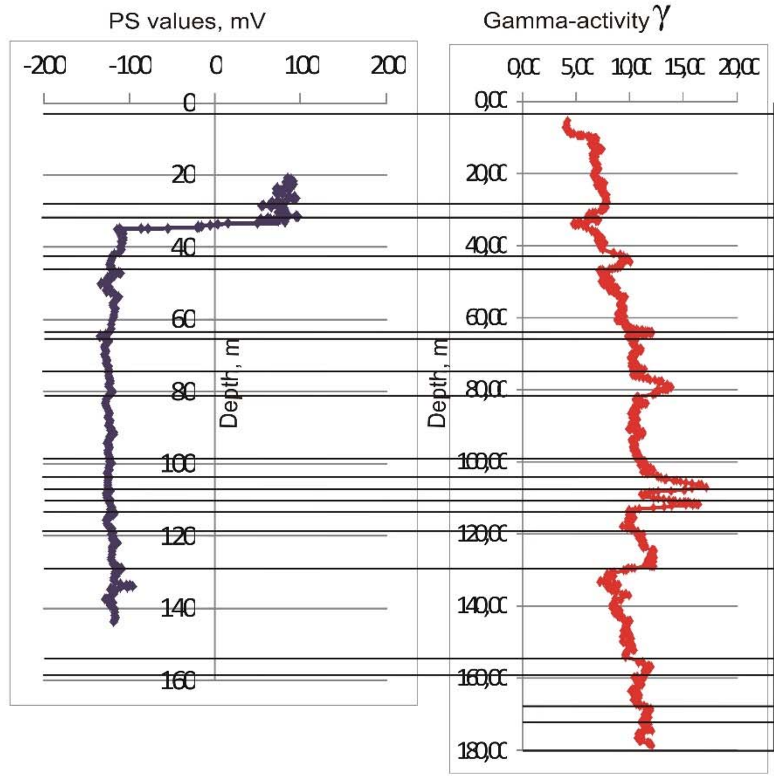


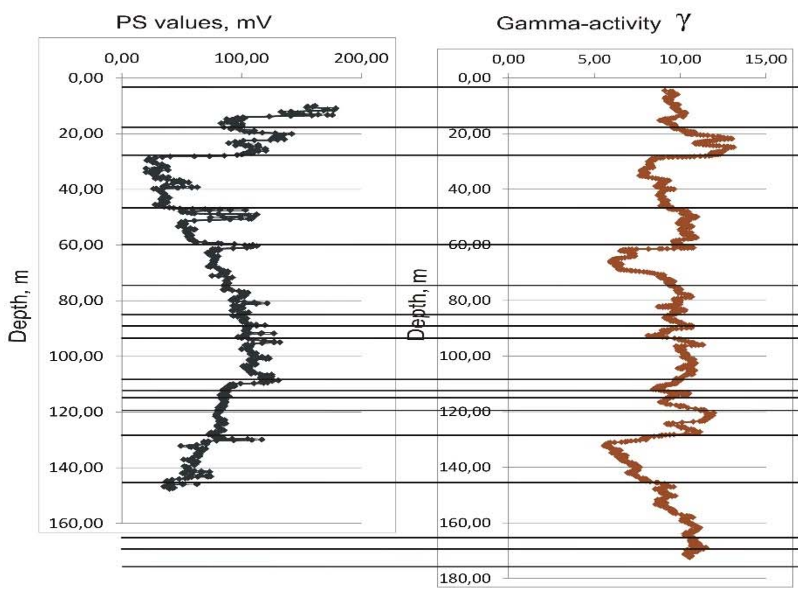
Figure 4. Graphs of the distribution of gamma-activity on the profile of 3-2.

According to the data of self-polarization potentials in the first zone (well 4) up to a depth of 40 m, only positive PS values are observed (from +3 to +95 mV), then only negative PS values are observed (up to -128 mV) (Figure 5). Negative values are probably due to the flow of fluid into the reservoir, which explains the highest values of gamma activity in this area. In the third zone (well 2), only positive PS values are observed (from +22 to +180 mV), which is possibly due to a high influx of liquid (Figure 6).



№ Layer	PS, mV	$\bar{\gamma}$	Lithologic column
1	–	–	
2	82.52	6.53	
3	74.51	7.05	
4	-68.64	6.60	
5	-120.97	9.22	
6	-120.68	8.79	
7	-127.50	11.09	
8	-126.63	10.53	
9	-122.00	12.73	
10	-123.62	10.52	
11	-123.50	11.38	
12	-124.04	15.08	
13	-124.59	12.26	
14	-121.65	14.64	
15	-121.76	10.09	
16	-117.32	11.63	
17	-116.54	9.21	
18	–	11.55	
19	–	10.66	
20	–	11.55	
21, 22, 23, 24, 25	–	11.34	

Figure 5. Well 4.



№ Layer	PS, mV	$\bar{\gamma}$	Lithologic column
1	–	–	
2	124.48	9.59	
3	111.47	11.60	
4	35.56	8.77	
5	67.29	10.22	
6	83.36	8.00	
7	98.59	9.87	
8	100.58	9.48	
9	108.40	9.75	
10	110.15	10.33	
11	101.95	9.38	
12	87.75	8.84	
13	85.24	9.59	
14	81.66	10.91	
15	65.86	7.12	
16	43.06	9.65	
17	–	10.88	
18	–	10.71	

Figure 6. Well 2.

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4. Conclusions

Frequent transitions of some lithological differences of rocks to others indicate a lagoon-sea, alluvial and eluvial-deluvial nature of precipitation formation. On all radarograms, the configuration of the axes of synphasis is obvious for interpretation, by which two types of areas can be distinguished [2]: 1) with pronounced synphasic axes of georadar signals, which indicates undisturbed geological sediment layers; 2) with low values of signal amplitudes, which indicates the weakening of rocks due to crushing and fracturing. Due to this, the morphology of the buried paleo-valley is clearly visible - the presence of drainage hollows at depths of about 6 m and the expansion of the springs of demolition and an increase in the amount of detrital material carried to the marine basin. This led to the accumulation of sandy-silty-clay deposits in a relatively short time. The highest values of gamma-activity are characteristic of clay layers. The caprock in this area consists of a pack of water layers and permeable zones. Relatively low temperatures are characteristic of the Daginsky hydrothermal system. We assume that the power spring is the supercritical fluid zone, just above the Conrad zone. Geophysical surveys, structural geomorphology and the study of aerial photographs will help to identify permeable thermally conductive zones.

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