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Research Article

APPLICATION OF THE GPR METHOD TO STUDY THE DISCHARGE ZONE OF HYDROTHERMAL SYSTEMS

***Veronika Yurevna Pavlova**
Kamchatka Vitus Bering State University, Russia
Tashkent State Technical University, Uzbekistan
** Author for Correspondense*

ABSTRACT
The paper presents the results of analysis of GPR data to study the discharge of some hydrothermal systems and its hydrogeological situation. The GPR method is successfully used for mapping the top of bedrocks disturbed as a result of tectonic movements, and for studying the stratification of the near-surface stratum of unconsolidated deposits. The georadar studies make it possible to identify vertical zones of increased heterogeneity and fragmentation of rocks, as well as flooded areas in loose deposits. This makes it possible to use this research method to study the structure of the upper part of hydrothermal systems. However, this promising direction in the study of hydrothermal systems is in its infancy, and there are practically no works devoted to this topic, which determines their importance.

***Keywords**: The GPR Method, Sakhalin, Kamchatka, Russia*

INTRODUCTION
When studying the geological structure of hydrothermal systems, it is important to study the structure of hydrothermal flow zones in the depths and on the day surface of the system (Rychagov *et al.*, 1993). The hydrothermal discharge zone is part of the caprock. Thermal springs owe their appearance on the earth's surface to the ratio of groundwater horizons, due to the geological structure of this area, and the relief profile of this area (Belousov and Belousova, 2002). The zone of discharge of hydrothermal systems is located near the Earth's surface, is often observed in the form of thermal manifestations and has been penetrated by many wells. This determines their greater accessibility for direct study.
Georadar studies make it possible to identify vertical zones of increased heterogeneity (fragmentation) and watering of the underlying rocks of landscapes, through which thermal waters are discharged (Shvartsman *et al.*, 2013). This makes it possible to use this method of research to study the zones of discharge of thermal waters and the upper part of hydrothermal systems. We can say that this is a new direction of using this research method to study the near-surface zone of hydrothermal systems.

MATERIALS AND METHODS
The subject of the study is the spatial structure of the discharge zones of some hydrothermal systems. The objectives of the research include: Detailed study of the structure of the upper stratum of the hydrothermal system using such a modern geophysical method as ground penetrating radar survey. Modern GPR survey within the Daginskaya (Sakhalin) and Karymshinsky (Kamchatka) hydrothermal systems was carried out for the first time. The information content of the results of georadar measurements is high, as it makes it possible to judge layered structures, geological heterogeneities, although at shallow depths.
The discharging of thermal waters in the Daginsky hydrothermal system (Sakhalin) is observed at the sites where the zone of rupture disruption has been opened by erosional incisions. The first discharge center (South section) 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) 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) 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.
Karymshinskaya hydrothermal system is located to the west of the volcanoes of the Eastern Kamchatka volcanic belt within the valley of the rivers Paratunka and Karymshina and is part of the Upper Paratunka geothermal system, dedicated to the area of the giant caldera of an ancient extinct supervolcano, which is located between the mountains of Yagodnoe, Tolsty mys, Goryahaya, Baby Kamen (Leonov and Rogozin, 2007). Structural position of the system is determined by the intersection of the lateral fault, extends along the axis of the valley with a cross fault to it. Thermal waters are confined to the reservoir represented by fractured vein zone within volcanic deposits of Miocene-Pliocene age (acidic tuffs).
The GPR method was performed using the OKO–250 georadar (center frequency 250 MHz, sounding depth 6-10 m, resolution 0.35 m) and the OKO–150 georadar (center frequency 150 MHz, sounding depth 10-12 m, resolution 0.25 m). A detailed description of the device and recommended measurement parameters are presented in the article (Pavlova, 2013).

RESULTS AND DISCUSSION

The Daginsky hydrothermal system (Sakhalin):
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. 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.
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 1). In the GPR profile, dry sands with gravel and pebbles are distinguished (the propagation velocity of an electromagnetic wave is 20.3 cm/ns, the dielectric constant is 2.19). These deposits are overlain by wet clayey sands (up to 1.5% water) with gravel and pebbles in the area of wells 5 and 4 (electromagnetic wave propagation velocity - 14.9 and 14.0 cm/ns, dielectric constant - 4.0 and 4.6) and dry sands in the area of the well No. 6 (electromagnetic wave propagation velocity - 26.3 cm/ns, dielectric constant - 1.29). Layers of high-moisture silt up to 1 m thick are distinguished in the section, which is evident from the values of the electromagnetic wave propagation velocity (3.8 and 3.7 cm/ns) and dielectric constant (60.3 and 65.6). These deposits are overlain (at the beginning of the profile) by clayey, silty, silty-clayey sands, with a layer thickness of up to 2 m (electromagnetic wave propagation velocity - 22.8 cm/ns, dielectric constant - 1.7). Peat also occurs on the surface (at the end of the profile), the thickness of which reaches 2 m (the propagation velocity of an electromagnetic wave is 20.2 and 22.2 cm/ns, the permittivity is 1.8 and 2.1). The crushing zone is clearly visible on the radarogram. Plots with a similar record are displaced relative

to each other vertically in the form of passing electromagnetic waves crossing horizontally located axes of in-phase. Frequent transitions of some lithological varieties of rocks into others indicate the lagoonal-marine, alluvial and eluvial-deluvial character of sediment formation.

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 the Daginsky thermal springs. According to the author, 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.

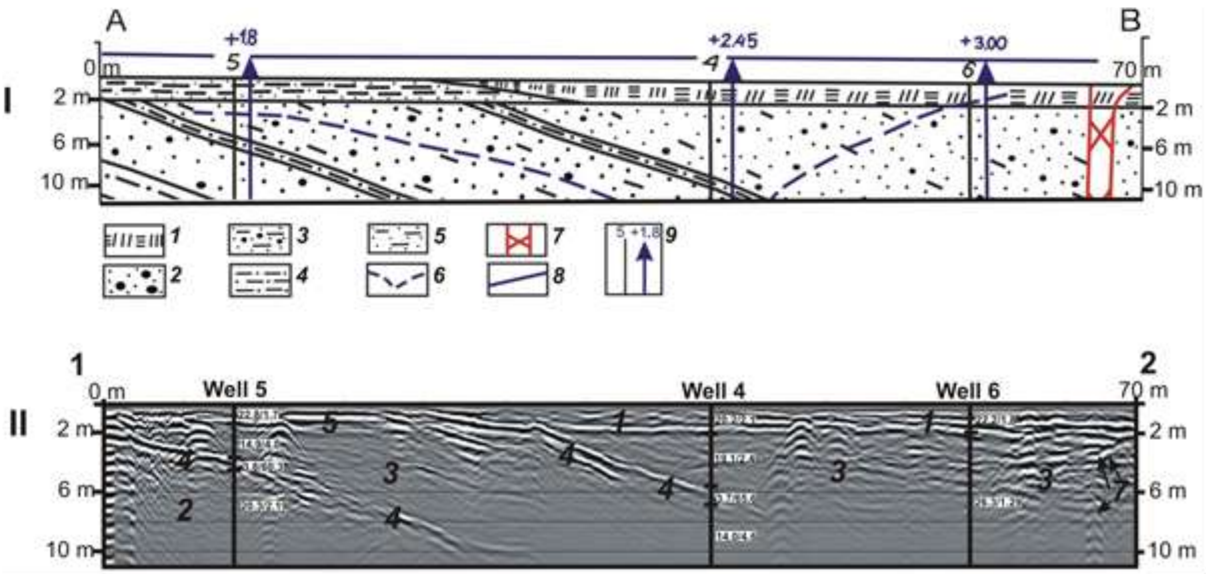

Figure 1: Comparison of the hydrogeological section A–B (I) with the GPR (II) profile 1–2 [2]. Above - hydrogeological section A–B in wells 5, 4, 6 (the numbers above the arrow indicate the steady pressure level from the surface: +18, +2.45 and 3.00 m, respectively). 1 - peat; 2 - sand with gravel and 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

The Karymshinskaya hydrothermal system (Kamchatka):

Directly on the surface of loose sediment deposited colluvial, alluvial and fluvioglacial origin, and only in the southern part of the site GPR surveys along the edge of the terrace come to the surface rocks and eluvium (Figure 2, 3). Sediments are characterized by average values of dielectric constant equal to 2.9 - 5, the average velocity of propagation of electromagnetic waves is 14 cm/ns. The boundaries are identified by the geometry of the in-phase axes on the radargrams.

The cap rock these rocks are massive tuffs, and in those places where the tuff fractured zones is unloaded thermal waters. The discharge zone is elongated along the fault. In this case, we have a medium-temperature system, dedicated to the same faults.

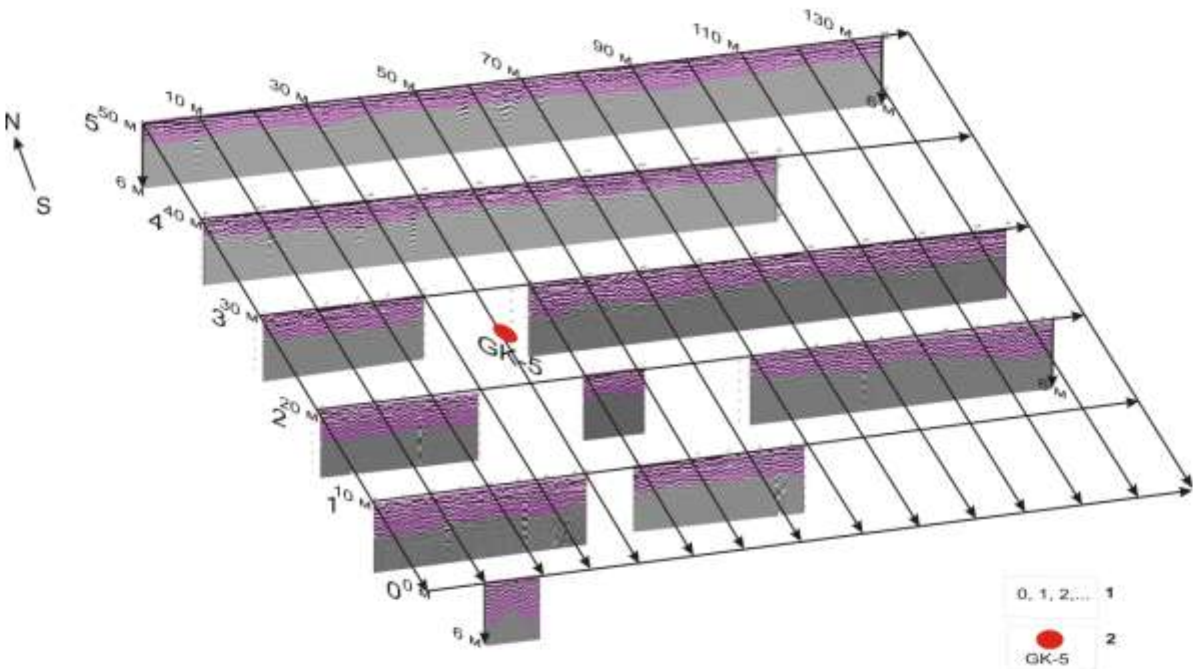

Figure 2: Geophysical model of the discharge zones of the Karymshinskaya hydrothermal system (the GPR profiling). 1 – shape, 2 – well

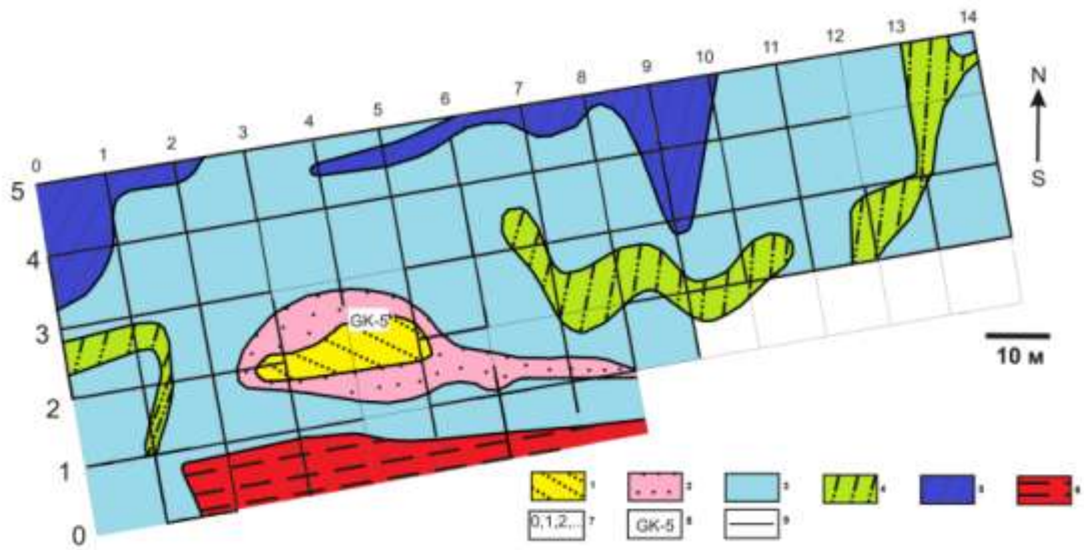

Figure 3: Geomorphological scheme area of GPR profiling.
1 - technologically impaired relief; 2 - local uplift in micro sculpture relief; 3 - the first terrace above the floodplain of the river Karymshina; 4 - inverted relief relics glaciofluvial stream flow; 5 - blocky colluvial deposits of origin, sometimes overlain by sediments terraces; 6 - eluvium rocks; 7 – shape; 8 – well; 9 – the GPR shape

Conclusion

The obtained results testify to the success of using the OKO-250 and OKO-150 georadar for a detailed study of the discharge zone of hydrothermal systems from 6 to 12 m.

New data on the structure of discharge zones have been obtained based on the use of ground penetrating radar surveys in the area of the Karymshinsky (Kamchatka) and Daginskaya (Sakhalin) hydrothermal systems. The revealed features of the propagation of electromagnetic waves in the wave pattern of radargrams indicate the fundamental possibility of establishing certain geological structures in the near-surface part of the discharge zones of hydrothermal systems, which are always characterized by a complex geological structure and a large number of faults of various types.

The results obtained serve as an important scientific and practical basis for the development of balneological and tourist-recreational centers in the study areas.

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