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Bol'she-Bannaya Hydrothermal System: New Thermometric Survey Data and the Position of the System Relative to Karymshina Caldera (South Kamchatka)

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ABSTRACT

This report presents new data obtained from a thermometric survey carried out by fieldwork between 2004 and 2007 at the area of Bol'she-Bannaya hydrothermal system, located in the valley of Bannaya River. As a result of this work thermometric mapping of the main thermal field of the hydrothermal system was done. The new thermometric map was compared to similar mapping made by Kamchatka Geological Survey in 1960s. The mapped area includes the main thermal field and has dimensions of about 400x400 m. A normal fault of NW strike crossing the valley of Bannaya River seems to control the thermal field. Faults limiting the rim of the Karymshina caldera in the NW area were also identified. They essentially redistribute the thermal water and steam flow coming from deeper sections. N-S and NE oriented structures previously identified in the area seem to be typical of greater depths. It is presented a conceptual model of the thermal anomaly in the Bol'she-Bannaya system.

1. INTRODUCTION

Bol'she-Bannaya hydrothermal system is one of the largest and well known systems in Kamchatka. It is situated at the Southern part of the Kamchatka Peninsula, 60 km far from the Petropavlovsk-Kamchatsky. The thermal manifestations are located at the head of the Bannaya River and mainly limited to the left river bank where the river valley gets wider and has relatively flat floor (Fig. 1). At the present time, many hot and pulsating springs, mud and steaming pots, warm soil areas with suppressed vegetation (Sobolevskaya, 2004) are known. In 1960s, before drilling activity started, the Bolshebannya group of hot springs included more than 500 natural seeps.

The right bank of the Bannaya river, near the thermal springs, is steep and rocky (Fig. 1). At this place the river undermines rock terraces 6-10 m high. The left bank is low and flat. The valley plain is stony, near the thermal seeps it is covered by sparse vegetation and moss. The first terrace is 3 m high and 170 m wide, the second one is 5 m high and 120 m wide. Both terraces are partially covered by geyserite sediments which form second order benches.

Figure 1: General view of the Bannaya river valley where the Bolshebannaya hydrothermal system is located and the thermal survey was done. View from east to west along the river flow. Arrows indicate the wellbores location numbered 38, 48, etc. Photo by Viktor N. Dvigalo, 2005.

Hot springs follow the river along 1.5 km. Thermal seeps occur at the valley plain, terraces and near the waterline. The temperature of seeps varies from 20-30 °C up to 90-98 °C, and the flow increases from several hundredths of l/sec at the summer up to 1,5-2 l/sec during spring snowmelting (Kraevoi et al., 1976). The total natural discharge of thermal manifestations including latent discharge to the Bannaya River was estimated at 60 l/sec by hydrochemical method before exploratory activity was started in 1970s.

2. GEOLOGICAL POSITION OF THE BOL'SHE-BANNAYA HYDROTHERMAL SYSTEM

In order to define the geological position of the Bol'she-Bannaya hydrothermal system (Fig. 2) fieldwork was carried out in 2004-2006. It allowed specifying the geological structure of the region within the heads of Bannaya, Karymchina, Karymshina, Paratunka rivers and Nachkinksy Creek (Southern Kamchatka). During the study in 2007, the largest known structure in Kamchatka, the giant Karymshina caldera, was identified in this area (Leonov and Rogozin, 2007). The caldera has oval shape and is elongated in a NW direction (25 km long and 15 km wide). The preliminary estimated volume of erupted products reaches 825 km^3, so that it could be considered as a supercaldera (Maison et al., 2004).

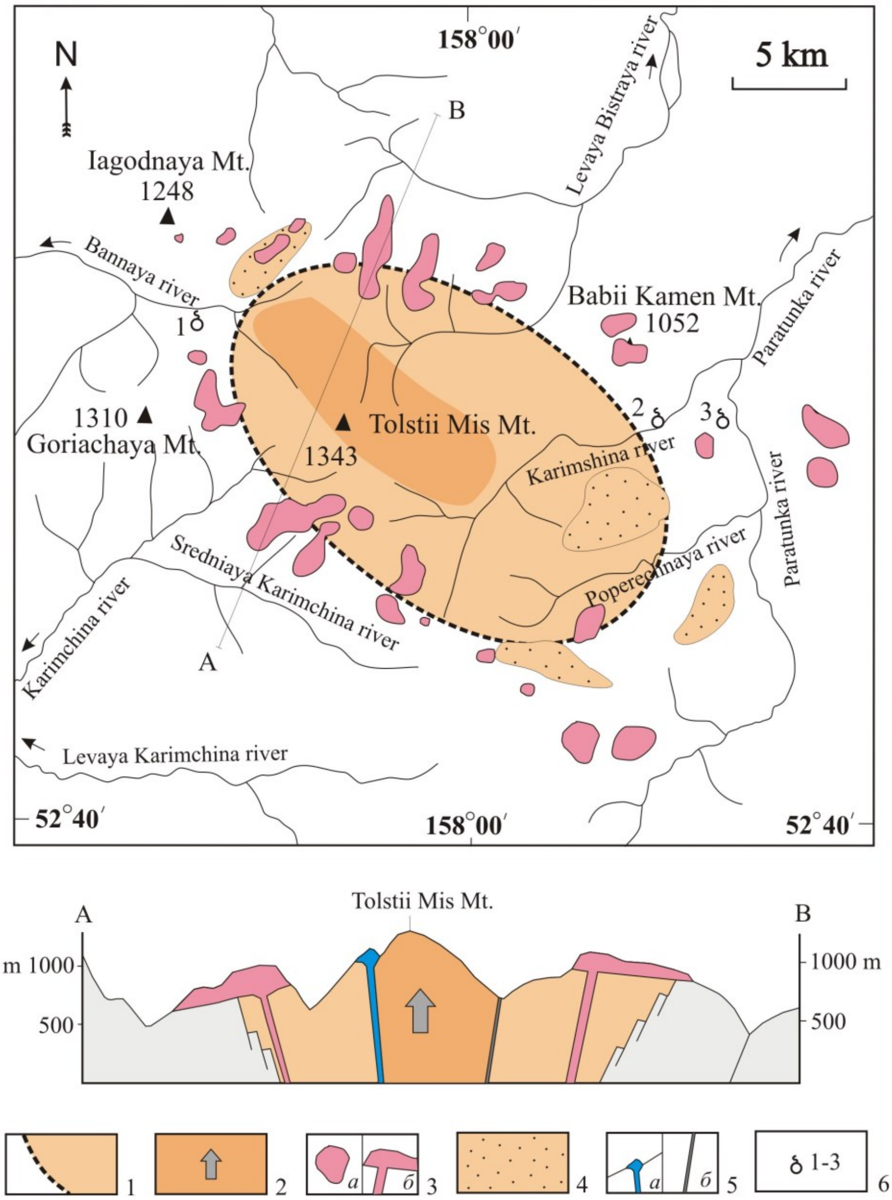

Figure 2: The generalized map showing the boundaries of the Karymshina caldera and its structure (Leonov and Rogozin, 2007). 1 – caldera boundaries and sediments filling the caldera (shown only in the cross section); 2 – resurgent uplift; 3 – rhyolite domes and associated lava flows: (a) – on the map, (b) – on the cross section; 4 – areas where lake deposits were found: tuffs and tuff siltstone; 5 – small volcanic edifices formed by basaltic lavas; 6 – ore-bearing veins located at resurgent uplift edges; 7 – thermal springs (1 – Bolshebannye, 2 – Karymchinskye, 3 – Verkhne-Paratunskye).

It should be noted that even in the 1960s, the geological survey defined a wide area with predominance of high-acidic rocks. These rocks were distinguished as a special dacite-rhyolite formation (later called Karymshinsky complex) and the area where the rocks are exposed was considered to be a large volcanic depression (Lonshakov, 1979). During following studies, estimations of the age and volume of the dacite-rhyolite formation and the size of the depression changed significantly (Serezhnikov and Zimin, 1976;

Sheimovich and Patoka, 1989; Sheimovichand Khatskin, 1996; Sheimovich and Golovin, 2003). Sheimovich and Golovin (2003) presented new estimations of the formation age corresponding to Eocene-Pleistocene.

In recent years we have studied outcrops of volcanogenic deposits and performed Ar-Ar dating of rocks related to Karymshina caldera. Based on these data we separate volcanogenic series which were treated by previous researchers as a single Karymshinsky complex. At least three stages of acidic volcanism during the Pliocene-Upper Pleistocene were identified in Southern Kamchatka. The age of the caldera was found to be 1.78 Ma (Bindeman et al., 2010). Our study reveals rock complexes that correspond to three stages in the formation of the Karymshina caldera: precalderic, caldera-forming and postcalderic.

Fieldwork allowed delineating the actual caldera boundaries at many places, determining accurately its shape and, moreover, describing some peculiarities of the later stage of volcanism and reconstructing the related resurgent uplift (Leonov and Rogozin, 2007). The position of thermal springs was considered from the new point of view. While early studies proposed the existence of a magma pocket in the interior of Mt. Goryachaya as the heat-source for the thermal water, our reconstruction of the caldera boundaries made it obvious that thermal springs are related to these boundaries (Fig. 3). We suggest that the heat source of the present hydrothermal system is a large magma pocket in the interior of the region above which the caldera was formed in Eocene-Pleistocene ages. This magma pocket also gave place to the resurgent dome appeared in Early – Middle Pleistocene.

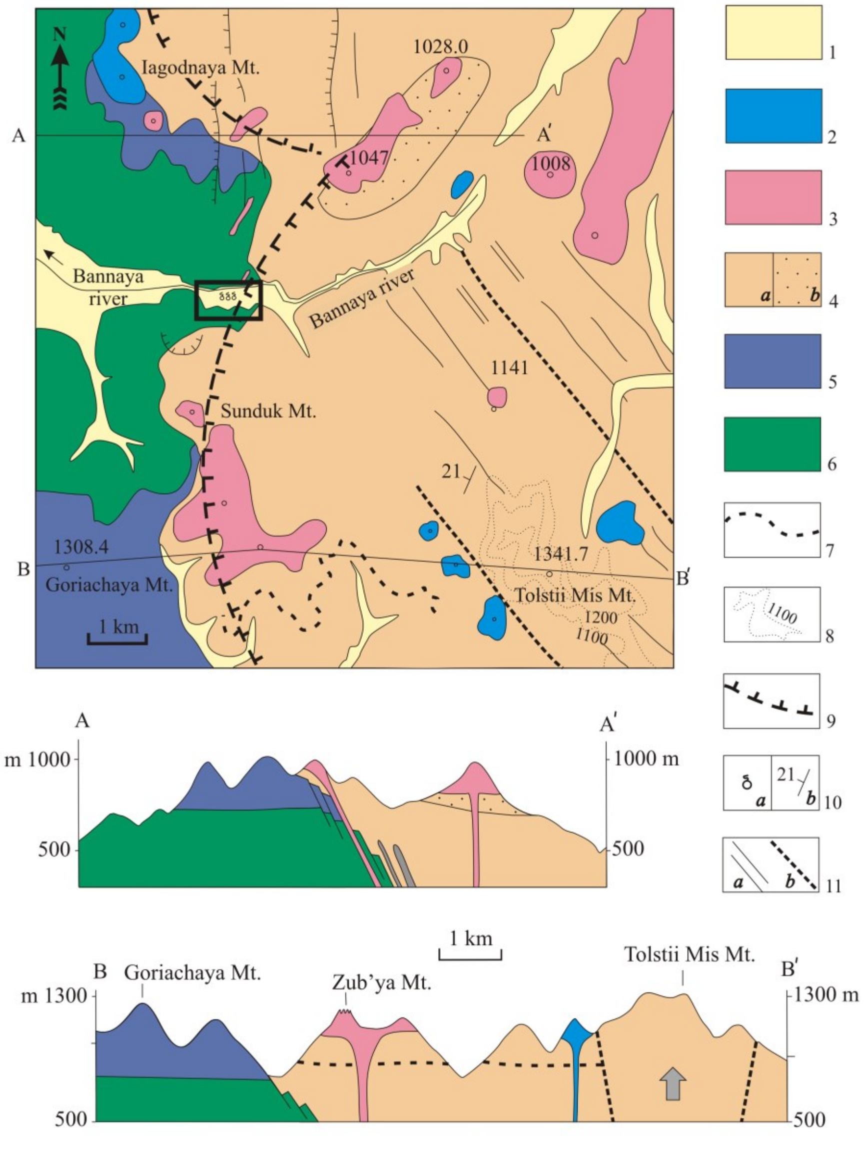

Figure 3: Outline of the geological structure and geological cross-sections of the head of Bannaya river. 1 – river valley deposits; 2 – small volcanic edifices formed by basaltic lavas; 3 –dykes and lava flows composed of rhyolites and rhyodacites; 4 – tuffs and ignimbrites of Karymshinsky complex (a), lake deposits: sand tuffs and tuff siltstone (b); 5 – dacite lavas, composing mounts Goryachaya and Yagodnaya; 6 – undivided ancient deposits; 7 – marking horizon of dacite lavas in the rock mass of Karymshinsky complex; 8 – topographic contour lines at the mount Tolstii Mis region (meters above the sea level); 9 – reconstructed boundaries of large depression filled by the rocks of Karymshinsky complex; 10 – (a) thermal springs; (b) dip and strike of rock layers; 11 – structures: (a) – fissures and downthrows, (b) – thrust-faults, bounding edges of the mount Tolstii Mis uplift. The rectangle in the middle of the figure represents the region where the thermal survey was done. A-A′ and B-B′ – cross section lines. At the cross section B-B′ arrow shows the lifted block of the mount Tolstii Mis.

3. RESULTS OF THERMOMETRIC SURVEYS

3.1 Results of thermometric survey done in 1960s at the Bol'she-Bannaya hydrothermal system

The previous thermometric survey at the area of Bol'she-Bannaya hydrothermal system was done more than 40 years ago during the detailed study of the Bolshe-Bannoye steam-hydrothermal field by the Kamchatkan Geological Survey (Kraevoi et al., 1976). The first thermometric map of hot springs was plotted, and some parts of the map are shown in Fig. 4. During the geological study, main tectonic dislocations were determined and it was found that dislocations having nearly N-S and NW strike are the most permeable.

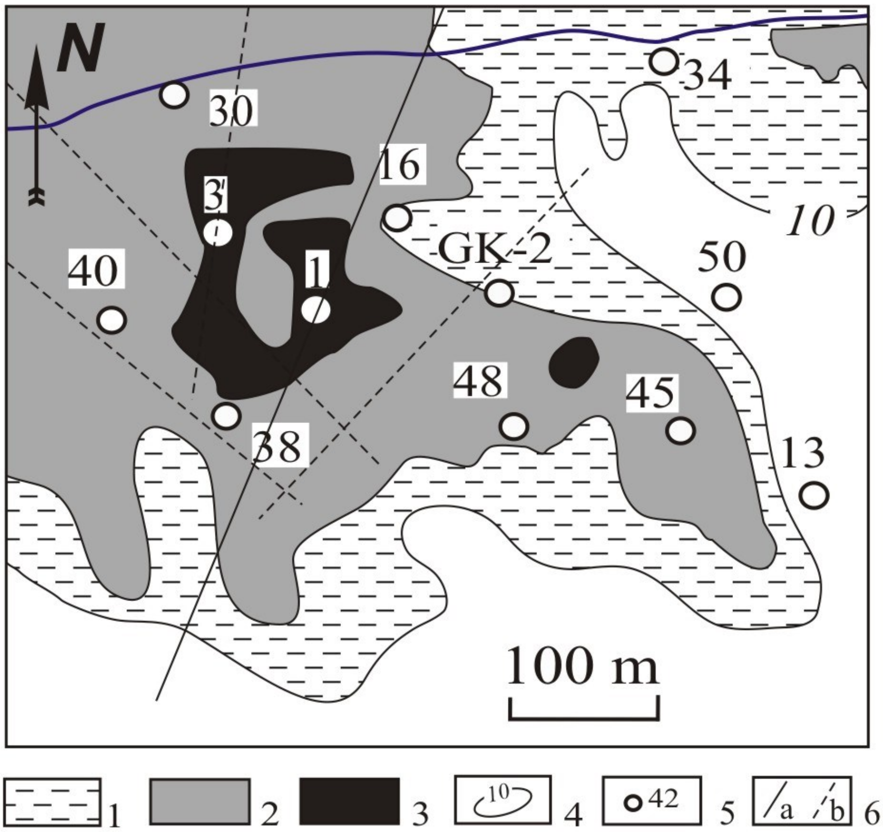

Figure 4: Thermometric map of the Bol'she-Bannye hydrothermal area according to Kraevoi et al (1976). 1-3 – areas with temperature at depth 0,7–1,0 m: 1 – 10-25°C, 2 – 25-50°C, 3 – 50-100°C; 4 – isotherms; 5 – exploratory and prospecting wells (digits denote wellbore numbers); 6 – main water-carrying fissure zones: a – confirmed, b – inferred.

In general, it was stated that the thermal field of Bol'she-Bannaya is extremely heterogeneous near the surface. At spots where active hydrothermal discharge takes place the soil temperature at 1 m depth reached 75-100°C. At the eastern part of the field, the temperature was lower and did not exceed 10°C. It agrees with thermal data from wellbores: the 100°C isotherm was found in the first meters at depth in the western part of the field, while in the eastern part it went down to 80 m depth and deeper (Kraevoi et al., 1976).

The comparison of the geothermal map with the geological survey data led to conclude that contact zones of subvolcanic bodies and dykes of acidic, moderate and basic composition with SE strike, act as conducts of high-temperature fluids.

It was noted that during exploratory exploitation the hot manifestations have changed: 7 out of 20 springs have vanished, the rest have shown flow decrease (Kraevoi et al., 1976), and new steam-seeps have appeared. In the early 1970s the geological studies held by the Kamchatkan Geological Survey at the Bol'she-Bannaya hydrothermal field were suspended. No more studies and monitoring activities were done in this area until recently.

3.2 Results of thermometric survey done in 2004–2007 at the Bol'she-Bannaya hydrothermal system

Our work at the Bol'she-Bannaya hydrothermal system started in 2004. At the first stage, our goal was to compose a comprehensive map of hot springs, locate them accurately using aerial photos, and restore the names of springs because some of the old names were lost. We described 70 hot springs at the main field, measured their temperatures, and characterized the related vegetation, bacterial mats and mineral deposits. This work resulted in a map of the thermal springs and a table of their main features (Sobolevskaya, 2004).

During the second stage in 2005-2007 with assistance of collaborators from the Laboratory of Geodezy and Distant Investigation Methods IVS FEB RAS (led by Vladimir N. Dvigalo) the topographic map (scale 1:2000) of the Bol'she-Bannaya hydrothermal system region was plotted. The map was the base for the thermometric survey which was done using a 20 m mesh (Fig. 5).

The soil temperature was measured with a thermocouple unit at 0.7–1.0 m depth. The studied area covers the main thermal field and has dimensions of 400×400 m. Two temperature zones with ranges of 20–50°C and 50–75°C were outlined. Also, seven spots with temperature exceeding 75°C were pointed out (they are shown by a red star in Fig. 5). The main feature of the thermal field is its elongation in a NW trend and the coincidence of its NE limit with the bed of the Yaschechny stream (Fig. 5). This eastern boundary of the field is represented in the terrain by a bench, assumed to be a normal fault with the upthrow block at the NE (Fig. 6).

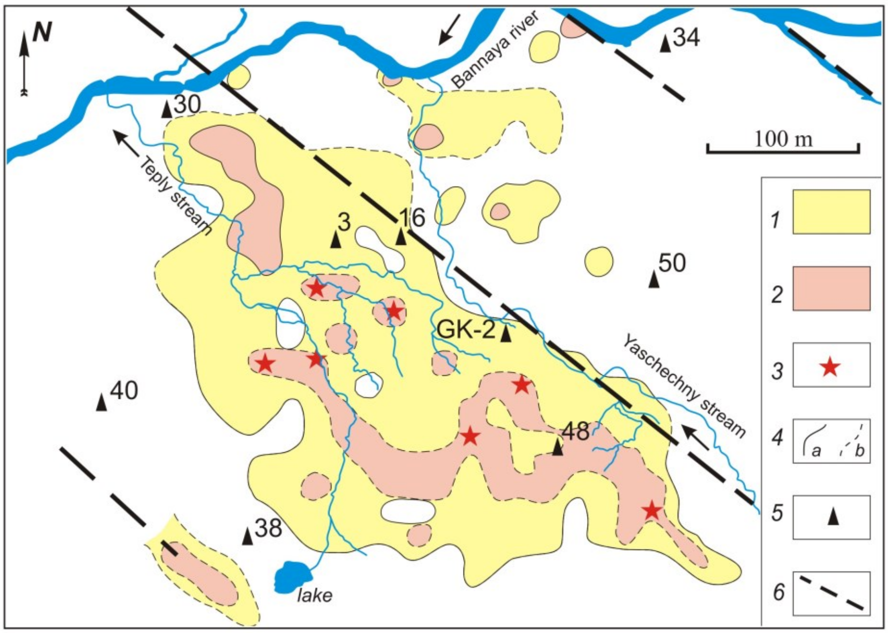

Figure 5: Thermometric map of the central part of Bolshe-Bannoye thermal field (based on the results of field works done in 2005-2007). The topographic base is done by Vladimir N. Dvigalo. 1-2 – areas with temperature at 0,7-1,0 m depth of 25-50°C (1) and 50-75°C (2); 3 – points with temperature from 75 to 95°C at 0,7-1,0 m depth; 4 – isotherms, a – confirmed, b – assumed; 5 – wells; 6 – inferred fractures.

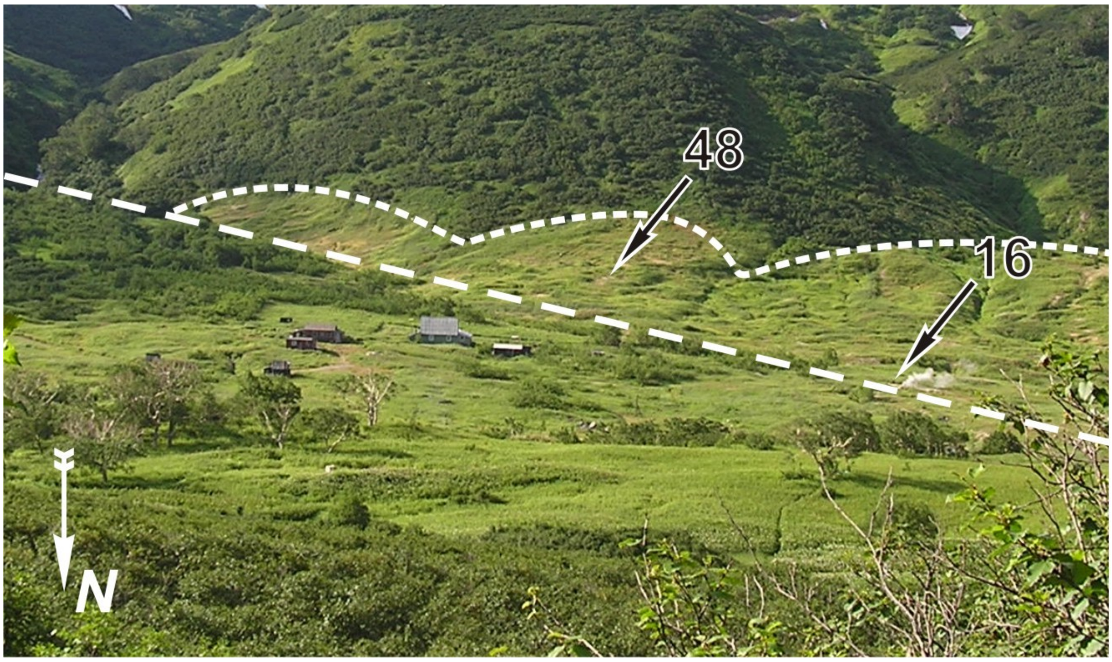

Figure 6: South-western part of Bolshe-Bannaya thermal field. Dashed line shows the trace of the fault following the NE boundary of the field. To the right of the fault wide areas of warm soil are marked by a dotted line. View from the north to the south. Photo by Vladimir L. Leonov, 2007.

4. DISCUSSION

Our model of the main thermal anomaly of the Bolshe-Bannya hydrothermal system is shown in Fig. 7. We propose that deep thermal fluids follow the trace of the NW normal fault to reach the surface, mainly at the downthrow block located at SW of the fault. In particular, the inclination of the fault plane to the SW is responsible for the formation of the thermal manifestations in surface, which are located along the fault and at the SW (see Figs. 5 and 7).

The normal fault of NW strike in the valley of the Bannaya River is not exceptional – faults with this trend are usual in the region (see Fig. 3). Large structures of NW orientation are limiting the resurgent uplift in the inner part of the Karumshina Caldera and can be seen in the Bolshe-Bannya hydrothermal system (see Figs. 2 and 3).

The NW trend of the main thermal field is also presented by many creeks and other thermal anomalies of the region, including the small thermal area at SW of the wellbore No. 38 (see Figure 5). Unfortunately the western part of the thermal system was not completely studied, so it is not known how far it extends to the NW.

The comparison of thermometric maps done by our group (Fig. 5) to those ones done by the Kamchatkan Geological Survey (Fig. 4) shows that in general the pattern of the thermal anomalies has not changed, yet there are some differences. We did not observe the extension of the thermal anomaly far to the NW. In addition, our data do not support the conclusion of the previous study (Kraevoi et al., 1976) about N-S and NE structures controlling the thermal manifestations.

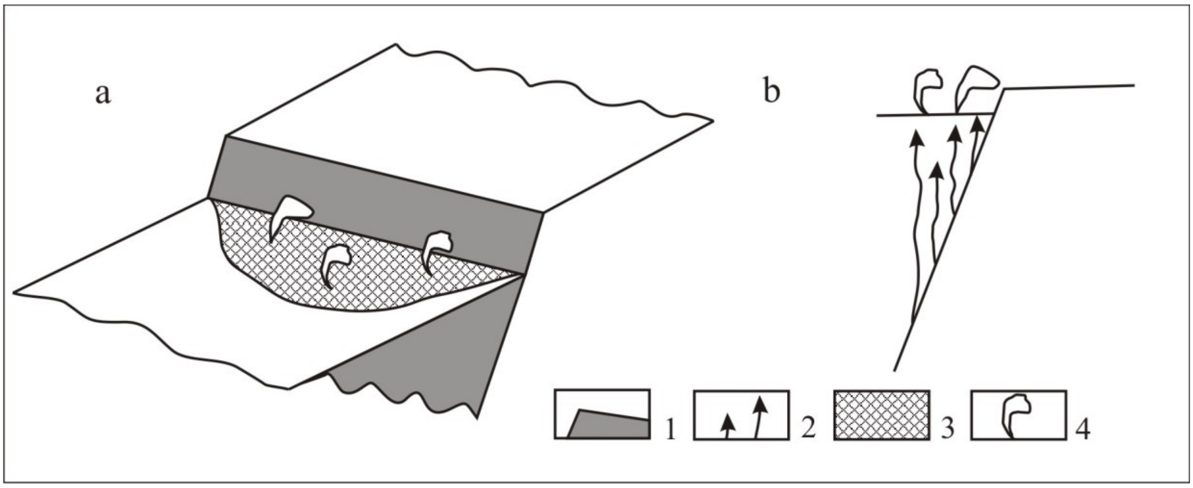

Figure 7: Conceptual model of the main thermal anomaly at the Bol'she-Bannaya hydrothermal system (a – isometric view, b – cross section). 1 –fault plane with NW trend which controls the thermal anomaly, 2 – thermal water and steam rising in the fault zone, 3 – the thermal anomaly at the surface, 4 – fumaroles and hot springs.

Kraevoi et al. (1976) claimed that contact zones of subvolcanic bodies and dykes of acidic, moderate and basic composition with SE strike are conductive channels for high-temperature fluids. They believed that chloride and sulfate concentrations in the water produced by the wells supported that conclusion (Kraevoi et al., 1976).

Subvolcanic bodies and NE-oriented dykes revealed by the geological survey and the wells are probably associated with the Karymshina Caldera boundary where the Bol'she-Bannoe field is located. The boundary at this region has a NE strike (see rectangle in Fig. 3) and is highly permeable.

The considered conditions under which the surface thermal anomaly within the Bol'she-Bannaya hydrothermal system was formed, and the relationship between the anomaly and the NE-oriented fault, are probably meaningful only for the uppermost part of the thermal field. In deeper sections the thermal water and steam flow is controlled by other channels, mainly faults which bind the Karymshina Caldera at the NW.

The hot springs located in the head of the Bannaya River could be considered as a large heat reservoir which could be used for producing electric power or directly for balneological purposes. The variation of the superficial temperature of the hot springs and thermal spots is an important evidence of possible changes in the hydrothermal system. Thus, it is recommendable a regular thermometric monitoring in the Bol'she-Bannoe thermal field in future.

5. CONCLUSIONS

1. A new thermometric map of the main thermal field at the Bol'she-Bannaya system is presented. The map is compared to a similar map done in the 1960s.

2. The faults with NW trend play an important role in the structure of the main thermal field at the Bolshe-Bannya hydrothermal system. The N-S and NE-oriented structures are less evident at the surface and seem to be more important at depth.

3. A schematic model of the main thermal anomaly in the Bolshe-Bannya system is presented. A normal fault with NW strike seems to be the main structural control of the system.

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