FADING HYDROTHERMAL ACTIVITY OF THE PIIPOVSKIYE SPRINGS GROUP AFTER THE 1996 UNDERWATER ERUPTION IN THE KARYMSKOYE CALDERA LAKE (KAMCHATKA)

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We focused our studies on hydrothermal activity of the Piipovskiye Springs – a group of high-temperature and high-flow-rate vents that have been operating in the Akademii Nauk Caldera for 20 years. The springs were formed as a result of two events that occurred almost simultaneously within the long-lived Karymsky volcanic center in 1996: underwater phreatic-magmatic eruption in the northern sector of the Karymskoye lake, and eruption of Karymsky volcano. Time evolution of their thermal activity appeared quite challenging.

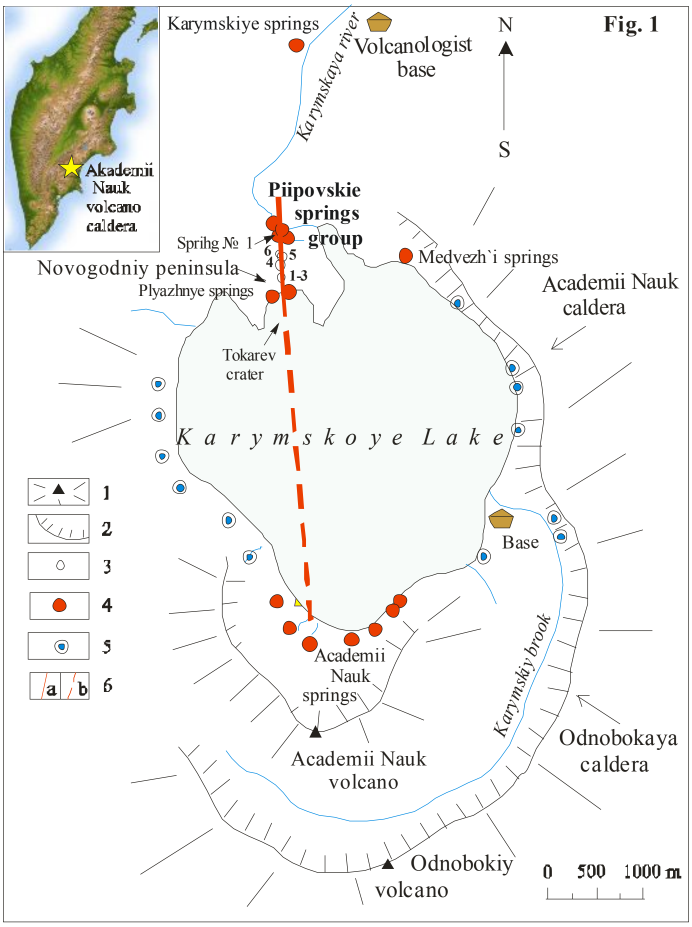
The above events of 1996 dramatically changed the caldera both morphologically and chemically [*Karpov et al.,* 1996; *Fedotov,* 1997; *Muraviev et al.,* 1997; *Fazlullin et al.,* 2000; *Karpov,* 2004]. Piled-up Novogodniy peninsular and underwater Tokarev crater were formed in the north part of the Karymskoye lake. North-eastern slope of the caldera was ruptured. Freshwater Karymskoye lake (pH=7.2, salinity 0.13 g/l) inhabited by a salmon species named "kokan`"(*Oncorhynchus nerka kennerlyi Suckley*) suddenly turned acidic (pH=3.2, salinity about 1 g/l). Water was heated up to 20^oC and mixed. Dissolved O_2 was totally removed. All the lake biota was completely wiped out.

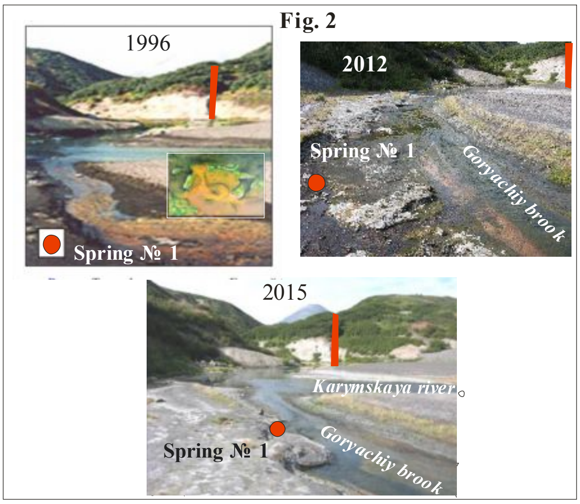
Along with tectonic [*Maguskin et al.,* 1997] and seismic [*Fedotov,* 1997; *Gordeev et al.,* 1998], processes that had taken place long before the 1996 crisis, the latter was preceded by certain changes with in the water environment of the lake itself. Thus, a few years prior to the eruption, chemical composition of the lake water showed increasing abundances of SO_4, Ca, H_3BO_3, Cl, Na and decreasing HCO_3, whereas pH first grew up to 7.8 and then began to drop [*Nikolaeva et al,* 2005].

One of the major issues of that period was the emergence of new thermal occurrences along a narrow zone of sub-meridional strike in the center of the Novogodniy peninsular. Besides, ancient hydrothermal vents were reactivated and a new geyser was formed in the south and south-east of the lake shore. Hydrothermal activity in the caldera immediately after the eruption was reported by [*Vakin, Pilipenko,* 1998]. Balance calculations were estimated by [*Taran et al.,* 2013].

Further on, we continued surveying the water environment in the caldera. Salinity and thermal regime of the lake were monitored for many years (1997-2015) [*Karpov et al.,* 2008; *Nikolaeva et al.,* 2018]. We also carried out long-term surveys of thermal water discharges measuring their pH, Eh, T^oC, conductance and flow rates. Of particular interest among the studied thermal occurrences within the caldera was a group of Piipovskiye springs (**Fig. 1**). These powerful vents discharging hot saline waters appeared in 1996 on the namesake terrace 200 m away from the Karymskaya river head. Thermal waters discharging from the vents formed the Goryachiy brook 2-3 m wide and about 100 m long. Some high-temperature gryphons showed gas bubbles. Surprising was the emergence of a strong bubbling spring named Burlyashchiy within the Karymskaya riverbed. Thermal vents also occurred on both sides of this river. The whole group of thermal vents (with spacings up to 200 m from each other) was located along a sub-meridional fissure zone. One of the most prominent features of this zone was a long fissure in the right side of the rock-defended terrace of the Karymskaya river [*Leonov,* 1997]. Newly-formed Piipovskiye springs showed complicated ion composition ($Cl-SO_4-HCO_3$ / Ca-Na, Na-Ca), total salinity of 2 g/l and more and abundant H_3BO_3 (> 40 mg/l) and H_4SiO_4 (> 350 mg/l). Within the group, springs differed from each other rather by the degree of mixing between their thermal waters and groundwater than by chemical composition. The latter was initially affected by acid fluids, with further increase of sodium chloride concentrations. Hydrochemical analogues for this type of waters had never been reported in Kamchatka before. Immediately after the lake eruption, gas composition of the springs was dominated by CO_2 (55.5%) that was further replaced by N_2; higher contents of H_2 (0.004%) were also reported. Among this group of springs and other thermal occurrences of the caldera, we should note an out standing Spring № 1. It showed unusual gas composition with rapid increase of CH_4 from 0.086 vol. % in September 1996 up to 50 vol. % in August 1997, with N_2 concentrations above 30 vol. %. The same situation was observed in the composition of heavy hydrocarbons in gasses. However, in 2000-2005 this spring showed irregular drop of CH_4 abundance down to 16 vol. %, along with reducing discharge of free gas down to a few dozen l/sec. In 2015 gas composition of the Piipovskiye springs group was dominated by N_2.

With time, this group of springs has undergone certain changes. Favorable environment for thermophilic microorganisms in areas of hydrothermal discharges has reduced significantly compared to that of 1996 (**Fig. 2**). Spring water is now of Cl-SO_4 / Na type. Discharge area itself has reduced 4-5 times. Temperature and salinity of thermal waters have dropped (**Fig. 3**). In general, peak temperatures of the Piipovskiye springs group are now 50-55°C, background temperature being about 40°C. Spring № 1 shows values of about 60°C.





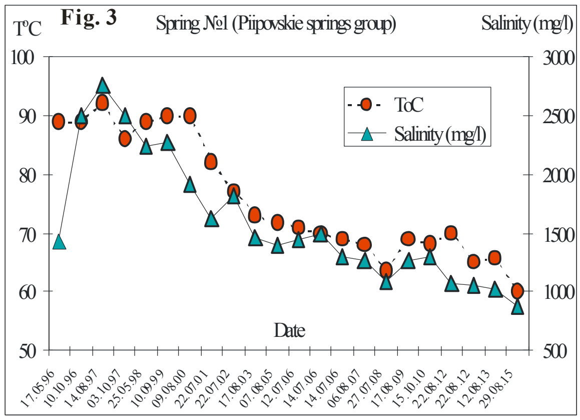


Fig. 1. Location of thermal springs in the Akademii Nauk caldera.(1)volcanic edifices; (2) calderas; (3) explosive-subsidental funnels in the Novogodniy peninsula; (4) thermal water discharge vents; (5) groundwater discharges; (6) direction of surface fracture in 1996 [*Leonov,* 1997] (a), assumed fracture of the lake bottom (b). Inset – map of Kamchatka with study area.

Fig. 2. View of the Goryachiy brook and colonies of thermophilic microorganisms in it (1996, 2012 and 2015).

Fig. 3. Distribution pattern of T°C and salinity in Spring № 1 inferred by 1996-2015 surveys.

Thus, the following factors have been reported in the result of our survey: reduction of thermal area of the Piipovskiye springs discharge, trend of levelling-up their temperature and salinity values, drop of flow rates and free gas discharge. We consider those as possible evidence of fading hydrothermal activity of the springs. However, renewed excitation of the nearby Karymsky volcano might trigger the revival of this hydrothermal activity.

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