Modern Postvolcanic Activity of Berutarube Volcano, Iturup Isl., the Kuril Islands

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Abstract. The data of 2017, characterizing the modern gas-hydrothermal activity of the Berutarube volcano (Iturup Island, the Southern Kuriles) are presented. It is shown that currently the volcano has intensive solfataric and hydrothermal activity, concentrated within the three main sites near summit part of the edifice. The maximum temperature of steam-gas outlets is 96.6 °C, thermal spring – 80 °C. According to the chemical composition, the hydrotherms of Berutarube volcano are ultra-acid (pH 1.5), mineralized, chloride-sulfate waters with a complex cationic composition.

1. Introduction
Berutarube volcano (a.s.l. – 1220 m) is one of the most inaccessible and poorly studied active volcanoes of the Southern Kuril Islands. The volcano forms the southern part of Iturup Island – Chasovoy peninsula: the extreme southern point – Cape Rocard, the extreme eastern point – Cape Gnevny (figure 1). The edifice of this is strongly destroyed, relatively flat (average gradient 11–13°) volcanic cone (diameter of the surface basement ~11 km) (figure 2). The slopes of the volcano are cut by deep barrancos and river valleys with deep canyons and numerous waterfalls, which greatly complicate the route to its top. The summit of the Berutarube volcano is greatly eroded and presents the chains of merged amphitheatres from the western and eastern sides and a small ridge dividing them and elongated in the meridional direction – its southern part serves as a maximum mark of volcanic edifice. From south and from north the top of the volcano is also complicated by a number of amphitheatres.

Primary volcanic relief is almost not preserved, although, perhaps, part of these erosion forms inherited the primary morphology of the explosive forms pre-existing here, as well as fragments of extrusive bodies. The composition of rocks of Berutarube volcano, according to [1], varies from basaltic andesites (53.05 SiO₂, 2.59 Na₂O, and 0.43 K₂O) to dacites (65.03 SiO₂, 3.31 Na₂O, 0.67 K₂O).

There are no literature data indicating the manifestations of volcano activity in historical time. New volcanic forms of the relief (funnels of explosions, crater) and the products of activity indicating the manifestation of recent volcanic activity is not observed. Previous researchers [2- 4] noted the presence of solfataric and hydrothermal activity.
2. Material and methods
In August 2017, during the expedition to Iturup Island, the Berutarube volcano was investigated with the aim of studying its current condition. The determinations of basic physical and chemical parameters of hydrothermal springs and solfataras (pH, temperature) and collection of samples of the thermal spring waters and Filyushin river were conducted during the researches. Portable pH-meter HANNA-Hi9025 was used to determine the pH of thermal waters in the field conditions. Temperature measurements of thermal springs and solfataric gases were carried out by Digitron-T200KC with electronic thermometer with thermal Converter KTXA 01.02 P-T310, the operating temperature range of the thermocouple from -200° to +1350 °C, the measurement accuracy is 0.1 °C. Analysis of the chemical composition of water samples was carried out in the Center of the collective use of IMGG FEB RAS.

![Figure 1. The geographical location of the Berutarube volcano and scheme of location of the areas with gas-hydrotherms at Berutarube volcano: 1 – Verkhny, 2 – Tsentral’ny, 3 – Nizhny.](image-url)
The content of Li+, Na+, K+, Ca^{2+}, Mg^{2+}, F^-, Cl^-, Br^-, NO_2^-, NO_3^-, SO_4^{2-} was determined by ion chromatography method on a high-effective liquid chromatograph LC-20 Prominence with conductometric cell (Shimadzu, Japan). Water samples were refined with membrane filters (0.45 mkm). The concentration of HCO_3^- and CO_3^{2-} was measured by titrimetric method with a visual indication of the titration end point. The content of inorganic carbon and total nitrogen was determined by thermocatalytic oxidation method on the analyzer TOC-L (Shimadzu, Japan). A portable pH meter WTW 3110 ProfiLine was used to measure the hydrogen index.

Figure 2. General view of the Berutarube volcano (view from the north), August 2018. Photo by A. V. Degterev.

3. Results and discussions
In this work, the available few data of domestic researchers presented in the publications and library materials are compared with the results of the expedition work in 2017.

The first brief information in the domestic literature about the thermal springs and fumaroles of the Berutarube volcano was given in the work of G.V. Korsunskaya [2], who examined the volcanoes of the Southern Kuril Islands in 1946: "Near the summit of 1030 m, at the bottom of a deep crater with steep and overhanging walls in the form of individual blocks, there are powerful fumaroles, during September and October clearly increased their activity. For 15 km from the volcano you could see two powerful white columns rising above the edge of the crater. The heat, coming from the hot gases, is felt at a distance of 1 km from the crater. During these months, many previously absent hot springs appeared" [2]. Unfortunately, there are no physical and chemical parameters of thermal springs and solfataras in this work. It should be noted that the "appearance" of new thermal sources and the "strengthening" of solfataric activity, noted by G.V. Korsunskaya, could be erroneous, due to, as often happens, to sharp seasonal changes in meteorological conditions in the Southern Kuriles.

For the period from 1996 till 2017 the reliable information about the modern activity of the Berutarube volcano in literature is absent. Due to its remoteness and inaccessibility, it has not been examined by scientists for more than 20 years.

In 1957, the thermal springs of Berutarube volcano were examined and tested by E.K. Markhinin. The results of these works, including a brief description and physico-chemical data about cold ferruginous and thermal sources, are presented in the monograph [3]. One of the volcano hot springs, tested in 1957, had a temperature of 30 °C and pH 2.4. By the chemical composition of the water of this spring (table), it can be attributed to mineral (TDS – 5.68 g/l) chloride-sulfate sodium-calcium-aluminum-ferruginous. The increased content of fluorine and silicic acid was founded in the water. Fumarolic activity in this work is not described, the physico-chemical parameters of solfataras were not given, and the scheme of location of solfataras and thermal springs of Berutarube volcano were
also not presented.

**Table 1.** The chemical composition of thermomineral waters of Berutarube volcano (in mg/l).

| Index | 1     | 2     | 3     |
|-------|-------|-------|-------|
| T, °C | 30.0  | 78    | 17    |
| pH    | 2.45  | 1.5   | 2.6   |
| Na⁺   | 207.0 | 137.0 | 62.0  |
| K⁺    | 9.8   | 10.5  | 5.0   |
| Ca²⁺  | 304.3 | 405.0 | 243.0 |
| Mg²⁺  | 69.3  | 85.0  | 58.0  |
| NH₄⁺  | 1.8   | –     | –     |
| Fe²⁺  | 71.0  | –     | –     |
| Fe³⁺  | 391.0 | –     | –     |
| Al³⁺  | 181.0 | –     | –     |
| H⁺    | 3.5   | –     | –     |
| Cl⁻   | 367.1 | 2380.0| 379.0 |
| HSO₄⁻ | 682.2 | –     | –     |
| SO₄²⁻ | 2075.2| 2380.0| 1590.0|
| H₂SiO₃⁻| 260.0| –     | –     |
| Si    | –     | 160.0 | 70.0  |
| B     | –     | 40.0  | 10.0  |
| F⁻    | 1.0   | < 0.5 | < 0.5 |
| Br⁻   | –     | 3.5   | 0.5   |
| Li⁻   | –     | < 0.05| < 0.05|
| IC    | –     | 1.0   | 1.5   |
| TN    | –     | 0.4   | 0.05  |

*Notes.* 1 – thermal spring (studied by E. K. Markhinin, 1957 [3]); 2 – thermal spring, 2017; 3 – waters of the Filyushin river, 2017. IC – inorganic carbon content, TN – total nitrogen content. A dash is not defined.

During the period from 1994 till 1997, the scientists of the laboratory of volcanology and volcanic danger of IMGG FEB RAS conducted the regime observations at three main sites of unloading of thermal waters and fumarolic gases of the Berutarube volcano [5]. The scheme of the sites location of the solfataric gas and thermal water outlets is presented in the reporting materials. The results of chemical analyses of solfataric gases are available only for 1994-1996; Berutarube volcano during this period did not show the signs of geochemical activation. The average temperature of fumaroles was within 101-104 °C, carbon dioxide (up to 95 %) and hydrogen sulfide (3-8 %) were dominated in the gas composition.

Route to Berutarube volcano, conducted in August 2017, climbed up the Filyushin river from the mouth to the summit part of the cone (figure 1, 2). This route was chosen due to the fact that known manifestations of solfataric-hydrothermal activity of the volcano are located in the bounds of near-summit amphitheatre, where Filyushin river originates from. Despite the small length of the river – only ~5.5 km, the climbing along its bed is quite difficult: the slopes of the valley are very steep, complicated by canyons and numerous waterfalls up to 5-10 m. According to the results of surveys in 2017, three main areas of discharge of thermal waters and fumarolic gases are located on the volcano: Verkhny (Upper), Tsentral’ny (Central) and Nizhny (Lower) (figure 1). Verkhny section (figure 1, 3) occupies the highest hypsometric level, locating at altitude of 935-940 a.s.l. near the outlet of
Filyushin river. It includes the largest fumarolic edifice at the Berutarube volcano (figure 3), named by the authors Bolshaya because of its size. Solfataric edifice, forming the end of the ridge between the two barrancos, has a size of ~4 × 8 m, there are two holes at its top: one of them has the form of a circle with a diameter of ~1 m, the other is crescentiform with sizes of 0.3 × 0.6 m. Clouds of steam and gas (75-80 °C) rise above the holes, and an intense boiling of mud mass was observed in the cavity of the edifice (it was not possible to measure the temperature with the available equipment because of the danger of collapse). A small, but relatively powerful output with a diameter of ~0.3 m (solfatare called Malaya) is located a few meters to the south of Bolshaya. Solfatare is characterized by an intensive output of a steam-gas mixture with a characteristic "roaring" sound, the maximum temperature reaches 82.8 °C here.

![Figure 3](image-url). Solfataric outputs of Verkhny section (a) and Tsentral’ny (b). Photo by A. V. Degterev.

The section Tsentral’ny, occupying the right bank of Filyushin river, is located below the slope, at altitude of 860-900 m a.s.l. (figure 1, 3). It is now the greatest manifestation of gas-hydrothermal activity of Berutarube volcano. Several large solfataric separated edifices (with a height of about a meter or more) and dozens of smaller, as well as hot springs are located on the area of ~0.02 km². The maximum temperature of the steam-gas mixture measured at one of the large solfataric outputs has reached 96 °C. At the same time, numerous sinteted sulfur formations, including very fresh ones, indicate the melting of crystalline sulfur, and show that the temperatures can be significantly higher than 115 °C (the melting temperature of crystalline sulfur) here. Within the Tsentral’ny section, we studied a relatively powerful hydrothermal outlet, which is a pulsating spring with a temperature of 78 °C, pH 1.5 and water flow rate of ~20 l/min, flowing down into the Filyushin river.

Its chemical composition is similar to the thermal spring described by E.K. Markhinin: its waters are chloride-sulfate with a complex cationic composition (table). Similar thermal and cold ferruginous springs form the geochemical image of Filyushin river. The waters of the river are acidic (pH 2.6), mainly sulfate calcium (table), the deposits of limonite are observed in river-bed, the thickness of which in some places reaches 20-30 cm or more.

The section Nizhny is located on the left bank of Filyushin river at the height of 800-810 m a.s.l. (figure 3). Within the site there are several small solfataras (79.3 °C), as well as thermal water outlets with temperatures up to 59 °C.

Berutarube volcano as a whole is now characterized by a high level of manifestation of gas-hydrothermal activity comparable to such volcanoes as Mendeleev volcano (Kunashir Island) and Sinarka volcano (Shiashkotan Island).

4. Conclusions
1. During field work in 2017, the first data about the current condition of the Berutarube volcano, the least explored volcano in the Southern Kuriles, were obtained for the last 20 years. It was found that the volcano is characterized by intensive fumarolic and hydrothermal activity.
manifestation of gas-hydrothermal activity are located within the near–summit area of the volcano. The maximum measured temperature of the steam-gas outlets (Tsentr'al'ny section) is 96.6 ° C, but judging by the molten sulfur flows, the temperature reached 115 ° C.

2. The hydrotherms of the volcano unloading in the near-summit part of the volcano have a temperature of 78-80 °C. Their chemical composition corresponds to ultra-acid (pH 1.5), mineralized, chloride-sulfate waters with a complex cationic composition. In thermal and cold springs, unloading on slopes and in the bed of river Felyushin, the deposits of limonite were found.

3. Significant changes in the nature of gas-hydrothermal activity of the volcano, in comparison with the results of researches in previous years (1946, 1957, 1994-1996) were not found. At the same time, the limited data (the absence of gas-hydrotherms location schemes, their detailed descriptions with physical and chemical characteristics and photographs) does not allow estimating the possible small-scale changes in the solfataric and hydrothermal activity of the volcano for whole period of observations.

5. References
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